Development and Psychopathology (2026), **38**, 2146–2158
doi:10.1017/S0954579426101862

CAMBRIDGE UNIVERSITY PRESS

Regular Article

Effects of parental stress-buffering on multiple measures of positive valence systems functioning

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Abstract

Adolescence involves social reorientation toward peers, increasing exposure to interpersonal stressors and vulnerability to psychopathology. The current study investigated the potential buffering effects of high-quality parent–child relationships (PCRs) on the associations between peer stress exposure and multiple measures of positive valence systems (PVS) functioning. The study included 165 adolescents, ages 9–16 (81 girls, $M_{age} = 11.93$, 78.18% White). Interviews were conducted to gather data on PCR quality and peer stress exposure. Adolescents self-reported their reward sensitivity, and behavioral reward sensitivity was derived from a reward learning paradigm. The reward positivity (RewP) was recorded during three tasks using monetary, social, and food reward stimuli. Contrary to our predictions, adolescents who had higher-quality PCR showed a blunted monetary RewP ($\beta = 0.17$, $p = .020$) and reduced behavioral reward sensitivity ($\beta = 0.15$, $p = .040$), when also reporting high levels of peer stress exposure. No significant interaction was found with other measures as the outcomes. The results suggest that high-quality PCR may not uniformly buffer against the effects of peer stress exposure and highlight differential effects for different PVS measures. Future research across multiple units of analysis is needed to elucidate the complex pathway to PVS-related psychopathology during this critical developmental stage.

Keywords: RewP; PVS; parent-child relationship; peer stress; reward sensitivity

(Received 5 December 2025 UTC; revised 9 June 2026 UTC; accepted 31 July 2026 UTC)

Adolescence is defined as the beginning of biological maturation (i.e., puberty), which typically starts in late childhood and lasts for more than 10 years (Sawyer et al., 2018). The transition to adolescence involves a dramatic social reorientation, during which youth seek autonomy from family and orient increasingly toward their peers (Nelson et al., 2005, 2016). Compared to younger children, adolescents spend less time with their family, replacing this instead by time alone and with friends (Lam et al., 2014; Larson & Richards, 1991; Larson et al., 1996). Because adolescents also report heightened sensitivity to peer evaluation, and often link peer acceptance and rejection to self-worth (Andrews et al., 2020; Blakemore & Mills, 2014; Lee et al., 2020; O'Brien & Bierman, 1988; Tang et al., 2019), this social transition also involves heightened exposure to interpersonal stressors, such as peer rejection (Scholte & Aken, 2007), peer conflict (Noakes & Rinaldi, 2006), and bullying (Cho et al., 2022; Espelage & Holt, 2001; Mitsopoulou & Giovazolias, 2015; Rey et al., 2022; Wang et al., 2009). Mild and infrequent stressors can be beneficial for psychosocial development (Johnson & Johnson, 1996; Scholte & Aken, 2007). However, when stress exposure is chronic, it can result in increased signs and symptoms of psychopathology, including depressive disorders, anxiety disorders, and substance use disorders (Copeland et al., 2013; Costello et al., 2011; La Greca & Harrison, 2005; LeMoult et al., 2020; Mullan et al., 2023; Rapee et al., 2019; Roberts et al., 1998).

Emerging research suggests that one possible mechanism by which peer stress exposure increases the risk for psychopathology in adolescence is through altered positive valence systems (PVS) functioning (Kujawa et al., 2020). The PVS is a domain of the NIMH Research Domain Criteria (RDoC), encompassing positive emotionality, and neurophysiological and behavioral processes related to anticipating, obtaining, and responding to positive or rewarding stimuli (National Institute of Mental Health, 2019). PVS function can be measured via multiple units of analysis, including self-report, behavior, and neural responses (National Institute of Mental Health, 2019). Reduced activation of PVS has been found in individuals with current psychopathology, including depression (Baskin-Sommers & Foti, 2015; Epstein et al., 2006; Halahakoon et al., 2020; Hill et al., 2023; Robinson et al., 2012). Research using functional magnetic resonance imaging (fMRI) and event-related potential (ERP) methodologies also suggests that reduced PVS activation may be a vulnerability marker for future depression in currently euthymic individuals (Keren et al., 2018; Kujawa & Burkhouse, 2017; Proudfit et al., 2015; Sharp et al., 2014).

Critically, stress exposure has been associated with blunted functioning of the PVS, and particularly neural and behavioral measures of reward sensitivity (for a review, see, e.g., Kujawa et al., 2020). Both laboratory-induced and naturalistic stress exposure have been associated with reduced activation of the PVS (Burani et al., 2021, 2022; Ethridge et al., 2018, 2020; Freeman et al., 2023;

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Cite this article: Zhou, Z., Sejourne, C., Panier, L., Allison, G. O., Argiros, A. P., & Weinberg, A. (2026). Effects of parental stress-buffering on multiple measures of positive valence systems functioning. *Development and Psychopathology* **38**: 2146–2158, https://doi.org/10.1017/S0954579426101862

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https://doi.org/10.1017/S0954579426101862 Published online by Cambridge University Press

Hanson et al., 2015, 2016; Hill et al., 2023; Lincoln et al., 2019; Pegg & Kujawa, 2024). In particular, reduced PVS activation has been repeatedly associated with interpersonal stress exposure. Cross-sectional studies in adolescents and emerging adults have found that blunted reward responsiveness was associated with greater peer stress exposure (Ethridge et al., 2018; Panier et al., 2022; Rappaport et al., 2019). Longitudinal research using fMRI has also found that peer victimization in early adolescence prospectively predicted decreased response to rewards in the medial prefrontal cortex later into adolescence (Casement et al., 2014). Thus, PVS functioning, and perhaps more specifically the PVS subconstruct of reward functioning, is a promising candidate for a mechanism of the effect of peer stress exposure on the emergence of depression.

However, not every adolescent exposed to peer stress develops psychopathology or shows altered PVS functioning (Anderson et al., 2020; Dennison et al., 2016; Hazel et al., 2014; Herman-Stahl & Petersen, 1996; Rudolph et al., 2020), suggesting it is also important to identify factors that buffer against the adverse effects of stress exposure. A high-quality parent–child relationship (PCR) may be one such buffer (Gunnar, 2017; Hazel et al., 2014; Lila et al., 2007; Rudolph et al., 2020; Scholte & Aken, 2007). Both cross-sectional (Barrera & Garrison-Jones, 1992; Steinberg, 2001) and longitudinal (Ge et al., 2009; for a review, see, e.g., Shore et al., 2018) data from children and adolescents indicate that high-quality PCRs are associated with lower levels of depression. Similarly, positive parenting behaviors (e.g., warmth, closeness) have been associated with more adaptive reward functioning in adolescents and adults (Griffith et al., 2025; Morgan et al., 2014; Schneider et al., 2012), suggesting PCRs can shape PVS functioning. In addition, there is evidence from child samples that parental support can reduce the negative outcomes of stressors (Gunnar, 2017). This has been demonstrated using both laboratory (Hostinar et al., 2015; Seltzer et al., 2010) and real-world stressors (Nystad et al., 2021; Patterson et al., 1989), and has been measured across multiple units of analysis, including cortisol reactivity (Hostinar et al., 2015; Nystad et al., 2021; Seltzer et al., 2010) and behavioral problems (Patterson et al., 1989).

Despite this, it is not clear whether a high-quality PCR continues to buffer against exposure to peer stress in adolescence, during which time adolescents often seek more social support from friends and peers than from family (Furman & Buhrmester, 1992; del Valle et al., 2010). The results of some studies suggest that parental buffering effects are reduced or diminished in adolescents (Burton et al., 2004; Hostinar et al., 2015; Yeung Thompson & Leadbeater, 2013). It is possible that as peers become more involved in adolescents' lives, peer support outweighs parental support in protecting against stressful events (Burton et al., 2004). Yet other research has suggested a continued parental buffering effect into adolescence (Ge et al., 2009), including studies that have investigated parental buffering of peer stress specifically (Conners-Burrow et al., 2009; Davidson & Demaray, 2007; Hazel et al., 2014; Rudolph et al., 2020; Tanigawa et al., 2011; Wenz-Gross et al., 1997). However, these studies have tended to focus on symptoms of psychopathology as outcomes (e.g., Conners-Burrow et al., 2009; Hazel et al., 2014; Rudolph et al., 2020; Tanigawa et al., 2011; Wenz-Gross et al., 1997). Although emerging research has shown that low PCR quality (e.g., conflict) moderates the association between depressive symptoms and reduced reward functioning (Hill et al., 2023), less is known about potential protective effects of parental buffering on PVS function.

Additionally, parents are not the only sources of stress-buffering for adolescents. Other family members, such as siblings (Fry et al., 2021; Gass et al., 2007; Milevsky & Levitt, 2005), and grandparents (Attar-Schwartz & Buchana, 2019; Lila et al., 2007; Milevsky & Levitt, 2005; Oliva & Arranz, 2005) are also important sources of support. Further, there is evidence that support from other family members has an incremental positive effect on adolescents' adjustment, over and above parental support (Fry et al., 2021; Levetan & Wild, 2016; Lila et al., 2007; Van Heerden & Wild, 2018). Thus, in addition to investigating the buffering role of high-quality PCRs, the current study also considered the quality of relationships with other family members (e.g., siblings, grandparents, and parents' marital status) as a protective factor against the adverse effects of peer stress exposure on PVS functioning in adolescence.

To achieve this, we used multiple measures of PVS functioning, focusing primarily on reward-related processes as a subcomponent of PVS. Past research showed that different measures of PVS often do not correlate strongly with each other (De Los Reyes et al., 2020; Park et al., 2023; Patrick & Hajcak, 2016), suggesting that each unit of analysis may be tapping into a slightly different aspect of the construct, and that they combine to influence functioning (De Los Reyes et al., 2020). By employing multiple units of analysis, the current study aims to provide a more holistic understanding of our research question. To that end, we included a self-report measure, a behavioral measure, and three neurophysiological measures of reward sensitivity. For our self-report measure, we used the PVS Scale (Khazanov et al., 2020), which measures participants' perception of their PVS functioning, including reward sensitivity. For our behavioral measure, we employed a well-validated reward learning paradigm (Pizzagalli et al., 2005), which captures participants' ability to learn from rewards and modulate behaviors accordingly.

Finally, at the neurophysiological level, we measured the reward positivity (RewP). The RewP occurs approximately 250–350 ms following the onset of reward feedback and is more positive in amplitude following reward feedback relative to loss or no-reward feedback (Holroyd et al., 2008; Proudfit, 2015). Converging evidence suggests that the RewP may be generated by the anterior cingulate cortex (ACC) and the striatum and reflect reward signaling from the midbrain dopamine system (Becker et al., 2014; Holroyd & Coles, 2002; Holroyd & Umemoto, 2016; Santesso et al., 2008). The RewP can be elicited with feedback signaling receipt of multiple types of reward, but there are only modest associations between the components elicited across tasks and incentives (Banica et al., 2022, 2023; Beatty et al., 2024; Distefano et al., 2018; Ethridge et al., 2017; Freeman et al., 2023), suggesting that different incentive types capture distinct variance in reward sensitivity and there is utility in assessing domain-specific responding. The current study therefore examined the RewP in tasks delivering monetary, social, and food rewards.

Taken together, the current study investigated whether high-quality relationships with parents or other family members could buffer against the effects of real-world peer stress on multiple measures of reward functioning and broader PVS functioning among pre-adolescents and early-to-mid adolescents (ages 9–16 years old). Building upon extant literature suggesting the protective role of parental support in buffering against the adverse effects of stress exposure (Ge et al., 2009; Hazel et al., 2014; Rudolph et al., 2020; Wenz-Gross et al., 1997), we hypothesized that a high-quality PCR would continue to buffer against the effects of peer stress during adolescence. Specifically, we predicted that greater peer stress would be associated with reduced PVS activity across units of measurement. We further predicted that this effect would

https://doi.org/10.1017/S0954579426101862 Published online by Cambridge University Press

be qualified by an interaction with PCR, such that, when the relationship with parents was of higher quality, the association between peer stress and measures of PVS function would be weaker. We also explored this same question with family relationships (excluding parental relationships) as a buffer.

Method

Participants

Participants were adolescents recruited from Montreal and the surrounding area using online and print advertisements. Adolescents were eligible if they were between the ages of 9 and 16 years old, fluent in either English or French and had not experienced a head trauma resulting in loss of consciousness for 10 minutes or longer in the previous five years. Based on the results of the screening process, 174 adolescents were eligible to participate.

From this sample, four participants were excluded from the present analyses due to poor quality EEG recordings for the Doors task, including fewer than six artifact-free trials at the electrode site of interest (Ethridge & Weinberg, 2018) and data with extensive artifacts that could not be adequately interpolated, and two were excluded because of technological difficulties with EEG equipment. Additionally, three participants were excluded due to missing self-report data. Therefore, the final sample consisted of 165 participants between the ages of 9 and 16 years old ($M_{age} = 11.93$, $SD = 1.71$), 49.09% of whom were female. Regression models were run on all available cases for each dependent variable, as a result, sample sizes differ slightly across analyses. Three additional participants were excluded from food RewP analyses due to poor EEG quality ($N = 162$), six participants were excluded from social RewP due to poor EEG quality ($N = 159$), and nine participants were excluded from the behavioral task due to missingness (i.e., did not complete the task) ($N = 156$). In the full sample, adolescents were 78.18% White, 9.70% Asian/Pacific Islander, 6.67% Biracial, 1.21% Black, 1.21% Hispanic, 1.82% a different race or ethnicity, and 1.21% preferred not to disclose their race or ethnicity. The median annual household income of the sample was C$100,000 - C $149,999 (range = $10,000–$19,999 to greater than $250,000). Parents of ten participants (6.06%) declined to disclose their annual family income. Among the adolescents, 77.58% were living with both parents in the same home, 10.91% were living with both parents part-time (i.e., shared custody), 8.48% were living with mother full-time, 1.21% were living with father full-time, 1.21% were living full-time with mother with father living at home part-time, and 0.61% chose not to provide this information.

Procedure

Eligible adolescents provided assent, and their parents completed informed consent. Participants then completed a battery of questionnaires using Qualtrics online survey software (SAP America Inc.). Once in the laboratory, parents and adolescents completed informed consent for the remaining study procedures. Adolescents completed a series of computer tasks while EEG was recorded. Within two weeks of the laboratory visit (either before or after), adolescents completed a diagnostic interview, the UCLA life stress interview (UCLA-LSI; Hammen, 1991), and three online behavioral games through Inquisit Web (Millisecond Software LLC, Seattle) on their personal devices. Clinical psychology graduate students or post-baccalaureate research coordinators conducted interviews in either English or French, and training and supervision of interviews was provided by a clinical psychology faculty member (AW) at monthly review meetings. Data were collected from April 2021 to November 2023. Due to COVID-19 restrictions on in-person data collection, the online portion (questionnaires and interviews) were conducted 1–10 months ($M = 4.63$, $SD = 2.03$, $N = 157$) prior to the in-person visit. Participants recruited after October 2023 ($N = 8$) completed the online portion within two weeks of the in-person visit.

In addition to completing the monetary, social, and food reward tasks, adolescents also completed two other EEG tasks. The order of the computer tasks was counterbalanced across participants. Each family received C$25/hour per participant for their participation in the laboratory visit and C$112.5 for the online part of the study. All procedures were approved by McGill University's Research Ethics Board.

Measures

Interview

The UCLA Life Stress Interview for Adolescents (UCLA-LSI; Hammen, 1991) was used to assess chronic and ongoing stress exposure in major role domains in the past two years (i.e., academic, peer, romantic relationship, family, health, finance, and disappointment). Interviewers rated domains of participant reported chronic stress on a scale from 1 (e.g., for peer support, absence of peer support, frequent peer rejection, and conflict) to 5 (e.g., absence of peer conflict, getting along well with others). For analyses, the ratings were reverse-coded, so that a higher rating indicates greater stress and lower quality relationships, and a lower rating indicates lower stress and higher-quality relationships. Peer stress is the rating of general social life (e.g., high stress/low quality – total isolation from peers or frequent peer conflicts and rejection; low stress/high quality – very popular, engages in frequent social activities, and gets along well with others). PCR quality assesses the average of the relationship with both parents (e.g., low quality – poor quality relationship with parents, no other family members for support; high quality – exceptional quality relationship with parents), and family relationship quality includes the relationship with other family members excluding parents as well as the marital relationship between parents (e.g., low quality – poor quality relationships with relatives, significant tension between parents, has no other family members for support; high quality – exceptional quality relationship with other family members and minimal conflicts between parents). Ratings were made during or immediately after the interview. To ensure reliability, the interview team and the supervisor (AW) held monthly meetings where a subset of ratings from each interviewer was re-rated collectively. If discrepancies between the interviewer and the team ratings appeared, interview details were revisited and discussed until consensus was achieved. For analyses, the consensus ratings were used. This approach aligns with methods from previous studies on chronic stress in adolescents (Mackin et al., 2019; Sandre et al., 2023; Snyder et al., 2019), and research indicates that consensus ratings are significantly more valid than individual interviewer ratings (Pulakos et al., 1996).

Self-report questionnaire

Participants completed the Positive Valence Systems Scale, 21 items (PVSS-21; Khazanov et al., 2020). The PVSS-21 is a 21-item self-report measure of the RDoC PVS domain. Items assess reward sensitivity over the past two weeks, and participants make their responses using a 9-point Likert scale ranging from 1 (extremely untrue of me) to 9 (extremely true of me). The PVSS-21 has

https://doi.org/10.1017/S0954579426101862 Published online by Cambridge University Press

demonstrated good internal consistency, test–retest reliability, and factorial validity across three diverse samples (Khazanov et al., 2020). The present investigation focused on the composite score calculated by averaging the 21 items. Any missing item was replaced with the average of the other two items of the same subscale for each participant (range = 2.14-9; alpha = 0.92). The scale was also distributed in English and French.

Tasks and materials

Probabilistic reward task

Outside of the lab, participants completed an online Probabilistic Reward Task (PRT; Pizzagalli et al., 2005) on their personal devices using Inquisit Web (Millisecond Software LLC, Seattle). The PRT is designed to provide a quantitative measure of reward responsiveness and reward learning by examining response bias for more- versus less-frequently rewarded stimuli (Pizzagalli et al., 2005). For more details on this task, see the supplement. Response bias, which measures the systematic preference for the response associated with the more frequent reward, was computed as:

$$\log b = \frac{1}{2}\log\left(\frac{Frequent_{correct} * Infrequent_{incorrect}}{Frequent_{incorrect} * Infrequent_{correct}}\right)$$

A higher log *b* value indicates a higher response bias toward the more frequently rewarded stimulus.

To elicit the RewP to monetary, social, and food rewards, participants completed the Doors task (Hajcak et al., 2005), the Island Getaway Task (IG; Kujawa et al., 2014), and the Plates task (Banica et al., 2022; for details on all EEG tasks, please see the supplement). All tasks were completed on an Intel Core i7 computer using Presentation (Neurobehavioral Systems, Inc.; Albany, CA) or PsychoPy (Peirce et al., 2019) software. All stimuli were displayed on a 19-in. (48.3 cm) computer monitor.

Electroencephalogram recording and data processing

During the Doors, IG, and Plates tasks, we recorded continuous EEG with a 32-electrode cap based on the standard 10/20 layout using a BrainVision actiCHamp system (Brain Products, Munich, Germany) with a ground electrode at site FPz. We recorded data at a sampling rate of 1,000 Hz. Offline analyses were done with BrainVision Analyzer software 2.2 (Brain Products, Munich, Germany). Unsegmented data were band-pass filtered with low and high cutoffs of 0.1 and 30 Hz, respectively, with a Butterworth zero-phase filter with a 24 db/octave roll-off.

For each trial in the Doors, IG, and Plates tasks, the EEG was segmented into 2,500 ms windows starting 1,000 ms before feedback onset and continuing for 1,500 ms post-feedback. In all tasks, data were then referenced to the average of the left (TP9) and right (TP10) mastoids. Ocular corrections were done using FT9 for horizontal eye movements and FP1 for vertical eye movements (Pegg et al., 2024) based on Gratton and Coles' (Gratton et al., 1983) method. We then conducted artifact rejection using an automatic procedure where individual channels were removed from a trial if they had a voltage difference of more than 150 μV within 200 ms intervals, a voltage difference of less than 0.5 μV within 100 ms intervals, and a voltage step of more than 30 μV between sample points. Each trial of the Doors, IG, and Plates tasks were re-segmented separately into 1,200 ms, 1,500 ms, and 1,200 ms segments, respectively, and separate averages for positive and negative feedback trials were then created. The mean voltage in the time window from −200 to 0 ms (Doors and Plates) or −200 to 0 ms (IG) pre-feedback served as a baseline and was subtracted from each data point.

In the Doors and Plates task, we quantified the RewP as the average activity from 250 to 350 ms following gain feedback at electrode site Cz, guided by previous research (Banica et al., 2022; Ethridge & Weinberg, 2018; Proudfit, 2015) and visual inspection of the grand averaged waveforms. For the IG task, previous research has demonstrated that while the RewP is still maximal at site Cz, the optimal time window for scoring is typically later than in Doors or Plates (Ethridge et al., 2017; Rappaport et al., 2019). Based on visual inspection of the grand averaged waveforms and topography, we quantified the social RewP as the average activity from 300 to 400 ms following acceptance feedback at site Cz.

We calculated the split-half reliability of the ERPs based on averages of odd and even trials. For the Doors task, the Spearman-Brown coefficient was $r = .69$ for gain-related neural activity and $r = .59$ for loss-related neural activity. For the IG task, the Spearman-Brown coefficient was $r = .79$ for acceptance-related neural activity and $r = .66$ for rejection-related neural activity. For the Plates task, the Spearman-Brown coefficient was $r = .68$ for gain-related neural activity and $r = .65$ for loss-related neural activity.

Unstandardized residual RewP scores (Meyer et al., 2017; $RewP_{resid}$) were calculated separately for neural activity elicited during the Doors, IG, and Plates tasks (Banica et al., 2022; Ethridge & Weinberg, 2018). Specifically, participants' ERPs to loss or rejection were modeled as the predictor, and ERPs to gain or acceptance served as the dependent variable in a regression analysis. Unstandardized residual scores from each regression analysis were saved and used as the monetary $RewP_{resid}$, the social $RewP_{resid}$, or the food $RewP_{resid}$.

Data analysis

Statistical analyses were performed using RStudio software version 4.3.1 (R Core Team, 2023). We used multiple regressions with robust standard errors to examine whether the interaction of peer stress and PCR quality predicts various measures of PVS functioning (i.e., monetary $RewP_{resid}$, social $RewP_{resid}$, food $RewP_{resid}$, PVSS averaged reward sensitivity, and response bias log *b*). The same set of analyses were then conducted with peer stress and relationship quality with other family members. All analyses were adjusted for adolescents' age, given its expected associations with reward function (Burani et al., 2019; Melo et al., 2023), PCR (Furman & Buhrmester, 1992; Larson et al., 1996), and peer stress exposure (Cho et al., 2022; Noakes & Rinaldi, 2006). Due to the presence of 36 pairs of siblings, adjustments were made for family clusters (i.e., robust standard errors). All variables were examined with Grubb's test for outliers (Grubbs, 1969), and any univariate outlier was winsorized by replacing it with the nearest non-outlying value.

Results

Reward-related neural activity

Figure 1 displays ERP waveforms of all participants' average neural response to reward/acceptance, loss/rejection, the residual score (e.g., gain regressed onto loss), and the topographic maps showing the difference activity (e.g., gain minus loss) for monetary, social, and food reward.

https://doi.org/10.1017/S0954579426101862 Published online by Cambridge University Press

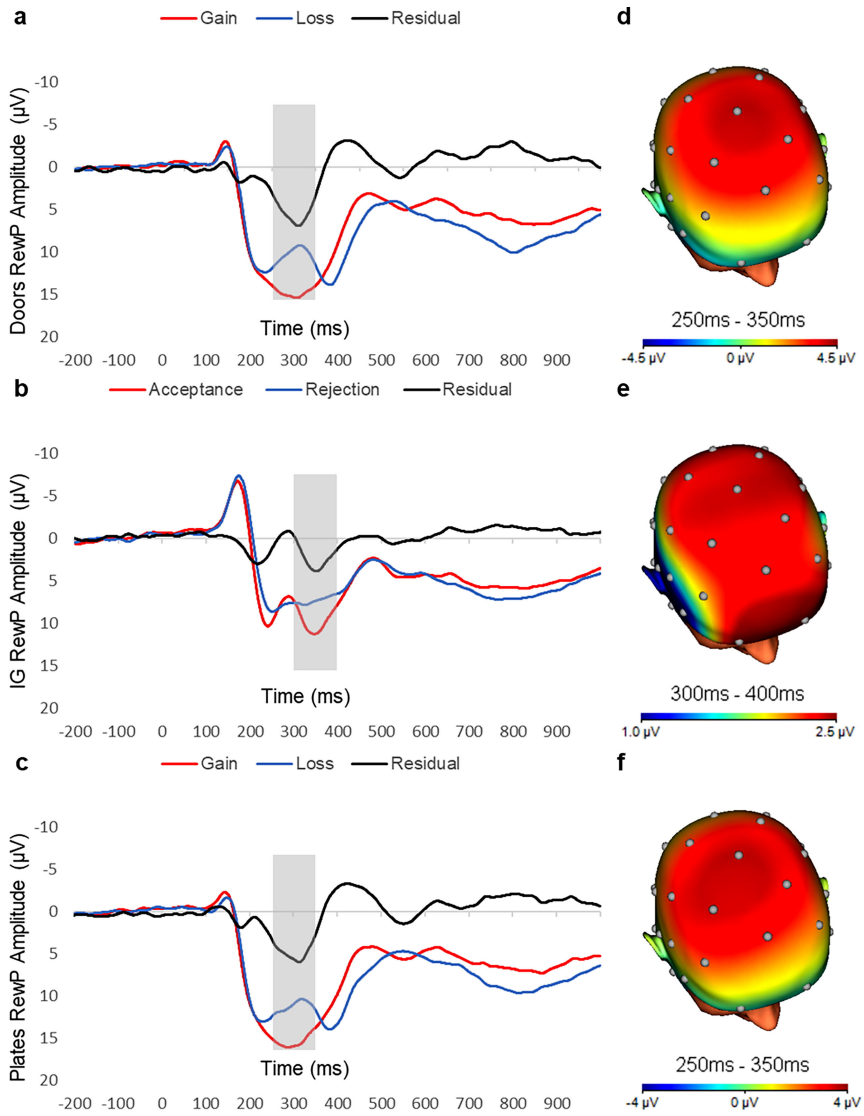


Figure 1. *ERP average waveforms and topographic maps following monetary, social, and food reward. Note.* The first column displays waveforms following gain, loss, and the residuals (gain regressed onto loss) wave, at electrode site Cz for a) monetary, b) social, and c) food reward. The second column displays topographic maps that show the average difference between gain and loss responses from d) and f) 250 ms to 350 ms post-feedback onset for monetary and food reward, and from e) 300 ms to 400 ms post-feedback onset for social reward.

Results of the Student's paired t-tests indicated statistically significant condition effects on neural activity at electrode site Cz for monetary reward (mean difference = 4.77; $t(164) = 9.89$, $p < .01$), social reward (mean difference = 2.57; $t(158) = 5.00$, $p < .01$), and food reward (mean difference = 4.41; $t(160) = 8.66$, $p < .01$), such that neural responses to positive feedback were significantly more positive than neural responses following negative feedback. Additionally, we ran a 2 (Condition: gain, loss) x 3 (Task: monetary, social, food) repeated-measures ANOVA to examine condition and task effects, and results were reported in the Supplement.

Table 1 shows the descriptive statistics for PCR quality, family relationship quality, chronic peer stress, age, self-reported reward sensitivity, behavioral response bias, and the $RewP_{resid}$ to monetary, social, and food reward. Table 1 also presents bivariate correlations among these variables. As indicated, PCR quality and family relationship quality are positively correlated, and both were positively associated with peer stress (note that a higher score indicates a *lower* quality relationship). Lower quality parent–child and family relationships and higher levels of peer stress were associated with lower self-reported PVS functioning. Among the different indicators of PVS functioning, there were generally small and non-significant associations, particularly across methods, with the following exceptions: there was a small positive correlation between the monetary RewP and behavioral measures of reward sensitivity. Additionally, the monetary RewP was positively correlated with both the social and food RewPs, which were not significantly correlated with one another.

Parental stress-buffering

Results of multiple regressions with robust standard errors are displayed in Table 2. The results showed that peer stress and PCR quality interacted to predict both the monetary $RewP_{resid}$ ($\beta = 0.17$, $p = .020$; Figure 2A) and behavioral reward sensitivity ($\beta = 0.15$, $p = .040$; Figure 2B). Specifically, greater peer stress was significantly associated with reduced reward sensitivity, but only in the context of *greater* PCR quality (less parental stress). Simple slope analyses (Table 3) revealed that, for the monetary $RewP_{resid}$, the slope of peer stress predicting the RewP was significant when the quality of PCR was high (low parental stress). When predicting behavioral reward sensitivity, though the three slopes differed significantly from one another, none were significant. The effect of the interaction between peer stress and PCR quality predicting

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Table 1. Descriptive statistics and bivariate correlations between parent–child and family relationship quality, peer stress, self-report, behavioral, and neural measures of reward sensitivity

	1.	2.	3.	4.	5.	6.	7.	8.	Mean	*SD*	Range
1. PCR quality	–								2.02	0.67	1 - 4
2. Family quality	**0.63*****	–							−3.78	0.81	1.5 - 5
3. Peer stress	**0.38*****	**0.45*****	–						−2.47	0.76	1 - 5
4. Age	**0.28*****	0.10	0.05	–					11.93	1.71	9 - 16
5. PVSS	**−0.25****	**−0.36*****	**−0.26****	−0.12	–				6.60	1.37	2.14 - 9.00
6. PRT logb	0.07	0.04	−0.02	−0.02	0	–			0.07	0.19	−0.56 - 0.60
7. Monetary RewP	−0.07	0.05	−0.08	−0.02	−0.10	**0.16***	–		0.19	5.92	−15.45 - 17.28
8. Social RewP	−0.03	0.05	0.03	0.15	0.02	0.07	**0.34*****	–	0.07	6.24	−17.21 - 17.11
9. Food RewP	−0.03	-0.08	−0.07	−0.07	−0.03	0.08	**0.37*****	0.07	0	6.37	−18.65 - 18.25

Note: *** $p < .001$; ** $p < .01$; * $p < .05$. Parent–Child Relationship Quality (PCR Quality), Family Relationship Quality (Family Quality; excluding parents), and Peer Stress were collected from UCLA-LSI with 1 being the least stressful (high-quality relationship) and 5 being the most stressful (low quality relationship), such that higher scores reflect lower quality relationships and greater stress exposure. PVSS = reward sensitivity measured by PVSS. PRT log*b* = behavioral response bias calculated from PRT task. Monetary RewP = monetary $RewP_{resid}$ amplitude (μV) elicited from the Doors task. Social RewP = social $RewP_{resid}$ amplitude (μV) elicited from the IG task. Food RewP = food $RewP_{resid}$ amplitude (μV) elicited from the Plates task. Data from 165 participants were available on Parent–Child Relationship Quality, Peer Stress, Age, PVSS, and Monetary RewP. Family Relationship Quality had 155 data points, PRT log*b* had 156 data points, Social RewP had 159 data points, and Food RewP had 162 data points.

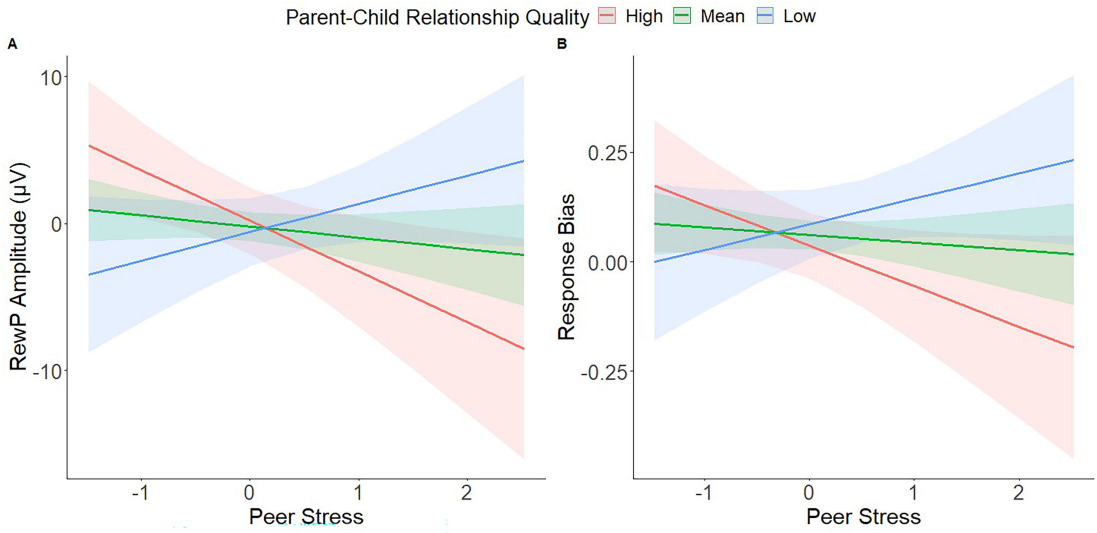


Figure 2. *Interaction plots moderated by different levels of parent–child relationship quality. Note.* Plots of simple slopes that depict the effect of chronic peer stress exposure on A) the amplitude of the monetary $RewP_{resid}$ and B) the degree of response bias (i.e., behavioral reward sensitivity) at high (-2 *SD*), average, and low (+2 *SD*) levels of parent–child relationship quality, adjusting for age and family clusters.

food $RewP_{resid}$ ($\beta = 0.12$, $p = .057$) was of a similar magnitude and in the same direction as the interaction predicting the monetary RewP as the outcome, but was not significant. No significant interaction was observed when predicting self-reported reward sensitivity ($\beta = -0.07$, $p = .395$) or social $RewP_{resid}$ ($\beta = 0.01$, $p = .876$) as the outcomes. Sensitivity analyses adjusting for different covariates are reported in the Supplement, including adolescent gender, the time between virtual and in-person lab visit, and adolescent depressive symptoms. The results reported here did not substantively change after inclusion of these covariates.

Exploratory analyses: other family stress-buffering

Results of multiple regressions revealed that no significant interaction between peer stress and family relationship quality (i.e., excluding parents) was found when predicting self-reported reward sensitivity, behavioral reward sensitivity, and neurophysiological measures of reward sensitivity as the outcomes ($ps > .136$). Detailed results are reported in the supplement.

Discussion

The present study examined whether a high-quality PCR buffers the association between peer stress exposure and measures of reward and broader PVS functioning in adolescents. We observed significant moderation for some, but not all, PVS measures, and the direction was contrary to our hypothesis. PCR quality moderated the association between peer stress exposure and both the monetary RewP and behavioral response bias but did not significantly moderate effects on self-report measures or on the social and food RewPs. Where moderation emerged, higher-quality PCRs were associated with *less* reward activation under conditions

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Table 2. Results of five separate robust-standard error multiple regression analyses investigating the effects of the interaction between peer stress and parent–child relationship quality on self-reported, behavioral, and neurophysiological measures of PVS functioning

Predictor	*b* (*SE*)	*β*	*p*	95% CI
Regression one: predicting self-reported reward sensitivity				
Peer stress	−0.34 (0.18)	−0.19	.056	[−0.63, -0.05]
PCR quality	−0.30 (0.16)	−0.15	.068	[−0.65, 0.05]
Age	−0.05 (0.06)	−0.06	.468	[−0.17, 0.08]
Peer stress × PCR quality	−0.20 (0.23)	−0.07	.395	[−0.58, 0.19]
Regression two: predicting behavioral reward sensitivity				
Peer stress	−0.02 (0.03)	−0.07	.504	[−0.06, 0.03]
PCR quality	0.02 (0.03)	0.06	.526	[−0.03, 0.07]
Age	−0.01 (0.01)	−0.05	.633	[−0.02, 0.01]
Peer stress × PCR quality	**0.06 (0.03)**	**0.15**	**.040**	**[-0.002, 0.11]**
Regression three: predicting monetary $RewP_{resid}$				
Peer stress	−0.76 (0.77)	−0.10	.325	[−2.06, 0.54]
PCR quality	−0.29 (0.67)	−0.03	.647	[−1.84, 1.26]
Age	−0.12 (0.27)	−0.03	.665	[−0.67, 0.43]
Peer stress × PCR quality	**2.01 (0.86)**	**0.17**	**.020**	**[0.29, 3.74]**
Regression four: predicting social $RewP_{resid}$				
Peer stress	0.30 (0.81)	0.04	.711	[−1.10, 1.70]
PCR quality	−0.83 (0.88)	−0.09	.350	[−2.49, 0.83]
Age	0.56 (0.32)	0.15	.080	[−0.03, 1.14]
Peer stress × PCR quality	0.14 (0.92)	0.01	.876	[−1.70, 1.99]
Regression five: predicting food $RewP_{resid}$				
Peer stress	−0.64 (0.79)	−0.07	.431	[−2.11, 0.82]
PCR quality	−0.11 (0.81)	−0.01	.877	[−1.82, 1.60]
Age	−0.26 (0.29)	−0.07	.367	[−0.86, 0.35]
Peer stress × PCR quality	1.45 (0.76)	0.12	.057	[−0.46, 3.36]

Note. Statistically significant values ($p < .05$) are bolded. A higher score on PCR Quality scale indicates a lower quality relationship.

Table 3. Simple slope analyses for associations between peer stress and behavioral reward sensitivity and monetary RewP at different levels of parent child relationship (PCR) quality

Predictor (±2 *SD*)	*b* (*SE*)	*p*	95% CI
Predicting behavioral reward sensitivity			
High PCR quality	−0.09 (0.05)	.062	[−0.19, 0.005]
Average PCR quality	−0.02 (0.03)	.523	[−0.07, 0.04]
Low PCR quality	0.06 (0.05)	.235	[−0.04, 0.16]
Predicting monetary $RewP_{resid}$			
High PCR quality	**−3.45 (1.58)**	**.031**	**[−6.58, −0.03]**
Average PCR quality	−0.76 (0.84)	.363	[−2.42, 0.89]
Low PCR quality	1.93 (1.44)	.183	[−0.92, 4.78]

Note. Statistically significant values ($p < .05$) are bolded.

of elevated peer stress. These findings suggest that the buffering role of PCRs is more complex than previously assumed and may operate differently across PVS measures.

Drawing on existing work on parental stress-buffering (Conners-Burrow et al., 2009; Davidson & Demaray, 2007; Hazel et al., 2014; Rudolph et al., 2020; Sejourne et al., 2025; Tanigawa et al., 2011; Wenz-Gross et al., 1997), we hypothesized a weaker association between exposure to peer stress and measures of PVS function in adolescents with a higher-quality relationship with their parents. Instead, the negative association between peer stress and the monetary RewP and behavioral measures of reward learning was significant only at high levels of PCR quality. These results are partially consistent with evidence that parental support is often a less reliable stress buffer in adolescence than in childhood (Burke et al., 2017; Burton et al., 2004; Hostinar et al., 2015; Martínez et al., 2024; Yeung Thompson & Leadbeater, 2013). Adolescents, compared to younger children, have a stronger natural interest in interacting with peers (Forbes & Dahl, 2010; Nelson et al., 2005, 2016) and spend less time overall with their parents and more time with peers (Lam et al., 2014; Larson & Richards, 1991; Larson et al., 1996). Additionally, social environments outside of family, including support from friends, classmates, and teachers, are critical for an adolescent's psychosocial development (Bronfenbrenner, 2005; Chu et al., 2010; Hombrados-Mendieta et al., 2012). During this period of social reorientation, support from parents may play a different role in an adolescent's social support network than we anticipated, and other sources (e.g., close friends or romantic partners; Cooley et al., 2015; Cuadros & Berger, 2016) may more effectively buffer against the effects of peer stress. This moderation pattern may also help explain some inconsistent findings in prior work examining associations between peer stress and reward functioning, such that studies that did not account for PCR quality may have averaged across youths at high and low levels of PCR quality, potentially obscuring the effects.

Additionally, prior work has also found evidence of a "reverse buffering" effect of close parental relationships on the association between peer stress exposure and an array of PVS-relevant outcomes. For instance, in a meta-analysis examining social support and depression in youth, Rueger and colleagues (2016) found that under certain stressful conditions (e.g., shared stressors between youth and source of support), youth may not be able to benefit fully from social support. Consistent with this, Chen and Kühner (2025) found that family support exacerbated the association between pandemic stress exposure and negative affect and unhappiness among children and adolescents. Furthermore, Desjardins and Leadbeater (2011) found that peer victimization longitudinally predicted increased depressive symptoms only among adolescents with high maternal emotional support. Interestingly, they also found that paternal support buffered the association, again pointing to the complex role social support from different figures may play in buffering against the effects of stress exposure.

Multiple mechanisms have been proposed to explain this reverse buffering effect (Rueger et al., 2016), including two related constructs, co-rumination and enmeshment (Ames-Sikora et al., 2017; Waller & Rose, 2010). Co-rumination refers to the excessive discussion of problems, especially focusing on rehashing negative events and dwelling on negative affect (Rose, 2002, 2021), and has been positively associated with PCR quality (Ames-Sikora et al., 2017; Bastin et al., 2021; Waller & Rose, 2010). However, it is also linked to enmeshment in PCRs (Waller & Rose, 2010), which can limit children's autonomy and independence, making them more susceptible to the effects of stress (Kivisto et al., 2015; Marusak et al., 2018). Further, co-rumination with parents has been found to predict internalizing symptoms in adolescents in

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both cross-sectional (Miller-Slough & Dunsmore, 2021; Waller & Rose, 2010) and longitudinal (Ioffe et al., 2020) research designs. In the context of high peer stress, adolescents with high-quality, and highly enmeshed, PCRs may engage in more co-rumination that inadvertently amplifies the adverse effects of stress exposure by prolonging the focus on peer-related problems. Enmeshment that limits autonomy may also contribute to PVS dysfunction, given that reward functioning has been associated with autonomy-related behaviors, such as environmental exploration (Freeman et al., 2020; Van Leijenhorst et al., 2010). However, there is also evidence that high-quality PCR is often characterized by autonomy support, rather than autonomy constraint (Jameel et al., 2024; Jiao, 2020), and our study did not assess these aspects of the relationship. Future studies should further explore this question by including measures of co-rumination, enmeshment, and autonomy support during periods of stress exposure to better understand when, and for whom, a high-quality PCR effectively buffers against peer stress.

Another possible explanation for our findings is that adolescents with the combination of elevated peer stress and blunted reward activation (e.g., a smaller RewP) *elicit* greater parental involvement. For example, youth with blunted reward activation may exhibit more anhedonic and depressive symptoms (Baskin-Sommers & Foti, 2015; Ellis et al., 2019; Epstein et al., 2006; Halahakoon et al., 2020; Thompson et al., 2023), especially when they are chronically exposed to stressors (Dennison et al., 2016; Goldstein et al., 2020). Additionally, research suggests that blunted reward functioning may itself generate future stress exposure through a stress generation pathway (Mackin et al., 2019), such that adolescents with blunted reward functioning may be prone to experience more interpersonal stressors over time, and in turn experience more depressive symptoms. Through both pathways, parents may increase their involvement in response to their child's distress (Van der Giessen et al., 2014; Werner et al., 2016). Future longitudinal studies are needed to explore the directionality of these associations.

Finally, the reverse buffering effects observed here might also reflect the effects of a "healthy context paradox" (Salmivalli, 2018; Yun & Juvonen, 2020), which refers to the phenomenon where the effect of victimization is worse in healthier contexts. Although this concept has been primarily examined in classroom settings, it is possible that adolescents who grow up in high-quality PCRs may experience peer stress as more salient and distressing. This interpretation remains speculative and future research is needed to directly test this possibility.

Outside of the parental relationship, our results also demonstrated that the quality of the relationship with other family members (e.g., siblings, grandparents, other extended family members) did not have a significant buffering role, which is contrary to findings suggesting an incremental value of family support (Levetan & Wild, 2016; Lila et al., 2007; Van Heerden & Wild, 2018). Although we hypothesized that adolescents would benefit from support from their broader family network, it is possible that adolescents are overall less likely to seek support from family members other than their parents regarding peer-related stressors (Nickerson & Nagle, 2005). Therefore, this form of support may be less relevant or effective in buffering the effects of peer stress on reward processing during this developmental period. Moreover, our measure of family relationship aggregates multiple types of relationships, including siblings, grandparents, other extended relatives, and the relationship between the parents. While some studies suggest that siblings and grandparents can play a protective role in the face of peer stress (Attar-Schwartz & Buchana, 2019; Fry et al., 2021; Lockwood et al., 2002), our design did not allow us to isolate whether a high-quality family relationship reflects sibling support, grandparent support, support from other extended family members, or all of them. As such, future research could investigate the buffering role of each type of relationship separately.

In addition to reverse stress-buffering effects, the current findings also suggest differential effects for different PVS measures across units of analysis, including a self-report questionnaire of PVS functioning, a behavioral monetary reward learning task, and RewPs elicited from monetary, food, and social rewards. In the current study, those measures were at most only modestly correlated with one another, which is consistent with the extant literature indicating that different measures of PVS are often not strongly associated (De Los Reyes et al., 2020; Park et al., 2023; Patrick & Hajcak, 2016). This lack of strong convergence suggests that each unit of analysis is tapping a slightly different aspect of the construct. For instance, RewP is contingent on rewarding feedback and captures unobservable, internal processes related to rewarding experiences (De Los Reyes et al., 2020). In contrast, behavioral indices of reward sensitivity reflect more observable, external processes, such as learning in response to rewards (De Los Reyes et al., 2020). Furthermore, the modest correlations among the RewPs may, at least in part, reflect some task-specific influences, such as task design (Lawhead et al., 2024), as has been observed in studies of other ERP components (Riesel et al., 2013). Although prior work has found associations between interpersonal stress exposure and neural responses to both monetary (Ethridge et al., 2018) and social rewards (Panier et al., 2022; Rappaport et al., 2019; Sejourne et al., 2025) across development (Pegg & Kujawa, 2024), we only observed significant effects of peer stress exposure on the monetary RewP. The reasons for this discrepancy are unclear, but may reflect methodological differences across studies, including variability in the type and chronicity of peer stress assessed and the developmental stage of participants, which warrant future research. These distinct but overlapping aspects of PVS likely combine to influence functioning, emphasizing the importance of a multi-method approach to fully capture the construct.

Limitations of the present study suggest directions for future research. First, high-quality PCRs may differentially moderate the association between peer stress and PVS functioning across stages of adolescence and for adolescents of different sex or gender. Doom and colleagues (2015) found that the stress-buffering role of parental support diminishes with adolescent pubertal development, partially due to hormonal changes during puberty. Additionally, a longitudinal study found that maternal support buffered against the impact of victimization only for early adolescent girls, whereas father support showed a significant buffering effect only among older adolescent boys (Yeung Thompson & Leadbeater, 2013). Future research with a larger sample size should explore how PCR interacts with peer stress across developmental stages, including transitions from early to late adolescence, as well as the impact of sex and gender differences. Second, the current sample is predominantly White and middle class, which limits the generalizability of the findings. Cultural norms may influence parenting practices and their impact on youth functioning (Lansford, 2022; Louie et al., 2013; Mousavi et al., 2016). Future research should therefore explore a more diverse sample.

In summary, the current study found that among adolescents experiencing higher peer stress, those with a higher-quality relationship with parents exhibited reduced neurophysiological and

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behavioral reward sensitivity, contrary to the expected buffering role of high-quality PCRs. These results suggest important directions for future research. Additionally, we found differential associations for different measures of PVS functioning, suggesting the importance of a multi-method approach for understanding reward processing in adolescence. This study thereby contributes to the literature on adolescent development by further exploring the interaction of peer stress, PCR, and reward processing, which can ultimately inform prevention and intervention strategies to promote adaptive family and peer relationships.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0954579426101862.

Data availability statement. The data and R code associated with this manuscript as well as the code and stimuli for the EEG tasks can be found at: https://osf.io/h6p5d/.

Acknowledgments. N/A.

Funding statement. This work was supported by a grant to A.W., from Canadian Institutes of Health Research (grant number: 427055).

Competing interests. The authors declare none.

Pre-registration statement. This work was not pre-registered.

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https://doi.org/10.1017/S0954579426101862 Published online by Cambridge University Press