Development and Psychopathology (2024), **36**, 69–81
doi:10.1017/S0954579422000967

CAMBRIDGE UNIVERSITY PRESS

Regular Article

Susceptibility to peer influence in adolescents: Associations between psychophysiology and behavior

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Abstract

The current study investigated in-the-moment links between adolescents' autonomic nervous system activity and susceptibility to three types of peer influence (indirect, direct, continuing) on two types of behavior (antisocial, prosocial). The sample included 144 racially ethnically diverse adolescents (46% male, 53% female, 1% other; $M_{age} = 16.02$ years). We assessed susceptibility to peer influence behaviorally using the Public Goods Game (PGG) while measuring adolescents' mean heart rate (MHR) and pre-ejection period (PEP). Three key findings emerged from bivariate dual latent change score modeling: (1) adolescents whose MHR increased more as they transitioned from playing the PGG alone (pre-influence) to playing while simply observed by peers (indirect influence) displayed more prosocial behavior; (2) adolescents whose PEP activity increased more (greater PEP activity = shorter PEP latency) as they transitioned from indirect influence to being encouraged by peers to engage in antisocial behavior (direct influence) engaged in more antisocial behavior; and (3) adolescents whose PEP activity decreased less as they transitioned from direct influence on prosocial behavior to playing the PGG alone again (continuing influence) displayed more continuing prosocial behavior (marginal effect). The discussion focuses on the role of psychophysiology in understanding adolescents' susceptibility to peer influence.

Keywords: antisocial; peer influence; prosocial; psychophysiology; susceptibility

(Received 7 April 2022; revised 19 July 2022; accepted 21 July 2022; First Published online 23 September 2022)

As adolescents spend more time together, peers' influence over one another increases (Steinberg & Lerner, 2004). Peer influence is not inherently negative and is, in fact, critical to healthy development (Allen & Antonishak, 2008). At the same time, it increases the risk of developing maladaptive behaviors (e.g., delinquency; Müller & Minger, 2013). For this reason, it is essential to understand the processes that lead some teens to be more susceptible to peer influence than others. The goal of the current study was to investigate in-the-moment relations between autonomic nervous system (ANS) activity and susceptibility to peer influence.

Peer influence

Although peer influence is often conceptualized as harmful, teens influence one another to engage in various behaviors. Of course, these actions include antisocial behaviors such as lying, stealing, and cheating (Calkins & Keane, 2009). At the same time, peers also influence each other to engage in prosocial behaviors such as helping, sharing, and cooperating (Dirks et al., 2018). Finally, teens encourage peers to engage in risky behaviors such as substance use which are not clearly categorized as prosocial or antisocial (Prinstein & Dodge, 2008).

Another important distinction is the degree of peer involvement in peer influence. We typically imagine peers influencing one another through the explicit encouragement of specific behaviors, a process termed direct influence. However, the mere presence of peers is enough to alter adolescent behavior, a phenomenon labeled indirect influence. In addition, even when teens are no longer in the presence of peers who directly influenced them, they may continue to engage in the behaviors that peers encouraged, a construct we call continuing influence.

Extant research uses inconsistent terminology when referring to types of peer influence; thus, it is important to clarify how our nomenclature maps onto existing work. Direct influence has elsewhere been termed peer feedback (van Hoorn et al., 2014, 2016), peer contagion (Cohen & Prinstein, 2006), exposure to social norms (Prinstein et al., 2011), and exposure to peer groups (Gardner & Steinberg, 2005). Likewise, indirect influence has been termed social evaluation (Somerville, 2013) or the presence of peer spectators (van Hoorn et al., 2014, 2016) or peer observers (Silva et al., 2016). The phenomenon of continuing influence has rarely been directly studied in the literature and, thus, is not referred to explicitly.

Experimental studies have documented teens' susceptibility to direct, indirect, and continuing peer influence on antisocial and risky behaviors. van Hoorn and colleagues (2014) demonstrated that adolescents display more antisocial behavior when encouraged to do so by peers, and Cohen and Prinstein (2006) found this same direct influence effect on both antisocial and risky behaviors. Teens also engage in more antisocial and risky behaviors simply when in the presence of peers compared to when they are alone, although this effect is typically weaker than the direct influence

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Cite this article: Meehan, Z. M., *et al.* (2024). Susceptibility to peer influence in adolescents: Associations between psychophysiology and behavior. *Development and Psychopathology* **36**: 69–81, https://doi.org/10.1017/S0954579422000967

effect (Gardner & Steinberg, 2005; Reynolds et al., 2014; Silva et al., 2016). Finally, the effects of direct influence on antisocial and risky behaviors continue even when peers are no longer present, although this continuing effect is less than the preceding effect of direct influence (Cohen & Prinstein, 2006; Prinstein et al., 2011; van Hoorn et al., 2014).

There is also experimental support for adolescents' susceptibility to direct and continuing peer influence on prosocial behaviors. Teens display more prosocial behavior when directly encouraged by peers to do so (van Hoorn et al., 2014) or when they learn that peers intend to engage in these behaviors themselves (Choukas-Bradley et al., 2015; Foulkes et al., 2018). Moreover, peer influence on prosocial behavior continues when peers are no longer present, although again, this effect often is weaker than the preceding effect of direct influence (Choukas-Bradley et al., 2015; Frey & Meier, 2004; van Hoorn et al., 2014). To our knowledge, only two studies have investigated indirect influence on prosocial behavior, and the findings differed. Whereas van Hoorn and colleagues (2016) showed that teens' prosocial behavior increased when simply in the presence of peers, van Hoorn and colleagues (2014) failed to find this effect.

With some exceptions, most investigations cited above compared two types of influence on one type of behavior. In the current study, we assessed three types of peer influence (indirect, direct, continuing) on two forms of behavior (antisocial, prosocial). In this way, we aimed to advance our understanding of the differential effects of indirect, direct, and continuing influence on both antisocial and prosocial behavior.

Susceptibility to peer influence

Adolescents are especially likely to conform to peers' expectations. In an investigation by Gardner and Steinberg (2005), adolescents engaged in equal amounts of risk-taking as adults when they were alone. However, adolescents but not adults increased their risk-taking in the presence of peers. This study exemplifies the literature demonstrating that adolescents can make wise choices as well as adults (e.g., Reyna & Panagiotopoulos, 2020), but are more likely to fail to use these skills when in the presence of peers (Albert et al., 2013).

Although teens are typically more susceptible to peer influence than adults (Steinberg & Monahan, 2007), some adolescents are more susceptible than others. Müller and Minger (2013) reviewed 66 studies of factors predicting susceptibility to peer influence on antisocial behavior. They concluded that the strongest and most reliable predictor was age, with those in early and middle adolescence being most susceptible.

Albert and Steinberg (2011) proposed a theory to explain adolescents' unique susceptibility to peer influence. They postulated that the adolescent brain is in a phase of development in which peers are particularly likely to activate a reward-sensitive motivational state (Cauffman et al., 2010). In the presence of peers, adolescents are especially likely to choose short-term gratification over long-term safety/benefit, because the simple presence of peers primes them to focus on immediate rewards. Although this framework focuses on antisocial and risky behaviors, the same reward-salient priming effect occurs around prosocial behaviors as well (e.g., Kwak & Huettel, 2016; van Hoorn et al., 2014, 2016).

Albert and Steinberg (2011) also theorized that heightened emotional arousal or blunted emotion regulation might increase adolescents' susceptibility to peer influence, a theory backed by empirical support (Chein et al., 2011; Cohen et al., 2016). Adolescents, more so than children or adults, show heightened emotional arousal (Somerville et al., 2013) and reduced emotion regulation (Perino et al., 2016; Somerville et al., 2011) when simply in the presence of peers. Furthermore, Gardner and colleagues (2008) found that individual differences in adolescents' emotion regulation corresponded to their susceptibility to peer influence on risky behaviors.

Indeed, in their recent review of neurobiological studies of adolescents' susceptibility to peer influence, Do and colleagues (2020) highlighted neural markers of both social reward processing and emotional arousal/dysregulation. They speculated that individual differences in both domains play an important role in differential susceptibility to peer influence, and they summarized investigations providing empirical support for this speculation (e.g., Chein et al., 2011; Pfeifer et al., 2011; Somerville et al., 2013; Welborn et al., 2016).

Notably absent from both reviews (Do et al., 2020; Müller & Minger, 2013) were investigations of psychophysiological factors predicting susceptibility to peer influence. However, prominent researchers have touted the promise of psychophysiology as an explanation for adolescent social behavior (e.g., Murray-Close, 2012a, 2012b; Prinstein & Giletta, 2020). In the current study, we examine physiological predictors of susceptibility to peer influence, and to the best of our knowledge, this is the first study to do so. Based on Albert and Steinberg's (2011) theorizing on the role of both emotional arousal and reward sensitivity in adolescents' susceptibility to peer influence, as well as Do and colleagues (2020) review of the role of neural markers of these constructs in the context of peer influence specifically, we chose physiological indices linked to emotional arousal and reward sensitivity. More broadly, the current study fits nicely within the theoretical framework of biological sensitivity to context (Ellis & Boyce, 2008), in that we investigate whether psychophysiology can help us understand which adolescents are especially likely to change their behavior in response to peer influence.

Psychophysiology and susceptibility to peer influence

Composed of the sympathetic (SNS) and parasympathetic nervous systems (PNS), the ANS is the most-studied physiological system in the peer literature (Murray-Close, 2012a). The SNS is responsible for excitatory functions (e.g., fight or flight), whereas the PNS is responsible for inhibitory and restorative functions (e.g., rest and restore; Murray-Close, 2012a).

The cardiovascular system is an excellent target for ANS study because multiple physiological measures can be derived from its output using electrocardiography (ECG) to record electrical signals of the heart and impedance cardiography (ICG) to record changes in blood volume. Perhaps the most recognizable metric of ECG is mean heart rate (MHR). MHR indexes either SNS activity (Anderson & Adolphs, 2014) or PNS activity (Thayer & Lane, 2000), depending upon the use of the vagal brake as assessed through respiratory sinus arrhythmia (RSA; Porges, 2001). However, when MHR increases following stressful and/or excitatory events such as peer influence, this physiological change may illustrate a normative emotional response (Stroud et al., 2009), serve as a reliable proxy of energy expenditure (Halsey et al., 2019), and suggest ANS activation driven by emotional arousal or dysregulation (Anderson & Adolphs, 2014). In fact, Wascher recently explicitly stated that increased MHR is considered a measure of emotional arousal in the context of evolutionary biology (Wascher, 2021).

https://doi.org/10.1017/S0954579422000967 Published online by Cambridge University Press

A second cardiac metric is pre-ejection period (PEP), a measure of cardiac contractility requiring both ECG and ICG. PEP is the moment between the depolarization of the left ventricle and when the cardiac valves close. PEP may be uniquely suited as an indicator of reward sensitivity (Beauchaine et al., 2013). Brenner and colleagues (2005) examined whether PEP, RSA, or heart rate reactivity best assessed reward responsivity and found PEP to be the most psychometrically strong metric. Additional studies have validated PEP as an index of reward sensitivity in social situations in particular (Brinkmann & Franzen, 2017; Franzen et al., 2019).

The current study

The goal of the current study was to examine ANS activity as a predictor of adolescents' susceptibility to peer influence. Strengths of the study include: (1) the study of susceptibility to three types of peer influence (indirect, direct, continuing), (2) the investigation of peer influence on two types of behavior (prosocial, antisocial), and (3) the use of two metrics of ANS activity (MHR, PEP). We hypothesized that adolescents who experienced greater ANS activity during peer influence would be more susceptible across all three types of peer influence on both types of behavior across both ANS activity indices.

An additional strength is the measurement of ANS activity at the same moment that adolescents experience peer influence and respond behaviorally. Most investigations assess youths' physiology in a different context than the behavior it is hypothesized to predict (see Murray-Close, 2012b for a review). Some studies simply assess baseline physiology and use it to predict social behavior (e.g., Crozier et al., 2008). Other investigations do assess physiology in a social context but use it to predict behavior as reported by the youth themselves or their parents, teachers, or peers (e.g., Hubbard et al., 2002). However, with few exceptions (e.g., Moore et al., 2018), researchers have not measured physiology and the behavior it is hypothesized to predict at the same moment. In the current study, we assessed both ANS activity and behavioral responses to peer influence at the same moment in time. Moreover, we analyzed their co-occurrence using bivariate latent change score modeling (Kievit et al., 2018), with a particular focus on the covariation of latent change scores indexing ANS activity and behavioral responding to peer influence (referred to as the "path of primary interest" in the Results).

A final strength of the study was the inclusion of both baseline measures of ANS activity and a self-report measure of emotion regulation as covariates in analyses. This approach allowed us to investigate whether state-like ANS activity predicted in-the-moment behavioral responses to peer influence over and above trait-like differences in emotional and physiological functioning. These covariates were particularly important in establishing that potential in-the-moment links between physiology and behavior were not simply the result of underlying individual differences in emotional or physiological functioning, but rather, that ANS activity in response to peer influence in fact served as a unique driver of behavior in that very moment.

Method

Overview

As part of a larger project involving a two-hour laboratory visit, 144 participants completed an experimental task assessing susceptibility to peer influence as we measured their ANS activity. In addition, adolescents reported on their ability to regulate emotions, and parents reported on family demographics. At the end of the visit, the experimenter debriefed adolescents (including an explanation of the deception described below), answered questions, and compensated adolescents and parents for their participation with \$20 and \$10, respectively.

Participants

Original cohort

During 2013–2014, we recruited participants from 74 4th- and 5th-grade classrooms in 9 schools in a mid-Atlantic state. We sent parental permission forms home with 1,910 children; 62% of children received parental consent, provided child assent, and completed data collection (N = 1191). Parents of 988 children agreed to be re-contacted for future studies.

Current cohort

From June 2019 to February 2020, we recruited a subsample of the original cohort through mail, email, and phone for additional data collection in 10th or 11th grade. We contacted all participants with up-to-date contact information, and we recruited all participants whose parents consented and who assented. Initial mail or email contacts were followed by a phone call, during which we thoroughly explained procedures to parents, including the fact that adolescents would be deceived.

The current cohort included 145 adolescents (46% male, 53% female, and 1% other) with an average age of 16.02 years (SD = 0.63). However, one participant ended the lab visit before the assessment of susceptibility to peer influence could be completed, resulting in an effective sample size of 144. This sample's racial/ethnic breakdown was 65% European American, 12% African American, 10% Latino American, 7% Asian American, and 6% mixed race or ethnicity. Parents reported annual household income as less than \$20,000 (3%), \$20,000–\$50,000 (16%), \$50,000–100,000 (22%), \$100,000–\$150,000 (22%), and greater than \$150,000 (36%).

We compared the 145 participants in the current cohort to the remaining 1044 participants in the original cohort on 4th or 5th grade variables, including demographics, peer victimization (teacher-, self-, and peer-report), peer rejection (teacher- and peer-report), and depressive and anxious symptoms (teacher- and self-report). Participants in the current cohort (64%) were more likely to be European American than youth who participated in the original study but not the current study (50%), $\chi^2(1) = 10.07$, p = .002.

Procedures and measures

Self-reported emotion regulation

Adolescents completed the Emotion Regulation Questionnaire (ERQ; Gullone & Taffe, 2012). A sample item was "I control my feelings about things by changing the way I think about them," and adolescents responded on a scale from *1 = Strongly Disagree* to *5 = Strongly Agree*. The measure possesses strong construct and convergent validity (Gullone & Taffe, 2012). We averaged ratings across the ten items, with higher scores reflecting greater emotion regulation, and labeled this variable Emotion Regulation. Cronbach's alpha was .69. Unfortunately, our data set did not include an analogous trait-like self-report measure of reward processing.

Susceptibility to peer influence

Adolescents completed a four-minute computerized version of the Public Goods Game (PGG) adapted from the protocol used by van Hoorn and colleagues (2014, 2016). The experimenter explained the rules using standardized instructions, visual aids, and comprehension checks. Adolescents believed they were one of four online players, all participating from different universities; in truth, the other three players were virtual. In each of 30 rounds, players received five tokens worth 3 cents each and decided how many to keep versus donate to a "public goods pot." During each round, all tokens donated to the pot were doubled in value, then distributed equally. During the game, participants were unaware of how many tokens other players donated or how many tokens they received after each round. However, at the end of the game, the experimenter told all participants that they had earned $5.

The best strategy to optimize individual gain was to keep all tokens, whereas the best strategy to optimize the group's gain was to donate all tokens. For this reason, we conceptualized keeping tokens as antisocial behavior and donating tokens as prosocial behavior. The experimenter conveyed this concept to participants through instructions (i.e., "The best way for ***you*** to make money is to keep your tokens" versus "The best way for ***you and the other players*** to make money is to donate your tokens").

The game was divided into four blocks. The first five rounds, labeled the Pre-Influence Block, were used to establish adolescents' baseline rate of donating/keeping tokens.

The next ten rounds were labeled the Indirect Influence Block and were used to assess whether adolescents changed their donating/keeping behavior when simply observed by peers. In these rounds, adolescents believed that five additional same-age peers also participating from other universities were online and observing, although in truth, these "observer peers" were also virtual. To reinforce this belief, photos of the observer peers (selected from a database of morphed adolescent faces) appeared on the screen throughout this block, although photos of the player peers were not on the screen.

The next ten rounds were labeled the Direct Influence Block and were used to assess whether adolescents changed their behavior when directly encouraged to do so by peers. In each round, the same five virtual peers who observed in the previous block now provided either positive feedback (thumbs-up icon below their photo) or no feedback (no icon) about adolescents' behavior. In a between-subjects design, participants were randomly assigned to either a condition in which peers encouraged the prosocial behavior of donating tokens ($N = 78$) or the antisocial behavior of keeping tokens ($N = 66$); of note, random assignment resulted in a somewhat uneven distribution of participants across conditions. In the Prosocial Condition, the more tokens adolescents donated, the more thumbs-up icons they received, whereas in the Antisocial Condition, the more tokens they kept, the more thumbs-up icons they received. Participants in the Prosocial Condition received five thumbs-up icons for donating five tokens, four or five icons for donating four tokens, three or four icons for donating three tokens, two or three icons for donating two tokens, one or two icons for donating one token, and no icons for donating zero tokens. These specifications were reversed for the Antisocial Condition.

The final five rounds were labeled the Continuing Influence Block and were used to assess the extent to which adolescents returned to their baseline donating/keeping behavior versus demonstrated continuation of peer influence once peers left. In these rounds, the peers' photos disappeared from the screen, indicating that they had gone offline. Before the game began, the experimenter explained and assessed adolescents' comprehension of the presence (through their photos) and influence (through thumbs-up icons) of the observer peers.

We averaged the number of tokens participants donated across the rounds of each block, resulting in variables labeled Token Donation Pre-Influence, Token Donation Indirect Influence, Token Donation Direct Influence, and Token Donation Continuing Influence.

The PGG was originally developed to study group cooperative behavior (Ledyard, 1995) and did not include a peer influence manipulation. High token donation has been validated as a form of prosocial behavior through positive associations with self-reports of altruism and trust as well as behavioral measures of charitable giving (Banerjee et al., 2021; Galizzi & Navarro-Martinez, 2019; Laury & Taylor, 2008). To our knowledge, no published studies have linked low token donation to antisocial behavior; however, in the larger data set for this project, token donation was negatively associated with self-reports of conduct problems, $r(144) = -.18$, $p = .03$, and callous-unemotional traits, $r(144) = -.21$, $p = .01$. The PGG has since been adapted by van Hoorn and colleagues (2014, 2016) as a lab-based simulation of peer influence through the inclusion of observers who either simply watch participants' token donation or actively encourage participants to either donate or keep their tokens. These researchers found that both simple observation by peers and direct encouragement by peers to donate tokens increased token donation, whereas direct encouragement by peers to keep tokens decreased token donation.

We made two adaptations to the PGG as administered by van Hoorn and colleagues (2014). First, we sequenced the blocks so that the Indirect Influence Block preceded the Direct Influence Block, whereas van Hoorn used the reverse order. Second, in the Direct Influence Block, we randomized participants to one of two conditions (Antisocial and Prosocial), whereas van Hoorn and colleagues added a third condition (no influence), which we did not include because of its redundancy with the Indirect Influence Block.

After the game, adolescents rated the extent to which the peers liked it if they kept tokens or donated tokens, each on a scale from *1 = not at all* to *5 = very much.* Adolescents in the Antisocial Condition (mean = 4.50) rated peers as liking token keeping more than adolescents in the Prosocial Condition (mean = 1.78), $F(1,143) = 207.12$, $p < .001$. In contrast, adolescents in the Prosocial Condition (mean = 4.46) rated peers as liking token donation more than adolescents in the Antisocial Condition (mean = 2.77), $F(1,143) = 71.22$, $p < .001$.

ANS activity

We recorded and analyzed MHR and PEP using the MindWare Mobile Cardio system and software. To measure MHR, we placed ECG electrodes in a standard lead two configuration: one above the right clavicle, one below the left rib cage, and one below the right rib cage. To measure PEP, we collected ICG using four additional ECG electrodes: two on the chest (one above the jugular notch and one below the xiphoid process) and two on the back (one 1.5" above the jugular notch and another 1.5" lower than the xiphoid process). The ICG signal is generated by passing a current between the two electrodes on the back and sensing the resulting voltage with the electrodes on the chest, which is modulated by the volume of blood in the chest. A small box attached to the sensor leads wirelessly transmitted adolescents' physiological recordings to a computer in the next room. After sensor placement, participants spent

https://doi.org/10.1017/S0954579422000967 Published online by Cambridge University Press

five minutes watching a neutral nature video to habituate to the sensors.

We sampled ECG and ICG data at a rate of 500 Hz and applied a muscle-nose band-pass filter with a low cutoff of 0.5 Hz and a high cutoff of 45 Hz. If we observed electrical interference noise in the ECG data, we applied a notch filter at 60 Hz. We quantified MHR as the average heart rate, and we quantified PEP as the average of the latency from the beginning of the ventricular depolarization (ECG Q peak) to the time the aortic valve opens and blood is ejected out of the left ventricle and into the aorta (B peak of the first-order derivative of ICG signals; dZ/dt; Sherwood et al., 1990). We detected the B peak using the maximum slope method. A single graduate assistant examined and removed artifacts within each interval for all participants.

Immediately before completing the PGG, participants completed a three-minute baseline assessment, during which time they sat quietly and relaxed. The duration of the PGG blocks varied due to the number of trials in each block, with the Pre-Influence and Continuing Influence Blocks lasting 30 seconds and the Indirect Influence and Direct Influence Blocks lasting 90 seconds. For both MHR and PEP, we averaged scores across the 30-second intervals of the baseline period (six intervals) or each block of the PGG (one or three intervals), and for variables with multiple intervals, we further averaged across intervals. A 30-second interval is sufficient to assess both MHR (Kobayashi, 2013) and PEP (Kortekaas et al., 2018; Sherwood et al., 1990).

These calculations resulted in ten variables assessing ANS activity labeled MHR (PEP) Baseline, MHR (PEP) Pre-Influence, MHR (PEP) Indirect Influence, MHR (PEP) Direct Influence, and MHR (PEP) Continuing Influence. Because shorter PEP latency indexes greater ANS arousal, to ease interpretation, we multiplied PEP scores by −1 so that higher scores represent greater ANS activity across both MHR and PEP. Throughout the remainder of the paper, we refer to “PEP activity” rather than “PEP scores,” with more activity meaning shorter PEP latency and less activity meaning longer PEP latency.

Missing data

The sample size for each measure of PEP and MHR ranged from 128 (89% of 144) to 134 (93%) and from 139 (97%) to 143 (99%), respectively. Missing data for ANS activity resulted from sensor placement errors, technical software issues, and physiological artifacts.

Results

Preliminary analyses

Descriptive statistics are presented in Table 1 and bivariate correlations in Table 2. We assessed gender and race/ethnicity as potential covariates using analyses of variance (ANOVA) with demographic variables predicting study variables. Although no differences in race/ethnicity emerged, females ($M = 81.68$) had higher MHR Baseline than males ($M = 77.50$), $F\ (1{,}140) = 4.59$, $p = .03$, and females ($M = 81.32$) had higher MHR Direct Influence than males ($M = 77.06$), $F\ (1{,}137) = 4.41$, $p = .04$. Thus, gender was included as a covariate in primary analyses.

Block × condition ANOVA for Token Donation

Next, we conducted a two-way ANOVA to examine whether Token Donation differed across the within-subjects Blocks (Pre-Influence, Indirect Influence, Direct Influence, and Continuing Influence) and between-subjects Conditions (Antisocial and Prosocial) of the PGG. Main effects for Block, $F\ (3{,}140) = 7.09$, $p < .001$, and Condition, $F\ (1{,}142) = 5.60$, $p = .02$, were qualified by a significant interaction, $F\ (3, 140) = 20.42$, $p < .001$. Post hoc comparisons using a Bonferroni correction for the Block main effect suggested that adolescents significantly increased their Token Donation from the Pre-Influence Block ($M = 1.84$) to the Indirect Influence Block ($M = 2.05$), suggesting that adolescents donated more tokens when observed by peers than when alone. We report this Block difference for the full sample because the between-subjects experimental manipulation (Antisocial vs. Prosocial) had not yet occurred.

Simple effects for Condition per Block suggested that adolescents in the Antisocial Condition did not differ from those in the Prosocial Condition on token donation in the Pre-Influence Block ($M_{\text{antisocial}} = 1.81$; $M_{\text{prosocial}} = 1.87$), $F\ (1, 142) = .09$, $p = .77$, or the Indirect Influence Block ($M_{\text{antisocial}} = 2.00$; $M_{\text{prosocial}} = 2.10$), $F\ (1, 142) = .24$, $p = .63$. However, adolescents in the Prosocial Condition donated more tokens than adolescents in the Antisocial Condition in both the Direct Influence Block ($M_{\text{antisocial}} = 1.65$; $M_{\text{prosocial}} = 2.50$), $F\ (1, 142) = 15.64$, $p < .001$, and the Continuing Influence Block ($M_{\text{antisocial}} = 1.53$; $M_{\text{prosocial}} = 2.44$), $F\ (1, 142) = 15.44$, $p < .001$. Thus, adolescents did not differ in their Token Donation before peer encouragement; however, adolescents in the Prosocial Condition donated more tokens than those in the Antisocial Condition thereafter, including when they were once again alone.

Simple effects for Block per Condition suggested that adolescents differed across Blocks in their Token Donation in both the Antisocial Condition, $F\ (3, 63) = 12.33$, $p < .001$, and Prosocial Condition, $F\ (3, 75) = 18.73$, $p < .001$. Post hoc comparisons suggested three significant differences between Blocks for the Antisocial Condition. Adolescents donated fewer tokens in the Direct Influence Block ($M = 1.65$) and the Continuing Influence Block ($M = 1.53$) than the Indirect Influence Block ($M = 2.00$); they also donated more tokens in the Pre-Influence Block ($M = 1.81$) than the Continuing Influence Block. Thus, when peers encouraged adolescents to keep their tokens, they decreased their donation below the level that they displayed when simply observed by peers, and they maintained this lower level of donation once peers were no longer observing them. Five significant differences between Blocks emerged for the Prosocial Condition. Adolescents donated more tokens in the Indirect Influence Block ($M = 2.10$), the Direct Influence Block ($M = 2.50$), and the Continuing Influence Block ($M = 2.44$) than the Pre-Influence Block ($M = 1.87$); they also donated fewer tokens in the Indirect Influence Block than the Direct Influence Block or the Continuing Influence Block. Thus, adolescents in the Prosocial Condition increased their Token Donation when they were observed by peers, they further increased their donation when peers encouraged them to do so, and they maintained this higher level of donation once peers were no longer observing them (see Figure 1).

Primary analyses

We used bivariate dual latent change score modeling (Kievit et al., 2018) to assess relations between adolescents' susceptibility to peer influence and ANS activity across the Blocks and Conditions of the PGG. We created six models, with each model including one transition between PGG Blocks (Pre-Influence to Indirect Influence, Indirect Influence to Direct Influence, and Direct Influence to

Table 1. Descriptive statistics

	Antisocial Condition				Prosocial Condition				Total Sample			
Variable	Mean	SD	*Min-Max*	*N*	Mean	SD	*Min-Max*	*N*	Mean	SD	*Min-Max*	*N*
ER	3.25	0.47	1.67–4.40	66	3.17	0.57	1.50–4.80	78	3.21	0.53	1.50–4.80	145
Pre-I Token	1.81	1.32	0.00–5.00	66	1.87	1.19	0.00–5.00	78	1.85	1.24	0.00–5.00	144
II Token	2.00	1.31	0.00–5.00	66	2.10	1.30	0.00–5.00	78	2.05	1.30	0.00–5.00	144
DI Token	1.65	1.23	0.00–5.00	66	2.50	1.32	0.00–5.00	78	2.11	1.35	0.00–5.00	144
CI Token	1.53	1.31	0.00–5.00	66	2.44	1.46	0.00–5.00	78	2.02	1.46	0.00–5.00	144
BL MHR	78.81	11.54	50.91–115.03	66	80.56	11.84	52.00–113.98	77	79.75	11.70	50.91–115.03	143
Pre-I MHR	79.71	11.68	48.32–108.05	63	80.49	12.76	51.38–124.03	76	80.13	12.24	48.32–124.03	139
II MHR	79.52	12.73	50.11–117.27	64	80.67	12.47	51.75–127.57	75	80.14	12.56	50.11–127.57	139
DI MHR	78.50	12.11	47.80–119.67	64	79.99	12.05	51.62–120.56	76	79.31	12.06	47.80–120.56	140
CI MHR	80.90	12.48	49.26–113.74	64	80.09	12.20	52.28–119.48	75	80.46	12.29	49.26–119.48	139
BL PEP	103.02	9.16	81.33–121.33	61	104.98	9.45	77.67–125.33	73	104.09	9.34	77.67–125.33	134
Pre-I PEP	100.00	9.97	78.00–120.00	57	101.66	10.00	72.00–124.00	71	100.92	9.98	72.00–124.00	128
II PEP	100.00	10.47	76.00–120.00	58	102.21	10.32	73.33–128.67	71	101.21	10.40	73.33–128.67	129
DI PEP	100.54	10.65	78.67–120.00	58	102.05	9.68	74.67–126.67	72	101.38	10.11	74.67–126.67	130
CI PEP	100.60	10.20	80.00–120.00	57	102.34	9.45	72.00–126.00	71	101.56	9.79	72.00–126.00	128

Note. ER = Emotion Regulation; Pre-I = Pre-Influence Block; II = Indirect Influence Block; DI = Direct Influence Block; CI = Continuing Influence Block; BL = Baseline; MHR = Mean Heart Rate; PEP = Pre-Ejection Period.

Table 2. Bivariate correlations

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. ER	–	.13	.23*	.19	.08	.06	.08	.12	.05	.04	–.08	–.08	.00	–.01	–.02
2. Pre-I Token	–.09	–	.91**	.82**	.71**	–.14	–.04	–.10	–.10	–.12	.06	.10	.10	.10	.01
3. II Token	–.09	.90**	–	.89**	.73**	–.21	–.13	–.15	–.19	–.20	.00	.04	.08	.07	.00
4. DI Token	.03	.85**	.89**	–	.78**	–.19	–.06	–.11	–.14	–.12	.01	.04	.05	.05	.00
5. CI Token	.05	.83**	.84**	.90**	–	–.17	–.13	–.16	–.18	–.15	–.13	–.13	–.14	–.11	–.13
6. BL MHR	–.30*	.10	.04	.00	–.04	–	.86**	.90**	.94**	.91**	.22	.14	.09	.10	.05
7. Pre-I MHR	–.13	.08	–.01	–.00	–.00	.83**	–	.92**	.91**	.87**	.24*	.29*	.23	.18	.13
8. II MHR	–.29*	.01	–.02	–.04	–.05	.88**	.94**	–	.96**	.94**	.27*	.29	.27*	.20	.13
9. DI MHR	–.27*	.01	–.03	–.04	–.10	.91**	.89**	.96**	–	.95**	.24*	.21	.17	.15	.09
10. CI MHR	–.28*	.05	.01	–.05	–.08	.89**	.82**	.89**	.93**	–	.31**	.23	.21	.20	.17
11. BL PEP	–.08	.04	.04	–.01	.06	.07	.13	.17	.14	.22	–	.86**	.88**	.89**	.89**
12. Pre-I PEP	–.10	.07	.08	–.01	.07	.13	.26	.27*	.23	.26	.91**	–	.96**	.95**	.94**
13. II PEP	–.14	.06	.07	.03	.09	.09	.22	.25	.18	.22	.93**	.95**	–	.97**	.95**
14. DI PEP	–.12	.09	.10	.07	.12	.09	.17	.23	.19	.22	.95**	.95**	.98**	–	.97**
15. CI PEP	–.15	.08	.08	.05	.12	.11	.22	.27*	.22	.25	.96**	.94**	.95**	.97**	–

Note. Estimates for the Antisocial Condition are presented below the diagonal; estimates for the Prosocial Condition are presented above the diagonal. ER = Emotion Regulation; Pre-I = Pre-Influence Block; II = Indirect Influence Block; DI = Direct Influence Block; CI = Continuing Influence Block; BL = Baseline; MHR = Mean Heart Rate; PEP = Pre-Ejection Period.
*$p < .05$; **$p < .01$

Continuing Influence) and one measure of ANS activity (MHR and PEP). We defined the first block as the first time point (T1) and the second block as the second time point (T2) for each transition. We chose to examine these three transitions discretely because of our interest in the psychophysiology underlying each distinct type of peer influence (indirect, direct, continuing). Each model was created using MPlus version 8 with maximum likelihood estimating with robust standard errors to account for skew and missing data (Muthén & Muthén, 1998–2017).

Latent change scores are conceptualized as the function of autoregressive and residual components. We created two latent change scores in each model, Change in Token Donation and Change in ANS Activity. We set the autoregressive path for each latent change score from T2 to T1 indicators to one and the T2

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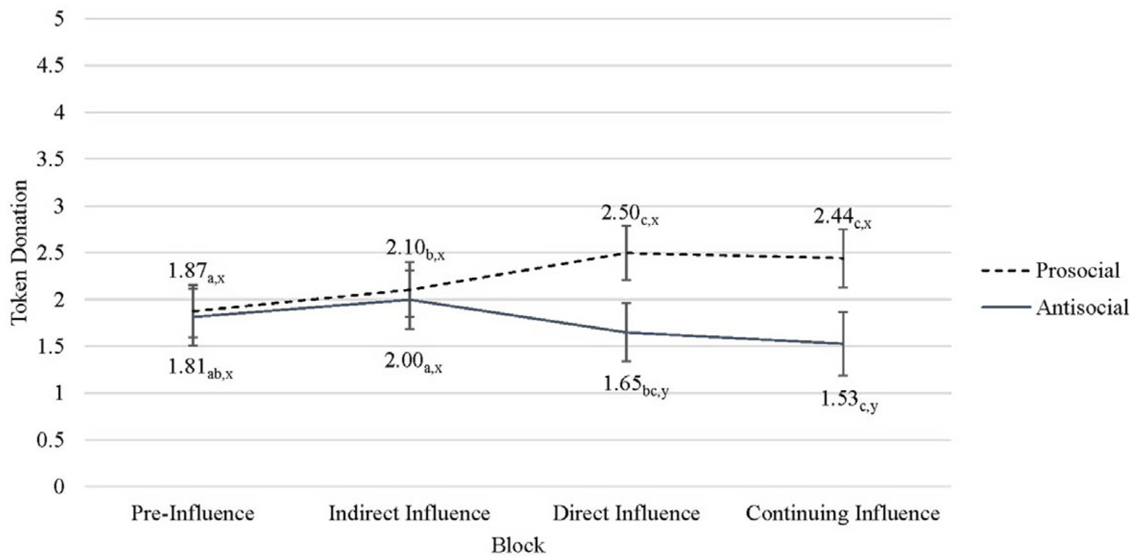

Figure 1. Token Donation differences by Block and Condition. *Note*. Error bars represent the 95% confidence interval. Different subscripts *a*, *b*, and *c* denote differences between Blocks within a Condition. Different subscripts *x* and *y* denote differences between Conditions within a Block.

indicator variance to zero. We set the T2 indicators with a loading fixed to one to account for residual variance. We allowed the T1 indicators to covary with their respective latent change scores. These parameter constraints allow the latent change scores to separate true score changes from measurement error. We regressed each of the two latent change scores onto each of the two T1 variables, resulting in four cross-lagged pathways. Finally, we covaried the T1 variables and the latent change scores (see Figure 2).

In each of the six models, the path of primary interest was path ρ, the covariation between Change in Token Donation and Change in ANS Activity. This path represents the real-time link between ANS activity and behavioral responding to peer influence. The model structure provides a rigorous test of this covariation, in that it takes into account the covariation of T1 ANS Activity and T1 Token Donation (path Φ), the prediction of Change in ANS Activity from T1 Token Donation (path γ1), and the prediction of Change in Token Donation from T1 ANS Activity (path γ2; Kievit et al., 2018). When significant effects emerged in either the MHR or PEP model for a transition, we tested whether the path of primary interest ρ differed between ANS indices in these two models (Paternoster et al., 1998). We included three covariates in each model: gender, Emotion Regulation, and MHR (PEP) Baseline when predicting that ANS variable.

For the second and third transitions, we modeled both the Antisocial and Prosocial Conditions and examined differences between them. We first compared a model in which all paths were constrained to be equal across Conditions to an unconstrained model (a model in which all paths were free to vary). If the χ^2 difference tests revealed that the models were significantly or marginally different, we then released the path of primary interest. If a second χ^2 difference test comparing a model in which all paths except the path of primary interest were constrained to be equal across Conditions to an unconstrained model resulted in equivalent models, we concluded that differences in path ρ could explain discrepancies between Conditions.

Below, we provide tables of results for models and Conditions when the path of primary interest ρ was significant (Tables 3–5). See Supplementary Tables 1–5 for the remaining models and Conditions in which the path of primary interest ρ was not significant.

Transition from Pre-Influence to Indirect Influence

The MHR [χ^2 (11) = 6.80, p = .81; CFI = 1.00; TLI = 1.00; SRMR = .04; RMSEA = .00] and PEP [(χ^2 (11) = 16.16, p = .14; CFI = .99; TLI = .98; SRMR = .09; RMSEA = .06] models both had excellent fit. However, path ρ was only significant for the MHR model. In that model, the Token Donation Latent Change Score was positively related to the MHR Latent Change Score (estimate = .19, p = .02), suggesting that the more adolescents' MHR increased as they transitioned from playing the PGG alone to being observed by peers, the greater their increase in token donation across this transition (see Table 3). For the PEP model, the relation between the Token Donation Latent Change Score and the PEP Latent Change Score was not significant (estimate = −.11, p = .17). Path ρ differed between the MHR and PEP models (z = 2.65, p = .008).

Transition from Indirect Influence to Direct Influence

The MHR model had excellent fit [(χ^2 (20) = 24.10, p = .24; CFI = 1.00; TLI = 0.99; SRMR = .07; RMSEA = .05]. However, the pathway of primary interest was not significant for either the Antisocial Condition (estimate = .12, p = .29) or the Prosocial Condition (estimate = .14, p = .16), and the two models did not differ, χ^2 difference (16) = 18.84, p = .28.

The PEP model had good fit [(χ^2 (20) = 32.65, p = .04; CFI = 0.98; TLI = 0.96; SRMR = .10; RMSEA = .10]. Although path ρ was not significant for the Prosocial Condition (estimate = .12, p = .13), it was significant for the Antisocial Condition (estimate = −.26, p = .03). Within the Antisocial Condition, path ρ differed between the MHR and PEP models (z = −2.33, p = .02). Furthermore, the model for the Antisocial Condition marginally differed from the model for the Prosocial Condition, χ^2 difference (16) = 23.75, p = .095. We compared an unconstrained model to a model in which only path ρ was allowed to vary across Conditions. These two models did not differ, χ^2 difference (15) = 18.62, p = .23, suggesting that differences in the covariation between the two latent change scores could explain differences between the Antisocial and Prosocial Conditions models. Thus, the more adolescents' PEP activity increased as they transitioned from simply being observed by peers to being directly

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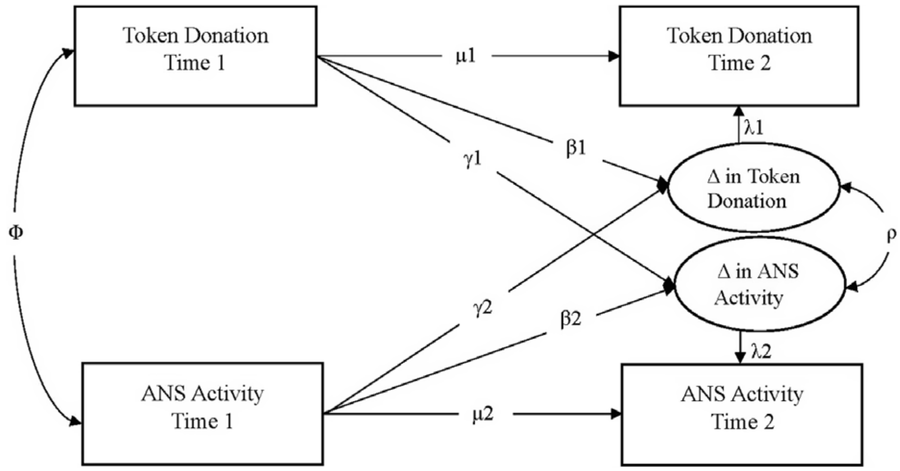

Figure 2. Template bivariate latent change score model of Token Donation and ANS activity. *Note*. Time 1 denotes the first block in each transition, and Time 2 denotes the second block in each transition. The ANS label serves as a proxy for MHR and PEP. Path labels in this model correspond to notation in the tables.

encouraged to engage in the antisocial behavior of keeping their tokens, the more their token donation decreased over this same transition (recall that PEP variables are reverse-scored, such that greater PEP activity indicates shorter PEP latency). In contrast, changes in PEP activity were not related to changes in token donation across this transition for adolescents whom peers encouraged to engage in the prosocial behavior of donating tokens (see Table 4).

Transition from Direct Influence to Continuing Influence

The MHR model had excellent fit [(χ^2 (20) = 15.66, p = .74; CFI = 1.00; TLI = 1.00; SRMR = .07; RMSEA = .00]. However, path ρ was not significant in the Antisocial (estimate = .14, p = .26) or Prosocial (estimate = −.07, p = .52) Conditions, and the two models did not differ, χ^2 difference (16) = 11.36, p = .79.

The PEP model had good fit [(χ^2 (20) = 29.36, p = .08; CFI = 0.99; TLI = 0.97; SRMR = .10; RMSEA = .08]. Although path ρ was not significant in the Antisocial Condition (estimate = −.06, p = .68), it was marginally significant in the Prosocial Condition (estimate = .17, p = .08). Within the Prosocial Condition, path ρ marginally differed between the MHR and PEP models (z = 1.70, p = .09). Furthermore, the model for the Antisocial Condition significantly differed from the model for the Prosocial Condition, χ^2 difference (16) = 31.58, p = .01. We compared an unconstrained model to a model in which only path ρ was allowed to vary across Conditions. These two models did not differ, χ^2 difference (15) = 9.26, p = .12, suggesting that differences in the covariation between the two latent change scores could explain differences between the Antisocial and Prosocial models. Because token donation decreased on average across this transition for participants in the Prosocial Condition, the proper interpretation of this finding is as follows: The less adolescents' PEP activity decreased as they transitioned from being directly encouraged to engage in the prosocial behavior of donating tokens to being alone, the less their token donation decreased over this same transition (marginal effect). In contrast, changes in PEP activity were not related to changes in token donation across this transition for adolescents whom peers encouraged to engage in the antisocial behavior of keeping tokens (see Table 5).

Discussion

The goal of the current study was to examine adolescents' ANS activity as an in-the-moment correlate of susceptibility to peer influence. We predicted that adolescents who experienced greater ANS activity during peer influence would be more susceptible across three types of influence (indirect, direct, continuing) on two types of behaviors (prosocial, antisocial) across two ANS indices (MHR, PEP).

Susceptibility to peer influence

We began by examining whether adolescents demonstrated susceptibility to peer influence while playing the PGG. Participants displayed all three types of influence across both types of behaviors. They donated more tokens when observed by peers than when alone (indirect influence effect), they donated more tokens (prosocial behavior) or fewer tokens (antisocial behavior) based on peers' differential encouragement (direct influence effect), and they continued to be influenced by peers' encouragement (both prosocial and antisocial) once peers were no longer present (continuing influence). These findings demonstrate the power of peer influence in adolescents' lives, especially given the contrived nature of the PGG. This robust evidence of susceptibility to peer influence in participants' behavior provided a firm foundation upon which to examine whether this susceptibility was related to ANS activity.

Psychophysiology and susceptibility to peer influence

Two assumptions of Albert and Steinberg's (2011) model of adolescent susceptibility to peer influence provide a framework for interpreting our findings. First, adolescents demonstrate a unique propensity toward affective reactivity to social stimuli (Somerville, 2013), evidenced by stress responses in multiple bodily systems (e.g., Stroud et al., 2009). Second, adolescents display a unique difficulty with cognitive control, particularly when faced with the opportunity for social reward (Somerville et al., 2011). In combination, these two tendencies "prime" adolescents toward an emotional mindset and reward-sensitive motivation state when in the presence of peers. In the following sections, we discuss in-the-moment links between ANS activity and susceptibility to peer influence at each transition of the PGG in terms of this theory.

Transition from Pre-Influence to Indirect Influence

The more adolescents' heart rates increased as they transitioned from playing the PGG alone to being observed by peers, the greater their increase in token donation. In other studies, increases in MHR indicate emotional arousal (Anderson & Adolphs, 2014; Wascher, 2021), particularly in the presence of peers (Stroud

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Table 3. Model of Mean Heart Rate with Token Donation for the transition from Pre-Influence to Indirect Influence

Variable	Estimate	(SE)	z	p
Intercepts				
Token Donation Pre-I	1.57	0.48	3.30	<.001
Token Donation II	0.00	0.00	999.00	—
MHR Pre-I	0.34	0.48	0.70	.49
MHR II	0.00	0.00	999.00	—
Token Donation Pre-I				
Gender	−0.12	0.08	−1.52	.13
Emotion Regulation	0.01	0.07	0.10	.92
MHR Pre-I				
Gender	0.05	0.04	1.11	.27
Emotion Regulation	0.02	0.04	0.47	.64
Baseline MHR	0.87	0.03	28.25	<.001
Token Donation II				
Token Donation Pre-I (μ1)	0.95	0.03	33.83	<.001
MHR II				
MHR Pre-I (μ2)	1.01	0.03	38.89	<.001
Change in Token Donation				
Token Donation Pre-I (β1)	−0.10	0.07	−1.36	.18
Token Donation II (λ1)	0.43	0.05	9.68	<.001
MHR Pre-I (γ2)	−0.11	0.05	−2.00	.04
Gender	0.14	0.08	1.72	.09
Emotion Regulation	0.17	0.06	2.81	.01
Change in MHR				
MHR Pre-I (β2)	−0.99	0.14	−7.29	<.001
MHR II (λ2)	0.37	0.04	8.86	<.001
Token Donation Pre-I (γ1)	−0.08	0.06	−1.24	.21
Gender	−0.02	0.08	−0.32	.75
Emotion Regulation	0.03	0.05	0.67	.51
Baseline MHR	0.91	0.13	7.24	<.001
Covariances				
Change in Token Donation with Change in MHR (ρ)	0.19	0.08	2.42	.02
Token Donation Pre-I with MHR Pre-I (Φ)	0.05	0.08	0.69	.49

Note. Estimates are standardized. Pre-I = Pre-Influence Block; II = Indirect Influence Block; MHR = Mean Heart Rate. The notation following each coefficient name refers to the corresponding pathway in Figure 2.

Table 4. Model of Pre-Ejection Period with Token Donation in the Antisocial Condition for the transition from Indirect Influence to Direct Influence

Variable	Estimate	(SE)	z	p
Intercepts				
Token Donation II	2.56	0.96	2.66	.01
Token Donation DI	0.00	0.00	999.00	—
PEP II	−1.00	0.51	−1.98	.05
PEP DI	0.00	0.00	999.00	—
Token Donation II				
Gender	−0.19	0.12	−1.57	.12
Emotion Regulation	−0.11	0.12	−0.91	.36
PEP II				
Gender	−0.03	0.05	−0.57	.57
Emotion Regulation	0.06	0.04	1.41	.16
Baseline PEP	0.92	0.02	42.54	<.001
Token Donation DI				
Token Donation II (μ1)	1.06	0.05	23.70	<.001
PEP DI				
PEP II (μ2)	1.01	0.02	47.94	<.001
Change in Token Donation				
Token Donation II (β1)	−0.33	0.08	−3.99	<.001
Token Donation DI (λ1)	0.49	0.08	6.50	<.001
PEP II (γ2)	−0.07	0.07	−0.98	.33
Gender	0.12	0.12	0.96	.34
Emotion Regulation	0.07	0.10	0.67	.50
Change in PEP				
PEP II (β2)	−1.24	0.27	−4.67	<.001
PEP DI (λ2)	0.21	0.03	7.26	<.001
Token Donation II (γ1)	−0.18	0.11	−1.61	.11
Gender	0.25	0.09	2.85	.01
Emotion Regulation	−0.15	0.11	−1.34	.18
Baseline PEP	1.20	0.28	4.36	<.001
Covariances				
Change in Token Donation with Change in PEP (ρ)	−0.26	0.12	−2.24	.03
Token Donation II with PEP II (Φ)	−0.11	0.16	−0.65	.51

Note. Estimates are standardized. II = Indirect Influence Block; DI = Direct Influence Block; PEP = Pre-Ejection Period. The notation following each coefficient name refers to the corresponding pathway in Figure 2.

et al., 2009), and endocrinological studies suggest that adolescents more so than children release stress hormones when observed by peers (Gunnar et al., 2009; Stroud et al., 2009). During this indirect influence, participants were likely trying to determine peers' expectations for their behavior. Neuroimaging studies support this contention, with adolescents displaying heightened activity in brain regions implicated in mentalizing (van Hoorn et al., 2016) and social perspective-taking (Van den Bos et al., 2011) when in the presence of peers. Thus, the simple presence of peers may prime adolescents to mount an emotional, physiological, endocrinological, and neurobiological response to mobilize efforts to match peers' expectations.

Transition from Indirect Influence to Direct Influence

For adolescents encouraged by peers to keep their tokens, a positive relation emerged between PEP activity and this antisocial behavior as they transitioned from indirect to direct influence (recall that PEP variables are reverse-scored, such that greater PEP activity indicates shorter PEP latency). In other studies, PEP has been uniquely associated with reward sensitivity (Brenner et al.,

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Table 5. Model of Pre-Ejection Period with Token Donation in the Prosocial Condition for the transition from Direct Influence to Continuing Influence

Variable	Estimate	(SE)	z	*p*
Intercepts				
Token Donation DI	1.13	0.66	1.72	.09
Token Donation CI	0.00	0.00	999.00	—
PEP DI	0.83	0.77	1.07	.29
PEP CI	0.00	0.00	999.00	—
Token Donation DI				
Gender	0.11	0.11	0.97	.33
Emotion Regulation	0.12	0.10	1.15	.25
PEP DI				
Gender	−0.03	0.06	−0.50	.62
Emotion Regulation	−0.07	0.05	−1.61	.11
Baseline PEP	0.90	0.03	32.63	<.001
Token Donation CI				
Token Donation DI (μ1)	0.90	0.04	21.01	<.001
PEP CI				
PEP DI (μ2)	1.02	0.03	32.85	<.001
Change in Token Donation				
Token Donation DI (β1)	−0.18	0.11	−1.60	.11
Token Donation CI (λ1)	0.64	0.10	6.32	<.001
PEP DI (γ2)	0.23	0.08	2.71	.01
Gender	−0.02	0.11	−0.14	.89
Emotion Regulation	−0.11	0.09	−1.18	.24
Change in PEP				
PEP DI (β2)	−0.73	0.24	−3.06	.002
PEP CI (λ2)	0.25	0.04	7.07	<.001
Token Donation DI (γ1)	0.04	0.13	0.13	.77
Gender	−0.04	0.12	−0.31	.76
Emotion Regulation	−0.09	0.13	−0.69	.49
Baseline PEP	0.60	0.30	32.63	.03
Covariances				
Change in Token Donation with Change in PEP (ρ)	0.17	0.10	1.73	.08
Token Donation DI with PEP DI (Φ)	0.01	0.13	−0.10	.92

Note. Estimates are standardized. DI = Direct Influence Block; CI = Continuing Influence Block; PEP = Pre-Ejection Period. The notation following each coefficient name refers to the corresponding pathway in Figure 2.

2005), especially when social rewards are explicit (Brinkmann & Franzen, 2017).

The differential finding for antisocial versus prosocial behavior suggests that adolescents may require more effort to comply with antisocial than prosocial peer encouragement. The display of peer-encouraged antisocial behavior may also result from a breakdown in behavioral regulation and impulse control (Somerville et al., 2011) that does not apply to prosocial behavior, as prosocial behavior is socially sanctioned. PEP activity during direct peer influence on antisocial behavior may also capture the physiological underpinnings of neurobiological susceptibility to peer influence inherent in documented maturational imbalances between competing brain systems (Chein et al., 2011; Cohen et al., 2016).

Transition from Direct Influence to Continuing Influence

The less adolescents' PEP activity decreased as they transitioned from being directly encouraged to engage in the prosocial behavior of donating tokens to being alone, the less their token donation decreased (marginal effect). Theorists speculate that adolescents may view themselves as the target of social evaluation even when they are alone, a phenomenon termed the *imaginary audience* (Somerville, 2013). This imaginary audience may have mitigated the return of both physiology and behavior to baseline levels for adolescents in the prosocial condition, especially if teens found conforming to the expectations of this imaginary audience socially rewarding.

The differential finding for prosocial versus antisocial behavior suggests that teens exert more effort to comply with prosocial than antisocial peer expectations in their peers' absence. When peers leave, acting in one's own self-interest may be effortless, whereas acting in others' interests may require some effort.

Alternative interpretations of physiological indices

We relied heavily on Albert and Steinberg's (2011) theory to select the constructs of emotional arousal and reward sensitivity as the focus of our study of adolescents' susceptibility to peer influence. We considered Do and colleagues' (2020) review of neural markers of susceptibility to peer influence as justification for this selection, given their explicit focus on neural markers of both constructs. Furthermore, our choice of MHR and PEP as indices of emotional arousal and reward processing, respectively, was solidly based in empirical literature (Anderson & Adolphs, 2014; Beauchaine et al., 2013; Brenner et al., 2005; Brinkmann & Franzen, 2017; Franzen et al., 2019; Halsey et al., 2019; Stroud et al., 2009; Wascher, 2021). For these reasons, throughout the preceding *Discussion,* we have interpreted our findings in this vein. However, physiological variables and psychological constructs do not share a one-to-one correspondence, and it is important to note other possible interpretations of our findings.

Beyond emotional arousal, researchers have interpreted MHR more specifically as a marker of stress (e.g., Von Dawans et al., 2011; Vrijkotte et al., 2000) or excitement (Drachen et al., 2010; Mitkidis et al., 2015; Wulfert et al., 2005). In the current study, increases in heart rate were linked to increases in token donation when adolescents transitioned from being alone to being observed by peers. Although we interpreted this MHR increase as a sign of emotional arousal, adolescents may have experienced peers' presence more specifically as stressful, exciting, or some combination of these emotions. Future researchers may want to incorporate self-ratings of emotion into procedures such as ours to gain a clearer view of adolescents' emotional experience when in the presence of peers, as well as how this experience may help identify those adolescents most susceptible to indirect peer influence.

Similarly, some researchers consider PEP to be an index of emotional reactivity (Evans et al., 2016; Seddon et al., 2020) rather than reward sensitivity. However, whereas alternative interpretations of MHR findings in our study seem distinctly possible, the link between PEP and reward sensitivity appears more robust, particularly in contexts of social evaluation, for three reasons. First, Beauchaine and colleagues (2012, 2013) used a four-step process to argue elegantly and forcefully for PEP as a marker of reward sensitivity and not emotional reactivity. Second, several rigorous studies have validated PEP as uniquely linked to reward sensitivity (Beauchaine et al., 2013; Franzen et al., 2019), particularly in social situations (Brinkmann & Frankzen, 2017). Finally, and of note, those scholars who consider PEP to index of emotional reactivity often measure PEP in the context of social evaluation and reward. For all of these reasons, we consider the explanation of PEP as an index of reward sensitivity to be most likely.

Limitations and future directions

An important limitation of the current study is that participants' token donation and keeping behavior during the PGG may index something other than susceptibility to peer influence. Specifically, participants may have interpreted observer peers' encouragement of token donation or keeping as an indication of normative behavior in this context. If that is the case, then participants may have donated or kept tokens not because peers encouraged them to do so, but because this understanding of normative behavior may have increased their belief that other players would do the same. The PGG is a prisoner's dilemma, in which players gain the most if everyone cooperates, but players lose the most if they cooperate when others do not. Thus, participants may have donated or kept tokens not because of peer influence but because of a desire to earn the most money possible, or they may have acted in response to both peer influence and a desire to earn money. For this reason, future researchers should assess behavioral susceptibility to peer influence using approaches that do not involve the prisoner's dilemma.

Furthermore, the ecological validity of token donation as a prosocial behavior and token keeping as an antisocial behavior is limited, in spite of positive associations between token donation and both altruism and charitable giving (Banerjee et al., 2021; Galizzi & Navarro-Martinez, 2019; Laury & Taylor, 2008) and negative associations between token donation and both conduct problems and callous-unemotional traits (larger data set for the current project). Furthermore, assessing both prosocial and antisocial behavior using the same measure (number of tokens donated/kept) ignores the fact that these two behaviors are not simply opposite ends of one continuum, although they are quite strongly negatively correlated across many studies (e.g., Carlo et al., 2014; Hardy et al., 2015; Hastings et al., 2000) and interventions that promote prosocial behavior often result in reductions in antisocial behavior (e.g., Vliek et al., 2014). Even so, individuals may display either high or low levels of both prosocial and antisocial behavior. Unfortunately, our measurement approach does not allow for this possibility; by using token donation as an assessment of both behaviors, the two constructs are inherently dependent, with participants who display high levels of one necessarily displaying low levels of the other. For these reasons, we encourage future researchers to develop new means of measuring susceptibility to peer influence that not only more closely mimic the behaviors important to teens but that also allow prosocial and antisocial behavior to be assessed as separate constructs.

Beyond these two primary concerns, our study was marked by three additional limitations. First, we did not examine RSA as a physiological correlate of susceptibility to peer influence. Given that RSA indexes emotion regulation, and given that emotional arousal is linked to susceptibility to peer influence (Albert & Steinberg, 2011; Somerville, 2013), the inclusion of RSA would advance our understanding of the role of psychophysiology in adolescents' susceptibility to peer influence. However, such an approach will require behavioral measures of susceptibility that last considerably longer than the blocks of the PGG, given that RSA require minutes and not seconds to capture (Shaffer et al., 2020). Second, we assessed susceptibility to peer influence on prosocial and antisocial behaviors, but not risky behaviors. We encourage researchers to utilize procedures suitable for the measurement of susceptibility to peer influence on risky behaviors in future studies of psychophysiology and peer influence. Finally, our sample was limited to adolescents. It will be important for future research to investigate links between psychophysiology and susceptibility to peer influence across the developmental spectrum from childhood to adulthood.

Conclusions

In the present study, we used bivariate dual latent change score modeling to examine the links between ANS activity (MHR, PEP) and two forms of behavior (prosocial, antisocial) under three types of peer influence (indirect, direct, continuing). Findings suggested that adolescents who experienced greater MHR activity during indirect influence engaged in more prosocial behavior, adolescents who experienced greater PEP activity during direct influence on antisocial behavior displayed more of that behavior, and adolescents who sustained greater PEP activity during continuing influence maintained greater engagement in prosocial behavior. To our knowledge, this is the first study of the physiological correlates of susceptibility to peer influence, and one of only a handful of studies to investigate in-the-moment associations between psychophysiology and youth behavior of any type. However, we look forward to seeing more investigations in this promising line of research in the future.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/S0954579422000967

Acknowledgments. The authors thank the adolescents and families who participated in this research, as well as the research assistants who helped to collect these data.

Funding statement. This research received no specific grant from any funding agency, commercial, or not-for-profit sectors.

Conflicts of interest. None.

References

Albert, D., Chein, J., & Steinberg, L. (2013). The teenage brain: Peer influences on adolescent decision making. *Current Directions in Psychological Science*, *22*, 114–120. https://doi.org/10.1177/0963721412471347

Albert, D., & Steinberg, L. (2011). Judgment and decision making in adolescence. *Journal of Research on Adolescence*, *21*, 211–224. https://doi.org/10.1111/j.1532-7795.2010.00724.x

Allen, J. P., & Antonishak, J. (2008). Adolescent peer influences: Beyond the dark side. In M. J. Prinstein & K.A. Dodge (Eds.), *Understanding peer influence in children and adolescents* (pp. 141–160). New York: Guilford Press.

Anderson, D. J., & Adolphs, R. (2014). A framework for studying emotions across species. *Cell*, *157*, 187–200. https://doi.org/10.1016/j.cell.2014.03.003

Banerjee, S., Galizzi, M.M., & Hortala-Vallve, R. (2021). Trusting the trust game: An external validity analysis with a UK representative sample. *Games*, *12*, 66. https://doi.org/10.3390/g12030066

Beauchaine, T. P. (2012). Physiological markers of emotional and behavioral dysregulation in externalizing psychopathology. *Monographs of the Society for Research in Child Development*, *77*, 79–86. https://doi.org/10.1111/j.1540-5834.2011.00665.x

Beauchaine, T. P., Gatzke-Kopp, L., Neuhaus, E., Chipman, J., Reid, M. J., & Webster-Stratton, C. (2013). Sympathetic-and parasympathetic-linked cardiac function and prediction of externalizing behavior, emotion regulation, and prosocial behavior among preschoolers treated for ADHD. *Journal of Consulting and Clinical Psychology*, *81*, 481–493. https://doi.org/10.1037/a0032302

Brenner, S. L., Beauchaine, T. P., & Sylvers, P. D. (2005). A comparison of psychophysiological and self-report measures of BAS and BIS activation. *Psychophysiology*, *42*, 108–115. https://doi.org/10.1111/j.1469-8986.2005.00261.x

Brinkmann, K., & Franzen, J. (2017). Blunted cardiovascular reactivity during social reward anticipation in subclinical depression. *International Journal of Psychophysiology*, *119*, 119–126. https://doi.org/10.1016/j.ijpsycho.2017.01.010

Calkins, S. D., & Keane, S. P. (2009). Developmental origins of early antisocial behavior. *Development and Psychopathology*, *21*, 1095–1109. https://doi.org/10.1017/S095457940999006X

Carlo, G., Mestre, M. V., McGinley, M. M., Tur-Porcar, A., Samper, P., & Opal, D. (2014). The protective role of prosocial behaviors on antisocial behaviors: The mediating effects of deviant peer affiliation. *Journal of Adolescence*, *37*, 359–366. https://doi.org/10.1016/j.adolescence.2014.02.009

Cauffman, E., Shulman, E. P., Steinberg, L., Claus, E., Banich, M. T., Graham, S., & Woolard, J. (2010). Age differences in affective decision making as indexed by performance on the Iowa Gambling Task. *Developmental Psychology*, *46*, 193–207. https://doi.org/10.1037/a0016128

Chein, J., Albert, D., O'Brien, L., Uckert, K., & Steinberg, L. (2011). Peers increase adolescent risk taking by enhancing activity in the brain's reward circuitry. *Developmental Science*, *14*, F1–F10. https://doi.org/10.1111/j.1467-7687.2010.01035.x

Choukas-Bradley, S., Giletta, M., Cohen, G. L., & Prinstein, M. J. (2015). Peer influence, peer status, and prosocial behavior: An experimental investigation of peer socialization of adolescents' intentions to volunteer. *Journal of Youth and Adolescence*, *44*, 2197–2210. https://doi.org/10.1007/s10964-015-0373-2

Cohen, A. O., Breiner, K., Steinberg, L., Bonnie, R. J., Scott, E. S., Taylor-Thompson, K., Rudolph, M., Chein, J., Richeson, J., Heller, A., Silverman, M., Dellarco, D., Fair, D., Galván, A., & Casey, B. J. (2016). When is an adolescent an adult? Assessing cognitive control in emotional and nonemotional contexts. *Psychological Science*, *27*, 549–562. https://doi.org/10.1177/0956797615627625

Cohen, G. L., & Prinstein, M. J. (2006). Peer contagion of aggression and health risk behavior among adolescent males: An experimental investigation of effects on public conduct and private attitudes. *Child Development*, *77*, 967–983. https://doi.org/10.1111/j.1467-8624.2006.00913.x

Crozier, J. C., Dodge, K. A., Fontaine, R. G., Lansford, J. E., Bates, J. E., Pettit, G. S., & Levenson, R. W. (2008). Social information processing and cardiac predictors of adolescent antisocial behavior. *Journal of Abnormal Psychology*, *117*, 253–267. https://doi.org/10.1037/0021-843X.117.2.253

Dirks, M. A., Dunfield, K. A., & Recchia, H. E. (2018). Prosocial behavior with peers: Intentions, outcomes, and interpersonal adjustment. In W. M. Bukowski, B. Laursen, & K. H. Rubin (Eds.), *Handbook of peer interactions, relationships, and groups* (pp. 243–264). The Guilford Press.

Do, K., Prinstein, M. J., & Telzer, E. H. (2020). Neurobiological susceptibility to peer influence in adolescence. In K. C. Kadosh (Ed.), *Handbook of developmental cognitive neuroscience* (pp. 1–24). Oxford University Press.

Drachen, A., Nacke, L.E., Yannakakis, G., & Pedersen, A.L. (2010). Correlation between heart rate, electrodermal activity and player experience in first-person shooter games. In *Proceedings of the 5th ACM SIGGRAPH Symposium on Video Games* (pp. 49–54). https://doi.org/10.1145/1836135.1836143

Ellis, B. J., & Boyce, W. T. (2008). Biological sensitivity to context. *Current Directions in Psychological Science*, *17*, 183–187. https://doi.org/10.1111/j.1467-8721.2008.00571.x

Evans, B. E., Stam, J., Huizink, A. C., Willemen, A. M., Westenberg, P. M., Branje, S., Meeus, W., Koot, H. M., & van Lier, P. A. (2016). Neuroticism and extraversion in relation to physiological stress reactivity during adolescence. *Biological Psychology*, *117*, 67–79. https://doi.org/10.1016/j.biopsycho.2016.03.002

Foulkes, L., Leung, J. T., Fuhrmann, D., Knoll, L. J., & Blakemore, S. J. (2018). Age differences in the prosocial influence effect. *Developmental Science*, *21*, e12666. https://doi.org/10.1111/desc.12666

Franzen, J., Brinkmann, K., Gendolla, G. H., & Sentissi, O. (2019). Major depression impairs incentive processing: Evidence from the heart and the face. *Psychological Medicine*, *49*, 922–930. https://doi.org/10.1017/S0033291718001526

Frey, B. S., & Meier, S. (2004). Social comparisons and pro-social behavior: Testing "conditional cooperation" in a field experiment. *American Economic Review*, *94*, 1717–1722. https://doi.org/10.1257/0002828043052187

Galizzi, M. M., & Navarro-Martinez, D. (2019). On the external validity of social preference games: A systematic lab-field study. *Management Science*, *65*, 976–1002. https://doi.org/10.1287/mnsc.2017.2908

Gardner, M., & Steinberg, L. (2005). Peer influence on risk taking, risk preference, and risky decision making in adolescence and adulthood: An experimental study. *Developmental Psychology*, *41*, 625–635. https://doi.org/10.1037/0012-1649.41.4.625

Gardner, T. W., Dishion, T. J. & Connell, A. M. (2008). Adolescent self-regulation as resilience: Resistance to antisocial behavior within the deviant peer context. *Journal of Abnormal Child Psychology*, *36*, 273–284. https://doi.org/10.1007/s10802-007-9176-6

Gullone, E., & Taffe, J. (2012). The emotion regulation questionnaire for children and adolescents (ERQ–CA): A psychometric evaluation. *Psychological Assessment*, *24*, 409–417. https://doi.org/10.1037/a0025777

Gunnar, M. R., Wewerka, S., Frenn, K., Long, J. D., & Griggs, C. (2009). Developmental changes in hypothalamus–pituitary–adrenal activity over the transition to adolescence: Normative changes and associations with puberty. *Development and Psychopathology*, *21*, 69–85. https://doi.org/10.1017/S0954579409000054

Halsey, L. G., Green, J. A., Twiss, S. D., Arnold, W., Burthe, S. J., Butler, P. J., Cooke, S. J., Gremillet, D., Ruf, T., Hicks, O., Minta, K. J., Prystay, T. S., Wascher, C. A., & Careau, V. (2019). Flexibility, variability and constraint in energy management patterns across vertebrate taxa revealed by long-term heart rate measurements. *Functional Ecology*, *33*, 260–272. https://doi.org/10.1111/1365-2435.13264

Hardy, S. A., Bean, D. S., & Olsen, J. A. (2015). Moral identity and adolescent prosocial and antisocial behaviors: Interactions with moral disengagement and self-regulation. *Journal of Youth and Adolescence*, *44*, 1542–1554. https://doi.org/10.1007/s10964-014-0172-1

Hastings, P. D., Zahn-Waxler, C., Robinson, J., Usher, B., & Bridges, D. (2000). The development of concern for others in children with behavior problems. *Developmental Psychology*, *36*, 531–546. https://doi.org/10.1037/0012-1649.36.5.531

Hubbard, J. A., Smithmyer, C. M., Ramsden, S. R., Parker, E. H., Flanagan, K. D., Dearing, K. F., Relyea, N. & Simons, R. F. (2002). Observational, physiological, and self–report measures of children's anger: Relations to reactive versus proactive aggression. *Child Development*, *73*, 1101–1118. https://doi.org/10.1111/1467-8624.00460

Kievit, R. A., Brandmaier, A. M., Ziegler, G., van Harmelen, A. L., de Mooij, S. M., Moutoussis, M., Goodyer, I. M., Bullmore, E., Jones, P.B., Fonagy, P., the NSPN Consortium, **Lindenberger, U., & Dolan, R.J.** (2018). Developmental cognitive neuroscience using latent change score models: A tutorial and applications. *Developmental Cognitive Neuroscience*, *33*, 99–117. https://doi.org/10.1016/j.dcn.2017.11.007

Kobayashi, H. (2013). Effect of measurement duration on accuracy of pulse-counting. *Ergonomics*, *56*, 1940–1944. https://doi.org/10.1080/00140139.2013.840743

Kortekaas, M. C., van Velzen, M., Grüne, F., Niehof, S. P., Stolker, R. J., & Huygen, F. (2018). Small intra-individual variability of the pre-ejection period justifies the use of pulse transit time as approximation of the vascular transit. *PloS One*, *13*, e0204105. https://doi.org/10.1371/journal.pone.0204105

Kwak, Y., & Huettel, S. A. (2016). Prosocial reward learning in children and adolescents. *Frontiers in Psychology*, *7*, 1539. https://doi.org/10.3389/fpsyg.2016.01539

https://doi.org/10.1017/S0954579422000967 Published online by Cambridge University Press

Laury, S. K., & Taylor, L. O. (2008). Altruism spillovers: Are behaviors in context-free experiments predictive of altruism toward a naturally occurring public good? *Journal of Economic Behavior & Organization*, *65*, 9–29. https://doi.org/10.1016/j.jebo.2005.05.011

Ledyard, J. O. (1995). Is there a problem with public goods provision? In J. Kagel & A. Roth (Eds.), *The handbook of experimental economics* (pp. 111–181). Princeton: Princeton University Press.

Mitkidis, P., McGraw, J.J., Roepstorff, A., & Wallot, S. (2015). Building trust: Heart rate synchrony and arousal during joint action increased by public goods game. *Physiology & Behavior*, *149*, 101–106. https://doi.org/10.1016/j.physbeh.2015.05.033

Moore, C. C., Hubbard, J. A., Morrow, M. T., Barhight, L. R., Lines, M. M., Sallee, M., & Hyde, C. T. (2018). The simultaneous assessment of and relations between children's sympathetic and parasympathetic psychophysiology and their reactive and proactive aggression. *Aggressive Behavior*, *44*, 614–623. https://doi.org/10.1002/ab.21786

Müller, C., & Minger, M. (2013). Which children and adolescents are most susceptible to peer influence? A systematic review regarding antisocial behavior. *Empirical Special Education*, *2*, 107–129.

Murray-Close, D. (2012a). Psychophysiology of adolescent peer relations I: Theory and research findings. *Journal of Research on Adolescence*, *23*, 236–259. https://doi.org/10.1111/j.1532-7795.2012.00828.x

Murray-Close, D. (2012b). Psychophysiology of adolescent peer relations II: Recent advances and future directions. *Journal of Research on Adolescence*, *23*, 260–273. https://doi.org/10.1111/j.1532-7795.2012.00831.x

Muthén, L., & Muthén, B. (1998–2017). *Mplus user's guide*. Los Angeles, CA: Muthén & Muthén.

Paternoster, R., Brame, R., Mazerolle, P., & Piquero, A. (1998). Using the correct statistical test for the equality of regression coefficients. *Criminology*, *36*, 859–866. https://doi.org/10.1111/j.1745-9125.1998.tb01268.x

Perino, M. T., Miernicki, M. E., & Telzer, E. H. (2016). Letting the good times roll: Adolescence as a period of reduced inhibition to appetitive social cues. *Social Cognitive and Affective Neuroscience*, *11*, 1762–1771. https://doi.org/10.1093/scan/nsw096

Pfeifer, J. H., Masten, C. L., Moore III, W. E., Oswald, T. M., Mazziotta, J. C., Iacoboni, M., & Dapretto, M. (2011). Entering adolescence: Resistance to peer influence, risky behavior, and neural changes in emotion reactivity. *Neuron*, *69*, 1029–1036. https://doi.org/10.1016/j.neuron.2011.02.019

Porges, S. W. (2001). The polyvagal theory: Phylogenetic substrates of a social nervous system. *International Journal of Psychophysiology*, *42*, 123–146. https://doi.org/10.1016/S0167-8760(01)00162-3

Prinstein, M. J., Brechwald, W. A., & Cohen, G. L. (2011). Susceptibility to peer influence: Using a performance-based measure to identify adolescent males at heightened risk for deviant peer socialization. *Developmental Psychology*, *47*, 1167. https://doi.org/10.1037/a0023274

Prinstein, M. J., & Dodge, K. A. (Eds.). (2008). *Understanding peer influence in children and adolescents*. Guilford Press.

Prinstein, M. J., & Giletta, M. (2020). Future directions in peer relations research. *Journal of Clinical Child & Adolescent Psychology*, *49*, 556–572. https://doi.org/10.1080/15374416.2020.1756299

Reyna, V. F. & Panagiotopoulos, C. (2020). Morals, money, and risk taking from childhood to adulthood: The neurodevelopmental framework of fuzzy-trace theory. In J. Decety (Ed.), *The social brain – A developmental perspective* (pp. 385–405). The MIT Press.

Reynolds, E. K., MacPherson, L., Schwartz, S., Fox, N. A., & Lejuez, C. W. (2014). Analogue study of peer influence on risk-taking behavior in older adolescents. *Prevention Science*, *15*, 842–849. https://doi.org/10.1007/s11121-013-0439-x

Seddon, J. A., Rodriguez, V. J., Provencher, Y., Raftery-Helmer, J., Hersh, J., Labelle, P. R., & Thomassin, K. (2020). Meta-analysis of the effectiveness of the Trier Social Stress Test in eliciting physiological stress responses in children and adolescents. *Psychoneuroendocrinology*, *116*, 104582. https://doi.org/10.1016/j.psyneuen.2020.104582

Shaffer, F., Meehan, Z. M., & Zerr, C. L. (2020). A critical review of ultra-short-term heart rate variability norms research. *Frontiers in Neuroscience*, *14*. https://doi.org/10.3389/fnins.2020.594880

Sherwood, A., Allen, M. T., Fahrenberg, J., Kelsey, R. M., Lovallo, W. R., & Van Doornen, L. J. (1990). Methodological guidelines for impedance cardiography. *Psychophysiology*, *27*, 1–23. https://doi.org/10.1111/j.1469-8986.1990.tb02171.x

Silva, K., Shulman, E. P., Chein, J., & Steinberg, L. (2016). Peers increase late adolescents' exploratory behavior and sensitivity to positive and negative feedback. *Journal of Research on Adolescence*, *26*, 696–705. https://doi.org/10.1111/jora.12219

Somerville, L. H. (2013). The teenage brain: Sensitivity to social evaluation. *Current Directions in Psychological Science*, *22*, 121–127. https://doi.org/10.1177/0963721413476512

Somerville, L. H., Hare, T., & Casey, B. (2011). Frontostriatal maturation predicts cognitive control failure to appetitive cues in adolescents. *Journal of Cognitive Neuroscience*, *23*, 2123–2134. https://doi.org/10.1162/jocn.2010.21572

Somerville, L. H., Jones, R. M., Ruberry, E. J., Dyke, J. P., Glover, G., & Casey, B. J. (2013). The medial prefrontal cortex and the emergence of self-conscious emotion in adolescence. *Psychological Science*, *24*, 1554–1562. https://doi.org/10.1177/0956797613475633

Steinberg, L., & Lerner, R. M. (2004). The scientific study of adolescence: A brief history. *The Journal of Early Adolescence*, *24*, 45–54. https://doi.org/10.1177/0272431603260879

Steinberg, L., & Monahan, K. C. (2007). Age differences in resistance to peer influence. *Developmental Psychology*, *43*, 1531–1543. https://doi.org/10.1037/0012-1649.43.6.1531

Stroud, L., Foster, E., Papandonatos, G., Handwerger, K., Granger, D., Kivlighan, K., & Niaura, R. (2009). Stress response and the adolescent transition: Performance versus peer rejection stressors. *Development and Psychopathology*, *21*, 47–68. https://doi.org/10.1017/S0954579409000042

Thayer, J. F., & Lane, R. D. (2000). A model of neurovisceral integration in emotion regulation and dysregulation. *Journal of Affective Disorders*, *61*, 201–216. https://doi.org/10.1016/S0165-0327(00)00338-4

van den Bos, W., van Dijk, E., Westenberg, M., Rombouts, S. A., & Crone, E.A. (2011). Changing brains, changing perspectives: The neurocognitive development of reciprocity. *Psychological Science*, *22*, 60–70. https://doi.org/10.1177/0956797610391102

van Hoorn, J., van Dijk, E., Güroğlu, B., & Crone, E. A. (2016). Neural correlates of prosocial peer influence on public goods game donations during adolescence. *Social Cognitive and Affective Neuroscience*, *11*, 923–933. https://doi.org/10.1093/scan/nsw013

van Hoorn, J., van Dijk, E., Meuwese, R., Rieffe, C., & Crone, E. A. (2014). Peer influence on prosocial behavior in adolescence. *Journal of Research on Adolescence*, *26*, 90–100. https://doi.org/10.1111/jora.12173

Vliek, L., Overbeek, G., & Orobio de Castro, B. (2014). "I want to behave prosocially and I can choose to do so": Effectiveness of TIGER (Kanjertraining) in 8-to 11-year-olds. *European Journal of Developmental Psychology*, *11*, 77–89. https://doi.org/10.1080/17405629.2013.811405

Von Dawans, B., Kirschbaum, C., & Heinrichs, M. (2011). The Trier Social Stress Test for Groups (TSST-G): A new research tool for controlled simultaneous social stress exposure in a group format. *Psychoneuroendocrinology*, *36*, 514–522. https://doi.org/10.1016/j.psyneuen.2010.08.004

Vrijkotte, T. G., Van Doornen, L. J., & De Geus, E. J. (2000). Effects of work stress on ambulatory blood pressure, heart rate, and heart rate variability. *Hypertension*, *35*, 880–886. https://doi.org/10.1161/01.HYP.35.4.880

Wascher, C. (2021). Heart rate as a measure of emotional arousal in evolutionary biology. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *376*, 20200479. https://doi.org/10.1098/rstlb.2020.0479

Welborn, B. L., Lieberman, M. D., Goldenberg, D., Fuligni, A. J., Galván, A., & Telzer, E. H. (2016). Neural mechanisms of social influence in adolescence. *Social Cognitive and Affective Neuroscience*, *11*, 100–109. https://doi.org/10.1093/scan/nsv095

Wulfert, E., Roland, B. D., Hartley, J., Wang, N., & Franco, C. (2005). Heart rate arousal and excitement in gambling: Winners versus losers. *Psychology of Addictive Behaviors*, *19*, 311–316. https://doi.org/10.1037/0893-164X.19.3.311