SUSCEPTIBILITY TO PEER INFLUENCE IN ADOLESCENTS: ASSOCIATIONS BETWEEN PSYCHOPHYSIOLOGY AND BEHAVIOR

by

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ABSTRACT

The goal of the current study was to investigate in-the-moment links between adolescents' sympathetic nervous system (SNS) activity and their susceptibility to three types of peer influence (indirect, direct, continuing) on two types of behavior (antisocial, prosocial). Our sample included 147 racially-ethnically diverse adolescents (46% male, 53% female, 1% other) in 10th or 11th grade. We assessed susceptibility to peer influence behaviorally using the Public Goods Game while simultaneously measuring adolescents' mean heart rate (MHR) and pre-ejection period (PEP). Three key findings emerged from our bivariate dual latent change score modeling analyses: 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 as they transitioned from being simply observed by peers (indirect influence) to being directly encouraged by peers to engage in antisocial behavior (direct influence) engaged in more antisocial behavior; 3) Adolescents whose PEP activity decreased less as they transitioned from being directly encouraged by peers to engage in prosocial behavior (direct influence) to playing the PGG alone again (continuing influence) displayed more continuing prosocial behavior (marginal effect). The discussion focuses on the differential interpretation of findings for MHR versus PEP, with MHR indexing emotional arousal and PEP indexing reward sensitivity.

Chapter 1

INTRODUCTION

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 sympathetic nervous system 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 or discouragement 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 or avoid the behaviors that peers discouraged, a construct we call continuing influence.

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 directly encouraged to do so by virtual 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 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 these effects do lessen (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 weakens (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 (Reynolds et al., 2014; van Hoorn et al., 2014), most investigations cited above compared only two types of influence on only 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

Compared with other age groups, 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, with early adolescents displaying a greater increase than late adolescents. This study exemplifies the literature demonstrating that adolescents can make wise choices as well as adults (e.g., Albert et al., 2013; Reyna & Farley, 2006; 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, with other notable predictors included antisocial attitudes, social competence, and peer orientation.

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, despite understanding the implications of their choices, 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., Bukowski et al., 2011; Kwak & Huettel, 2016; van Hoorn et al., 2014, 2016).

Albert and Steinberg (2011) also theorized that heightened emotional arousal or decreased capacity for emotion regulation might increase adolescents' susceptibility to peer influence, a theory also 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 degree of 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. For example, greater activation in brain regions central to reward processing, including the ventral striatum (VS), orbitofrontal cortex, and ventromedial prefrontal cortex (PFC), is linked to increased susceptibility to peer influence (e.g., Chein et al., 2011; Welborn et al., 2016). Greater activation in neural circuits central to emotional arousal/dysregulation, including the medial PFC, VS, and heightened connectivity between the two, is also associated with greater susceptibility (e.g., Pfeifer et al., 2011; Segalowitz et al., 2012; Somerville et al., 2013).

Notably absent from both the review by Müller and Minger (2013) and Do and colleagues (2020) were investigations of psychophysiological factors (e.g., peripheral nervous system) 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.

Psychophysiology and Susceptibility to Peer Influence

Composed of the sympathetic (SNS) and parasympathetic nervous system (PNS), the autonomic nervous system (ANS) is the most-studied physiological system in the peer influences 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). Because reward sensitivity and emotional arousal have been linked to increased SNS activity (Anderson & Adophs, 2014; Brenner et al., 2005), SNS activity may serve as a stronger indicator of this susceptibility than PNS. For this reason, we focus on the SNS in the current study.

The cardiovascular system is an excellent target for SNS 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). Depending on the context, MHR may index either SNS activity (emotional arousal or dysregulation; Anderson & Adophs, 2014) or PNS activity (emotion regulation; Thayer & Lane, 2000). However, when MHR increases following stressful events such as peer influence, this physiological change illustrates a normative stress response (Stroud et al., 2009), serves as a reliable proxy

of energy expenditure (Halsey et al., 2019), and suggests SNS activation driven by emotional arousal or dysregulation (Anderson & Adophs, 2014; Seyle, 1976; Wascher, 2021).

A second cardiac metric is pre-ejection period (PEP), a measure of cardiac contractility requiring both ECG and ICG. As the heart beats, PEP is the moment between the depolarization of the left ventricle and when the cardiac valves close. Because this process depends on SNS activation, PEP offers a second quantification of the influence of the SNS on cardiovascular functioning. PEP may be uniquely suited as an indicator of reward sensitivity (Beauchaine et al., 2013; Richter & Gendolla, 2009). 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).

In the current study, we included both MHR and PEP as SNS predictors of susceptibility to peer influence. Based on the reasoning and evidence provided above, we considered MHR to more closely index emotional arousal and PEP to more tightly assess reward sensitivity.

The Current Study

The goal of the current study was to examine SNS 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 SNS activity (MHR, PEP) to index two processes theorized to drive susceptibility to peer influence (emotional arousal and reward processing, respectively). We hypothesized that adolescents who experienced greater SNS activity during peer influence would be more susceptible across all three types of peer influence on both types of behavior across both SNS activity indices.

An additional strength is the measurement of SNS 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; Sijtsema et al., 2010). 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., Beauchaine et al., 2008; 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 SNS 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 a latent change score indexing SNS activity with a second latent change score indexing behavioral responding to peer influence (referred to as the "path of primary interest" in the *Results)*. For this reason, although

we have referred to physiological constructs as “predictors” of susceptibility to peer influence throughout this *Introduction*, from this point forward, we use the term “correlate.”

A final strength of the study was the inclusion of both baseline measures of SNS activity and a self-report measure of emotion regulation as covariates in analyses. This approach allowed us to investigate whether SNS activity predicted behavioral responses to peer influence over and above trait-like differences in adolescents’ emotional and physiological functioning.

Chapter 2

METHOD

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 SNS 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 and

parents would monitor their child without adolescents' knowledge. Families who verbally agreed to participate scheduled a laboratory visit.

The current cohort included 147 adolescents (46% male, 53% female, 1% other) with an average age of 16.02 years (*SD* = 0.63). 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 147 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 (teacher- and self-report) and anxious (teacher- and self-report) symptoms. 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%), $\chi^2(1) = 10.07$, $p < .01$.

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 Self-Reported Emotion Regulation. Cronbach's alpha was .69.

Susceptibility to Peer Influence

Adolescents completed a four-minute computerized version of the Public Goods Game (PGG), previously used by van Hoorn and colleagues (2014) to assess susceptibility to peer influence. The experimenter explained the rules at the start of the game 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 "player peers" were virtual. In each of the 30 rounds of the game, each player 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 the other players donated or how many tokens they received from the pot 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 entire 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.

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. Participants were randomly assigned to either a condition in which the peers encouraged the prosocial behavior of donating tokens or the antisocial behavior of keeping tokens. 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 thumbs-up icons for donating four tokens, three or four thumbs-up icons for donating three tokens, two or three thumbs-up icons for

donating two tokens, one or two-thumbs-up icons for donating one token, and no thumbs-up 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 the 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.

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 to reflect the progression of peer influence from simple presence to direct encouragement, whereas van Hoorn used the reverse order. Second, in the Direct Influence Block, we randomized participants to one of two conditions (Antisocial, 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), $F(1,143) = 71.22$, $p < .001$.

SNS 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 sensor placed at the jugular notch and another 1.5” lower than the electrode placed below 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.

We standardized the sampling method for each measure. We sampled ECG and ICG data at a rate of 500Hz and applied a muscle-nose band-pass filter with a low cutoff of 0.5Hz and a high cutoff of 45Hz. If we observed electrical interference noise in the ECG data, we applied a notch filter at 60Hz. We quantified MHR as the average

heart rate in 30-second intervals. We quantified PEP as the average of the 30-second intervals 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.

After sensor placement, participants spent five minutes watching a neutral nature video to habituate to the sensors. Immediately before completing the PGG, participants completed a three-minute baseline assessment, during which time they sat quietly and relaxed. A small box attached to leads from the sensors wirelessly transmitted adolescents' physiological recordings to a computer in the next room. For both MHR and PEP, we averaged across the 30-second intervals of the baseline period or each block of the PGG. These calculations resulted in ten variables assessing SNS activity labeled MHR (or PEP) Baseline, MHR (or PEP) Pre-Influence, MHR (or PEP) Indirect Influence, MHR (or PEP) Direct Influence, and MHR (or PEP) Continuing Influence.

Missing Data

Two of the 147 participants only completed remote data collection, and one ended the lab visit before the PGG could be completed, resulting in an effective sample size of 144. However, the sample size for each of the five measures of PEP and MHR ranged from 128 (89% of 144) to 134 (93%) and from 139 (97%) to 143

(99%), respectively. Missing data for SNS activity resulted from sensor placement errors, technical software issues, and physiological artifacts.

Chapter 3

RESULTS

Preliminary Analyses

Descriptive statistics are presented in Table 1, and bivariate correlations are presented in Table 2. We assessed gender and race/ethnicity as potential covariates using one-way 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, $p < .05$, and females (M = 81.32) had higher MHR Direct Influence than males (M = 77.06), F (1,137) = 4.41, $p < .05$. For this reason, gender was included as a covariate in the primary analyses described below.

Table 1 Descriptive Statistics

Variable	Antisocial Condition			Prosocial Condition			Total Sample		
	Mean	SD	*N*	Mean	SD	*N*	Mean	SD	*N*
ER	3.25	0.47	66	3.17	0.57	78	3.21	0.53	145
Pre-I Token	1.81	1.32	66	1.87	1.19	78	1.85	1.24	144
II Token	2.00	1.31	66	2.10	1.30	78	2.05	1.30	144
DI Token	1.65	1.23	66	2.50	1.32	78	2.11	1.35	144
CI Token	1.53	1.31	66	2.44	1.46	78	2.02	1.46	144
BL MHR	78.81	11.54	66	80.56	11.84	77	79.75	11.70	143
Pre-I MHR	79.71	11.68	63	80.49	12.76	76	80.13	12.24	139
II MHR	79.52	12.73	64	80.67	12.47	75	80.14	12.56	139
DI MHR	78.50	12.11	64	79.99	12.05	76	79.31	12.06	140
CI MHR	80.90	12.48	64	80.09	12.20	75	80.46	12.29	139
BL PEP	103.02	9.16	61	104.98	9.45	73	104.09	9.34	134
Pre-I PEP	100.00	9.97	57	101.66	10.00	71	100.92	9.98	128
II PEP	100.00	10.47	58	102.21	10.32	71	101.21	10.40	129
DI PEP	100.54	10.65	58	102.05	9.68	72	101.38	10.11	130
CI PEP	100.60	10.20	57	102.34	9.45	71	101.56	9.79	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	-.1	-.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.

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

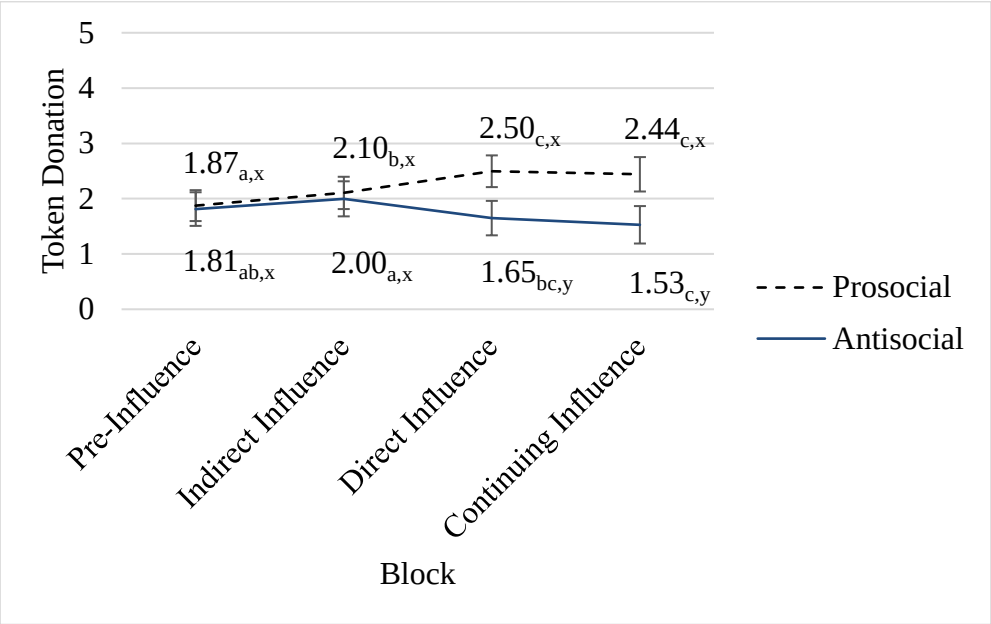
Block x Condition ANOVA for Token Donation

Next, we conducted a two-way ANOVA to examine whether Token Donation differed across the within-subjects Blocks (Pre-Influence, Indirect Influence, Direct Influence, Continuing Influence) and between-subjects Conditions (Antisocial, Prosocial) of the PGG. Main effects for Block, F (3,140) = 7.09, $p < .001$, and Condition, F (1,142) = 5.60, $p < .05$, 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 the experimental manipulation of 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 adolescents in 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 adolescents in 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).

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.

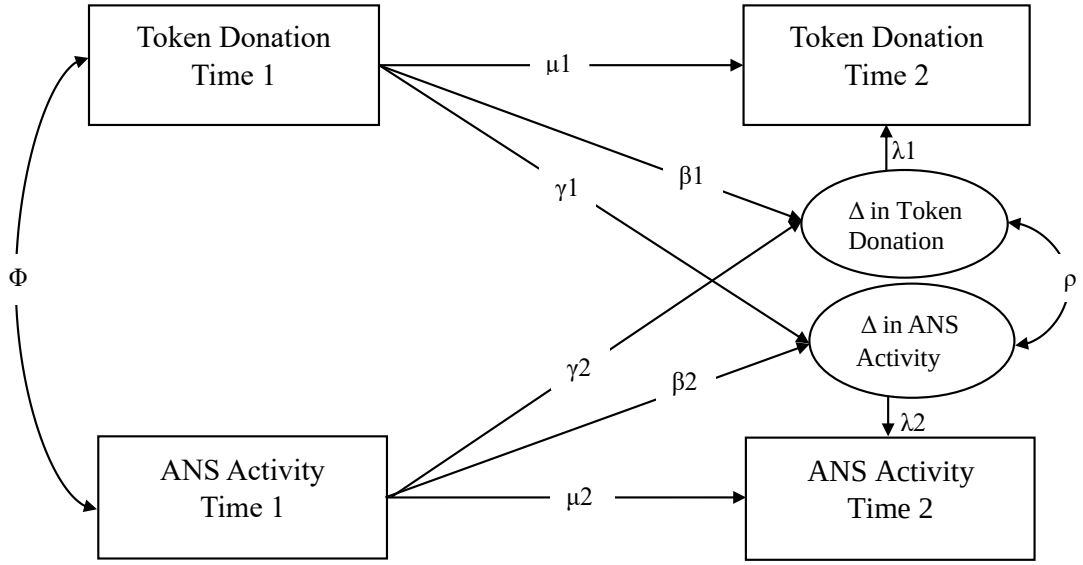
Primary Analyses

We used bivariate dual latent change score modeling (Kievet 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, Direct Influence to Continuing Influence) and one measure of ANS activity (MHR, 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, rather than use growth curve modeling, because of our interest in the psychophysiology underlying each of the three distinct type of peer influence (indirect, direct, continuing). Each model was created using MPlus version 8 with maximum likelihood estimating to account for variable 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 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).

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.

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. As described in the *Introduction*, this path represents the real-time link between adolescents' 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. As described above, we included the demographic covariate of gender. Each model also included Emotion Regulation, along with MHR (PEP) Baseline as a covariate 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 pathways were constrained to be equal across the two Conditions to a model in which pathways 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 the fully constrained model to the model with this path released resulted in equivalent models, we concluded that differences in path ρ could explain discrepancies between Conditions. We provide tables for models and conditions when the path of primary interest was 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, $p < .05$), 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, *ns*). Path ρ differed between the MHR and PEP models (*z* = 2.65, *p* .008).

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	< .0001
Token Donation II	0.00	0.00	999.00	*ns*
MHR Pre-I	0.34	0.48	0.70	*ns*
MHR II	0.00	0.00	999.00	*ns*
Token Donation Pre-I				
Gender	-0.12	0.08	-1.52	*ns*
Emotion Regulation	0.01	0.07	0.10	*ns*
MHR Pre-I				
Gender	0.05	0.04	1.11	*ns*
Emotion Regulation	0.02	0.04	0.47	*ns*
Baseline MHR	0.87	0.03	28.25	<.0001
Token Donation II				
Token Donation Pre-I (μ1)	0.95	0.03	33.83	< .0001
MHR II				
MHR Pre-I (μ2)	1.01	0.03	38.89	< .0001
Change in Token Donation				
Token Donation Pre-I (β1)	-0.10	0.07	-1.36	*ns*
Token Donation II (λ1)	0.43	0.05	9.68	< .0001
MHR Pre-I (γ2)	-0.11	0.05	-2.00	< .05
Gender	0.14	0.08	1.72	< .10
Emotion Regulation	0.17	0.06	2.81	<.01
Change in MHR				
MHR Pre-I (β2)	-0.99	0.14	-7.29	< .0001
MHR II (λ2)	0.37	0.04	8.86	< .0001
Token Donation Pre-I (γ1)	-0.08	0.06	-1.24	*ns*
Gender	-0.02	0.08	-0.32	*ns*
Emotion Regulation	0.03	0.05	0.67	*ns*
Baseline MHR	0.91	0.13	7.24	<.0001
Covariances				
Change in Token Donation with MHR (ρ)	0.19	0.08	2.42	< .05
Token Donation Pre-I with MHR Pre-I (Φ)	0.05	0.08	0.69	*ns*

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.

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, *ns*) or the Prosocial Condition (estimate = .14, *ns*), 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, *ns*), it was significant for the Antisocial Condition (estimate = -.26, $p < .05$). 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 a fully-constrained 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, *ns*, 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 encouraged to engage in the antisocial behavior of keeping their tokens, the more their token donation decreased over this same transition. 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).

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	*ns*
PEP II	-1.00	0.51	-1.98	<.05
PEP DI	0.00	0.00	999.00	*ns*
Token Donation II				
Gender	-0.19	0.12	-1.57	*ns*
Emotion Regulation	-0.11	0.12	-0.91	*ns*
PEP II				
Gender	-0.03	0.05	-0.57	*ns*
Emotion Regulation	0.06	0.04	1.41	*ns*
Baseline PEP	0.92	0.02	42.54	<.0001
Token Donation DI				
Token Donation II ($\mu 1$)	1.06	0.05	23.70	<.0001
PEP DI				
PEP II ($\mu 2$)	1.01	0.02	47.94	<.0001
Change in Token Donation				
Token Donation II ($\beta 1$)	-0.33	0.08	-3.99	<.0001
Token Donation DI ($\lambda 1$)	0.49	0.08	6.50	<.0001
PEP II ($\gamma 2$)	-0.07	0.07	-0.98	*ns*
Gender	0.12	0.12	0.96	*ns*
Emotion Regulation	0.07	0.10	0.67	*ns*
Change in PEP				
PEP II ($\beta 2$)	-1.24	0.27	-4.67	<.0001
PEP DI ($\lambda 2$)	0.21	0.03	7.26	<.0001
Token Donation II ($\gamma 1$)	-0.18	0.11	-1.61	*ns*
Gender	0.25	0.09	2.85	<.01
Emotion Regulation	-0.15	0.11	-1.34	*ns*
Baseline PEP	1.20	0.28	4.36	<.0001
Covariances				
Change in Token Donation with PEP (ρ)	-0.26	0.12	-2.24	<.05
Token Donation II with PEP II (Φ)	-0.11	0.16	-0.65	*ns*

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.

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, *ns*) or Prosocial (estimate = -.07, *ns*) 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, *ns*), 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 a fully-constrained 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, *ns*), 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).

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	<.10
Token Donation CI	0.00	0.00	999.00	*ns*
PEP DI	0.83	0.77	1.07	*ns*
PEP CI	0.00	0.00	999.00	*ns*
Token Donation DI				
Gender	0.11	0.11	0.97	*ns*
Emotion Regulation	0.12	0.10	1.15	*ns*
PEP DI				
Gender	-0.03	0.06	-0.50	*ns*
Emotion Regulation	-0.07	0.05	-1.61	*ns*
Baseline PEP	0.90	0.03	32.63	<.0001
Token Donation CI				
Token Donation DI ($\mu 1$)	0.90	0.04	21.01	<.0001
PEP CI				
PEP DI ($\mu 2$)	1.02	0.03	32.85	<.0001
Change in Token Donation				
Token Donation DI ($\beta 1$)	-0.18	0.11	-1.60	*ns*
Token Donation CI ($\lambda 1$)	0.65	0.10	6.32	<.0001
PEP DI ($\gamma 2$)	0.23	0.08	2.71	< .01
Gender	-0.02	0.11	-0.14	*ns*
Emotion Regulation	-0.11	0.09	-1.18	*ns*
Change in PEP				
PEP DI ($\beta 2$)	-0.73	0.24	-3.06	<.01
PEP CI ($\lambda 2$)	0.25	0.04	7.07	<.0001
Token Donation DI ($\gamma 1$)	0.04	0.13	0.13	*ns*
Gender	-0.04	0.12	-0.31	*ns*
Emotion Regulation	-0.09	0.13	-0.69	*ns*
Baseline PEP	0.60	0.30	32.63	<.0001

Covariances				
Change in Token Donation with PEP (ρ)	0.17	0.10	1.73	< .10
Token Donation DI with PEP DI (Φ)	0.01	0.13	-0.10	*ns*

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.

Chapter 4

DISCUSSION

The goal of the current study was to examine adolescents' SNS activity as an in-the-moment correlate of susceptibility to peer influence. We predicted that adolescents who experienced greater SNS 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 SNS indices (MHR, PEP).

Susceptibility to Peer Influence

We began by first examining whether adolescents demonstrated susceptibility to peer influence while playing the PGG. Participants demonstrated 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 procedure.

When comparing these results to those of the developers of the PGG (van Hoorn et al., 2014), we find both similarities and differences. Similar to van Hoorn and colleagues (2014), participants in the Prosocial Condition donated more tokens and participants in the Antisocial Condition donated fewer tokens when peers directly encouraged them to do so. However, we found that participants donated more tokens

when simply observed by peers than when initially alone, whereas van Hoorn and colleagues (2014) did not. Furthermore, we found greater support than van Hoorn and colleagues (2014) for participants continuing the level of donation encouraged by peers when those peers were no longer present. Thus, our findings provide stronger evidence than van Hoorn and colleagues' (2014) results for susceptibility to peer influence across types of influence. This robust evidence of susceptibility to peer influence in our participants' behavior provided a firm foundation upon which to examine whether this susceptibility was related to SNS activity across the transitions of the PGG.

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 primary findings. First, adolescents demonstrate a unique propensity toward affective reactivity to social stimuli (Burnett et al., 2011; 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 (Steinberg, 2008), 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, which increases the subjective value of rewards and preference for short-term benefits while decreasing impulse control. In the following sections, we discuss in-the-moment links between SNS activity and susceptibility to peer influence at each transition of the PGG in the

context of this model.

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 across this transition. The specificity of this link to MHR and not PEP suggests that adolescents viewed the presence of peers as emotionally arousing and stressful but not necessarily reward-oriented. In other studies, increases in MHR indicate emotional arousal under stressful conditions (Anderson & Adophs, 2014; Seyle, 1976; Wascher, 2021), particularly in the presence of peers (Stroud 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 fit in with peers' expectations.

But how did adolescents know what peers' expectations were during the indirect influence block since peers did not provide any feedback? Clues to answering this question can be found in the fact that adolescents on average increased their token donation when observed by peers compared to when alone, with those adolescents

who displayed greater MHR activity in response to peer observation also displaying more of this prosocial behavior. Thus, it seems that teens believed that peers wanted them to display prosocial behavior, and they conformed to this unspoken expectation.

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. PEP activity is an SNS metric associated uniquely with reward sensitivity (Brenner et al., 2005; Franzen et al., 2019), which may explain why PEP and not MHR emerged as the SNS correlate of susceptibility to peer influence during the transition in which peers made their expectations known.

The differential finding for antisocial versus prosocial behavior suggests that adolescents require more effort to comply with antisocial than prosocial peer expectations, because PEP activity quantifies the effort expended during reward pursuit. 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 whereas antisocial behavior is not. 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 over this same transition (although this finding was only marginal). Less is known about continuing influence than indirect or direct influence. However, theorists speculate that adolescents may view themselves as the target of social evaluation even when they are alone, a phenomenon termed the *imaginary audience* (Elkind & Brown, 1979; Somerville, 2013). This imaginary audience may have mitigated the return of both physiology and behavior to baseline levels for adolescents in the prosocial condition. Furthermore, the specificity of this finding to PEP and not MHR suggests that teens may have 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. Said differently, when once-influential peers leave, acting in one's own self-interest may be effortless, whereas acting in others' interests may require some effort. Neurobiological evidence suggests that decision-making in charity donation requires teens to focus on others rather than themselves (Zhang & Gläscher, 2020). When primed to believe that prosocial behavior is socially sanctioned, teens may preserve this other-oriented focus to maintain a cooperative self-image (Luo, 2018).

Limitations and Future Directions

Our study was marked by two primary limitations, each of which suggests directions for future research. First, we did not examine PNS correlates of

susceptibility to peer influence. Given that PNS measures such as respiratory sinus arrhythmia (RSA) index emotion regulation, and given that emotional arousal is linked to susceptibility to peer influence (Albert & Steinberg, 2011; Somerville, 2013), the inclusion of PNS measures 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 PNS measures such as RSA require minutes and not seconds to capture. 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.

Conclusions

In the present study, we used bivariate dual latent change score modeling to examine the links between SNS 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.

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