Original article

Heart Rate and Antisocial Behavior: Mediation and Moderation by Affiliation With Bullies. The TRAILS Study

Jelle J. Sijtsema, Ph.D.[a,b,*], René Veenstra, Ph.D.[a], Siegwart Lindenberg, Ph.D.[a], Arie M. van Roon, Ph.D.[c], Frank C. Verhulst, M.D., Ph.D.[d], Johan Ormel, Ph.D.[b], and Harriëtte Riese, Ph.D.[b,e]

[a] Interuniversity Center for Social Science Theory and Methodology, University of Groningen, Groningen, The Netherlands
[b] Interdisciplinary Center of Pathology of Emotion Regulation, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands
[c] Department of Internal Medicine, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands
[d] Erasmus University Medical Centre, Sophia Children's Hospital, Rotterdam, The Netherlands
[e] Department of Epidemiology, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands

A B S T R A C T

Purpose: Low heart rate (HR) has been linked to antisocial behavior (ASB). However, the effect of low HR may be mediated by affiliation with bullies. We hypothesized that individuals with low HR are more likely to affiliate with bullies and in turn are influenced by these peers.
Methods: Data come from two waves of a subsample of the TRAILS study (N = 809; 44.0% boys; mean age of 11.0 years at T1 and 13.5 years at T2). ASB was measured using the Antisocial Behavior Questionnaire at both waves. HR was assessed during rest at T1. Affiliation with bullies was assessed via peer nominations at T1. Possible gender differences were taken into account, and all analyses were adjusted for family context (i.e., family breakup and socioeconomic status).
Results: Regression analyses showed that lower HR was only associated with ASB in (pre)adolescents who affiliated with bullies. Moreover, the effect of lower HR on boys' ASB was partly mediated by affiliation with bullies.
Conclusions: Our findings show that (pre)adolescents, and in particular boys, seem to be in environments that match their biological disposition and in turn are shaped by this environment.
© 2013 Published by Elsevier Inc. on behalf of Society for Adolescent Health and Medicine.

IMPLICATIONS AND CONTRIBUTION

The association between low HR and more ASB was both mediated (in boys) and moderated by affiliation with bullies. Although small, these effects suggest that there are significant relationships between physiology and peer context contributing to the development of ASB in adolescents.

Low resting heart rate (HR) is one of the most replicated biological correlates of antisocial behavior (ASB) in childhood and adolescence [1,2]. This relationship has typically been ascribed to various underlying mechanisms such as temperamental characteristics like fearlessness and stimulation seeking [3,4]. The importance of temperamental characteristics has been well documented theoretically [3–5] and in recent empirical accounts [6,7], but a major issue remains unaddressed: the possibility that the relationship between individuals with HR and ASB is also dependent on the social context [8,9]. In pre- and early adolescence, we can distinguish between the peer and family context as the two important social contexts that may affect behavior. In this period, individuals develop more intimate peer relationships, spend more time with peers, and move away from their parents [10,11]. Therefore, in the current study, we will mainly focus on the effects of the peer context on the relationship between HR and ASB, while adjusting for the family context (i.e., socioeconomic status [SES] and family breakup).

Dodge and Pettit [8] argue that certain risk factors exert influence only in the presence (or absence) of another risk factor, suggesting moderation by context. Indeed, previous studies report that peers influence each other's behavior with regard to ASB in general [12,13] and delinquency [14,15] and aggression [16] in particular. However, this does not mean that adolescents are passive victims of their social context. Certain characteristics

* Address correspondence to: J.J. Sijtsema, Ph.D., Interuniversity Center for Social Science Theory and Methodology, University of Groningen, 9712 TG Groningen, The Netherlands.
E-mail address: j.j.sijtsema@rug.nl (J.J. Sijtsema).

may predispose individuals to actively select themselves into risky peer contexts, which in turn results in ASB [16,17], thus suggesting a mediation effect of context. Peer contexts characterized by bullying could play an important role, as bullying is a precursor for ASB and criminality [18,19]. This may be explained from a stimulation-seeking perspective. That is, (pre)adolescents with lower HR have a predisposition to sensation seeking to raise their autonomic activity to a more optimal state that may trigger ASB [3,7]. Contexts in which peers bully others are likely to be characterized by dangerous risky situations (e.g., aggressive behaviors may result in status loss and physical harm), and as such, these situations and peers may be more attractive to individuals with lower HR. It is well known that the so-called self-regulation processes make individuals select themselves into contexts that match their predisposed preferences [20,21].

Once preadolescents with lower HR are in such a peer context, their autonomic underarousal and the concomitant sensation seeking may make them especially likely to be influenced by this context, which amounts to a cross-sectional moderation effect. Such exposure effects have also been reported in relation to the interaction between low HR and community violence on childhood aggression [22].

In combination, the mediation and moderation effects would suggest a vicious cycle of ASB; low HR predisposes adolescents to seek out or, to be in peer contexts characterized by bullying behavior, and being in such a context promotes more ASB. In the current study, we test these two conditional effects by assessing the relationship between the individual risk factor *biological underarousal*, assessed via low HR, and ASB in the presence or absence of peer contexts characterized by bullying behavior. These were tested both cross-sectionally and across a 2.5-year time span, using a large sample of pre- and young adolescents.

Methods

Subjects

Data were collected in the TRAILS (TRacking Adolescents' Individual Lives' Survey) study, a large prospective population study of Dutch adolescents with bi- or triennial measurements from age 11 years to at least early adulthood [23]. Parental informed consent was obtained after the procedures had been fully explained. Detailed information about sample selection and analysis of nonresponse bias is reported elsewhere [24]. The two measurement waves ran from March 2001 to July 2002 (T1) and September 2003 to December 2004 (T2). At T1, of the 2,230 children (mean age = 11.09 years, standard deviation [SD] = .56) enrolled in the study, 2,149 (96.4%; mean age = 13.56 years, SD = .53) participated at T2.

Measures

Antisocial behavior. ASB was assessed with the self-reported Antisocial Behavior Questionnaire [25] in individuals at age 11 years (T1) and 13.5 years (T2). Participants responded on a five-point scale ("no, never" to "seven or more times") whether they had ever partaken in antisocial activities, such as stealing, fighting, substance abuse, and damaging things (31 items at T1 and 26 at T2; α values > .85). The two Antisocial Behavior Questionnaire measures differed to the extent that the T2 measure did not include questions on alcohol and soft drug use, smoking, running away from home, and police contact.

Heart rate. At T1, cardiac autonomic function was assessed by a three-lead electrocardiogram, while participants were in a supine position and breathing spontaneously for 4 minutes. Participants were in the supine position for approximately 5 minutes before measurements began. Recordings were digitized (sample rate = 100 Hz; using a DAS-12 data acquisition card for notebooks, Keithley Instruments, Cleveland, OH) and stored on a hard disk for off-line analyses. Dedicated software ([pre-]CARSPAN) [26] was used to detect R-peaks, to check signal stationarity, to correct for artifacts, and to calculate the interbeat interval (IBI; in milliseconds) between two heartbeats. IBI is inversely related to HR by the equation $HR = 60,000/IBI$. HR was expressed in beats per minute. Blocks were considered invalid if they contained artifacts with a duration of >5 seconds, if the total artifact duration was >10% of the registration, or if the block length was < 100 seconds. HR recordings were missing (n = 76) because of recording failure (41%) or signal-analysis failure (59%). Moreover, 18% of the sample did not have HR data because of practical constraints (i.e., moving to another town or time constraints). HR was collected from 1,753 (78.6%) TRAILS participants. These participants differed from the whole TRAILS population in that they were slightly younger at T1 ($t = 10.66$, $p < .001$), less antisocial at T1 and T2 (t values > 2.51, p values < .05), and tended to come less often from broken families at T1 ($t = 1.89$, $p < .06$).

Affiliation with bullies. Affiliation with bullies was measured at T1 by assessing peer-nominated bullying behavior in a subsample of 1,065 (47.8%) TRAILS participants. In 76.0% of these participants, we also assessed HR. Classrooms with at least 10 regular TRAILS participants were included in the peer nomination assessment. Children in special education, in small schools, and who repeated or skipped a grade were not part of the subsample. A previous study showed that the peer nomination subsample contained fewer children who were at risk for aggression and who came from adverse family contexts than the full TRAILS sample [27]. Selective attrition of these participants may have led to slightly underestimated effects.

Peers nominated their classmates on bullying behavior (i.e., "by whom are you bullied?"). Respondents could make unlimited nominations across gender within the classroom. For the affiliation with bullies score, we were only interested in the perpetrators of bullying behavior, that is, the bullies. Thus, incoming nominations on bullying behavior were added up and divided by the number of possible nominations within the classroom to obtain an individual measure of bullying behavior [27,28]. Although no definition of bullying was provided, bully scores were based on the reports by all classmates, and therefore provided a previously used reliable and valid measure [27]. Next, because we were interested in determining the extent to which friends would influence ASB in pre- and young adolescents, we assessed friends' behavior. To this end, respondents were also asked, "Who do you like most?" (unlimited nominations), and the final variable affiliation with bullies was calculated as the mean proportion of peer ratings on bullying behavior of liked peers (range = 0 − 1).

Family context. SES was assessed at T1 by creating a scale consisting of parents' education, job, and household income (α = .84). SES was measured as the standardized average of these five items [29]. Furthermore, parents were interviewed about their family situation at T1. Parents could indicate whether they were divorced, lived in a single-parent household, or whether the

Table 1
Means, standard deviations, range (unless indicated differently), and tests for gender differences of study variables

	Girls (N = 454)		Boys (N = 355)		Gender differences
	Mean (SD)	Range	Mean (SD)	Range	
Family breakup at T1 (1 = yes; 0 = no)	19.4%	—	19.2%	—	$\chi^2 = .01$, $p = .94$
SES at T1	.04 (.77)	−1.75 to 1.63	.03 (.76)	−1.85 to 1.72	$t = .02$, $df = 796$, $p = .99$
HR at T1 (beats per minute)	78.45 (11.06)	51.56 to 115.92	75.26 (10.41)	49.83 to 111.67	$t = 4.19$, $df = 807$, $p < .001$
Affiliation with bullies at T1 (proportion mean scores)	.10 (.19)	.00 to 1.00	.24 (.26)	.00 to 1.00	$t = -8.91$, $df = 807$, $p < .001$
ASB at T1	.19 (.21)	.00 to 1.52	.41 (.37)	.00 to 2.55	$t = -10.18$, $df = 807$, $p < .001$
ASB at T2	.22 (.26)	.00 to 1.62	.32 (.32)	.00 to 2.08	$t = -4.96$, $df = 770$, $p < .001$

The *affiliation with bullies* score represents the average mean score of the proportion of friends who bully (see Method section for further details).
HR = heart rate; ASB = antisocial behavior; SD = standard deviation; SES = socioeconomic status.

child had a stepparent. These three measures were combined into a categorical family breakup measure, indicating whether one or more of these situations was applicable (0 = no, 1 = yes).

Data analysis

We calculated descriptive statistics of all study variables and the correlations between them. We used χ^2 analysis and independent sample *t* tests to test for gender differences. Because of skewed distributions, we logarithmically transformed ASB at T1 and T2 and affiliation with bullies before the statistical analyses. In all analyses, we took gender differences into account and adjusted for family context by including SES and family breakup as covariates in the analyses.

Mediation analyses

To assess the indirect (mediation) effect of HR on ASB via affiliation with bullies, we tested the following three paths: (a) the effect of HR on affiliation with bullies, (b) the effect of affiliation with bullies on ASB, and (c) the direct effect of HR on ASB [30]. Subsequently, we tested (c') to determine whether the direct effect (c) significantly decreased when adding the mediator (i.e., affiliation with bullies) to the model. Partial mediation occurs when the *c* path significantly decreases; complete mediation occurs when the *c* path approaches zero. We also tested whether the mediation effect was moderated by gender. To formally test this moderated mediation effect, we used the macro constructed by Preacher et al [31] that allows for bootstrap testing based on 5,000 iterations. Bootstrapping generates *k* random samples (*k* = 5,000) from the original distribution. This process yields *k* estimates of the indirect effect, which serve as empirical nonparametric approximations of the sampling distributions and thereby allow for non-normal multivariate distributions in the data. ASB was standardized to compare the relative effects in the mediation analyses.

Moderation analyses

To examine the associations between HR and affiliation with bullies' behavior and ASB, multiple linear regressions were used. In the first step, we included main effects of HR, gender, and affiliation with bullies. In a second step, we added two-way interactions between HR and affiliation with bullies to the model. In the final step, we tested for three-way interactions with gender. We calculated simple slopes for the significant interaction

effect to test whether HR affected ASB at different levels of affiliation with bullies [32]. To enhance the ease of interpreting the interaction effect, we standardized the continuous independent variables *HR, affiliation with bullies,* and *SES* to a mean of zero and a standard deviation of one.

Results

Descriptive analyses

Table 1 shows summary statistics of all study variables. Approximately one-fifth of the boys and girls came from broken families. Independent sample *t* tests showed that boys and girls did not differ in SES and generally came from average SES backgrounds. Furthermore, girls' HRs were on average three to four beats per minute higher compared with boys. Boys and girls also significantly differed with regard to affiliation with bullies. That is, in girls, 10% of their friends showed bullying behavior, compared with 24% in boys. Given the potential range of ASB, participants scored rather low on ASB, although as expected, boys scored higher on individual ASB than girls at both age 11 (T1) and 13.5 (T2) years.

Correlations are presented in Table 2. HR was inversely related to affiliation with bullies and ASB at age 11 years in girls, and marginally to ASB at age 13.5 years in boys ($r = -.10$, $p = .06$). Moreover, only in boys, affiliation with bullies was significantly correlated to ASB at ages 11 and 13.5 years. Finally, ASB scores were stable over time as indicated by the high correlations.

Table 2
Correlations between family breakup, SES, HR, affiliation with bullies, and ASB (girls above and boys below the diagonal)

Variable	1	2	3	4	5	6
1. Family breakup at T1	—	−.20**	.05	.07	.10*	.16**
2. SES status at T1	−.18**	—	−.05	−.11*	−.10*	−.11*
3. HR (beats per minute) at T1	−.03	.03	—	−.11*	−.10*	−.03
4. Affiliation with bullies at T1	.14**	−.10	.01	—	.07	.09
5. ASB at T1	.06	−.10	−.06	.14**	—	.49**
6. ASB at T2	.13*	−.09	−.10	.18**	.56**	—

The *affiliation with bullies* score represents the average mean score of the proportion of friends who bully (see Method section for further details).
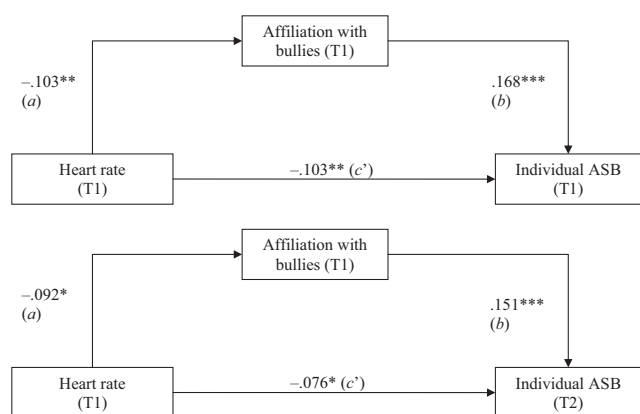* $p < .05$, ** $p < .01$.

Figure 1. Graphical presentation of the unstandardized effects of HR on affiliation with bullies (path *a*), affiliation with bullies on individual ASB (path *b*), and the direct effect (path *c'*) of HR on individual ASB. The total effect of HR on individual ASB is −.121 at T1 and −.090 at T2. Model summary for individual ASB at T1 (N = 798): R^2 = 6.0%, F_{793} = 12.72, $p < .001$. Model summary for individual ASB at T2 (N = 763): R^2 = 5.8%, F_{758} = 11.62, $p < .001$. HR = heart rate; ASB = antisocial behavior. * $p < .05$, ** $p < .01$, *** $p < .001$.

Mediation analyses

Our mediation hypothesis was that preadolescents with low HR will select themselves into peer groups characterized by bullying behaviors, which, in turn, would be associated with more individual ASB. Figure 1 presents the indirect effects of HR on ASB at ages 11 and 13.5 years, adjusted for family breakup and SES. Both in pre- and early adolescence, there was a significant indirect effect of lower HR on ASB via affiliation with bullies. Follow-up tests showed that these indirect effects were significantly moderated by gender. More specifically, at T1, there was a significant partial indirect effect of HR on individual ASB via affiliation with bullies but only in boys (indirect effect = −.013, $p < .05$, 95% confidence interval [CI]: −.034 to −.002). With regard to ASB at T2, a similar indirect effect was found (indirect effect = −.014, $p = .06$, 95% CI: −.037 to −.002). For girls, affiliation with bullies marginally mediated the relationship between lower HR and ASB at T1 (indirect effect = −.009, $p = .10$, 95% CI: −.025 to −.001). More specifically, being a girl moderated the relationship between low HR and affiliation with bullies.

Moderation analyses

Our moderation hypothesis was that preadolescents with lower HR are especially sensitive to the influence of peers who

bully. Table 3 presents the multiple regression results of the effect of HR and affiliation with bullies on individual ASB at ages 11 and 13.5 years, adjusted for family breakup and SES. The first column presents main effects on ASB that are in line with the correlations. In the second column, our analyses show that affiliation with bullies moderated the relationship between HR and ASB at age 11 years. Figure 2 shows the significant interaction between HR and affiliation with bullies ($b = −.016$, 95% CI = −.029 to −.003). In preadolescents with peers who bullied less, HR was unrelated to ASB at age 11 years ($b = .000$, $p = .97$, 95% CI = −.018 to .018). In contrast, in preadolescents who affiliated with bullies, lower HR was associated with more ASB at age 11 years ($b = −.028$, $p < .01$, 95% CI = −.046 to −.010).

In the second part of Table 3, we show the results for ASB in individuals at age 13.5 years. In this model, only main effects significantly predicted ASB. Being a boy and more affiliation with bullies were associated with more ASB. Lower HR was only marginally associated with higher ASB scores. We also computed three-way interactions between gender, resting HR, and affiliation with bullies on ASB at ages 11 and 13.5 years, but these interactions were nonsignificant (not reported in Table 3).

Discussion

In the current study, we hypothesized that lower HR would be indirectly related to ASB via affiliation with bullies (mediation effect), and in turn, this affiliation would have a disadvantageous influence on individuals with regard to ASB (moderation effect). Our findings supported the mediation hypothesis in boys by showing that lower HR was indeed related to ASB partially via affiliation with bullies both in pre- and early adolescence. This provides some support for the suggestion that, in line with stimulation-seeking theory [4], theories on peer selection [33], and self-selection into contexts [20,21], individuals with lower HR select themselves into or are more likely to be in environments that promote ASB. The effects were small but consistent cross-sectionally and prospectively over time. Given that we only found evidence for partial mediation, other currently understudied or (e.g., personality) even unknown influencing factors or social contexts may be important as well. In girls, we found no support for a mediation effect of affiliation with bullies. Thus, it seems that the relationship between HR and ASB in girls is mediated by other factors that do not include peer contexts characterized by bullying and may be unrelated to seeking sensational contexts [7]. This is partly in line with a recent meta-analysis on the link between sensation seeking and aggression [5], demonstrating that this association was twice as strong in boys com-

Table 3
Regression analyses of HR and affiliation with bullies on individual ASB at T1 and T2

Parameters	ASB at T1		ASB at T2	
	B (SE)	B (SE)	B (SE)	B (SE)
Intercept	.168 (.010)***	.166 (.010)***	.178 (.010)***	.177 (.010)***
Gender (1 = boy; 0 = girl)	.130 (.014)***	.132 (.014)***	.058 (.015)***	.057 (.015)***
HR	−.014 (.007)*	−.014 (.007)*	−.012 (.007)†	−.012 (.007)†
Affiliation with bullies	.017 (.007)*	.009 (.011)	.022 (.007)**	.022 (.007)**
Heart rate × affiliation with bullies[a]	—	−.014 (.006)*	—	−.010 (.007)
R^2	15.2%	15.7%	7.7%	7.9%

The analyses were corrected for SES and family breakup.
The *affiliation with bullies* score represents the average mean score of the proportion of friends who bully (see Method section for further details).
R^2 = percentage of explained variance.
  [a] Two-way interactions with gender were also tested, but were nonsignificant.
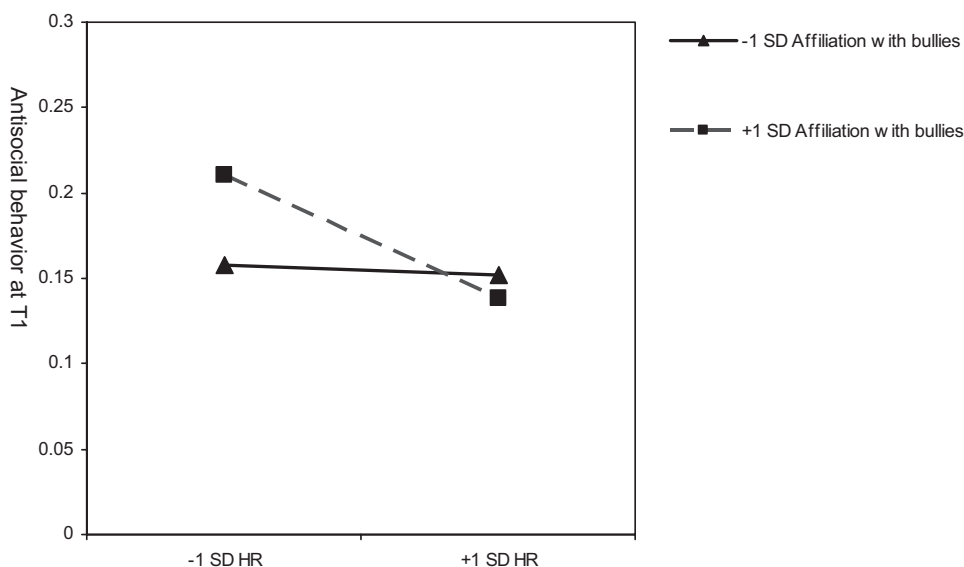 † $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$.

Figure 2. Moderation effect between HR and affiliation with bullies on individual ASB at T1. SD = standard deviation.

pared with girls. However, the authors of the meta-analysis also argued that this effect might be ascribed to a difference between clinical and community samples, given that almost all clinical samples consisted of male participants.

We also found support for the moderation hypothesis in preadolescents (in a cross-sectional design). In peer contexts characterized by more affiliation with bullying behavior, lower HR was associated with more ASB. This moderation effect among preadolescents lends some support for the assumption that biological underarousal is only associated with negative outcomes in the presence of another risk factor (e.g., in peer contexts where affiliation with bullies is highly prevalent) [8]. However, caution is warranted because this effect could not be shown for the later period, 2.5 years after the HR data were collected. The interplay between HR and peer contexts may be especially relevant in preadolescence. In this period, peer contexts characterized by bullying may deviate more from the behavioral norm than during adolescence, given that in adolescence most peers increase in ASB, which could mask a moderation effect [34,35]. In preadolescence, affiliation with bullies may thus exert more influence on those who are (biologically) more prone to stimulation seeking.

Our findings need to be discussed in light of several limitations. First, we only assessed peer nominations and behavior within classrooms. This is a limitation because there is evidence that peers outside school, from the neighborhood, or sports club also have a strong effect on individual ASB [36], especially given the lack of supervision and monitoring by adults in these contexts. Second, our dependent variable ASB slightly differed in the two measurement waves. This may not be a strong limitation because not all items are equally applicable at different ages. For example, capturing deviant behavior by asking preadolescents in elementary school whether they smoke or drink is valid. However, in secondary school, the same behaviors can no longer be regarded as deviant behaviors or are no longer indicative of ASB in the sense that these behaviors no longer deviate from those of the average early adolescent. Also, our measure of ASB encompassed several types of behaviors, including aggression and de-

linquency. Hence, our results may differ to some extent when analyzing these subtypes of ASB separately. Third, the current effects are small in magnitude, and caution is warranted in interpreting the current findings. However, difficulties of detecting interactions and small amounts of explained variance are not uncommon in field studies, such as the TRAILS study [37]. Finally, it should be noted that for a strict assessment of mediation, the measurement of HR should precede the development of the peer context in time. In our data, HR and context were measured at the same measurement wave. Although resting HR is relatively stable [4,38], we cannot rule out the possibility that affiliation with bullies affects both resting HR and ASB. There is accumulating evidence that supports the idea that social contexts may shape physiological processes such as the functioning of the autonomic nervous system [39,40].

Despite these limitations, the current study has three major strengths. First, we analyzed unique data in a large general population sample, which allowed for testing hypotheses of the effect of peer context on the relationship between HR and ASB. Although such a relationship has been suggested earlier [9], data constraints (i.e., both peer and physiological data are needed) did not make it possible to test such hypotheses. The second major strength relates to the implications of our findings. This study holds important implications for the view on the development of ASB and for possible interventions in particular. Our findings show that (pre)adolescents, and in particular boys, seem to be in self-selected contexts that match their biological disposition and in turn are shaped by this context. Efforts to identify and monitor (pre)adolescents with lower HR may help prevent them from seeking out contexts characterized by bullying. One solution may be to present these youth with viable alternatives that provide similar levels of stimulation and sensation (e.g., sports activities). Although such efforts may well be extended to (pre)adolescents in general, those individuals with lower HR appear to be more at risk than others for developing ASB when they affiliate with bullies. This also suggests that contexts characterized by

one type of problem behavior can affect other domains of problem behavior in pre- and early adolescence.

Acknowledgments

References

[1] Lorber MF. Psychophysiology of aggression, psychopathy, and conduct problems: A meta-analysis. Psychol Bull 2004;130:531–52.
[2] Ortiz J, Raine A. Heart rate level and antisocial behavior in children and adolescents: A meta-analysis. J Am Acad Child Adolesc Psychiatry 2004;43:154–62.
[3] Raine A, Venables PH, Mednick SA. Low resting heart rate at age 3 years predisposes to aggression at age 11 years: Findings from the Mauritius Child Health Project. J Am Acad Child Adolesc Psychiatry 1997;36:1457–64.
[4] Raine A. Biosocial studies of antisocial and violent behavior in children and adults: A review. J Abnorm Child Psychol 2002;30:311–26.
[5] Wilson LC, Scarpa A. The link between sensation seeking and aggression: A meta-analytic review. Aggress Behav 2011;37:81–90.
[6] Armstrong TA, Boutwell BB. Low resting heart rate and rational choice: Integrating biological correlates of crime in criminological theories. J Crim Justice 2012;40:31–9.
[7] Sijtsema JJ, Veenstra R, Lindenberg S, et al. Mediation of sensation seeking and behavioral inhibition on the relationship between heart rate and antisocial behavior: The TRAILS study. J Am Acad Child Adolesc Psychiatry 2010;49:493–502.
[8] Dodge KA, Pettit GS. A biopsychosocial model of the development of chronic conduct problems in adolescence. Dev Psychol 2003;39:349–71.
[9] Scarpa A, Raine A. The psychophysiology of human antisocial behavior, In: Nelson RJ, ed. Biology of Aggression. Oxford, UK: Oxford University, 2006:447–62.
[10] Fallon BJ, Bowles TV. The effect of family structure and family functioning on adolescents' perceptions of intimate time spent with parents, siblings, and peers. J Youth Adolesc 1997;26:25–43.
[11] Larson RW, Richards MH, Moneta G, et al. Changes in adolescents' daily interactions with their families from ages 10 to 18: Disengagement and transformation. Dev Psychol 1996;32:744–54.
[12] Ary DV, Duncan TE, Duncan SC, Hops H. Adolescent problem behavior: The influence of parents and peers. Behav Res Ther 1999;37:217–30.
[13] Patterson GR, Debaryshe BD, Ramsey E. A developmental perspective on antisocial behavior. Am Psychol 1989;44:329–35.
[14] Burk WJ, Steglich CEG, Snijders TAB. Beyond dyadic interdependence: Actor-oriented models for co-evolving social networks and individual behaviors. Int J Behav Dev 2007;31:397–404.
[15] Vitaro F, Pedersen S, Brendgen M. Children's disruptiveness, peer rejection, friends' deviancy, and delinquent behaviors: A process-oriented approach. Dev Psychopathol 2007;19:433–53.
[16] Sijtsema JJ, Ojanen T, Veenstra R, et al. Forms and functions of aggression in adolescent friendship selection and influence: A longitudinal social network analysis. Soc Dev 2010;19:515–34.
[17] Jaccard J, Blanton H, Dodge T. Peer influences on risk behavior: An analysis of the effects of a close friend. Dev Psychol 2005;41:135–47.
[18] Griffin R, Gross A. Childhood bullying: Current empirical findings and future directions for research. Aggression Violent Behav 2004;9:379–400.
[19] Wolke D, Woods S, Bloomfield L, Karstadt L. The association between direct and relational bullying and behaviour problems among primary school children. J Child Psychol Psychiatry 2000;41:989–1002.
[20] Dohmen T, Falk A. Performance pay and multidimensional sorting: Productivity, preferences, and gender. Am Econ Rev 2011;101:556–90.
[21] Lindenberg S. Social rationality, semi-modularity and goal-framing: What is it all about? Analyse und Kritik 2008;30:669–87.
[22] Scarpa A, Tanaka A, Haden SC. Biosocial bases of reactive and proactive aggression: The roles of community violence exposure and heart rate. J Community Psychol 2008;36:969–88.
[23] Huisman M, Oldehinkel AJ, de Winter A, et al. Cohort profile: The Dutch TRacking Adolescents' Individual Lives' Survey; TRAILS. Int J Epidemiol 2008;37:1227–35.
[24] de Winter AF, Oldehinkel AJ, Veenstra R, et al. Evaluation of non-response bias in mental health determinants and outcomes in a large sample of pre-adolescents. Eur J Epidemiol 2005;20:173–81.
[25] Moffitt TE, Silva PA. Self-reported delinquency: Results from an instrument for New Zealand. Aust N Z J Criminol 1988;21:227–40.
[26] Dietrich A, Riese H, Sondeijker FE, et al. Externalizing and internalizing problems in relation to autonomic function: A population-based study in preadolescents. J Am Acad Child Adolesc Psychiatry 2007;46:378–86.
[27] Veenstra R, Lindenberg S, Oldehinkel AJ, et al. Bullying and victimization in elementary schools: A comparison of bullies, victims, bully/victims, and uninvolved preadolescents. Dev Psychol 2005;41:672–82.
[28] Dijkstra JK, Lindenberg S, Veenstra R. Same-gender and cross-gender peer acceptance and peer rejection and their relation to bullying and helping among preadolescents: Comparing predictions from gender-homophily and goal-framing approaches. Dev Psychol 2007;43:1377–89.
[29] Veenstra R, Lindenberg S, Oldehinkel AJ, et al. Temperament, environment, and antisocial behavior in a population sample of preadolescent boys and girls. Int J Behav Dev 2006;30:422–32.
[30] Preacher KJ, Hayes AF. Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. Behav Res Methods 2008;40:879–91.
[31] Preacher KJ, Rucker DD, Hayes AF. Addressing moderated mediation hypotheses: Theory, methods, and prescriptions RID A-5936-2008. Multivariate Behav Res 2007;42:185–227.
[32] Frazier PA, Tix AP, Barron KE. Testing moderator and mediator effects in counseling psychology research. J Couns Psychol 2004;51:115–34.
[33] McPherson M, Smith-Lovin L, Cook JM. Birds of a feather: Homophily and social networks. Annu Rev Sociol 2001;27:415–44.
[34] Agnew R. An integrated theory of the adolescent peak in offending. Youth Soc 2003;34:263–99.
[35] Moffitt TE. Adolescence-limited and life-course-persistent antisocial behavior: A developmental taxonomy. Psychol Rev 1993;100:674–701.
[36] Kiesner J, Poulin F, Nicotra E. Peer relations across contexts: Individual-network homophily and network inclusion in and after school. Child Dev 2003;74:1328–43.
[37] McClelland GH, Judd CM. Statistical difficulties of detecting interactions and moderator effects. Psychol Bull 1993;114:376–90.
[38] Crozier JC, Dodge KA, Fontaine RG, et al. Social information processing and cardiac predictors of adolescent antisocial behavior. J Abnorm Psychol 2008;117:253–67.
[39] Del Giudice M, Ellis BJ, Shirtcliff EA. The Adaptive Calibration Model of stress responsivity. Neurosci Biobehav Rev 2011;35:1562–92.
[40] McEwen BS. Physiology and neurobiology of stress and adaptation: Central role of the brain. Physiol Rev 2007;87:873–904.