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Regular Article

Heart rate (variability) and the association between relational peer victimization and internalizing symptoms in elementary school children

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Abstract

Relational victimization typically emerges first during the elementary school period, and has been associated with increased levels of internalizing symptoms in children. Individual differences in autonomic nervous system functioning have been suggested as a potential factor linking social stressors and internalizing symptoms. The aim of this study was therefore to examine whether heart rate and heart rate variability mediated the association between relational victimization and internalizing symptoms in 373 mainstream elementary school children. Children were assessed in 2015 (T_0; Grades 3–5, M age = 9.78 years, 51% boys) and reassessed in 2016 (T_1). Heart rate and heart rate variability were assessed during a regular school day at T_1. A multi-informant (teacher and peer report) cross-time measure of relational victimization, and a multi-informant (self- and teacher report) measure of internalizing problems at T_1 was used. Results showed that heart rate variability, but not heart rate, mediated the association between relational victimization and internalizing symptoms. This study provides tentative support that in children from a general population sample, a psychobiological factor may mediate the association of relational victimization with internalizing symptoms.

Keywords: autonomic nervous system, children, internalizing symptoms, relational victimization

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Relational victimization typically emerges during the elementary school period (Craig, 1998), possibly due to the increased social awareness of children (Björkqvist, Lagerspetz, & Kaukiainen, 1992). Relational victimization is a common phenomenon, with approximately 10%–15% of elementary school children being a victim on a regular basis (Currie et al., 2012). The impact of relational victimization may already be profound in this period as it has been associated with childhood internalizing symptoms (Gini, Card, & Pozzoli, 2018; van der Wal, de Wit, & Hirasing, 2003; Veenstra et al. 2005; Zwiersynska, Wolke, & Lereya, 2013). Given this impact of childhood relational victimization, it seems important to understand factors that may explain why relational victimization is related to internalizing symptoms already at these young ages. Autonomic nervous system (ANS) functioning, indexed by, for instance, heart rate and heart rate variability, has been suggested as a factor underlying the relation between social stressors and internalizing symptoms (Hastings et al., 2008). However, studies on the potential mediating role of ANS activity in the association of classroom relational victimization with internalizing symptoms in children attending mainstream elementary schools is limited. The goal of this study is therefore to examine whether variation in ANS activity (heart rate and heart rate variability) explain the association between exposure to relational victimization and internalizing problems in a sample of 373 children, aged 9–12 years old (2015 [T_0]; Grades 3–5, 2016 [T_1]; Grades 4–6), who attended mainstream elementary schools in the Netherlands.

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The ANS, Victimization, and Internalizing Problems

Childhood relational peer victimization is described as deliberate and repeated behavior intended to actively exclude a child from social activities, or to threaten or damage a victim's relationship or credibility among peers by spreading rumors or gossiping (Crick & Bigbee, 1998). As such, it is a threat to children's fundamental need to be part of the larger peer group and therefore considered a social stressor (Williams, Frogas, & Von Hippel, 2013). Such social stressors may be associated with autonomic nervous system (ANS) responses. However, an excessive and prolonged stress system activation has been associated with increased blood pressure, cardiovascular disease, and mortality as the stress system becomes overstrained (Porges, 2001, 2005). It has therefore been suggested that the physiological stress system becomes downregulated when stress exposure is severe or prolonged, in order to counteract the increased risk of disease or mortality (Miller, Chen, &

Zhou, 2007). This downregulation of the stress system may be expressed by changes in parasympathetic activity (PA). Heart rate (variability) is influenced by sympathetic activity (SA) and PA (Berntson & Cacciopo, 2004). The SA and PA affect the firing of electrical impulses that stimulate heart contraction. The PA regularly sends inhibitory signals, thereby temporary reducing heart rate. However, prolonged stress may result in attenuation of the PA impact on the heart (Michels et al., 2013). As a consequence, heart rate variability is reduced, and heart rate may increase.

In particular, downregulation of heart rate variability has been suggested to be associated with internalizing symptoms (Beauchaine, Gatzke-Kopp, & Mead, 2007; Chandola, Heraclides, & Kumari, 2010; El-Sheikh, Harger, & Whitson, 2001). According to the polyvagal theory (Porges, 2007), individuals with reduced autonomic regulation show deficits in their adaptation to the changing environmental demands. The absence of the flexible sending of inhibitory signals by the PA to regulate heart rate, resulting in lower heart rate variability, may hinder an adaptive response to stimuli in the environment. For instance, heart rate must be regulated to remain calm in stressful social experiences and to consider effective responses to mitigate the threatful event (Porges, 2007). Low heart rate variability may thus hinder children to seek adequate responses to the experiences of relational victimization. In addition, increased heart rate and low heart rate variability might be interpreted as an inability to regulate the emotions and cope with the stress associated with relational victimization (Murray-Close, 2013). As such, it may hinder children's effective response to, and may signal an internal inability to effectively cope with, the threatening situation. The inability to cope with threatening situations might further be linked to the inability to inhibit anxious responses and depressive thoughts in social situations (Leadbeater & Hoglund, 2009; Pittig, Arch, Lam, & Craske, 2013). Difficulties in emotion regulation were associated with anxious thoughts and panic attacks in social settings (Beauchaine et al., 2007; Hinnant & El-Sheikh, 2009; Pittig et al., 2013; Porges 2001, 2007) and with symptoms of internalizing problems (Neumann, Van Lier, Frijns, Meeus, & Koot, 2011).

Childhood Relational Victimization, ANS, and Internalizing Symptoms

Despite the theoretical frameworks of a psychobiological pathway linking social stressors to internalizing problem, the empirical testing is far from complete as only parts or the projected pathways were tested, and most studies were not conducted in children. However, it was found that relational victimization experiences in the classroom predicted decreased heart rate variability in 6- to 10-year-old children (Michels et al., 2013). Other studies related individual differences in heart rate and heart rate variability to internalizing symptoms. For instance, in adults, reduced heart rate variability was associated with internalizing problems (Beauchaine, 2001; Beauchaine & Thayer, 2015; Pittig et al., 2013). In line with these results, children with (borderline)clinical levels of internalizing symptom showed decreased heart rate variability and increased heart rate compared to non-(borderline)clinical controls (Dieleman et al., 2015; Dietrich et al., 2007; Hastings et al., 2008; Kagan & Snidman, 1999; Monk et al., 2001; Scarpa et al., 1997). Thus, although parts of the hypothesized pathway of relational victimization to internalizing problems via heart rate (variability) were studied, the full mediational pathway of heart rate (variability) underlying the association between relational victimization and internalizing symptoms is understudied.

The Present Study

The goal of this study was to assess the association of children's experiences of relational peer victimization, heart rate and heart rate variability, and internalizing symptoms. To this end, we followed 373 children (aged 8–10 years at first assessment) attending mainstream elementary schools. These children's heart rate (variability), and their exposure to peer victimization were assessed in the naturalistic setting of the school. We expected that relational victimization is associated with increased levels of heart rate and decreased levels of heart rate variability, and increased levels of internalizing symptoms. In addition, we expected higher heart rate and lower heart rate variability to be associated with internalizing problems. We furthermore hypothesized that heart rate and heart rate variability would mediate the association between relational victimization and internalizing problems.

Method

Participants

Data of this study are part of the project "Happy Children, Happy Adolescents?" a longitudinal study among primary school children on their sociocognitive and behavioral development in the school context (Behnsen, Buil, Koot, Huizink, & van Lier, 2018; de Wilde, Koot, & van Lier, 2016). Data were collected in 19 mainstream primary schools, in the eastern and central part of the Netherlands. Data used in the present study come from 503 children and were collected in 2015 (T_0; Grades 3–5, *M* age = 9.78 years, *SD* = 1.05; range = 8–10 years old; 51% boys) and 2016 (T_1; Grades 4–6, *M* age = 10.89 years, *SD* = 1.05; range = 9–12 years old). The sample consisted mostly of children of middle and high socioeconomic status (SES) families (see Table 1). Only heart rate and heart rate variability data with not more than 10% artifacts were used, leading to discarding data of 130 children having too many artifacts for data analysis (see Design section for procedure for artifact removal). This resulted in usable data for data analyses of $N = 373$ children (*M* age at $T_1 = 10.89$ years, *SD* = 1.05; range = 9–12 years old; 50% boys). Children with usable cardiac data did not differ significantly from children with nonuseable data on self- and peer-reported relational victimization at T_0, $t\ (503) = -0.55$, $p = .53$ and $t\ (503) = -0.84$, $p = .69$, and at T_1, $t\ (503) = -0.46$, $p = .83$ and $t\ (503) = -0.59$, $p = .58$. Children with usable cardiac data did not differ significantly from children with nonuseable data on self- and teacher-reported depressive symptoms, $t\ (503) = 1.13$, $p = .26$ and $t\ (503) = 0.32$, $p = .75$, and on self- and teacher-rated anxiety symptoms, $t\ (503) = 1.35$, $p = .17$, and depressive symptoms, $t\ (503) = 0.45$, $p = .65$. Children with usable cardiac data also did not differ significantly from other children on sex distribution $\chi^2\ (503) = -0.31$, $p = .85$, age, $t\ (503) = 0.68$, $p = .59$, or pubertal status, $\chi^2\ (503) = -0.84$, $p = .79$. The characteristics of the study sample are depicted in Table 1.

Procedures

Ethical approval was obtained from the medical ethical review board of the VU Medical Centre (protocol number: NL37788.029.1). Parents of participants were asked to provide informed consent after the procedure was fully explained. Self- and peer-reported data and test scores were collected during 1 school day. Typically, children completed questionnaires in the morning in their classroom during a 45-min session. Children were sitting in an exam setting and were supervised by

Table 1. Characteristics of the study sample

	M	*SD*	Range
Age at T_1	10.89	1.05	9–12
Pubertal status	2.13	0.91	1.00–5.00
	Percentage (%)		
Male	51		
Low socioeconomic status	15		
Grade at T_1			
4th grade	22		
5th grade	48		
6th grade	30		

two research assistants. The teacher was not present in the classroom when children completed the questionnaires. In the afternoon, children were tested individually in a quiet room in the school. During this 45-min session, children completed nonstressful tasks, and their cardiac activity was assessed during four time points. Trained research assistants assisted in data collection at the primary schools. Cardiac activity was assessed in between cognitive tasks in order to guarantee a more realistic resemblance of a typical school day than previous implemented psychosocial stress procedures because children during a typical school day also perform cognitive tasks. The research assistants were trained in using the VU University Ambulatory Monitoring Device (VU-AMS) for heart rate measurement (De Geus, Willemsen, Klaver, & Van Doornen, 1995). Questionnaires for teachers were administered online in the same month as children were assessed.

To facilitate a feasible heart rate measurement in such a large group of children in the school setting, we chose the portable VU-AMS handlebar, a modified version of the VU-AMS (see Measures section for a more detailed description) for cardiac data collection. To avoid that data on somatic activity would be confounded with cardiovascular activity, participants were instructed to sit still throughout the entire testing session. Children's heart rate was assessed at four time points, during an assessment block in which children completed cognitive tests on cognitive control and socioemotional functioning. Cardiovascular activity was assessed before, in between (two times), and after the cognitive testing. Thus, heart rate and heart rate variability were measured four times for 2 min, during a span of approximately 45 min, resulting in a total of 8 min of both heart rate and heart rate variability data. The first assessment took place around 12:30 p.m. The second assessment took place approximately 30 min later, during a break in between the cognitive tasks. The third measurement took place approximately 6 min later, during a second break. The fourth measurement took place at the end of the cognitive tasks, approximately 5 min later. In order to try to establish a constant and calm breathing pattern during heart rate measurements, participants were instructed to follow a calm breathing pattern (4 bpm inhaling and 4 bpm exhaling, I:E ratio 4 : 4) depicted by a moving bar on an iPad app during all cardiac measurement points (Bernardi, Valle, Coco, Calciati, & Sleight, 1996).

Measures

We used a multiple-informant approach to assess relational victimization and internalizing symptoms, as different informants might provide useful information on different perspectives regarding various contexts in which symptoms are expressed in the school setting (Kraemer et al., 2003).

Relational victimization was assessed across two annual waves (2015 and 2016). Teacher-reported relational victimization was assessed with the Social Experiences Questionnaire (Crick & Grotpeter, 1996). Teachers completed this questionnaire on every child in the classroom. Items included questions such as "Who is excluded (e.g., from games) if a classmate is angry at him or her?" Questions are answered on a 5-point visually aided Likert scale ranging from 1 = *not true at all* to 5 = *very true*). The questionnaire showed good reliability with Cronbach's α of 0.84 in our sample.

Peer-reported relational peer victimization was assessed through peer nominations. Children were presented with a list of names of their classmates and were asked to nominate an unlimited number of peers in the classroom who were relationally victimized (Crick & Bigbee, 1998). Children were not allowed to nominate themselves. Items included questions such as "Who is told lies about by another child to make others not like him or her anymore?" and "Who is often not allowed to join (for example, a game) because of another child?" To account for differences in class size, the sum scores of victimization were divided by the number of participating children in the classroom minus 1, as self-nomination was not possible. The questionnaire showed good reliability with Cronbach's α of 0.79 in our sample.

The correlations between the teacher and peer reports of relational victimization were $r = .33$ and .33 ($ps < .01$) at T_0 and T_1, respectively. Although modest, this was comparable to previous research that used combined peer- and teacher-rated victimization scores (Ladd & Kochenderfer-Ladd, 2002). The correlations within constructs over time were $r = .55$ and .34 ($ps < .01$) for teacher and peer reports, respectively. The four relational victimization scores were standardized and used as indicators for the overall (latent) victimization score (see Statistical Analyses section and Figure 1).

Internalizing symptoms were assessed through teacher reports and self-reports in 2016. Standardized values were used as indicators for the latent scores of internalizing symptoms. Self-reports of internalizing symptoms were assessed with the Revised Child Anxiety and Depression Scale (RCADS; |Chorpita, Yim, Moffitt, Umemoto, & Francis, 2000). The RCADS is a questionnaire measuring symptoms of the most prevalent DSM-defined anxiety disorders and major depressive disorder. The two subscales assessing generalized anxiety disorder and major depressive disorder were used. Items were scored on a 4-point Likert type scale with anchors *never* and *always*. In this study, a total anxiety score was used by summing ratings on generalized anxiety disorder items and the major depressive disorder score was used as a total depression score. The RCADS is a reliable and valid self-report questionnaire (Chorpita et al., 2000) and showed good reliability with Cronbach's $\alpha = 0.79$ for the anxiety scale and 0.70 for the major depressive scale in our sample. The correlation between the anxiety and the depression scale was $r = .57$ ($ps < .01$).

Teacher-reported internalizing symptoms were assessed with the Problem Behavior At School Interview (PBSI; Erasmus, 2000). The PBSI is a 42-item instrument that measures internalizing and externalizing symptoms in children as perceived by teachers. In the present study, the 12-item internalizing scale, consisting of a 5-item anxiety scale and a 7-item depression scale, was used. Teachers rated children on a 5-point Likert scale, ranging from 0 (*never*) to 4 (*often*). Examples of items are

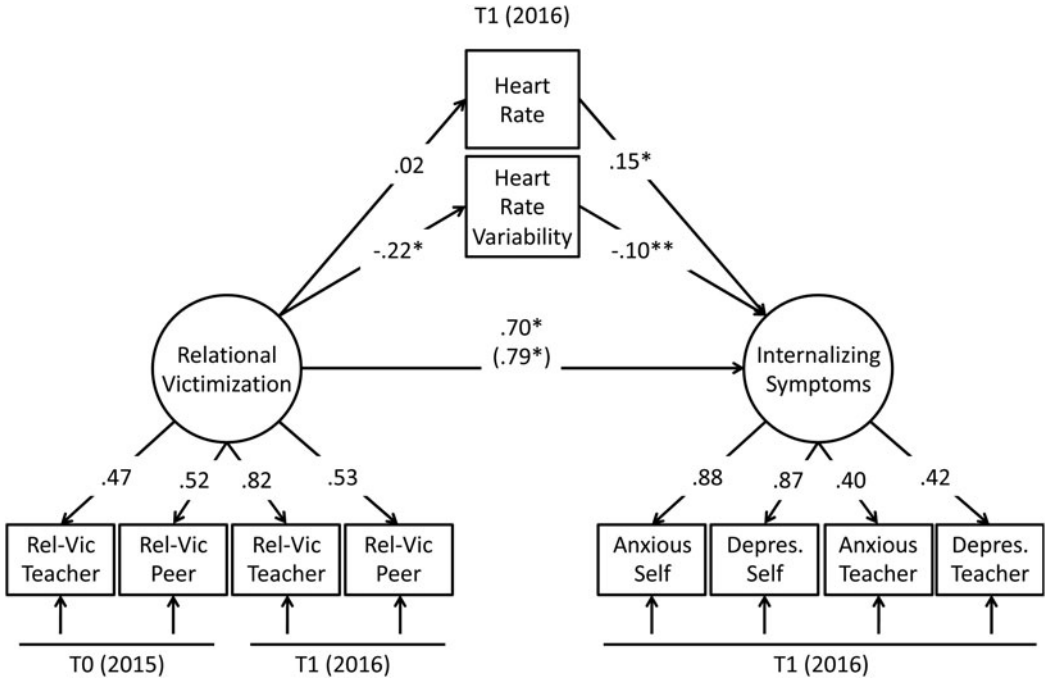

Figure 1. The indirect effect of relational victimization on internalizing problems via heart rate and heart rate variability. Entries of regression paths are standardized regression estimates. Rel-Vic, relational victimization. Depres., depressive symptoms. *$p < .05$. **$p < .01$.

"This child is nervous or tense" and "This child has a lack of energy." The PBSI showed good reliability with Cronbach's α = 0.83 for the anxiety scale and 0.84 for the major depressive scale in our sample. The correlation between the anxiety and the depression scale for teacher report was $r = .73$ ($ps < .01$).

The correlations between the teacher and self-report were $r = .19$ and .24 ($ps < .01$) for anxiety and depression, respectively. These correlations coincide with earlier studies using multi-informant reports of internalizing symptoms (De Los Reyes et al., 2015). The self- and teacher-reported anxiety and depressive symptoms scores were standardized and used as indicators for the overall (latent) internalizing problems score (see Figure 1 and Statistical Analyses section).

Heart rate and heart rate variability were assessed with the VU-AMS (De Geus et al., 1995; see www.vu-ams.nlfor more information). The device collects electrocardiogram and impedance cardiography readings to assess heart rate (De Geus & Van Doornen, 1996). VU-AMS data were imported into the VU-AMS5fs software to create a visual representation of cardiac data, to manually correct for missing data (DeGeus & Van Doornen, 1996). Artifacts longer than 5 s or more than 10% percent of the whole registration period were discarded (Sijtsema, Van Roon, Groot, & Riese, 2015). Heart rate of the electrocardiogram was averaged across all valid beats by the first author (DeGeus et al., 1995).

Heart rate was based on the average heart rate in beats per minutes across the four measurement points. Heart rate variability was based on the average standard deviation of interbeat-intervals measured in milliseconds across the four measurement points. This indicator is a widely used short-term indicator of heart rate variability and has been shown to index parasympathetic rather than sympathetic nervous system functioning (Jarrin et al., 2015; Munoz et al., 2015; Polanczyk et al., 1998). We used a portable handlebar device connected to the VU-AMS. The correlation of heart rate and heart rate variability between handlebar and the electrodes was $r = .82$, $p < .01$ and $r = .86$, $p < .01$, respectively (data not published, but available from the first author).

Control variables

Pubertal status was controlled for as advanced pubertal maturation has been linked to increased stress system activity (Galeev, Igisheva, & Kazin, 2002; Spear, 2009) and internalizing symptoms (Natsuaki et al., 2009). Pubertal status was assessed using the Pubertal Developmental Scale (Carskadon & Acebo, 1993), which consisted of three self-assessment questions about physical growth, pubic hair, and skin changes. Two subsequent questions assessed breast growth and onset of menstruation for girls, and voice changes and beard growth for boys. Answers were provided on a 4-point Likert scale: 1 = *has not started yet*, 2 = *just started*, 3 = *surely started*, and 4 = *is completed*. Point values were averaged for all items to give a Pubertal Developmental Scale score (please see Petersen, Crocket, Richards & Boxer, 1988, for the extended rating procedure). Pubertal status was distinguished into five groups: 1 = prepubertal, 2 = beginning pubertal, 3 = midpubertal, 4 = advanced pubertal, and 5 = postpubertal (Petersen et al., 1988). Cronbach's α was 0.72 for boys and 0.78 for girls in our sample.

Time of assessment of heart rate and heart rate variability was entered as a control variable as mean levels of heart rate may decrease during the day (Kario, 2010; Umetani, Singer, McCraty, & Atkinson, 1998).

Children's sex was entered as a control variable because boys, compared to girls, have been found to have higher levels in heart rate variability (Sinnreich, Kark, Friedlander, Sapoznikov, & Luria, 1998), and higher levels of relational victimization (Murray-Close et al., 2014; Rose & Rudolph, 2006) and internalizing problems (Hasting et al. 2008). Sex was coded as 1 = *boys* and 2 = *girls*.

Children's age in years at T1 (range = 9–12 years) was entered as a control variable as older children showed increased heart rate variability (Lenard, Studinger, Mersich, Kocsis, & Kollai, 2004; Sinnreich et al., 1998; Tanaka, Monahan, & Seals. 2001), more internalizing symptoms (Mendle et al., 2014), and higher levels of relational victimization (Prinstein, Cheah, & Guyer, 2005).

Low SES was assessed through parental occupation using the Dutch Working Population Classifications of Occupations Scheme (Statistics Netherlands, 2001). The highest occupation level (from father or mother) was considered to reflect household SES. Low SES was defined as being unemployed of having an elementary job or less. Household SES was dummy coded as 0 = *medium to higher level SES*, 1= *unemployed to lower level SES*.

Statistical analyses

Data were analyzed in two steps. In the first step, we ran separate regression models to test for associations between each of the hypothesized paths that comprise the mediation pathway. To account for the multi-informant data of relational victimization and internalizing symptoms, a factor score of relational victimization and internalizing problem was considered.

In the second step, we tested for mediation by heart rate and heart rate variability in the association of relational victimization with internalizing problems. To this end, a mediation model as depicted in Figure 1 was fitted. To test for mediation, we used 5,000 bootstrap resamples with replacement and bias-corrected 95% confidence intervals (95% CI; Preacher & Hayes, 2004) to estimate the significance of indirect effects. Mplus version 7 (Asparouhov & Muthen, 2012; Muthen & Muthen, 1998) was used for fitting the regression models. The estimates of the regression paths that comprise our hypothesized mediation pathway were controlled for possible effects of time of collection of cardiovascular data during the assessment day, pubertal status, sex, age, and SES. Standard errors were adjusted for clustering of data at the classroom level using a sandwich estimator (Williams, 2000). Maximum likelihood estimation with robust standard errors was used in order to account for the nonnormal distributions and missing data in the model. Model fit was determined using the comparative fit index (CFI) and Tucker–Lewis index (TLI), and the standardized root mean square residual. For the CFI and TLI values of .95 and higher indicate acceptable fit (Bentler & Bonett 1980), and values of .08 on the standardized root mean square residual and lower indicate acceptable fit (Marsh, Hau, & Wen, 2004).

Results

Descriptive statistics

Raw means and standard deviations of the study variables, and the correlations between the study variables are depicted in Table 2. With regard to our study hypotheses, significant correlations were found between self- and peer-reported victimization with self- and teacher-reported indicators of internalizing problems. A significant negative association between heart rate variability and teacher-reported relational victimization was found. Significant correlations were found between heart rate and heart rate variability with indicators of internalizing symptoms in the expected direction, although the correlations for heart rate were not consistently significant across informants.

Table 2. Means and standard deviation of, and correlations between, study variables

	M	*SD*	Range	1	2	3	4	5	6	7	8	9
1. Depressive per teacher	0.70	0.70	0.00–3.33	—								
2. Anxious per teacher	0.79	3.72	0.00–3.40	.76**	—							
3. Depressive per self	5.84	4.17	0.00–25.00	.28**	.31**	—						
4. Anxious per self	3.89	3.22	0.00–15.00	.28**	.29**	.60**	—					
5. Rel. Victim. T_0 teacher	0.62	0.74	0.00–4.00	.28**	.30**	.23**	.12*	—				
6. Rel. Victim. T_1 teacher	0.57	0.75	0.00–4.00	.58**	.58**	.31**	.28**	.35**	—			
7. Rel. Victim. T_0 peer	1.33	.11	0.00–16.00	.24**	.26**	.24**	.15*	.34**	.36**	—		
8. Rel. Victim. T_1 peer	2.56	2.76	0.00–19.00	.27**	.28**	.26**	.18**	.32**	.37**	.57**	—	
9. Heart rate	66.92	20.20	66.95–168.31	.07	.14*	.08	.09	.05	–.03	.03	.04	—
10. Heart rate variability	166.63	63.89	31.56–382.6	–.19**	–.21**	–.09	–.13*	–.07	–.15**	–.07	–.08	–.53*

Note: Raw means (and *SD*) are given, while standardized scores of relational victimization and anxious and depressive symptoms were used in the analyses. Rel. Victim., relational victimization. T_0 = 2015. T_1 = 2016. *$p < .05$. **$p < .01$.

Associations of relational victimization, heart rate (variability), and internalizing symptoms

We first tested for associations between (a) relational victimization and internalizing symptoms, (b) relational victimization and heart rate (variability), and (c) heart rate (variability) and internalizing problems in separate regression models. The estimates of the regression paths were controlled for possible effects of time of collection of cardiovascular data during the day of assessment, pubertal status, sex, SES, and age. As can be seen in Table 3 (direct effects), the association between relational victimization and internalizing symptoms ($\beta = .79$, $p < .001$) was significant. The association of relational victimization with heart rate ($\beta = .02$, $p = .75$) was not significant, but was significant for heart rate variability ($\beta = -.22$, $p < .05$). Both heart rate and heart rate variability showed a significant association with internalizing symptoms ($\beta = .15$, $p < .01$ and $\beta = -.10$, $p < .01$, respectively).

In the second step, the mediation model was fitted to test for mediation by heart rate and heart rate variability of the link between victimization and internalizing symptoms (CFI = .95, TLI = .96, RMSEA = .06). Results are in Figure 1 and in Table 3 (indirect effect). The indirect effect of victimization on internalizing symptoms via heart rate was not significant ($B = 0.00$, 95% CI [−0.02, 0.03]; see Table 3). The indirect effect of victimization on internalizing symptoms via heart rate variability was significant ($B = 0.02$, 95% CI [0.01, 0.06]). When allowing for the indirect paths, the path of relational victimization to internalizing problems stayed significant ($\beta = .70$, $p < .01$; see Figure 1), thereby suggesting partial mediation of the association of relational victimization with internalizing problems by heart rate variability.

Discussion

Previous studies have shown that experiences of relational victimization are related to internalizing problems in elementary school. In this study, we found that heart rate variability, but not heart rate, was a significant mediator in the association between relational peer victimization and internalizing symptoms. The results of this study thus suggest that already in the elementary school period, in which children may become first exposed to experiences like relational victimization, such experiences become embodied in the ANS responses of children, to explain the association with childhood development of internalizing problems.

Higher levels of relational victimization in our sample were associated with more internalizing symptoms, which was in accordance with previous studies among children (7–14 years old; Gini et al., 2018; Zwiersynska et al., 2013). The significant link between relational victimization and lower levels of heart rate variability was also found by others (Michels et al., 2013). In addition, in accordance with earlier studies, lower heart rate variability was associated with internalizing problems (Dieleman et al., 2015; Hastings et al., 2008). We extended these previous studies in two ways. First, we combined the previously found association into one model, and thereby showed that lower levels of heart rate variability among relationally victimized children mediated the association between these children's victimization and their higher levels of internalizing symptoms. However, it is important to note that heart rate variability only partly explained the association between relational victimization and internalizing symptoms. Other, nonincluded factors, at the psychobiological level of children or at other regulatory systems, such as brain activation or emotion regulation, may additionally explain how internalizing problems may develop among relationally victimized children. Second, we used a general population sample of mainstream elementary school children, assessed in a real-life situation. It has previously been suggested that anxiety symptoms are associated with more pronounced changes of heart rate variability in a clinical sample (Dieleman et al., 2015). Our results suggest that negative social experiences such as peer victimization among mainstream elementary school children are associated with decreased tonic heart rate variability and subsequent internalizing symptoms. Thus, this suggests that individual differences in heart rate variability link to internalizing symptoms both in clinical and in general population samples of children.

The fact that heart rate variability mediated the pathway from relational victimization to internalizing problems was in line with our expectation. As hypothesized, our findings might suggest attenuation of the flexible inhibitory impulses of the parasympathetic system on the heart, due to the stress implicated with relational victimization, leading to lower heart rate variability. Low heart rate variability has also been linked to low emotion regulation and increased stress vulnerability also in children (Porges, 2005), thereby linking to internalizing problems. As described earlier, it is possible that reduced heart rate variability in social situations is interpreted as threatening and thus leads to anxious thoughts.

In contrast with our hypothesis, heart rate did not mediate the association of relational victimization with internalizing problems. A possible explanation for this finding may be that heart rate is influenced by both sympathetic and parasympathetic nervous system functioning, and thus might represent a very heterogeneous index of arousal. Moreover, heart rate is influenced by acute experiences, while we tested for the association with a nonacute stressor. That is, we did not experimentally induce a victimization experience. Therefore, heart rate as assessed in our study might not be a significant mediator in the association between our assessment of relational victimization and internalizing symptoms. However, heart rate was linked to internalizing symptoms, and thus still seems to be an important marker for childhood internalizing problems.

It is noteworthy that, in our study, we assessed tonic heart rate (variability), not heart rate (variability) in response to a direct stressor (phasic). Thus, we assessed more general functioning of heart rate variability instead of heart rate variability responses to a specific social stressor. Phasic heart rate variability versus tonic heart rate variability has often been differently associated with stressful experiences in the peer context (for a review, see Beauchaine et al., 2007). Our study therefore extended earlier work using experimentally induced social stressors, by assessing tonic ANS activity in a naturalistic setting of elementary school children, and linking this to these children's exposure to peer victimization. For instance, Newman (2014) found no difference in phasic heart rate variability following an experimentally induced social exclusion experience between young adults with a history of high versus low exposure to bullying. We showed that in childhood, reduced tonic heart rate variability was linked to peer relational victimization. Thus, our results propose that association of relational victimization with phasic heart rate variability do not generalize to the association of such experiences in naturalistic settings with assessments of tonic heart rate variability. Consequently, in addition to social stress procedures, future studies should further assess stress activity in the school context because it represents the natural environment in which children

might be exposed to victimization. Related results might shed more light on generalizable individual differences in ANS functioning in the peer context.

Overall, our results suggest that exposure to elementary school peer relational victimization in everyday classrooms may be considered a severe stressor. We found it to be associated with a process of downregulation of heart rate variability, with subsequent associations with increased levels of anxious and depressive symptoms. Our findings therefore suggest a nonadaptive biopsychological processes in children experiencing relational victimization (see, in this regard, Vaillancourt, Hymel, & McDougall, 2013). In addition to this, an earlier study by Will, van Lier, Crone, and Güroğlu (2016) showed that chronic peer problems were related to higher activation in brain regions related to emotion regulation in response to a social exclusion experience in an experimental setting. Collectively, these studies highlight the detrimental effect of exposure to peer victimization and suggest that in children from the general population, such experiences may become embodied in the psychophysiology of these children, already at young ages.

Limitations and future directions

The current study has a number of limitations that need to be considered. A first potential limitation is the assessed sample of elementary school children. Although the children studied came from a general population sample of mainstream elementary schools, both the schools and the children in our study do not necessarily represent the broader Dutch population. Schools were not randomly selected, and only schools that were willing to participate in the study were included. The sample consisted mostly of children of middle and higher SES families. It needs to be assessed whether our findings extend to broader populations. A second limitation may be the design of the study. We cannot exclude the possibility that other stressors, also from outside the school setting, may have affected these children's heart rate (variability) output. We can also not exclude the possibility that children may have already had low levels of heart rate variability, which may have predisposed them to become a victim of relational bullying. In addition, we cannot rule out that internalizing symptoms caused victimization. However, a prior study among elementary school children did not find such pathways from internalizing symptoms to peer victimization (van Lier et al., 2012). A third potential limitation is that we used a handlebar rather than sticker electrodes for cardiac measurements. Due to this, potentially important ANS output measures for pure sympathetic nervous system functioning, such as pre-injection period, could not be calculated and used in our study. We found that heart rate variability, a marker of parasympathetic nervous system functioning, was a significant mediator in the assessed association. A measure such as pre-injection period would have been needed to assess potentially dysregulated sympathetic nervous system functioning linked to relational victimization. The use of the handlebar, instead of electrodes, was needed for practical reasons due to testing large number of children in elementary schools on a regular school day.

Implications

The current study provided tentative support for a psychobiological factor linking relational victimization to internalizing symptoms in a sample of typically developing children attending mainstream elementary schools. Our findings have implications for teachers, mental health workers, and general practitioners. Apart from preventing relational victimization altogether, the results of this study suggest that stress management training could help children in coping with the stress related to relational victimization (McHugh, Dawson, Scrafton, & Asen, 2010). As an example of stress management techniques, heart rate variability-biofeedback training can help children to make connections between their physical and emotional state and their behavior (McHugh et al., 2010). By increasing victimized children's awareness of their physical and emotional state, these children can furthermore be trained to employ ways of self-calming strategies (e.g., with breathing exercises) and to choose effective emotion regulation strategies and behavioral responses during stressful situations.

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