Mediation of Sensation Seeking and Behavioral Inhibition on the Relationship Between Heart Rate and Antisocial Behavior: The TRAILS Study

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Objective: Why is low resting heart rate (HR) associated with antisocial behavior (ASB), i.e., aggression and rule breaking, in adolescence? Theory suggests that personality traits mediate this relationship but differently with age. In the present study this age-effect hypothesis is tested; we expected that the relationship between HR and aggression would be mediated in preadolescence by the personality trait behavioral inhibition, but not by sensation seeking. However, the relationship between HR and rule breaking in adolescence was predicted to be mediated by sensation seeking, but not by behavioral inhibition. Hypotheses were tested separately for boys and girls. **Method:** HR in supine position was assessed in repondents to the TRacking Adolescents' Individual Lives Survey (TRAILS) (N = 1,752; 48.5% boys) at age 11 years. Rule breaking and aggression at age 16 were assessed with two subscales from the Youth Self Report (YSR) questionnaire. Personality (i.e., sensation seeking and behavioral inhibition) was measured at ages 11, 13.5, and 16 with the Early Adolescent Temperament Questionnaire–Revised (EATQ-R), Behavioral Inhibition System/ Behavioral Activation System (BIS/BAS) scales, or NEO Personality-Index Revised (NEO-PI-R). **Results:** In boys, lower HR was associated with aggression and rule breaking in adolescence. The association between HR and rule breaking was mediated by sensation seeking in adolescence but not in preadolescence. Girls' HR was not associated with ASB, and no mediating effects were found. **Conclusions:** Our findings support the age-effect hypothesis in boys' rule breaking behavior. This shows that the association between HR and ASB depends on age, gender, and subtype of ASB. J. Am. Acad. Child Adolesc. Psychiatry, 2010;49(5):493–502. **Key Words:** heart rate, rule breaking, aggression, gender

Low heart rate (HR) is one of the strongest and most often replicated physiological correlates of antisocial behavior (ASB) in childhood and adolescence.[1] However, longitudinal studies focusing on developmental pathways and studies on the relationship of HR to subtypes of ASB (i.e., aggression, rule breaking) are still lacking.[2,3] Often, two theoretical explanations for the relationship between HR and ASB are given.[4] According to the stimulation-seeking theory, some adolescents are constantly underaroused, which is presumably marked by a low HR and a subjective unpleasant state.[4-6] Behaving antisocially is assumed to increase HR and to be accompanied by a more comfortable state. Alternatively, in the fearlessness theory, a general lack of anxiety and inhibition is assumed to be required to conduct ASB.[5,7] Despite their differences, both theories suggest that the relationship between HR and ASB may be mediated by personality traits.

Before we focus on these mediation factors, we take a closer look at the established relationship between HR and ASB.[1,5,8] Previous studies typically focused on one type of ASB or used ASB as

This article is discussed in an editorial by Dr. David C. Rettew on page 441.

an aggregate measure of rule-breaking and aggressive behavior. There are a few notable exceptions showing that a distinction of subtypes of ASB may be useful,[9,10] and aggression and rule breaking have been shown to be distinct, although correlated, subtypes of ASB.[11] To consider a mediation model, we lean on previous findings on the relationships between "HR and personality" and "personality and ASB." Low resting HR has been associated with high levels of impulsivity or low levels of inhibition and with high levels of sensation and novelty seeking in adolescents and adults.[12-14] Previous studies on the relationship between personality and ASB show that both low inhibition and sensation seeking have been linked to aggression and rule-breaking.[15] Likewise, low inhibition in childhood has been shown to lead to rule-breaking in adolescence and to aggression in general.[16,17] Efforts to distinguish between these two personality traits have been hampered by conceptual and measurement overlap, making it thus impossible to tap into the different relationship of HR with sensation seeking and behavioral inhibition and the different contribution of personality traits on aggression and rule breaking.

In the present study we assessed whether the personality traits "sensation seeking" and "low behavioral inhibition" could mediate the relationship between HR and ASB. In addition, we considered the possibility that both "sensation seeking" and "fearlessness" theories are true, but for different age groups and subtypes of ASB. This has not been tested before, but is inspired by previous research showing distinct developmental pathways for rule breaking and (physical) aggression. Incidences of rule breaking rise in adolescence, with a peak of offending in middle adolescence,[18] whereas physical forms of aggression are relatively frequent in childhood but steadily decline in adolescence. These findings on ASB seem in accordance with the developmental pathways of personality traits, as children have lower behavioral inhibition compared with adolescents and adults.[19] Sensation seeking, however, shows a rise from the beginning of adolescence, with a peak at the age of 15 to 16 years. Behavioral inhibition may thus be more linked to aggression, and sensation seeking more to rule breaking.

How then is this age effect related to HR? In line with the fearlessness theory, low HR may be associated with low inhibition in preadolescents, which in turn is linked to aggression. However, in adolescence, low HR may be associated with both sensation seeking and rule breaking but, to our knowledge, not with aggression and behavioral inhibition. From recent brain research, we also know that children who were low on behavioral inhibition become high on sensation seeking later in life.[20] This development in personality could imply that those who are characterized by low HR are less inhibited in preadolescence and are likely the ones who are characterized by high sensation seeking in adolescence, which in turn is then related differently to aggression and rule breaking. To address these differences in developmental pathways, we tested an age-effect hypothesis in the present study. More precisely, we expected (a) that behavioral inhibition in preadolescence, but not in adolescence, mediates the relationship between HR and aggression. On the other hand, we expected (b) sensation seeking in adolescence, but not in preadolescence, to mediate the relationship between HR and rule breaking.

If at all, previous studies focused only on cross-sectional associations between HR and ASB and HR and personality traits (with a few longitudinal exceptions[7,9,21,22]). Moreover, samples in which HR was measured were typically small and comprised mostly clinical cases. To overcome these limitations, we tested the mediation models longitudinally, in a large population-based sample. In addition, we assessed personality at three different ages during preadolescence and adolescence (i.e., age 11, 13.5, and 16 years) and in three different ways, to increase the generalizability and robustness of the findings. We formulated no specific hypotheses regarding gender differences. However, previous studies showed that girls have higher HR in general,[2,22] whereas boys score in general higher on aggression and rule breaking.[23,24] Hence, we tested the mediating role of sensation seeking and behavioral inhibition on the relation between resting HR and rule breaking and aggressive behavior in adolescence separately for boys and girls.

METHOD

Participants

Data were collected in a general population of TRacking Adolescents' Individual Lives Survey (TRAILS), a large prospective population study of Dutch adolescents with bi- or triennial measurements from age 11 to at least age 25 (see Huisman et al. [25] for a full

description of the sample). Parental informed consent was obtained after the procedures had been fully explained. Detailed information about sample selection and analysis of nonresponse bias has been reported elsewhere.[26] The three assessment waves ran from March 2001 to July 2002 (T1), September 2003 to December 2004 (T2), and September 2005 to December 2007 (T3). At T1, 2230 children (mean age = 11.09 years, SD = 0.56 year) enrolled in the study of whom 2149 (96.4%; mean age 13.56 years, SD = 0.53 year) participated at T2 and 1816 (81.4%; mean age 16.27 years, SD = 0.73 year) at T3.

Measures

Aggression and Rule Breaking Behavior. The ASB subtypes aggression and rule breaking behavior were assessed as self-reported measures as part of the broadband Youth Self Report (YSR) at age 16 years.[27] The YSR covers behavioral and emotional problems in the past 6 months. Good reliability and validity of the American version were confirmed for the Dutch version.[28] The rule breaking subscale consisted of 15 items (α = .76) assessing behaviors such as rule-breaking, truancy, and stealing. The adapted aggression subscale consisted of eight items (α = .71) assessing physical acts against persons or things (i.e., fighting, being cruel to others). Subjects responded on a three-point scale (0 = true, 1 = somewhat true, 2 = very often or true).

Heart Rate. At age 11 years, cardiac autonomic function was assessed by a three-lead electrocardiogram while participants were in supine position and breathing spontaneously. Dedicated software ([pre-]CARSPAN, previously used, e.g., in Dietrich et al.[29]) 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 (bpm). Blocks were considered invalid if they contained artifacts with a duration of more than 5 seconds, if the total artifact duration was more than 10% of the registration, or if the block length was less than 100 seconds. Heart rate recordings were missing (n = 76) because of recording failure (41%) or signal analysis failure (59%).

Sensation Seeking and Behavioral Inhibition. Personality traits sensation seeking and behavioral inhibition were assessed at age 11 with two subscales of the parent-reported Early Adolescent Temperament Questionnaire Revised (EATQ-R).[30] Scales were constructed based on a previous TRAILS studies.[31] Sensation seeking was assessed with the high-intensity pleasure/surgency subscale, consisting of six items (α = .77) such as, "my child would find it exciting to travel to e.g., India or Africa" and "my child would fear the thought of skiing down a steep hill at high speed (reversely coded)." Behavioral inhibition was assessed with the effortful control subscale, consisting of eleven items (e.g., "my child finds it easy to focus on a task"; "is usually able to stick with her/his plans and goals") with good internal consistency (α = .86). Subjects responded on a five-point scale (1 = almost never true, 5 = almost always true).

At age 13.5 years, the Behavioral Inhibition System/ Behavioral Activation System (BIS/BAS) scales were used to measure behavioral inhibition and sensation seeking.[32] Behavioral inhibition (BIS) was assessed with seven items (α = 0.68), such as "I worry about making mistakes" and "I have very few fears compared to my friends [reversely coded]." Sensation seeking was assessed with the four-item fun seeking subscale (α = 0.44), comprising items such as "I crave excitement and new sensations" and "I will often do things for no other reason than that they might be fun." Subjects responded on a four-point scale (1 = untrue, 2 = somewhat untrue, 3 = somewhat true, 4 = true).

At age 16 years, we assessed behavioral inhibition and sensation seeking as part of the self-reported Revised Neuroticism-Extroversion-Openness Personality-Inventory (NEO-PI R).[33] Behavioral inhibition was measured with six items of the impulsivity subscale (α = 0.57; e.g., "I find it difficult to resist temptations" and "I can always control my feelings [reversely coded]"), after dropping two items because of low internal consistency. Sensation seeking was assessed with the adventurism subscale, comprising seven items (α = 0.59), such as "I hunger for excitement" and "I like the thrill of the roller-coaster." One item ("I like to wear clothes that stand-out or are colorful") was dropped from the original subscale because of low internal consistency. Item scores ranged from 1 (fully disagree) to 5 (fully agree).

Data Analysis

First, summary statistics were given by calculating means (SD) of the study variables. Second, to test our mediation hypotheses, we computed linear regression models using one-tailed tests. Rule breaking and aggression scores were logarithmically transformed to correct for skewness (i.e., many participants scored zero on the scale). After transformation, both variables were still skewed but considerably less.

To test mediation properly,[34] we tested first whether there was a direct association of HR with ASB (i.e., rule breaking or aggression). Furthermore, we tested the association of HR with personality. Finally, we tested whether the association between HR on ASB was mediated. Evidence for complete mediation is given when the direct association between HR and ASB becomes zero, while allowing personality to mediate this relationship. Partial mediation is applicable when this direct association becomes significantly

TABLE 1 Heart Rate, Antisocial Behavior, and Personality Traits in Study Population: Means, Standard Deviations, and Gender Differences

	Girls			Boys			Gender Differences		
	N	Mean	SD	*N*	Mean	SD	*T*	*df*	*p*
Age 11 years									
Heart rate (bpm)	902	78.72	11.05	851	75.36	10.60	6.49	1751	<.001
Effortful control (EATQ-R)	829	3.35	0.65	780	3.11	0.70	7.28	1607	<.001
Surgency (EATQ-R)	824	3.18	0.94	781	3.41	0.91	−4.84	1603	<.001
Age 13.5 years									
Behavioral inhibition (BIS)	858	2.66	0.51	800	2.37	0.50	11.93	1656	<.001
Fun-seeking (BAS)	858	2.67	0.48	800	2.70	0.50	−1.40	1656	.16
Age 16 years									
Aggression (YSR)	714	0.10	0.13	619	0.15	0.18	−6.06	1331	<.001
Rule breaking (YSR)	715	0.24	0.17	619	0.29	0.17	−5.78	1332	<.001
Impulsivity (NEO-PI-R)	713	2.87	0.55	619	2.77	0.52	3.42	1330	<.01
Adventurism (NEO-PI-R)	713	3.50	0.55	619	3.73	0.55	−7.50	1330	<.001

Note: Independent-samples *t* tests were used to calculate mean differences between boys and girls. BAS = Behavioral Activation Scale; BIS = Behavioral Inhibition Scale, bpm = beats per minute; EATQ-R = Early Adolescent Temperament Questionnaire Report–Revised, NEO-PI-R = Neuroticism-Extroversion-Openness Personality Inventory–Revised; YSR = Youth Self Report.

lower. To test whether mediation was significant, we applied the conservative Sobel test as well as a bootstrap approach,[35] which enabled us to calculate the 95% confidence intervals of the mediation effect. Bootstrapping generates *k* random samples (*k* is here 1,000) 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. Macros for this procedure were downloaded from http://www.comm.ohio-state.edu/ahayes. Regression analyses were conducted separately per mediator and gender.

RESULTS

Summary Statistics

Table 1 shows means, standard deviations, and gender differences of the study variables. Boys and girls differed significantly on almost all variables. Supine HR at age 11 years was 3 to 4 bpm higher in girls. Boys scored higher on rule breaking and aggression at age 16 . Regarding personality traits, girls were higher than boys on effortful control at age 11 and behavioral inhibition at age 13.5, and scored higher on impulsivity at age 16. Boys scored higher on surgency and adventurism, at age 11 and 16 respectively.

HR and ASB: EATQ-R

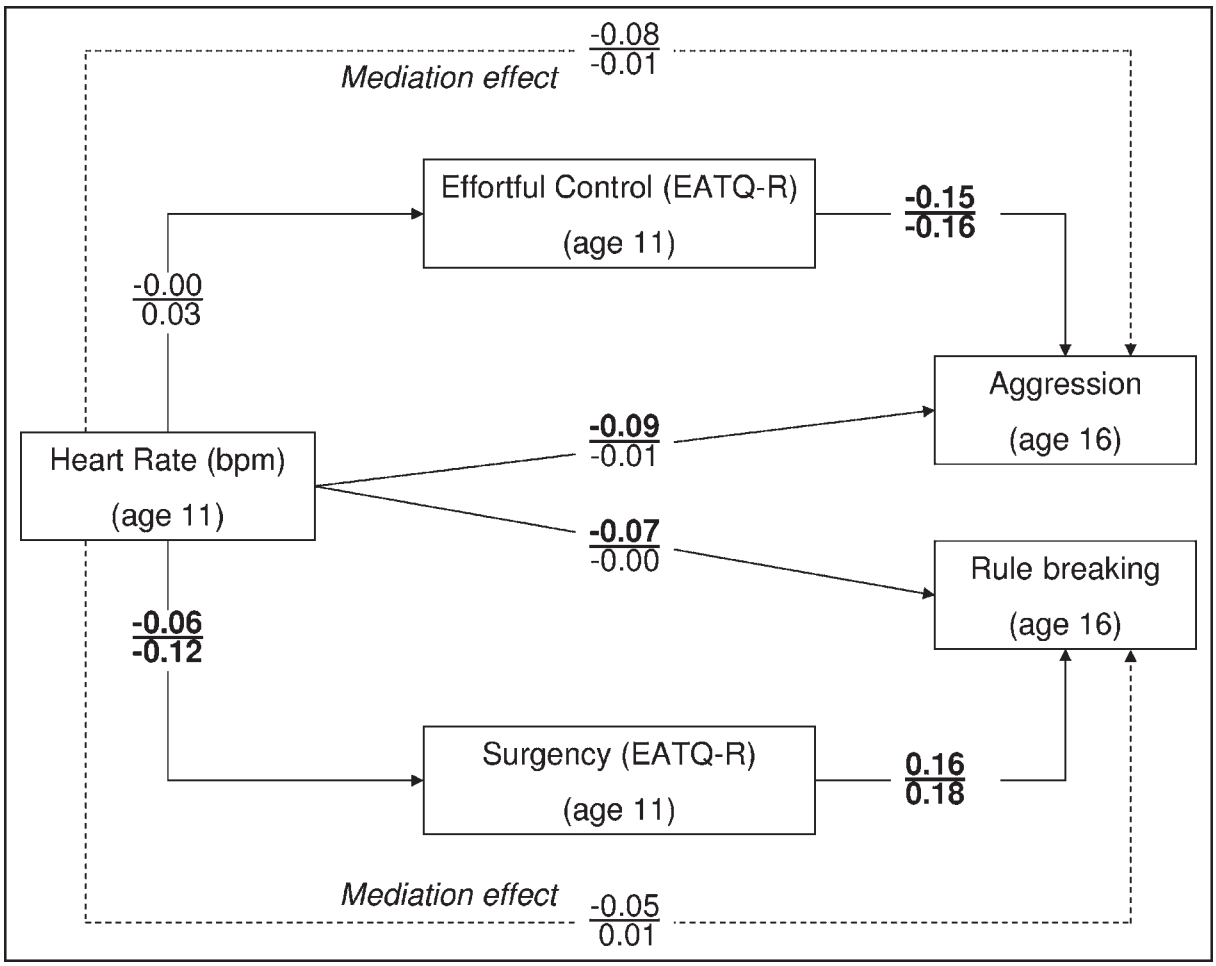
Regression analyses were conducted to study the prospective relations between HR at age 11 and rule breaking at age 16. Beta values of all the separate paths are reported in Figure 1. Boys' HR at age 11 negatively predicted rule breaking at age 16 ($\beta = -0.07$, t = −1.74, p = .04) and was negatively associated with the EATQ-R surgency measure ($\beta = -0.06$, t = −1.74, p = .04). Regression analyses showed that the association between boys' HR and rule breaking dropped in strength, while allowing surgency at age 11 to mediate this relationship (mediation effect: $\beta = -0.05$, t = −1.16, p = .13). This mediation effect did not reach significance in the Sobel and bootstrapping test. In girls, HR was associated only with surgency ($\beta = -0.12$, t = −3.42, p < .01).

In boys, lower HR was significantly associated with more aggression at age 16 ($\beta = -0.09$, $t = -2.32$, $p = .01$); but, again, personality (effortful control) did not mediate this relationship. In girls, HR was not associated with effortful control or aggression, and thus no mediation effects were found. Boys and girls low on effortful control at age 11 were more aggressive at age 16 (for both, $\beta < -0.15$, t < −3.54, p < .001).

HR and ASB: BIS/BAS

Results of the mediation analysis with the BIS/BAS measures are presented in Figure 2. HR was negatively associated with fun seeking at age 13.5 ($\beta = -0.07$, t = −1.90, p = .03 for boys, and $\beta = -0.06$, t = −1.77, p = .04 for girls). Moreover, fun seeking at age 13.5 was signifi-

FIGURE 1 Graphic presentation of the associations between the following: heart rate and personality; personality and antisocial behavior; heart rate and antisocial behavior; and the mediating effect of personality. Note: Values are regression beta values belonging to the particular pathways (one-tailed tests; significant regression beta values [$p < .05$] are given in boldface type; Boys are represented above the line and girls below. Dashed lines indicate indirect or mediation effects of personality on the relationship between heart rate and antisocial behavior). Personality was assessed at age 11 years via the Early Adolescent Temperament Questionnaire Report–Revised (EATQ-R). Bpm = beats per minute. [a]Mediation significant.

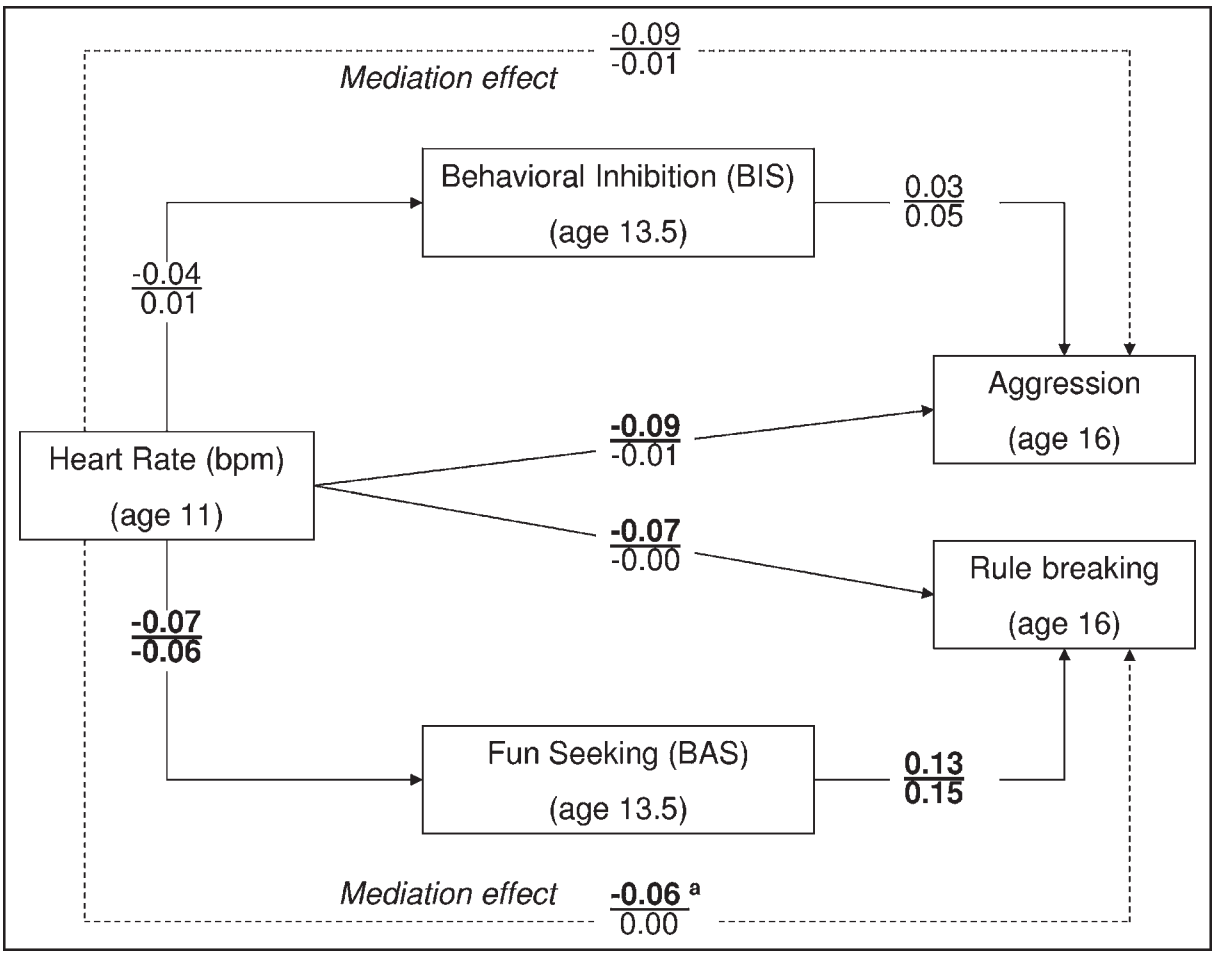


cantly associated with rule breaking at age 16 ($\beta > 0.13$, $t > 3.11$, $p < .01$). As hypothesized, there was evidence that boys' fun seeking at age 13.5 mediated the relationship between HR and rule breaking (Figure 2). The Sobel test ($Z = -1.66$, $p = .05$) and the bootstrapping method (−0.0002; 95% CI between −0.0003 and .0000) showed that the mediation effect was marginally significant. Behavioral inhibition was unrelated to HR and aggression and thus no mediation effects were found.

HR and ASB: NEO-PI-R

HR at age 11 was negatively associated with adventurism at age 16 ($\beta = -0.16$, $t = -4.13$, $p < .01$ for boys, and $\beta = -0.09$, $t = -4.13$, $p < .01$ for girls). Boys' adventurism at age 16 mediated the relationship between HR and rule breaking, because the association between HR and rule breaking came close to zero ($\beta = -0.02$, $t = -0.55$, $p = .29$; Figure 3), while allowing for mediation of adventurism. The Sobel test ($Z = -3.61$, $p < .001$) and the bootstrapping method (−0.0008; 95% CI between −0.0012 and −0.0004) showed that this reduction of the direct association between HR and rule breaking was significant. In girls and boys, impulsivity was associated with aggression ($\beta > 0.31$, $t > 8.82$, $p < .001$). However, no mediation effects were found, because HR was

FIGURE 2 Graphic presentation of the associations between the following: heart rate and personality; personality and antisocial behavior; heart rate and antisocial behavior; and the mediating effect of personality. Note: Values are regression beta values belonging to the particular pathways (one-tailed tests; significant regression beta values [$p < .05$] are given in boldface type. Boys are represented above the line and girls below. Dashed lines indicate indirect or mediation effects of personality on the relationship between heart rate and antisocial behavior). Personality was assessed at age 13.5 via the Behavioral Inhibition Scale/Behavioral Activation Scale (BAS/BIS). Bmp = beats per minute. [a]Mediation significant.



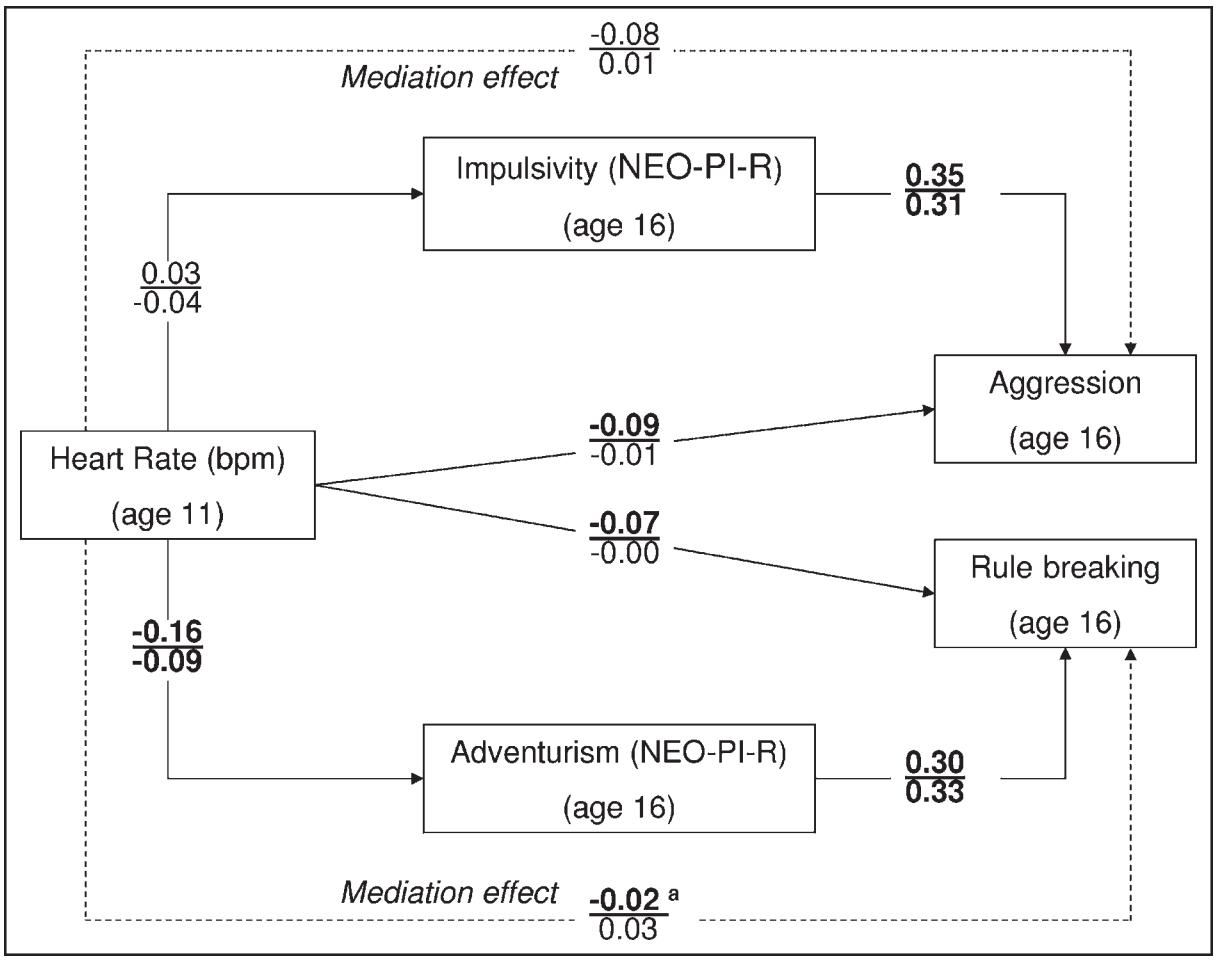
not associated with impulsivity or aggression (in girls).

DISCUSSION

We showed that it is useful to distinguish between boys and girls and subtypes of ASB when studying the relationship between HR and ASB. Moreover, in boys, we were able to show part of the underlying mechanism of the relationship between low resting HR at age 11 and rule breaking at age 16, namely, the mediating role of sensation seeking at age 13.5 and 16. More importantly, in line with our age-effect hypothesis, this relation was not mediated by behavioral inhibition and thus provides evidence for different associations between HR in preadolescence and ASB in adolescence. In girls, no mediation effects were found.

The current study has some limitations. First, we could not make statements about the predictive value of HR on ASB. Our findings show only that HR at age 11 is related to ASB at age 16, but not to change in ASB from age 11 to 16. Our second limitation was the assessment of behavioral inhibition. Ideally we wanted to assess a measure of impulsivity or a lack of being able to control one's own behavior. Although our effortful control measure (EATQ-R) came close, there were some items

FIGURE 3 Graphic presentation of the associations between the following: heart rate and personality; personality and antisocial behavior; heart rate and antisocial behavior; and the mediating effect of personality. Note: Values are regression beta values belonging to the particular pathways (one-tailed tests; significant regression beta values [$p < .05$] are given in boldface type. Boys are represented above the line and girls below. Dashed lines indicate indirect or mediation effects of personality on the relationship between heart rate and antisocial behavior). Personality was assessed at age 16 via the Neuroticism-Extroversion-Openness Personality Inventory–Revised (NEO-PI-R). Bpm = beats per minute. [a]Mediation significant.



that were more related to cognitive than behavioral inhibition constructs. The assessment of the BIS/BAS scales was ideally timed, on average 2 years after HR and 3 years before ASB assessment. However, the BAS fun-seeking scale had low internal consistency. The NEO-PI-R measure of impulsivity was the most ideal tool to assess behavioral inhibition. To overcome limitations and to increase comparability with other studies, we included all three measures of behavioral inhibition and sensation seeking. In this way we showed robust findings regarding the mediating roles of personality characteristics in adolescence. Third, we only found partial mediation of personality; this means that there are other factors that may also mediate the relationship between HR and ASB.

Apart from these limitations, our study has several strong points. We were able to study a physiological measure in relation to psychopathology in a large, nonclinical, general population. Moreover, we assessed both parent- and self-reported personality characteristics at different time points and showed robust findings with regard to the relation with HR and ASB. Using different raters at different ages had advantages. In preadolescence, children were on average 11 years old, and parents may thus have had a better perspective on the child's personality at that time. However, in

early and middle adolescence, when participants were on average 13.5 and 16 years old, youth are more likely to have a clearer perspective on their own personality than their parents.

As suggested on a theoretical basis,[1] we showed that lower HR was associated with more sensation seeking in adolescent boys, which was in turn associated with higher levels of rule breaking. Our findings were also partly in accordance with previous studies in which the age-specific effects of HR on ASB and of HR on personality were found. We showed that boys' HR was related only to sensation seeking at age 13.5 and 16, and not at age 11. Although we did not find support for the relationship between HR and behavioral inhibition in preadolescence, this relationship was also absent at ages 13.5 and 16, as we predicted. These findings are partly in line with research that suggests that after childhood, behaviorally disinhibited children become more open to novelty (or sensation) seeking later in life.[20] Although we did not find a mediation effect of behavioral inhibition in preadolescence, there was an indication that the mediation effect of sensation seeking became stronger during adolescence. This effect could at least offer some explanation to the increase of sensation seeking and rule breaking in adolescence found previously.[19]

In the current study, interesting gender differences were found. HR predicted rule breaking and aggression only in boys, and not in girls. Taking a closer look at Ortiz and Raine's meta-analysis,[1] it turns out there were only two studies among adolescent girls in which associations between HR and ASB were found. These studies had relatively small sample sizes (N = 36 and N = 44) and the assessment of ASB in one study is questionable (i.e., disruptive behavior as rated by teachers). However, there is stronger evidence that fails to replicate that low resting HR is associated with ASB in adolescent girls.[36-38] In a sample of late adolescents (16 to 18 years; N = 585), only antisocial boys had lower resting HR.[37] Furthermore, in a clinical sample of girls (12.5 years; N = 206), no significant association between HR and conduct disorder was found.[38] Along with the findings in the present study, this may have implications for future studies assessing the association between HR and adolescent girls' ASB.

In line with a previous study,[10] HR was associated with aggression in adolescent boys. Findings are mixed however, because in a recent study among adopted adolescents it was shown that low resting HR was associated only with rule breaking and not aggression.[9] A possible reason for these different results may be that aggression is a more heterogeneous construct compared with rule breaking. Whereas the latter is generally related to delinquency, aggression taps into a wide range of behaviors entailing many different forms (and functions) related to different outcomes.[39,40] Instrumental (or proactive) aggression, for instance, is intended behavior and may therefore be unrelated to behavioral inhibition. This difference in aggression also shows up in the findings that instrumental aggression has been associated with low resting HR, whereas reactive aggression, as a direct response to stimuli, was unrelated to resting HR.[41] Therefore, future studies may profit from distinguishing between different types of aggressive behavior and assessing HR both during rest and mental stress conditions to obtain HR reactivity measures.

Based on the fearlessness theory, we expected, in preadolescence, that low behavioral inhibition would mediate the negative relationship between HR and aggression. However, we did not find this mediation effect and thus we did not find evidence for the fearlessness theory. This finding may be interpreted in light of findings indicating that externalizing problems up until early adolescence are also partly related to anxiety problems.[42,43] There may thus be important differences in the underlying mechanisms leading to adolescent ASB. On the one hand, we have a group of (especially male) youth who are characterized by high levels of fear and anxiety. On the other hand, however, we deal with a group that is characterized by low levels of fear and anxiety as suggested by fearlessness theory.[44] Future studies are needed to unravel these possible group differences.

Ortiz and Raine's[1] meta-analysis resulted in an overall average effect size of $d = -0.44$, indicating lower resting heart rate in antisocial children compared with both normal controls and psychiatric controls. In the current study, for boys, calculations of effect sizes from correlations[45] showed small effect sizes ($d = -0.19$ for the negative relationship between HR and aggression and $d = -0.14$ for the negative relationship between HR and rule breaking). These differences in effect sizes in our study compared with the meta-analysis may be caused by publication bias, which is known to inflate effect estimates that tend to be in the hypothesized direction in meta-analyses.

In sum, boys with lower HR in preadolescence

appeared to be most at risk for rule breaking and aggression at age 16 years. In line with our age-effect hypothesis, sensation seeking mediated the relationship between HR and rule breaking only in adolescence but not in preadolescence. For intervention practices, this has several implications. As suggested by Ortiz and Raine,[1] interventions that teach youths to engage more in prosocial, law-abiding activities could provide other ways to satisfy sensation seeking in adolescence and thus to more optimal levels of autonomic arousal. However, one such cognitive behavioral intervention, aimed at reducing oppositional and aggressive behavior, positively affected only children with relatively high HR.[46] Those with significantly lower HR did not profit from the intervention. This shows that it is difficult to provide activities for youth with the lowest HR that can fulfill the same need of sensation as, for instance, rule breaking can. From another perspective, given the mediation effect of sensation seeking, low HR may not only be associated with rule breaking or other ASB but may also be associated with risky behavior in general. Taking more risk may have negative consequences (e.g., stealing may lead to incarceration), but can also have beneficial effects (e.g., stepping up for someone in a fight may be socially rewarding), making the behavioral effects associated to low HR dependent upon contextual factors as well.

Finally, we want to address the discussion on whether resting HR could, and should, be used as a marker of the development of ASB over time.[3] Our findings showed that HR measures obtained with a strict acquisition and analysis protocol were associated with ASB in boys but not in girls. Despite the small effect sizes, the relative ease of assessing HR at rest, even when using a protocol, the robust findings (see the meta-analysis by Ortiz and Raine[1]), and the associations with ASB over time (current study), could make HR a valuable addition to the early identification of behavioral problems in boys. &

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