Problem behavior and heart rate reactivity in adopted adolescents: Longitudinal and concurrent relations.

Bimmel, N.; van IJzendoorn, M.H.; Bakermans-Kranenburg, M.J.; Juffer, F.; de Geus, E.J.C.

published in
Journal of Research on Adolescence
2008

DOI (link to publisher)
10.1111/j.1532-7795.2008.00557.x

document version
Publisher's PDF, also known as Version of record

JOURNAL OF RESEARCH ON ADOLESCENCE, 18(2), 201–214

Problem Behavior and Heart Rate Reactivity in Adopted Adolescents: Longitudinal and Concurrent Relations

Nicole Bimmel, Marinus H. van IJzendoorn, Marian J. Bakermans-Kranenburg, and Femmie Juffer

Leiden University

Eco J. C. De Geus

Free University

The present longitudinal study examined resting heart rate and heart rate variability and reactivity to a stressful gambling task in adopted adolescents with aggressive, delinquent, or internalizing behavior problems and adopted adolescents without behavior problems (total $N = 151$). Early-onset delinquent adolescents showed heart rate *hypo*reactivity to the stress-eliciting gambling task compared to late-onset delinquent adolescents and adolescents without behavior problems. Heart rate, heart rate variability, and reactivity to stress were not related to environmental factors such as early-childhood parental sensitivity, parental socioeconomic status, or adoptee's health status at arrival. We conclude that the distinction between delinquency and aggression and between childhood-onset and adolescence-onset delinquency is important for the study of stress reactivity in adolescents.

Genetic and biological processes have been suggested to play an etiological role in the development of aggressive and antisocial behavior (Raine, 1993). Changes in both the central nervous system and the autonomic nervous system (ANS) functioning may predispose to aggressive and

Requests for reprints should be sent to Marinus H. van IJzendoorn, Leiden University, Centre for Child and Family Studies, PO Box 9555, 2300 RB Leiden, The Netherlands. E-mail: vanijzen@fsw.leidenuniv.nl

antisocial behavior (Raine, 1997; Suomi, 2000). The present longitudinal study examined resting heart rate and heart rate reactivity to a stressor in adolescents with and without aggressive, delinquent, or internalizing behavior problems. This study is the first to assess these associations in adopted children, who are raised by their biologically unrelated adoptive parents. In adoptive families, genetic influences that predispose children for developing behavior problems are less likely to be intensified by a problematic rearing environment (gene–environment correlation; Rutter, Moffitt, & Caspi, 2006).

PSYCHOPHYSIOLOGICAL CORRELATES OF ANTISOCIAL BEHAVIOR AND OTHER BEHAVIOR PROBLEMS

The psychophysiological correlates of aggressive, antisocial, and violent behavior are somewhat ambiguous, and there have been mixed results in studies relating tonic levels of autonomic activity to behavior problems. In contrast to the inconsistent findings relating global arousal to antisocial behavior, low resting heart rate is the best-replicated biological correlate of antisocial and aggressive behavior in child and adolescent populations, both in male and female samples (for meta-analyses see Ortiz & Raine, 2004; Raine, 1996). In addition to tonic levels of autonomic arousal, antisocial behaviors have been related to heart rate *hyporeactivity* to various environmental stimuli or (stress) situations (Ortiz & Raine, 2004; Popma et al., 2006; Raine, Venables, & Williams, 1990a, 1990b). These findings suggest that antisocial behavior may be associated with ANS underarousal in terms of low sympathetic and high parasympathetic nervous system activity. This pattern of underarousal may trigger a lack in anxiety, fearlessness, and unresponsiveness to aversive social contexts and may entice individuals into seeking out stimulation, for example by engaging in antisocial or criminal behaviors (Fox, Schmidt, & Henderson, 2000).

Not all studies were successful in establishing a relation between heart rate or heart rate reactivity on the one hand and aggressive or antisocial behavior problems on the other hand (for an example see Van Hulle, Corley, Zahn-Waxler, Kagan, & Hewitt, 2000). Different definitions and measurements of antisocial behavior may be responsible for these diverging results. For example, most studies have assessed antisocial behavior in general (e.g., stealing, truancy, fighting, lying, and teasing; Moffitt, 1993) without differentiating between aggressive and nonaggressive forms of antisocial behavior. Besides such different *types* of antisocial behavior, there are groups of individuals with different developmental *courses* of these problem behaviors (Caspi & Moffitt, 1995; Loeber, 1982; Moffitt,

1993; Moffitt & Caspi, 2001). Differences in heart rate and heart rate reactivity between adolescence-limited and life-course persistent antisocial individuals have been reported: Adolescent-limited antisocial individuals had higher resting heart rates and greater electrodermal orienting responses than their persistent antisocial peers (Raine, Venables, & Williams, 1995), and low resting heart rate assessed at ages 7, 9, and 11 years was particularly characteristic of life-course persistent offenders (Moffitt & Caspi, 2001). Differences in heart rate and heart rate reactivity between adolescence-limited and life-course persistent antisocial individuals may be essential in studying stress reactivity in antisocial adolescents.

Whereas low resting heart rate and hyporeactivity to stress have been linked to antisocial problem behaviors, higher resting heart rates and/or *hyper*reactivity have been linked to problems of an internalizing nature, such as anxiety (Mezzacappa et al., 1997), behavioral inhibition (Kagan, Reznick, & Snidman, 1987, 1988), and emotional disturbances (Garralda, Connell, & Taylor, 1991). Heightened physiological responsivity in inhibited individuals may reflect a tendency to respond to uncertainty and novel situations with stress, which, in turn, may lead to future anxiety disorders (Kagan et al., 1987, 1988).

THE CURRENT STUDY: HEART RATE AND HEART RATE REACTIVITY IN ADOPTED ADOLESCENTS

In the current study we compared adolescents with behavior problems to adolescents without these problems. We additionally distinguished between (1) aggressive (e.g., fighting, attacking others, teasing) and delinquent behavior problems (e.g., stealing, lying, truancy, fire setting, vandalism); (2) late-onset and early-onset delinquent and aggressive behavior problems; (3) internalizing and externalizing behavior problems; (4) males and females; and (5) resting heart rate and heart rate reactivity to a stressor. Measures of heart rate reflect the contribution of parasympathetic and sympathetic nervous system influences to resting heart rate and heart rate reactivity. Mainly parasympathetic influences to resting heart rate and heart rate reactivity can be easily obtained in a noninvasive design as used here, by time- or frequency domain based measures of heart rate *variability* (Bigger et al., 1992; Penttila et al., 2001; Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology, 1996).

The present study examined the potential influence on heart rate of early environmental factors (health condition at arrival indexing quality of care before adoption, adoptive parents' socioeconomic status (SES), and adoptive mothers' sensitivity in early childhood) and controlled for any

influence of IQ, cigarette smoking (Ortiz & Raine, 2004), and physical conditioning through sports participation (De Geus, Boomsma, & Snieder, 2003). The primary distinguishing feature between this study and previous research in this area is that the association between heart rate and behavior problems is examined in adopted adolescents. In nonadoptive families the parents may transmit a genetic predisposition for antisocial behavior to their children and also provide a rearing environment that provokes antisocial behaviors (Rutter et al., 2006). Adoptive families provide the opportunity to unravel these confounding influences.

METHOD

Participants

Participants were 151 14-year-old internationally adopted children (67 boys and 84 girls), participating in a longitudinal study which began in infancy with 160 children (Jaffari-Bimmel, Juffer, van IJzendoorn, Bakermans-Kranenburg, & Mooijaart, 2006; Juffer, Hoksbergen, Riksen-Walraven, & Kohnstamm, 1997; Stams, Juffer, & van IJzendoorn, 2002). All adoptive families were randomly recruited through Dutch adoption organizations. The children were adopted before the age of 6 months ($M = 9.9$ weeks; $SD = 5.33$) from Sri Lanka ($n = 93$), South Korea ($n = 38$), and Colombia ($n = 20$). The adoptive parents were white, predominantly (upper) middle-class, and screened for the absence of a criminal past before the adoption.

Procedure

Families were visited at home at 5, 6, 9, and 12 months. Mothers and children came to the laboratory at 12, 18, and 30 months. At 7 years, the Child Behavior Checklist (CBCL; Achenbach, 1991) was administered. At 14 years, the families were visited at home to measure heart rate of the adolescents during completion of a questionnaire in the absence of the experimenter that served as a baseline, and during a stressful gambling task with the experimenter present. All adolescents were visited by the same experimenter. The experimenter was blind to the incidence of behavior problems of the adolescents. During the home visit the adoptive mother completed the CBCL.

Measures

Behavior problems. Mothers completed the CBCL (Achenbach, 1991; Verhulst, Van der Ende, & Koot, 1996) to assess the adolescent's behavior

problems. The present paper examined the following syndromes: aggression and delinquency (being part of the broad-band syndrome externalizing behavior problems), and the broad-band syndrome internalizing behavior problems. Adolescents without behavior problems (hereafter: ''comparisons'') did not exceed the cutoff point of any of the behavior problem syndromes ($n = 92$). Adolescents with a particular syndrome (i.e., aggressive, $n = 19$; delinquent, $n = 25$, or internalizing, $n = 46$) were compared with these comparisons. In addition, early-onset delinquents ($n = 10$) were compared with late-onset delinquents ($n = 15$), and early-onset aggressive adolescents ($n = 10$) were compared with late-onset aggressive adolescents ($n = 9$). Early-onset and late-onset delinquency and aggression were distinguished on the basis of their scores at 7 years and at 14 years. Early-onset adolescents were delinquent or aggressive at both 7 and 14 years, and late-onset adolescents exceeded the cutoffs at 14 years but not at 7 years. Comorbidity of the syndromes precluded comparisons between syndromes. In order to control for co-occurring symptoms of delinquency and aggression, we controlled for the continuous scores for the syndrome scales in the analyses (ANCOVA); for example, in the analyses of the delinquency syndrome the continuous score on aggression was used as a covariate.

Heart rate. For the recording of heart rate with the VU-AMS device (the Vrije Universiteit Ambulatory Monitoring System, VU-AMS; De Geus & van Doornen, 1996), three disposable ECG electrodes were placed on the adolescent's chest. The questionnaire and the gambling task were administered while the adolescents were seated, so their gross body movement was close to zero. The device continuously recorded all interbeat intervals. From the interbeat interval time series, an average HR was extracted each 10-second period. Mean heart rates and heart rate variability (RMSSD; root mean square of standard differences in interbeat intervals) for resting and stress conditions were computed from all 10-second periods. This yielded the following heart rate measures: (1) resting heart rate, defined as the mean heart rate and heart rate variability during completion of a questionnaire (baseline); (2) heart rate during stress, defined as the mean heart rate and heart rate variability during the gambling task (stressor); and (3) heart rate reactivity, defined as the change in heart rate from baseline to stressor. The registration of heart rate was successful in all adolescents. The correlation between mean heart rates and heart rate variability was $-.56$. The standard deviations for RMSSD were large (a common phenomenon with RMSSD; see also Vrijkotte, van Doornen, & De Geus, 2000). However, no extreme outliers (HR mean

<30 or >200 and RMSSD >200) were found in the raw data, and no outlying means were identified on the basis of standardized scores (z-values) larger than 3.29 or smaller than -3.29 (Tabachnick & Fidell, 2001). Previous studies have shown the validity of the method (Kupper et al., 2004; Vrijkotte et al., 2000).

Gambling task (cost benefit reasoning task). The stressor was a gambling task (Bechara, Damasio, Damasio, & Anderson, 1994), which elicits decision making under risky conditions with cues for rewards and for punishment. In this task the subjects sat in front of four decks of cards and were given a €20 loan of money (10 coins of €1,-; 40 coins of €.20; and 40 coins of €.05). The subjects were told that they had to choose one card at a time, from any of the four decks, until they were told to stop. Turning each card carried an immediate reward (€1,- in decks A and B and €.50 in decks C and D). Unpredictably, however, the turning of some cards also carried a penalty (which was large in decks A and B and small in decks C and D). The subjects were free to switch from any deck to another, as often as they wished and at any time. They were not told ahead of time how many cards they had to pick. The task was stopped after a series of 100 cards. The subjects had no way of predicting when a penalty would arise in a given deck and no way to calculate with precision the net gain or loss from each deck. Decks A and B were disadvantageous in the long run and decks C and D were advantageous in the long run.

Intelligence. The adolescents completed the abbreviated Groningen Intelligence Test (subtests cipher, enumerate words, and word matrices; Luteijn & van der Ploeg, 1983).

Physical condition and smoking. The adolescents were asked about sports, smoking, and smoking of soft drugs (marijuana or cannabis such as hash and weed, and herbal drugs).

Health condition on arrival. Health condition on arrival was computed by the standardized summation of three variables: birth weight, incidence of prematurity, and health problems on arrival (reversed), including variables such as symptoms of malnourishment, dehydration, anemia, or paratyphoid (see Stams et al., 2002).

SES. SES was a combination of the educational and vocational background of both parents (see Stams et al., 2002).

Early childhood maternal sensitive responsiveness. Maternal sensitive responsiveness was assessed in free-play and task episodes of

mother–child interaction at home and in the laboratory (see for a detailed description Stams et al., 2002).

RESULTS

Descriptives and Background Variables: Relations With Behavior Problems and Heart Rate

There were no significant differences between adolescents with and without behavior problems in age on arrival, health condition on arrival, number of card selections from advantageous/disadvantageous decks during the gambling task, number of sports, and using soft drugs. Adolescents without behavior problems ($M = 14.6$, $SD = .6$) were somewhat older than adolescents with early- and late-onset aggressive behavior problems ($M = 14.0$, $SD = .0$, standardized difference [effect size] $d = 1.05$, and $M = 14.1$, $SD = .3$, $d = .86$, respectively), and early-onset aggressive adolescents were somewhat younger than adolescents with late-onset delinquent behavior problems ($M = 14.5$, $SD = .5$, $d = 1.28$). More boys than girls were deviant on early- and late-onset aggression (80% and 78% boys, respectively) and early-onset delinquency (80% boys). Early-onset aggressive and early-onset delinquent adolescents had lower IQ ($M = 90.6$, $SD = 17.1$, $d = .67$, and $M = 90.8$, $SD = 16.0$, $d = .68$, respectively) than children without behavior problems ($M = 100.4$, $SD = 11.9$). Late-onset delinquents smoked more than all other groups ($d = 1.09$).

Neither resting heart rate and heart rate variability nor reactivity of heart rate and heart rate variability were associated with the descriptive and background variables gender, number of card selections from advantageous/disadvantageous desks during the gambling task, IQ, number of sports, or smoking. Moreover, there were no significant correlations between health condition on arrival, maternal sensitivity in early childhood, and parental SES on the one hand and heart rate, heart rate variability, and reactivity to stress on the other hand. Therefore, no covariates were used in the subsequent analyses (Tabachnick & Fidell, 2001).

Aggressive, Delinquent, and Internalizing Problem Behaviors: Associations with Resting Heart Rate

There were no significant differences in resting heart rate and heart rate variability between the various behavior problem groups (early-onset and late-onset aggressive, early-onset and late-onset delinquent, and internalizing problem behaviors) and the comparisons (Table 1).

TABLE 1
Behavior Problems, Resting Levels of Heart Rate and Heart Rate Variability, and Their Reactivity to a Stress-Eliciting Task ($N = 151$)[a]

		Resting Levels				*Reactivity*			
		Heart Rate		*Heart Rate Variability*		*Heart Rate*		*Heart Rate Variability*	
	N	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Normal	92	77.74	8.68	55.75	27.97	1.84	3.60	− 4.70	20.31
Aggressive	19	80.94	8.27	52.70	29.27	1.26	2.90	− 1.71	11.44
Early-onset	10	80.38	8.60	50.01	26.46	1.21	2.66	− 2.90	14.93
Late-onset	9	81.56	8.36	55.69	33.48	1.31	3.30	− .38	6.31
Delinquent	25	78.67	8.44	56.83	33.12	1.17	3.77	− 5.56	15.38
Early-onset	10	77.42	7.00	41.59	11.78	− 1.65[b]	3.03	2.47[c]	7.07
Late-onset	15	79.43	9.35	65.97	38.53	2.86	3.15	− 10.37	17.14
Internalizing	46	79.15	8.68	54.74	32.37	1.50	3.94	− 6.10	24.08

[a]Total sample size is 151; because of comorbidity the summation of all *n*'s is larger than 151.
[b]Early-onset delinquent adolescents differ significantly from late-onset delinquent and normal adolescents.
[c]Early-onset delinquent adolescents differ significantly from late-onset delinquent adolescents.

Heart Rate Reactivity to a Stressor

With regard to *reactivity* of heart rate and heart rate variability, the *changes* from baseline level to the stressor (gambling task), the early-onset delinquents showed large differences in both heart rate and heart rate variability when compared to either the comparisons or the late-onset delinquents (see Table 1). Adolescents without behavior problems and late-onset delinquents showed an increase in heart rate from baseline level to the stressor ($F[1, 111] = 7.17$, $p < .01$ and $F[1, 21] = 11.72$, $p < .01$, respectively), whereas early-onset delinquents did not show an increase. The effect size was $d = .51$ for the group without behavior problems and $d = 1.49$ for the late-onset delinquents, so the differences with the early-delinquency group were substantial. In both comparisons, aggression was not a significant covariate ($F[1, 111] = .67$, $p > .10$ and $F[(1, 21)] = .49$, $p > .10$, respectively). These results were parallelled by measures of heart rate variability. Late-onset delinquents and comparisons showed a decrease in heart rate variability from baseline to stressor, whereas early-onset delinquents did not show a decrease (although the difference was significant only for the late-onset delinquency group ($F[1, 21] = 5.68$,

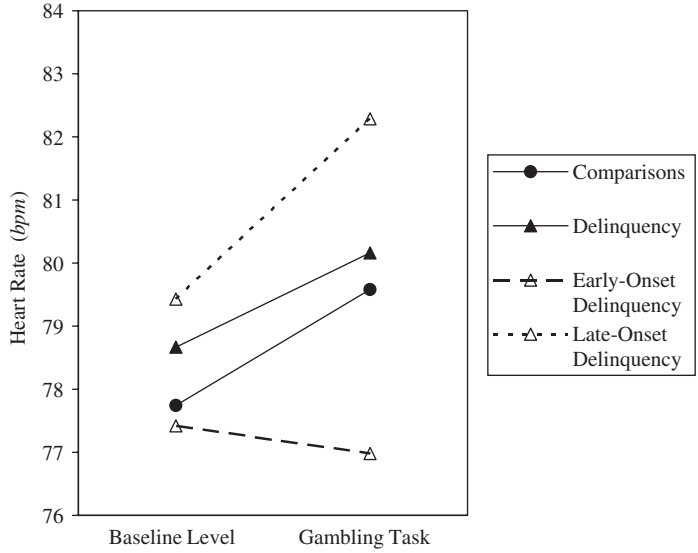

FIGURE 1 Heart rate (bpm) for all, early-onset, and late-onset delinquency and comparisons during baseline and stressor.

$p < .05$, $d = 1.04$). Aggression was a significant covariate ($F[1, 21] = 4.92$, $p < .05$, $d = 2.14$). Figures 1 and 2 graphically present the changes in heart rate (Figure 1) and heart rate variability (Figure 2) for comparisons, for the combined delinquent group, and for the early-onset and late-onset delinquent groups.

DISCUSSION

Resting heart rate and heart rate reactivity to a stressful situation were assessed in adopted adolescents with and without aggressive, delinquent, and internalizing behavior problems. There were no significant differences between the groups in resting heart rate, but heart rate reactivity to a stressor showed rather strong differences. Early-onset delinquents showed heart rate *hypo*reactivity to a stress-eliciting task compared with late-onset delinquent adolescents and adolescents without behavior problems. Quay (1993) suggested that subjects with undersocialized conduct disorder are less anxious or inhibited in the presence of cues for rewards and also less sensitive to cues for punishment, as shown in lower levels of noradrenergic function and electrodermal responsiveness. In the present study we replicated and extended previous findings by showing similar differences in the response of the *para*sympathetic system during

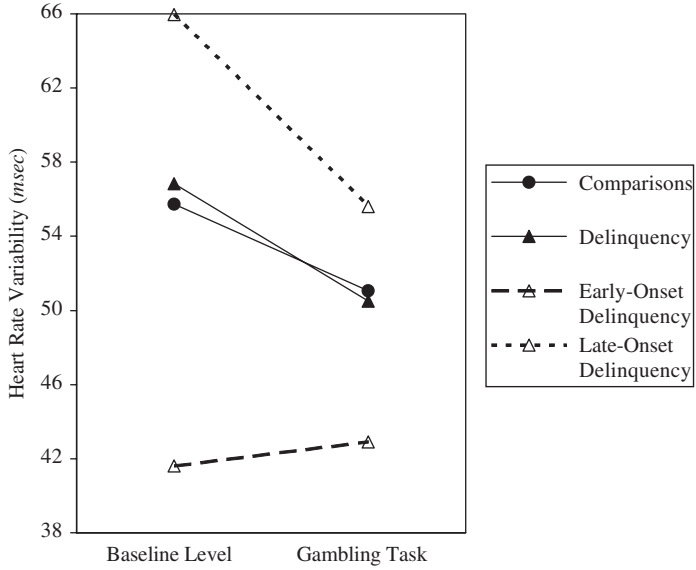

FIGURE 2 Heart rate variability for all, early-onset, and late-onset delinquency and comparisons during baseline and stressor.

a stress-eliciting gambling task. All group differences in heart rate responses were paralleled by reciprocal differences in heart rate variability, which is known to reflect mainly cardiac parasympathetic tone (Bigger et al., 1992; Penttila et al., 2001).

The differences in heart rate reactivity between the late-onset delinquents and adolescents without behavior problems were not significant, which is in line with Raine et al.'s (1995) results. Adolescence-onset delinquents may develop in the same way as their nonantisocial peers, except for a period in which they show more exploratory and limit-testing behavior that is typical of puberty, for example delinquent or antisocial behavior. This may be seen as a normative attempt to gain independence and autonomy. After puberty these behaviors may decrease to normative levels of behavior problems (Caspi & Moffitt, 1995; Fox et al., 2000; Moffitt, 1993; Moffitt & Caspi, 2001). Note that in our study late-onset delinquents smoked more than all other groups, which may also be considered indicative of exploratory or risk-taking behavior characteristic for puberty. For internalizing problems, no differences in stress reactivity were found.

A limitation of our study is the rather low number of participants in the various problem behavior groups. The early- and late-onset delinquent groups included only 10 and 15 adolescents, respectively. However, they were compared with a larger group of 92 adolescents without behavior

problems, and only through this comparison were we able to profile the delinquent groups. Moreover, although the rather low number of participants decreases the power for finding significant effects, we found significant effects for the early-onset delinquent adolescents, making the power issue in this respect obsolete. Secondly, data of birth families of the adopted children were lacking (e.g., behavior problems and SES of the biological parents). A final limitation is the use of parent-reported behavior problem scores. However, parent-reported problem behavior (CBCL) in early adolescence has been shown to be predictive of mental health service use, even 5 years later (Laitinen-Krispijn, Van der Ende, Wierdsma, & Verhulst, 1999).

Notably, the different forms of aggression (early-onset and late-onset aggression) did not show any significant differences in heart rate reactivity. Our findings suggest that delinquency and aggression may follow different developmental trajectories, and that early-onset delinquency—but not aggression—is characterized by stress hyporeactivity. The antisocial behavior assessed by Raine et al. (1995) and Moffitt and Caspi (2001), with different results for early- and late-onset antisocial individuals, may be more similar to the CBCL delinquency syndrome than to the aggression syndrome. We conclude that the differentiation between delinquency and aggression and between childhood-onset and adolescence-onset delinquency is crucial for our understanding of the development of externalizing problem behaviors.

ACKNOWLEDGMENTS

We acknowledge the financial support received from Leiden University, Wereldkinderen, Stichting Kind en Toekomst, and NWO (VIDI; SPINOZA PRIZE). We wish to thank the adolescents and their parents for their kind cooperation.

REFERENCES

Achenbach, T. M. (1991). *Integrative guide for the 1991 CBCL/4-18, YSR, and TRF profiles*. Burlington, VT: University of Vermont Department of Psychiatry.

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition, 50*, 7–15.

Bigger, J. T., Jr., Fleiss, J. L., Steinman, R. C., Rolnitzky, L. M., Kleiger, R. E., & Rottman, J. N. (1992). Correlations among time and frequency domain measures of heart period variability two weeks after acute myocardial infarction. *American Journal of Cardiology, 69*, 891–898.

Caspi, A., & Moffitt, T. E. (1995). The continuity of maladaptive behavior: From description to understanding in the study of antisocial behavior. In D. Cicchetti & D. Cohen (Eds.), *Manual of developmental psychopathology* (pp. 472–511). New York: Wiley.

De Geus, E. J. C., Boomsma, D. I., & Snieder, H. (2003). Genetic correlation of exercise with heart rate and respiratory sinus arrhythmiaq1. *Official Journal of the American College of Sports Medicine*, *35*, 1287–1295.

De Geus, E. J. C., & van Doornen, L. J. P. (1996). Ambulatory assessment of parasympathetic/sympathetic balance by impedance cardiography. In J. Fahrenberg & M. Myrtek (Eds.), *Ambulatory assessment: Computer-assisted psychological and psychophysiological methods in monitoring and field studies* (pp. 141–163). Kirkland, WA, USA: Hogrefe & Huber Publishers.

Fox, N. A., Schmidt, L. A., & Henderson, H. A. (2000). Developmental psychophysiology: Conceptual and methodological perspectives. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of psychophysiology* (pp. 665–686). Cambridge: Cambridge University Press.

Garralda, M. E., Connell, J., & Taylor, D. C. (1991). Psychophysiologic anomalies in children with emotional and conduct disorders. *Psychological Medicine*, *21*, 947–957.

Jaffari-Bimmel, N., Juffer, F., van IJzendoorn, M. H., Bakermans-Kranenburg, M. J., & Mooijaart, A. (2006). Social development from infancy to adolescence: Longitudinal and concurrent factors in an adoption sample. *Developmental Psychology, 42*, 1143–1153.

Juffer, F., Hoksbergen, R. A. C., Riksen-Walraven, J. M. A., & Kohnstamm, G. A. (1997). Early intervention in adoptive families: Supporting maternal sensitive responsiveness, infant–mother attachment, and infant competence. *Journal of Child Psychology and Psychiatry, 38*, 1039–1050.

Kagan, J., Reznick, J. S., & Snidman, N. (1987). The physiology and psychology of behavioral inhibition. *Child Development*, *58*, 1459–1573.

Kagan, J., Reznick, J. S., & Snidman, N. (1988). Biological bases of childhood shyness. *Science*, *240*, 167–171.

Kupper, N. H., Willemsen, G., van den Berg, M., de Boer, D., Posthuma, D., Boomsma, D. I., et al. (2004). Heritability of ambulatory heart rate variability. *Circulation*, *110*, 2792–2796.

Laitinen-Krispijn, S., Van der Ende, J., Wierdsma, A. I., & Verhulst, F. C. (1999). Predicting adolescent mental health service use in a prospective record-linkage study. *Journal of the American Academy of Child and Adolescent Psychiatry, 38*, 1073–1080.

Loeber, R. (1982). The stability of antisocial and delinquent child behavior: A review. *Child Development*, *53*, 1431–1446.

Luteijn, F., & van der Ploeg, F. A. E. (1983). *Groninger Intelligentie Test [Groningen Intelligence Test]*. Lisse, the Netherlands: Swets & Zeitlinger.

Mezzacappa, E., Tremblay, R. E., Kindlon, D., Saul, J. P., Arseneault, L., Seguin, J., et al. (1997). Anxiety, antisocial behavior, and heart rate regulation in adolescent males. *Journal of Child Psychology and Psychiatry, 38*, 457–469.

Moffitt, T. E. (1993). Adolescence-limited and life-course persistent antisocial behavior: A developmental taxonomy. *Psychological Review, 100*, 674–701.

Moffitt, T. E., & Caspi, A. (2001). Childhood predictors differentiate life-course persistent and adolescent-limited pathways among males and females. *Development and Psychopathology, 13*, 355–375.

Ortiz, J., & Raine, A. (2004). Heart rate level and antisocial behavior in children and adolescents: A meta-analysis. *Journal of the American Academy of Child and Adolescent Psychiatry, 43*, 154–162.

Penttila, J., Helminen, A., Jartti, T., Kuusela, T., Huikuri, H. V., Tulppo, M. P., et al. (2001). Time domain, geometrical and frequency domain analysis of cardiac vagal outflow: Effects of various respiratory patterns. *Clinical Physiology, 21*, 365–376.

Popma, A., Jansen, L. M. C., Vermeiren, R., Steiner, H., Raine, A., Van Goozen, S. H., et al. (2006). Hypothalamus pituitary adrenal axis and autonomic activity during stress in delinquent male adolescents and controlsq2. *Psychoneuroendocrinology, 31*, 948–957.

Quay, H. C. (1993). The psychobiology of undersocialized aggressive conduct disorder: A theoretical perspective. *Development and Psychopathology, 5*, 165–180.

Raine, A. (1993). *The psychopathology of crime: Criminal behavior as a clinical disorder*. San Diego: Academic Press.

Raine, A. (1996). Autonomic nervous system activity and violence. In D. M. Stoff & R. B. Cairns (Eds.), *Neurobiological approaches to clinical aggression research* (pp. 145–168). Mahwah, NJ: Lawrence Erlbaum.

Raine, A. (1997). Psychophysiology and antisocial behavior: A biosocial perspective and a prefrontal dysfunction hypothesis. In D. Stoff, J. Breiling, & J. D. Maser (Eds.), *Handbook of antisocial behavior* (pp. 289–304). New York: Wiley.

Raine, A., Venables, P. H., & Williams, M. (1990a). Autonomic orienting responses in 15-year-old male subjects and criminal behavior at age 24. *American Journal of Psychiatry, 147*, 933–937.

Raine, A., Venables, P. H., & Williams, M. (1990b). Relationships between central and autonomic measures of arousal at age 15 years and criminality at age 24 yearsq3. *Archives of General Psychiatry, 47*, 1003–1007.

Raine, A., Venables, P. H., & Williams, M. (1995). High autonomic arousal and electrodermal orienting at age 15 years as protective factors against criminal behavior at age 29 years. *American Journal of Psychiatry, 152*, 1595–1600.

Rutter, M., Moffitt, T. E., & Caspi, A. (2006). Gene-environment interplay and psychopathology: Multiple varieties but real effects. *Journal of Child Psychology and Psychiatry, 47*, 226–261.

Stams, G. J. M., Juffer, F., & van IJzendoorn, M. H. (2002). Maternal sensitivity, infant attachment, and temperament in early childhood predict adjustment in middle childhood: The case of adopted children and their biologically unrelated parents. *Developmental Psychology, 38*, 806–821.

Suomi, S. J. A. (2000). Biobehavioral perspective on developmental psychopathology: Excessive aggression and serotonergic dysfunction in monkeys. In A. J. Sameroff & M. Lewis (Eds.), *Handbook of developmental psychopathology* (2nd ed., pp. 237–256). New York: Kluwer Academic/Plenum Publishers.

Tabachnick, B. G., & Fidell, L. S. (2001). *Using multivariate statistics*. Boston: Allyn & Bacon.

Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *Circulation, 93*, 1043–1065.

Van Hulle, C. A., Corley, R., Zahn-Waxler, C., Kagan, J., & Hewitt, J. K. (2000). Early childhood heart rate does not predict externalizing behavior problems at age 7 years. *Journal of the American Academy of Child and Adolescent Psychiatry, 39*, 1238–1244.

Verhulst, F. C., Van der Ende, J., & Koot, H. M. (1996) *Handleiding voor de CBCL/4-18 [Manual for the child behavior checklist/4-18, Dutch version]*. Rotterdam, the Netherlands: Erasmus University Rotterdam.

Vrijkotte, T. G. M., Van Doornen, L. J. P., & De Geus, E. J. C. (2000). Effects of work stress on ambulatory blood pressure, heart rate, and heart rate variability. *Hypertension, 35*, 880–886.