



University of Pennsylvania
ScholarlyCommons

Publicly Accessible Penn Dissertations


1-1-2015

Risk Factors for Antisocial Behavior in Juveniles: A Multidisciplinary Perspective

Jill Portnoy

University of Pennsylvania, jill.portnoy@gmail.com

Follow this and additional works at: <http://repository.upenn.edu/edissertations>

 Part of the [Criminology Commons](#), and the [Criminology and Criminal Justice Commons](#)

Recommended Citation

Portnoy, Jill, "Risk Factors for Antisocial Behavior in Juveniles: A Multidisciplinary Perspective" (2015). *Publicly Accessible Penn Dissertations*. 1119.

<http://repository.upenn.edu/edissertations/1119>

This paper is posted at ScholarlyCommons. <http://repository.upenn.edu/edissertations/1119>

For more information, please contact libraryrepository@pobox.upenn.edu.

Risk Factors for Antisocial Behavior in Juveniles: A Multidisciplinary Perspective

Abstract

In order to understand the etiology of childhood and adolescent delinquency, researchers now recognize the need to identify risk factors for antisocial behavior across multiple disciplinary domains. Relative to psychological and social factors, biological factors have been the focus of little criminological research. This dissertation addresses this limitation by examining biological risk factors for antisocial behavior in children and adolescents. This dissertation consists of three papers that examine heart rate and hormones in relation to aggression and other antisocial behavior problems in youth. The first paper examines the relationship between reduced heart rate and antisocial behavior. Although low heart rate is a well-replicated biological correlate of antisocial behavior, the mechanism underlying this relationship remains largely unknown. This study addressed this limitation by examining possible mediators of the relationship between heart rate and antisocial behavior in a community sample of adolescent boys. This paper is the first to show that impulsive sensation seeking underlies the relationship between aggression and heart rate. The second paper examines the interaction between heart rate reactivity to stress and neighborhood disadvantage in a community sample of male and female young adolescents. Heart rate reactivity to stress interacted with neighborhood disadvantage to predict antisocial behavior, with a stronger association between neighborhood disadvantage and antisocial behavior amongst subjects with low heart rate reactivity. The third paper examines whether interactions between biological systems predict antisocial behavior in male and female young adolescents. In males, low cortisol reactivity was associated with higher levels of aggression and rule-breaking behavior, but only among subjects with low 2D:4D (i.e., high prenatal testosterone). Together, the papers in this dissertation advance our understanding of the development of antisocial behavior in youth by identifying how biological factors both in interaction with the social environment and in interaction with one another contribute to the etiology of delinquency. At a theoretical level, findings highlight the need for research that examines variables across multiple disciplines in order to understand the development of antisocial behavior. At an intervention level, findings suggest that biological factors could be potential targets for behavioral change.

Degree Type

Dissertation

Degree Name

Doctor of Philosophy (PhD)

Graduate Group

Criminology

First Advisor

Adrian Raine

Keywords

Aggression, Cortisol, Delinquency, Heart Rate, Neighborhood, Testosterone

Subject Categories

Criminology | Criminology and Criminal Justice

RISK FACTORS FOR ANTISOCIAL BEHAVIOR IN JUVENILES: A
MULTIDISCIPLINARY PERSPECTIVE

Jill Portnoy

A DISSERTATION

in

Criminology

Presented to the Faculties of the University of Pennsylvania

in

Partial Fulfillment of the Requirements for the

Degree of Doctor of Philosophy

2015

Supervisor of Dissertation

Graduate Group Chairperson

Adrian Raine, D.Phil.

Charles Loeffler, Ph.D.

Richard Perry University Professor,
Departments of Criminology,
Psychology, and Psychiatry

Jerry Lee Assistant Professor of
Criminology

Dissertation Committee

Sara Jaffee

Associate Professor, Department of Psychology

John MacDonald

Associate Professor, Departments of Criminology and
Sociology

Adrian Raine

Richard Perry University Professor, Departments of
Criminology, Psychiatry, and Psychology

ACKNOWLEDGMENT

Thank you first and foremost to my advisor, Adrian Raine. I am incredibly grateful for your support and am so appreciative of all the time you have taken to help me grow as a researcher. I cannot begin to express how much I appreciate all of your advice, guidance, and support through this process.

Thank you also to John MacDonald and Sara Jaffee. I appreciate you both taking the time to be a part of my committee. Your advice on both my research and my career plans has been invaluable. Thank you to Frances Chen and Anna Rudo-Hutt. I could not have finished this dissertation without your advice, words of encouragement, or our many tea and cake breaks! Thank you to all the past and current members of the Raine Lab and the Penn criminology PhD students. It was wonderful to go through the program with all of you! I am very indebted to Knakiya Hagans and Addie Métivier- I would be lost without you both. Finally, thank you to my friends, family, and especially Hank for supporting me these past four years.

Several individuals contributed to versions of the papers in this dissertation. I would like to acknowledge and thank Adrian Raine, Frances Chen, Dustin Pardini, Rolf Loeber, Richard Jennings, Anna Rudo-Hutt, Yu Gao, Liana Soyfer, Andrea Glenn, Olivia Choy, and Douglas Granger for their contributions to these papers.

ABSTRACT

RISK FACTORS FOR ANTISOCIAL BEHAVIOR IN JUVENILES: A MULTIDISCIPLINARY PERSPECTIVE

Jill Portnoy

Adrian Raine

In order to understand the etiology of childhood and adolescent delinquency, researchers now recognize the need to identify risk factors for antisocial behavior across multiple disciplinary domains. Relative to psychological and social factors, biological factors have been the focus of little criminological research. This dissertation addresses this limitation by examining biological risk factors for antisocial behavior in children and adolescents. This dissertation consists of three papers that examine heart rate and hormones in relation to aggression and other antisocial behavior problems in youth. The first paper examines the relationship between reduced heart rate and antisocial behavior. Although low heart rate is a well-replicated biological correlate of antisocial behavior, the mechanism underlying this relationship remains largely unknown. This study addressed this limitation by examining possible mediators of the relationship between heart rate and antisocial behavior in a community sample of adolescent boys. This paper is the first to show that impulsive sensation seeking underlies the relationship between aggression and heart rate. The second paper examines the interaction between heart rate reactivity to stress and neighborhood disadvantage in a community sample of male and female young adolescents. Heart rate reactivity to stress interacted with neighborhood

disadvantage to predict antisocial behavior, with a stronger association between neighborhood disadvantage and antisocial behavior amongst subjects with low heart rate reactivity. The third paper examines whether interactions between biological systems predict antisocial behavior in male and female young adolescents. In males, low cortisol reactivity was associated with higher levels of aggression and rule-breaking behavior, but only among subjects with low 2D:4D (i.e., high prenatal testosterone). Together, the papers in this dissertation advance our understanding of the development of antisocial behavior in youth by identifying how biological factors both in interaction with the social environment and in interaction with one another contribute to the etiology of delinquency. At a theoretical level, findings highlight the need for research that examines variables across multiple disciplines in order to understand the development of antisocial behavior. At an intervention level, findings suggest that biological factors could be potential targets for behavioral change.

TABLE OF CONTENTS

ACKNOWLEDGMENT II

ABSTRACT..... III

LIST OF TABLES VII

LIST OF ILLUSTRATIONS VIII

GENERAL INTRODUCTION 1

Paper 1 Summary 3

Paper 2 Summary 5

Paper 3 Summary 6

**PAPER 1. HEART RATE AND ANTISOCIAL BEHAVIOR: THE MEDIATING
ROLE OF IMPULSIVE SENSATION SEEKING 8**

Abstract..... 8

Background..... 9

Methods..... 13

Results 22

Discussion..... 25

Paper 1 Tables and Figures 33

**PAPER 2: HEART RATE STRESS REACTIVITY MODERATES THE
RELATIONSHIP BETWEEN NEIGHBORHOOD DISADVANTAGE AND
ANTISOCIAL BEHAVIOR 37**

Abstract..... 37

Background..... 38

Methods..... 45

Results	52
Discussion	54
Paper 2 Tables and Figures	61
PAPER 3: PRENATAL TESTOSTERONE MARKER MODERATES THE RELATIONSHIP BETWEEN CORTISOL REACTIVITY AND SELF- REPORTED EXTERNALIZING BEHAVIOR IN YOUNG ADOLESCENT MALES	71
Abstract	71
Background	72
Methods	80
Results	87
Discussion	88
Paper 3 Tables and Figures	95
GENERAL DISCUSSION	99
BIBLIOGRAPHY	102

LIST OF TABLES

Table 1.1. Bivariate Correlations Between Observed Study Variables.....	33
Table 1.2. Bivariate Correlations Between Observed Study Variables and Covariates...	34
Table 2.1. Bivariate Correlations Between Key Study Variables.....	61
Table 2.2. Regressions Predicting Parent-Reported Outcomes.....	62
Table 2.3. Regressions Predicting Child-Reported Outcomes.....	64
Table 2.4a. Parent-Reported Externalizing Behavior for Subjects with High (+ 1 SD) and Low Levels (-1 SD) of Neighborhood Disadvantage and Heart Rate Reactivity.....	66
Table 2.4b. Parent-Reported Aggression for Subjects with High (+ 1 SD) and Low Levels (-1 SD) of Neighborhood Disadvantage and Heart Rate Reactivity.....	66
Table 2.4c. Parent-Reported Rule-Breaking for Subjects with High (+ 1 SD) and Low Levels (-1 SD) of Neighborhood Disadvantage and Heart Rate Reactivity.....	66
Table 3.1. Descriptive Statistics by Sex.....	95
Table 3.2. Bivariate Correlations.....	96

LIST OF ILLUSTRATIONS

Figure 1.1. Mediation Model Predicting Aggression.....	35
Figure 1.2. Mediation Model Predicting Nonviolent Delinquency.....	36
Figure 2.1a. Relationship Between Externalizing Behavior and Neighborhood Disadvantage at Different Levels of Heart Rate Reactivity.....	67
Figure 2.1b. Relationship Between Aggression and Neighborhood Disadvantage at Different Levels of Heart Rate Reactivity.....	68
Figure 2.1c. Relationship Between Rule-Breaking and Neighborhood Disadvantage at Different Levels of Heart Rate Reactivity.....	69
Figure 2.2. Simple Slopes of Parent-Reported Externalizing Behavior, Aggression, and Rule-Breaking on Neighborhood Disadvantage at High (+1 SD) and Low (-1 SD) Levels of Heart Rate Reactivity.....	70
Figure 3.1. Simple Slopes of Self-Reported Externalizing Behavior, Aggression, and Rule-Breaking on Cortisol Reactivity at High (+1 SD) and Low (-1 SD) Levels of Left 2D:4D in Males.....	97
Figure 3.2. Simple Slopes of Self-Reported Externalizing Behavior, Aggression, and Rule-Breaking on Cortisol Reactivity at High (+1 SD) and Low (-1 SD) Levels of Right 2D:4D in Males.....	98

GENERAL INTRODUCTION

Crime and violence are important public health concerns (Mercy, Rosenberg, Powell, Broome, & Roper, 1993; Shepherd & Farrington, 1993); in 2010, homicide was the second leading cause of death amongst 15 to 24 year olds in the United States, and assaults accounted for over 1.4 million of the injuries treated in emergency rooms (Centers for Disease Control and Prevention, 2012). Early interventions may be critical to addressing this problem given that offending increases dramatically during adolescence (Moffitt, 1993), and tends to peak around the ages of 14 to 18 years (Farrington, 1990; Gottfredson & Hirschi, 1990; Smith, 2007). Males who begin their criminal careers as children ages 10 to 13 years tend to be the most prolific offenders and to have the longest criminal careers that last into adulthood (Farrington et al., 2006). In addition to the health impacts and other social costs of early antisocial behavior, individuals who are antisocial as children and adolescents continue to impose significant financial costs to society throughout their lives and into adulthood (Cohen, 1998; Scott, Knapp, Henderson, & Maughan, 2001). In order to design effective, evidence-based interventions in response to this problem, researchers have advocated for the identification of risk and protective factors for crime and antisocial behavior (Farrington, 2000, 2007; Tonry & Farrington, 1995). By identifying early childhood and adolescent risk factors for antisocial behavior, it may be possible to target these risk factors early in life and to avoid later social and financial costs.

Multidisciplinary approaches that incorporate social, psychological, and biological factors are increasingly viewed as necessary in order to understand the etiology

of antisocial behavior (Beauchaine & Gatzke-Kopp, 2012; Burnette & Cicchetti, 2012; Cicchetti, 2010). Nonetheless, relative to social factors, biological risk factors for antisocial behavior have been less intensively studied by criminological researchers. This is an important limitation, given that biosocial research has begun to identify numerous biological risk factors for childhood antisocial behavior, including reduced autonomic nervous system arousal and abnormal hormonal activity (reviewed in Portnoy et al., 2013). Of these biological factors, a low heart rate is one of the best-replicated correlates of child and adolescent antisocial behavior (Lorber, 2004; Ortiz & Raine, 2004; Portnoy & Farrington, 2015). Low heart rate has also been proposed as a putative biomarker, or objective index, of conduct disorder (Moffitt et al., 2008) and is listed in the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; *DSM-V*, The American Psychiatric Association, 2013) as a physiological risk factor for conduct disorder. Despite this well-replicated relationship, important questions remain about the relationship between heart rate and behavior.

Hormones, including testosterone, and cortisol, are also often examined in relation to antisocial behavior (Archer, 1991; Susman et al., 1987, 2010). Increased testosterone is thought to be related to socially dominant behavior, which could manifest itself in the form of aggressive behavior in adolescents (Rowe, Maughan, Worthman, Costello, & Angold, 2004), although some results in children and adolescents are inconsistent (Granger et al., 2003). On the other hand, reduced cortisol is often thought to be characteristic of antisocial youth (Pajer, Gardner, Rubin, Perel, & Neal, 2001). The release of cortisol is regulated by the hypothalamic-pituitary-adrenocortical (HPA) axis, which is activated by psychological stressors (Dickerson & Kemeny, 2004). Reduced

stress reactivity is thought to be characteristic of individuals with high levels of antisocial behavior (van Goozen & Fairchild, 2008), because these individuals may be less fearful of the negative consequences of their actions (Raine, 1993; 2002a). Nonetheless, many studies of cortisol and antisocial behavior in children and adolescents are inconsistent (Alink et al., 2008).

The purpose of this dissertation is to provide a more comprehensive examination of risk and protective factors for antisocial behavior by examining biological factors in relation to antisocial behavior in children and adolescents. This dissertation consists of three papers that examine biological risk factors for antisocial behavior in juveniles. These papers focus on heart rate and hormonal risk factors for antisocial behavior, in part because these biological factors are relatively inexpensive and simple to operationalize (Gao et al., 2012), which may make them attractive to criminological researchers who want to incorporate a multidisciplinary approach. There are also many important questions about the relationship of these biological factors with antisocial behavior that remain unanswered. In addition to heart rate and hormones, these papers also examine psychological, neighborhood, and family factors in relation to juvenile antisocial behavior. Together, these papers contribute to our understanding of the etiology of child and adolescent antisocial behavior by identifying early risk factors for antisocial behavior across multiple domains.

Paper 1 Summary

The first paper in this dissertation examines psychological and biological factors in relation to antisocial behavior. This paper focuses on the relationship between heart

rate and antisocial behavior. Low heart rate is a well-replicated correlate of antisocial behavior (Lorber, 2004; Ortiz & Raine, 2004; Portnoy & Farrington, 2015) and it has been argued that a low resting heart rate is likely the best-replicated biological correlate of child and adolescent antisocial behavior (Ortiz & Raine, 2004). Although several theoretical explanations for the low heart rate-antisocial behavior relationship have been proposed, surprisingly little research has examined potential mediators of this relationship. A long-standing theoretical explanation, stimulation-seeking theory, argues that low autonomic arousal is an unpleasant physiological state, leading those with low resting heart rates to seek stimulating behaviors, including antisocial behaviors, in order to increase their level of physiological arousal to an optimal level (Quay, 1965; Raine, 2002a). An alternative interpretation, fearlessness theory, hypothesizes that low heart rate is a marker of low fear, which could impede early fear conditioning and may facilitate criminal acts that require a degree of fearlessness to complete (Raine, 1993, 2002a). In the first paper of this dissertation, I examine sensation-seeking and fearlessness as possible mediators of the heart rate-antisocial behavior relationship. This paper uses data from 16 year old males participating in the Pittsburgh Youth Study. Heart rate was measured in a laboratory setting at rest, during a stress task, and during a cognitive task. Subjects completed self-reported measures of antisocial behavior, impulsive sensation seeking, and state fear. Impulsive sensation-seeking, but not fearlessness, mediated the relationship between a low heart rate and aggressive behavior. Findings provide support for an impulsive sensation seeking model of antisocial behavior. By examining biological and psychological variables, this paper provides a

more comprehensive explanation of why some adolescents with a low heart rate are at an increased risk of delinquent behavior.

Paper 2 Summary

The second paper of this dissertation examines the interaction between biological factors and the neighborhood environment in predicting antisocial behavior in late childhood/early adolescence. Although researchers have a long-standing interest in how neighborhood features affect behavior (e.g., Shaw and McKay, 1942), little is known about how biological functioning may moderate the impact of neighborhood disadvantage on antisocial behavior. This is an important limitation, because research into biological moderators could help to explain why some adolescents living in disadvantaged neighborhoods become delinquent while others do not.

This paper uses data from 335 11-12 year old males and females participating in the Healthy Brains and Behavior Study. Resting heart rate and heart rate reactivity to a stressor were measured in the laboratory and antisocial behavior was assessed using parent- and child-reported measures. An index of neighborhood disadvantage was derived from the block-group in which the subject resided. Heart rate reactivity to stress and neighborhood disadvantage interacted to predict parent-reported rule-breaking and aggressive behavior, with a stronger association between neighborhood disadvantage and antisocial behavior amongst subjects with low heart rate reactivity. In addition, high heart rate reactivity *protected* individuals living in disadvantaged neighborhoods from engaging in antisocial behavior. This is the first paper to find that heart rate stress reactivity interacts with the neighborhood environment to predict delinquency. These

findings could explain why disadvantaged neighborhoods are more harmful to some adolescents than to others. This paper also suggests the importance of future criminological research that integrates multiple levels of measurement to understand the etiology of externalizing behavior.

Paper 3 Summary

Although reduced cortisol is often thought to be characteristic of individuals with high levels of antisocial behavior, results are often inconsistent (Alink et al., 2008). Similarly, results often vary across studies of testosterone and antisocial behavior (Book, Starzyk, & Quinsey, 2001; Book & Quinsey, 2005). This heterogeneity across studies makes it important to identify potential factors that may moderate these relationships. This paper examines 2D:4D, a marker of prenatal testosterone exposure, as a moderator of the cortisol-antisocial behavior and testosterone-antisocial behavior relationships. Data for this study comes from 335 year old male and female 11-12 year olds participating in the Healthy Brains and Behavior Study. Saliva samples were collected before and after a stress task and later assayed for cortisol. Testosterone levels were determined from a morning saliva sample, and left and right hand 2D:4D were measured. Subjects and caregivers reported on the child's rule-breaking and aggressive behavior. In males, low cortisol reactivity was associated with higher levels of self-reported aggression and rule-breaking behavior, but only among subjects with low 2D:4D (i.e., high prenatal testosterone). This is the first study to examine the interaction between 2D:4D and cortisol in adolescents. These findings demonstrate the importance of considering multiple biological systems in order to understand early antisocial behavior.

Furthermore, the moderating role of prenatal testosterone suggests that very early risk factors, even those that originate before birth, may help us to understand the development of antisocial behavior in childhood and adolescence.

PAPER 1. HEART RATE AND ANTISOCIAL BEHAVIOR: THE MEDIATING ROLE OF IMPULSIVE SENSATION SEEKING

Abstract

Although a low resting heart rate is considered the best-replicated biological correlate of antisocial behavior, the mechanism underlying this relationship remains largely unknown. Sensation-seeking and fearlessness theories have been proposed to explain this relationship, although little empirical research has been conducted to test these theories. This study addressed this limitation by examining the relationship between heart rate and antisocial behavior in a community sample of 335 adolescent boys. Heart rate was measured during a series of cognitive, stress, and rest tasks. Participants also completed self-report measures of state fear, impulsive sensation seeking, and both aggressive and nonaggressive forms of antisocial behavior. Impulsive sensation seeking, but not fearlessness, significantly mediated the association between low heart rate and aggression. This study is the first to show that impulsive sensation seeking partly underlies the relationship between aggression and heart rate, and is one of the few to examine the mechanism of action linking heart rate to antisocial behavior. Findings at a theoretical level highlight the role of impulsive sensation seeking in understanding antisocial behavior and at an intervention level suggest it as a potential target for behavioral change.

Background

Autonomic nervous system activity has long been examined in relation to psychopathy, aggression, and antisocial behavior (e.g., Davies & Maliphant, 1971; Hare, 1968). Psychophysiological indices of autonomic activity, which are noninvasive to record and capture nearly immediate physiological changes in response to external stimuli, include skin conductance, heart rate, and skin-potential response. Of these measures, a low resting heart rate is considered the best-replicated biological correlate of antisocial behavior in children and adolescents (Ortiz & Raine, 2004). One meta-analysis of 45 independent effect sizes and a total of 5,868 children reported an effect size of $d = -.44$ ($p < .0001$) for the relationship between resting heart rate and antisocial behavior (Ortiz and Raine, 2004). In another meta-analysis, Lorber (2004) found an effect size of $d = -.38$ ($p < .05$) for studies of resting heart rate and aggression, while a more recent meta-analysis of 115 independent effect sizes reported an overall effect size of $d = -.20$ ($p < .001$) for the relationship between resting heart rate and antisocial behavior (Portnoy & Farrington, 2015). The relationship between low heart rate and antisocial behavior is unlikely to be the result of artifact; several key variables—including body size, intelligence, exercise, and socioeconomic status—have not been found to reduce the strength of this relationship substantially (Portnoy & Farrington, 2015; Raine, 2002a). Despite this well-documented association between a low heart rate and antisocial behavior, important gaps in our understanding of this relationship remain. These gaps include a limited understanding of the mechanism linking heart rate to antisocial behavior, as well as limitations in our understanding of the particular types of antisocial

behavior that are associated with heart rate. The purpose of this paper is to address these limitations.

Mediating Mechanism

Perhaps surprisingly, given the large amount of research examining the heart rate–antisocial behavior relationship, the mechanism underlying this relationship remains largely unknown, although several theoretical explanations have been proposed. One theoretical explanation, sensation-seeking theory, rests on the premise that a low resting heart rate is a marker of low autonomic arousal (Raine, 2002a). Low arousal is hypothesized to be an unpleasant physiological state, leading those with low resting heart rates to seek stimulating behaviors, including antisocial behaviors, to increase their level of physiological arousal to a more optimal level (Quay, 1965; Raine, 2002a). Despite its status as a long-standing theory of antisocial behavior (Quay, 1965), the theory has been subjected to little empirical verification.

An alternative interpretation of the heart rate–antisocial behavior relationship, fearlessness theory, recognizes that the testing situation during which heart rate is measured may itself be at least mildly stressful. The “resting” states when heart rate is typically monitored—usually a 2- to 3-minute period prior to the beginning of a series of experimental tasks that are novel to the child in an unfamiliar laboratory setting—are likely to contain a modest element of anticipatory anxiety. Additionally, the measurement of heart rate often co-occurs with the administration of more stressful procedures, such as exposure to aversive stimuli or participation in a stressor task. A low heart rate, therefore, may indicate a relative lack of fear in response to moderate stressors

(Raine, 1993; Venables, 1987). Fearlessness is thought to be related to antisocial behavior, as committing criminal and antisocial acts would be facilitated by a lack of fear regarding the antisocial context and potential punishment if apprehended (Raine, 2002a). Additionally, poor fear conditioning and lack of anticipatory fear are well-replicated risk factors for antisocial behavior (Gao, Raine, Venables, Dawson, & Mednick, 2010; van Goozen, Snoek, Matthys, van Rossum, & van Engeland, 2004). These findings suggest that a relative lack of fear may underlie the heart rate–antisocial behavior relationship.

Most empirical support for the sensation-seeking and fearlessness theoretical interpretations has been indirect. For example, in one sample, fearlessness, stimulation seeking, and having a low resting heart rate at age 3 years predicted aggression at age 11 years (Raine, Reynolds, Venables, Mednick, & Farrington, 1998; Raine, Venables, & Mednick, 1997). Recently, a novel study provided a more direct test of these explanations (Sijtsema et al., 2010). Resting heart rate was measured in a sample of males and females at age 11 years, and antisocial behavior was measured at age 16 years. Resting heart rate was not associated with antisocial behavior in females. In males, however, sensation seeking at ages 13.5 and 16 years, but not at age 11 years, partially mediated the relationship between resting heart rate at age 11 years and rule breaking at age 16 years. Fearlessness, in contrast, did not mediate the relationship between heart rate and aggression.

Although this study was an important step toward improving our understanding of the heart rate–antisocial behavior relationship, some limitations preclude firm conclusions. First, the study tested fearlessness theory using measures of behavioral inhibition, effortful control, and impulsivity, rather than a more direct measure of fear.

Although behavioral inhibition and impulsivity are closely related to fear, they are not identical constructs, leaving open the possibility that low fear may underlie the heart rate–antisocial behavior relationship. Another important limitation was that although the authors tested sensation seeking as a mediator of the heart rate–rule-breaking relationship, they did not test whether sensation seeking also mediated the relationship between heart rate and aggression. It remains unknown whether sensation seeking also partly underlies the heart rate–aggression relationship, leaving a critical gap in our understanding of this association. It also should be noted that Sijtsema et al. (2010) analyzed heart rate measured only during rest rather than including a more trait-like estimate of heart rate that could not be derived from the measurement of heart rate during rest alone.

Behavioral Specificity

Also, it is unknown whether the relationship between cardiac activity and antisocial behavior is specific to particular types of antisocial behavior. In a meta-analysis, Lorber (2004) found that resting heart rate was significantly ($p < .05$) associated with aggression ($d = -.38$) and conduct problems ($d = -.33$), but not with psychopathy ($d = .06$). However, Lorber's (2004) meta-analysis did not include any psychopathy studies with child or adolescent samples, leaving open the possibility that a low heart rate may be associated with psychopathy in youths. Consistent with this possibility, Baker et al. (2009) found that a low resting heart rate at ages 9–10 years predicted psychopathy at ages 9–10 years and 11–14 years in a community sample. In a more recent meta-analysis, low resting heart rate was found to be associated with higher levels of

psychopathy (Portnoy & Farrington, 2015). Again, however, few studies in the meta-analysis examined psychopathic traits in youth (only 6 independent effect sizes, including the current study), leaving unresolved the question of whether a low heart rate characterizes adolescents with psychopathic-like characteristics.

Current Study

The purpose of the current study is to address these limitations by determining whether heart rate measured during rest, cognitive challenge, and stress is associated with antisocial behavior. I hypothesize that a low heart rate will be associated with higher levels of antisocial behavior. I also hypothesize that the relationship between heart rate and antisocial behavior will be mediated by fearlessness and sensation seeking. Additionally, I predict that any indirect effects will remain significant after controlling for hypothesized confounders of the heart rate–antisocial behavior relationship.

Methods

Participants

The data for this study come from the youngest of the three samples making up the Pittsburgh Youth Study. Full details of background characteristics and initial participant recruitment in 1987–1988 when children (all male) were 7 years of age are given in Loeber et al. (1998). Briefly, 868 first-grade boys from public schools in Pittsburgh, PA, were assessed by caretakers, teachers, and the boys themselves on 21 serious antisocial behaviors. The 250 most antisocial boys were selected for further

study, together with 253 boys randomly selected from the remainder, to make a total sample of 503. As such, this population-based community sample, although representative of the children in public schools in the city of Pittsburgh, was weighted toward containing more antisocial boys so that sufficient numbers of such boys would be represented.

Of the original sample of 503 individuals, 335 individuals (66.6%) participated in a substudy on the biosocial bases of aggressive and violent behavior. The 10-year attrition of 168 individuals (33.4%) for the substudy broke down as follows: 31 participants lived out of the area, 20 were in jail, 45 refused the larger Pittsburgh Youth Study, 35 refused the biosocial study, 27 canceled appointments repeatedly, and 10 failed to decide on participation. Participants were compared with nonparticipants on initial data collected at 7 years of age to assess for bias. No evidence of selective attrition was found based on early data; participants did not differ significantly from nonparticipants on socioeconomic status (SES), ethnicity (Black vs. White), initial risk status, delinquency seriousness (no or minor delinquency vs. moderate or serious delinquency), or violence seriousness (no violence vs. gang fighting and attacks).

The 335 participants had a mean age of 16.15 years at the time of testing ($SD = .89$). Overall, 41.2% of participants were Caucasian and 58.8% were African American. Full written informed consent was obtained from the boys and their parents, and study protocols were approved by the institutional review boards at both the University of Southern California and the University of Pittsburgh.

Psychophysiological Testing Procedure

Heart rate was measured continuously during an initial resting period (3 minutes), a social stressor task (4 minutes), a cognitive task (8 minutes), and a final resting period (3 minutes). During the first rest, participants were seated and told that for the next few minutes, nothing would happen and they should sit still with their eyes closed. After a few minutes, the participants were told that they would hear some tones but that there was nothing they needed to do except to stay still. Subjects then completed a social stressor task (Raine, Lencz, Bihrl, LaCasse, Colletti, 2000). This task was video recorded to increase the level of stress experienced by subjects. Subjects were instructed to spend 2 minutes thinking about the worst or most stressful thing that had ever happened to them. After 2 minutes, they were told to describe the event to an experimenter for an additional 2 minutes. Only the heart rate measurements recorded during the first 2 minutes (the thinking period) of the stress task were analyzed in this study, as the act of speaking may interfere with the measurement of cardiovascular activity (Lynch, Long, Thomas, Malinow, & Katcher, 1981).

Version 4.08 of the degraded stimulus version of the Continuous Performance Task (CPT; Nuechterlein, Parasuraman, & Jiang, 1983) was then administered according to the author's guidelines. Visually degraded numbers ranging from 0 to 9 were flashed on a computer screen (placed 1 m from the participant in his line of vision) for 40 ms at the rate of one per second. The participants' task was to press a response button on a Gravis joystick every time he saw the figure "0" but not to respond to all other stimuli. Targets had a 0.25 probability of occurrence. After 10 presentations of the target stimulus only, participants were given two practice blocks with 80 trials/block (for a total of 160 trials). Thereafter, six blocks with 80 trials in each block (for a total of 480 trials)

were presented, lasting 8 minutes. After completing the CPT, subjects completed the final resting task. They were again told that for the next few minutes, nothing would happen and they should sit still with their eyes closed.

Cardiovascular Recording and Data Reduction

Heart rate was recorded using a Grass model 12 acquisition system (Grass Products, Warwick, RI). Sensor Medics Ag/AgCl electrodes (Sensor Medics Corp., Homestead, FL) were placed below the right collarbone and below the left lower rib using MediTrace conductivity gel (Covidien, Mansfield, MA). Respiration rate was measured using a strain gage placed around the chest in conjunction with a strain gage bridge transducer coupler, and it was sampled at 5 Hz. The electrocardiography signal was digitized at 256 Hz and stored for offline processing sequence.

The time between successive R-waves was stored and input together with respiration rate into the PSPAT software program, which conducted artifact correction, performed spectral analysis of the cardiac data, and corrected for any nonstationarity in the data (Weber, Molenaar, & van der Molen, 1992). The heart rate levels were calculated by averaging interbeat intervals throughout each task and converting values to beats per minute.

Aggression Measures

Reactive and Proactive Aggression

Both reactive and proactive aggression were measured using the reactive and proactive subscales of the Reactive-Proactive Questionnaire (RPQ; Raine et al., 2006). The RPQ is a self-report instrument with 12 proactive items (e.g., “Had fights with others to show who was on top”) and 11 reactive items (e.g., “Reacted angrily when provoked by others”).

Respondents rated how often they had engaged in the items on a three-point scale (0 = never, 1 = sometimes, and 2 = often). The scores on each subscale were summed to create total reactive aggression and total proactive aggression scores. The RPQ has been shown to be a valid and reliable assessment of reactive and proactive aggression in this sample (Raine et al., 2006), as well as in other samples (Baker, Raine, Liu, & Jacobson, 2008; Fossati et al., 2009; Fung, Raine, & Gao, 2009). Outliers greater than 3 standard deviations away from the mean for each scale were coded as missing (Tabachnick & Fidell, 2013), resulting in the exclusion of two cases for the reactive aggression scale and four cases for the proactive aggression scale.

Violent Delinquency

Subjects were administered the Self-Reported Delinquency Scale (SRD; described in more detail in Stouthamer-Loeber & Stallings, 2008). Subjects indicated the number of times in the past year they had committed a series of violent and nonviolent delinquent acts. The definition of violence adopted by the National Academy of Sciences Panel on the Understanding and Control of Violent Behavior (“behaviors by individuals that intentionally threaten, attempt, or inflict physical harm on others,”) was used to classify behaviors as violent (Reiss & Roth, 1993:2). Six items met this criterion (e.g., “How

many times in the past year have you hit someone with the idea of hurting them”). Because there was a high skew toward zero on most of the items, dimensional frequency scores were not appropriate. Instead, subjects were given a score of 1 if they had committed the violent behavior and a score of 0 if they had not committed the behavior. The scores for each of the six included items were summed to create a total violent delinquency score. This type of variety scoring has been shown to have advantages over frequency scoring in terms of reliability and construct validity (Bendixen, Endresen, & Olweus, 2003). The internal reliability (Cronbach’s alpha) for the scale was .61 in this sample.

Psychopathy

The Child Psychopathy Scale (CPS; Lynam, 1997) was completed by the boys. The instrument was designed to operationalize, in childhood and adolescence, the traits found in the Psychopathy Checklist-Revised (Hare, 1991). The instrument is well validated in this population (Falkenbach, Poythress, & Heide, 2003; Lynam, 1997), and the internal reliability (Cronbach’s alpha) of the scale in this sample is .92 (Raine et al., 2006).

Nonviolent Delinquency

Seventeen items from the SRD instrument were used to create a nonviolent delinquency scale (e.g., “How many times in the past year have you purposely damaged or destroyed property that did not belong to you”). Subjects were given a score of 1 if they had committed the nonviolent act and a score of 0 if they had not committed the

behavior. These scores were summed to create a total nonviolent delinquency score. The internal reliability (Cronbach's alpha) for the index was .71 in this sample.

Impulsive Sensation Seeking

Impulsive sensation seeking was assessed using the impulsive sensation-seeking subscale of the Zuckerman-Kuhlman Personality Questionnaire (ZKPQ; Zuckerman, Kuhlman, Joireman, Teta, & Kraft, 1993). The impulsive sensation-seeking scale contains 19 items that assess a lack of planning, impulsive behavior, and the tendency to take risks in the pursuit of excitement or novelty (e.g., "I like doing things just for the thrill of it"). Items are coded as 1 if the subject indicates the item is true and 0 if the item is false. Higher scores indicate a higher level of impulsive sensation seeking. The impulsive sensation-seeking scale has been shown to be reliable and valid (Zuckerman & Kuhlman, 2000; Zuckerman et al., 1993), and it has a Cronbach's alpha of .73 in this sample.

State Fear

Subjects completed the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) five times throughout the experimental session. Subjects were shown 20 words that describe feelings and emotions, and then they indicated the extent to which they felt that way at that moment on a five-point Likert scale. For each item, I calculated each participant's average score across the five administrations of the PANAS. Although the PANAS was originally designed to measure two dimensions of affect—positive and negative (Watson et al., 1988)—more recent psychometric research revealed

that a three-factor solution that includes an Afraid factor may be a better fit for the items on the PANAS (Gaudreau, Sanchez, & Blondin, 2006; Killgore, 2000; Mehrabian, 1997). Therefore, the 20 average item scores were subjected to a principal factor analysis with an Oblimin rotation (delta = .2) using SPSS statistical software (IBM SPSS Statistics Version 20.0; SPSS Corporation, Chicago, IL). Four factors had eigenvalues > 1. However, a four-factor solution failed to satisfy the constraints of Cattell's scree test. Therefore, only three factors were retained. Factor 1 consisted of 10 Positive Affect items (e.g., interested and excited) with factor loadings between .48 and .84 (Cronbach's alpha = .91). Factor 2 consisted of 7 Negative Affect items (e.g., distressed and upset) with factor loadings between .42 and .80 (Cronbach's alpha = .80). The "scared," "nervous," and "afraid" items loaded onto Factor 3, with factor loadings of $-.90$, $-.53$, and $-.95$, respectively.

Because of the a priori focus on fearlessness, only items on the third factor were used in the analyses that follow. The scores for these three items were summed to create an index of fearfulness during the testing session, with higher scores indicating increased state fearfulness. I used a measure of state, rather than trait fearfulness, because fearlessness theory argues that low heart rate reflects low fear during the actual measurement of heart rate. Nine outliers with scores greater than three standard deviations from the mean were coded as missing. The internal reliability (Cronbach's alpha) for the third factor was .79. All correlations among the nervous, afraid, and scared items were significant and ranged from .55 to .84.

Covariates

Body mass index (BMI), race, socioeconomic status (SES), maternal teenage pregnancy, and physical activity were examined as possible confounders of the heart rate– antisocial behavior relationships. BMI was derived from height measured using a stadiometer attached to the wall, and weight was measured using digital scales. BMI was calculated as kilograms/m². Race was coded as 0 for African American or 1 for Caucasian (Stouthamer-Loeber & Stallings, 2008). SES was used as an indicator of early social adversity. SES was measured during the boys’ age 7 assessments using the Hollingshead (1975) index, which is based on parental occupational prestige and education level. Additional details on the measure can be found in Loeber et al. (1998). Maternal teenage pregnancy was used as an additional indicator of early psychosocial adversity. Mothers reported their age at the birth of the boy during the age 7 assessment. Mothers 20 years of age or older at the birth of the boy were given a score of 0. Teenage mothers (mothers that were less than 20 years of age at the birth of the boy) were given a score of 1. To develop a measure of physical activity, subjects were asked how many times in the past month they had participated in a series of physical activities (e.g., jogging, football, and other) for at least 30 minutes. The totals for each activity were summed to create a physical activity score, with two scores greater than three standard deviations from the mean coded as missing. Self-reported physical activity questionnaires have been shown to be reliable and valid among adolescents (Sallis, Buono, Roby, Micale, & Nelson, 1993).

Statistical Analyses

Bivariate correlations among the observed study variables were performed using SPSS statistical software (IBM SPSS Statistics Version 20.0). Structural equation models were estimated in Mplus Version 7 to test impulsive sensation seeking and state fear as mediators of the heart rate–aggression and heart rate–nonviolent delinquency relationships. Parameter estimates were calculated using maximum likelihood with robust standard errors to account for non-normality in the data. To test the significance of the indirect effects, bias-corrected confidence intervals (CIs) for the indirect effects were generated using 1,000 bootstrap samples. A bootstrap approach was used, as opposed to the more traditional Sobel test, because the bootstrap method has higher statistical power and makes more realistic assumptions about the sampling distribution of the indirect effect (MacKinnon, Lockwood, & Williams, 2004).

The percentage of missing data for the observed study variables ranged from 0 percent for the violent and nonviolent delinquency scores to 6.6 percent for heart rate measured during the CPT. Missing data were handled using full-information maximum likelihood procedures, which often provide more efficient parameter estimates than other approaches to handling missing data (Olinsky, Chen, & Harlow, 2003).

Results

Bivariate Associations

Bivariate correlations among the observed variables are shown in Table 1.1. A low heart rate was associated with higher levels of reactive aggression, proactive aggression, violent delinquency, and nonviolent delinquency ($p < .05$ for most

relationships), although heart rate was not associated with psychopathy ($p > .05$). Increased impulsive sensation seeking was associated with higher levels of the antisocial behavior measures ($p < .05$). State fear was not significantly associated with heart rate ($p > .05$), and contrary to expectations, high state fear was associated with increased reactive aggression and psychopathy scores ($p < .05$). Because physical activity and race were the only hypothesized confounds to be associated with heart rate and at least one antisocial behavior measure ($p < .05$; see Table 1.2), only these variables were included as covariates in the mediation analyses.

Measurement Models

Given the high intercorrelations among the heart rate measures ($r = .81$ to $.91$), the four observed heart rate measures were used to create a latent variable representing trait heart rate. Because subjects may have experienced an increased stress level during the first resting period because of the novelty of the experimental situation, including the application of electrodes, the errors of heart rate measured during the first rest and heart rate during stress were freely correlated. The model provided an excellent fit for the data (root mean square error of approximation [RMSEA] = $.000$ with a 90% CI of $.000$ to $.10$; comparative fit index [CFI] = 1.00 ; standardized root mean square residual [SMSR] = $.001$). All standardized factor loadings were statistically significant ($p < .001$) and ranged from $.86$ to $.96$.

A latent variable was created to represent aggression using the violent delinquency, proactive aggression, and reactive aggression scores. Because there were

only three indicators, the model fit could not be evaluated, although all standardized factor loadings were statistically significant ($p < .001$) and ranged from .68 to .92.

Structural Models

As shown in Figure 1.1, this paper first tested impulsive sensation seeking as a mediator of the heart rate–aggression relationship (with physical activity and race included as covariates). This model provided an excellent fit for the data (RMSEA = .04 with a 90% CI of .02 to .07; CFI = .99; SRMR = .02). As expected, impulsive sensation seeking significantly mediated the association between heart rate and aggression (indirect effect: $\beta = -.05, p < .05$), and it rendered the direct effect of heart rate on aggression nonsignificant ($\beta = -.08, p > .10$). The mediated effect explained 35.71% of the total effect of heart rate on aggression. The next mediation model (shown in Figure 1.2) tested impulsive sensation seeking as a mediator of the heart rate–nonviolent delinquency relationship (with physical activity and race included as covariates). This model also provided an excellent fit for the data (RMSEA = .03 with a 90% C.I. of .000 to .07; CFI = .997, SRMR = .01). Impulsive sensation seeking significantly mediated the association between heart rate and nonviolent delinquency (indirect effect: $\beta = -.04, p < .05$). The mediated effect explained 26.67% of the total effect of heart rate on nonviolent delinquency, although the direct effect of heart rate on nonviolent delinquency remained significant ($\beta = -.11, p < .05$).

Analyses were then conducted that examined fear as a mediator of the heart rate–aggression and heart rate–nonviolent delinquency relationships. Contrary to expectation, the indirect effects in these models were not statistically significant ($p > .1$).¹

Discussion

The objective of this study was to address important gaps in the literature by investigating the mechanism underlying the heart rate-antisocial behavior relationship and examining heart rate in relation to multiple types of antisocial behavior. In this study low heart was associated with higher levels of aggression and nonviolent delinquency and impulsive sensation seeking mediated the relationship between heart rate and both aggression and nonviolent delinquency. This is the first study to show that impulsive sensation seeking mediates the relationship between heart rate and aggression and is one of few studies to explore the previously unknown mechanism of action linking heart rate to antisocial behavior. Findings provide support for an impulsive sensation seeking model of antisocial behavior (Zuckerman, 2007) and provide further support for heart rate as a putative biomarker for conduct disorder (Moffitt et al., 2008).

Mediation

The findings of this study contribute to a growing body of indirect research suggesting sensation seeking as a mediator of the heart rate-antisocial behavior

¹ In order to confirm that the null findings were not the result of problems with the measurement of fear, these analyses were repeated using a measure of state anxiety (Spielberger, Gorsuch, & Lushene, 1970), parent-reported scores on the Anxious/Depressed scale of the Child Behavior Checklist (Achenbach & Edelbrock, 1983), as well as a latent fear variable based on the observed PANAS fear measures. All results were substantively unchanged, with the indirect effects remaining nonsignificant in each mediation model tested.

relationship. These include a meta-analysis of 40 studies, 43 independent effect sizes, and a total of 32,217 participants that found sensation seeking to be positively related to aggression (Wilson & Scarpa, 2011). Resting heart rate at age 3 years has also been found to characterize both sensation seeking behavior at 3 years and aggressive behavior at 11 years (Raine et al., 1997, 1998). Together, these findings support the possibility that some individuals with low heart rates engage in criminal and aggressive behavior as a form of sensation seeking behavior in order to increase their optimal levels of arousal.

This sensation seeking model of antisocial behavior is potentially consistent with other criminological theories of antisocial behavior. Gottfredson and Hirschi (1990) argue in their general theory of crime that individuals low in self-control tend to be adventuresome and risk-taking—in addition to displaying more typical impulsive-like traits such as the inability to delay gratification—and that low self-control is the underlying cause of criminal behavior. Impulsive sensation seeking, therefore, appears to play a role in their conceptualization of self-control. Other researchers have also identified a close link between impulsivity and sensation seeking (Zuckerman, 1993). Though some results have varied (Whiteside & Lynam, 2001), psychometric research in the domain of personality has found that impulsivity and sensation seeking items load onto a single factor (Zuckerman et al., 1993), suggesting a close empirical link between the two traits. In addition, like sensation seeking, impulsivity is thought to be associated with reduced physiological arousal (Eysenck, 1993; Mathias & Stanford, 2003). At least two studies, however, found that the relationship between heart rate and antisocial behavior remained significant after controlling for a measure of self-control (Armstrong, Keller, Franklin, & Macmillan, 2009; Cauffman, Steinberg, & Piquero, 2005). It is

possible, therefore, that the combined trait of impulsive sensation seeking, rather than impulsivity alone, best explains the heart rate-antisocial behavior relationship, though this possibility requires further investigation.

Like Sijtsema et al. (2010), the current study found that fearlessness did not underlie the heart rate-antisocial behavior relationship. The current finding advances this new knowledge by including a more direct measure of state fear during the testing session, as well as including a more robust measure of aggression and examining a more stable, trait-like estimate of heart rate. There are several possible explanations as to why fearlessness did not mediate the relationship between low heart rate and antisocial behavior. First, it is important to note that high levels of antisocial behavior and heightened anxiety are often comorbid (Marmorstein, 2007; Sareen, Stein, Cox, & Hassard, 2004). Although anxiety and fear are not identical constructs, they are moderately correlated (Sylvers, Lilienfeld, & LaPrairie, 2011), suggesting that antisocial adolescents may not actually display reduced anxiety and fearfulness on a day-to-day basis as compared to their prosocial peers.

There are other possible explanations for the null finding. Fearlessness has been hypothesized to explain the low heart rate-antisocial behavior relationship in part because a lack of fear of socializing punishments in childhood could impair fear conditioning, and in turn, disrupt conscience development (Raine, 2002a). Therefore, it may be the case that heart rate is linked to antisocial behavior through its putative effects on conscience development. In preliminary support of this possibility, Armstrong and Boutwell (2012) found that the relationship between low heart rate and the intent to commit assault in a vignette scenario was mediated by the respondent's perceived likelihood of experiencing

guilt or shame should they commit the act described in the vignette. Further research that examines heart rate in the context of both fear conditioning and conscience development may provide a useful next step in testing the fearlessness explanation of the heart-rate antisocial behavior relationship.

Heart Rate and Psychopathy

This study found that low heart rate was associated with increased aggression and nonviolent delinquency, but as in many prior studies (Lorber, 2004), psychopathy was not associated with heart rate. This study extended our current understanding by documenting a null finding in an adolescent, community sample. Though psychopaths grow up to be among the most violent and prolific offenders (Porter & Woodworth, 2006), the current results show that, at least during adolescence, the etiology of their aggression may differ from that of their non-psychopathic peers. Prior research has shown that youths with callous-unemotional traits, which are key features of psychopathy, display distinct emotional, cognitive, and personality characteristics as compared to other antisocial youth (Frick & White, 2008). The results of the current study suggest that there are likely differences in autonomic nervous system functioning in psychopathic youth, as well. It should be cautioned, however, that a recent study using a sample of East Asian youth between the ages of 11 and 17 years found that low heart rate was significantly associated with overall levels of psychopathic traits (Raine, Fung, Portnoy, Choy, & Spring, 2014). Although, a recent meta-analysis reported a significant association between low resting heart rate and psychopathy (Portnoy & Farrington,

2015), few studies examined psychopathy with children. Because of this, I caution against firm conclusions regarding the psychopathy-heart rate relationship in adolescents.

Limitations

Results from this study should be interpreted in light of some limitations. One limitation of the current study was that all measures were concurrent, which did not allow for the confirmation of the temporal ordering of the variables in the mediation model. It should be noted, however, that low heart rate predicts antisocial behavior in prospective longitudinal research (Farrington, 1997; Jennings, Piquero, & Farrington, 2013; Raine et al., 1997; Sijtsema et al., 2010) and sensation seeking predicts aggression at later ages (Raine et al., 1998). There is, therefore, a strong theoretical basis for assuming the correct temporal ordering of the variables.

Limitations also included the fact that the sample in this study included only boys. It is possible that the current findings may not generalize to females, with a recent study documenting inconsistent relationships between sensation seeking and heart rate in females (Wilson & Scarpa, 2013). On the other hand, resting heart rate was significantly associated with both male and female antisocial behavior in meta-analyses (Ortiz & Raine, 2004; Portnoy & Farrington, 2015), providing suggestive evidence that findings may also generalize to females. Additionally, although this was a community sample that was representative of the children in public schools in Pittsburgh, PA, the sample was weighted toward having more antisocial boys. Thus, this sample was not fully representative of American adolescents. Nonetheless, it should be noted that heart rate has been associated with antisocial behavior in both high-risk (e.g., Lösel & Bender,

1997) and community samples (e.g., Armstrong et al., 2009; Raine et al., 1997), thus increasing the possibility that these results could generalize to other groups.

There are other theoretical explanations of the heart rate-antisocial behavior relationship that could not be tested in the current study. Raine (2002a), for instance, suggested that reduced right hemisphere functioning could underlie both low resting heart rate and antisocial behavior. In support of this possibility, the right hemisphere is dominant for the modulation of sympathetic cardiac functioning (Nagai, Hoshida, & Kario, 2010; Yoon, Morillo, Cechetto, & Hachinski, 1997) and its reduced functioning is associated with reduced cardiac activity (Barron, Rogovski, & Hemli, 1994). Right hemisphere structural and functional abnormalities have also been linked to antisocial behavior (Narayan et al., 2007; Raine et al., 2005; Raine, Yaralian, Reynolds, Venables, & Mednick, 2002). Given that resting heart rate and antisocial behavior are both partly heritable (Hanson et al., 1989; Rhee & Waldman, 2002), another possibility is that the same genes encode for both heart rate and processes that predispose to antisocial behavior (Baker et al., 2009; Ortiz & Raine, 2004). Each of these explanations, though theoretically justified, requires further investigation.

Contributions and Future Directions

The above limitations should be viewed in the context of several strengths to this study. Importantly, the current findings advance our understanding of the mechanism underlying the heart rate-aggression relationship by showing for the first time that impulsive sensation seeking mediated this association. Additionally, while it is argued that low heart rate is diagnostically specific to conduct disorder (Ortiz & Raine, 2004—

heart rate is not known to be associated with any other psychiatric condition, including alcoholism or schizophrenia), the current study took this research a step further by demonstrating that low heart rate may be associated only with non-psychopathic forms of antisocial behavior in adolescents.

The current study also showed that the heart rate-aggression relationship was robust, given that heart rate was associated with a measure of violent delinquency, as well as reactive and proactive aggression. These relationships were also present when a more stable, trait-like measure of heart rate was employed that captured heart rate activity across several conditions, including during rest, during cognitive challenge, and during an emotional challenge. These robust results provide added support for the claim that low heart rate may potentially serve as a putative biomarker for conduct disorder (Moffitt et al., 2008).

The results of this study point to the need for further research that seeks alternative mechanisms that may contribute to the heart rate-nonviolent delinquency relationship. Results of this and other research could have important implications for treating antisocial behavior. Stadler et al. (2008), for instance, showed that a behavioral intervention for children with disruptive behavior disorders was less effective for children with low baseline heart rates. These findings indicate that children with low heart rates may require specialized interventions. In light of the current findings, interventions for children with low autonomic arousal may be most effective when aimed at encouraging children to participate in prosocial, stimulating behaviors that can partly fulfill their need for stimulation. Examining low heart rate in the context of behavioral interventions could

provide a promising avenue for future research efforts that could be further bolstered by future investigations into mediating mechanisms.

Paper 1 Tables and Figures

Table 1.1 Bivariate Correlations Between Observed Study Variables ($N = 301-335$)

	1	2	3	4	5	6	7	8	9	10	11
<i>Heart Rate</i>											
1. Heart rate rest 1	1.00										
2. Heart rate CPT	.82**	1.00									
3. Heart rate stress	.91**	.83**	1.00								
4. Heart rate rest 2	.81**	.90**	.81**	1.00							
<i>Antisocial Behavior</i>											
5. Reactive	-.12*	-.15**	-.14*	-.16**	1.00						
6. Proactive	-.11	-.11	-.11*	-.13*	.62**	1.00					
7. Violent	-.08	-.12*	-.13*	-.15**	.37**	.50**	1.00				
8. Nonviolent	-.13*	-.13*	-.13*	-.13*	.37**	.45**	.62**	1.00			
9. Psychopathy	-.07	-.04	-.08	-.07	.49**	.50**	.25**	.37**	1.00		
<i>Potential Mediators</i>											
10. Impulsive sensation seeking	-.09	-.10	-.09	-.10	.30**	.23**	.25**	.25**	.43**	1.00	
11. Fear	-.03	-.02	.03	-.01	.15**	.06	-.01	.01	.12*	.10	1.00
<i>Mean</i>	68.28	68.21	67.97	65.96	7.05	2.62	.48	.71	4.21	9.75	3.68
<i>SD</i>	10.24	10.06	10.06	10.13	4.06	3.14	.92	1.42	2.01	3.67	.79

Note: Heart rate rest 1 = heart rate during first rest; Heart rate stress = heart rate during stressor; Heart rate CPT = heart rate during the Continuous Performance Task, Heart rate rest 2 = heart rate during the final rest; Reactive = reactive aggression; Proactive = proactive aggression; Violent = violent delinquency; Nonviolent = nonviolent delinquency; Impulsive sensation seeking = score on the impulsive sensation seeking scale of the Zuckerman-Kuhlman Personality Questionnaire; Fear = Positive and Negative Affect Schedule state fear score.

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

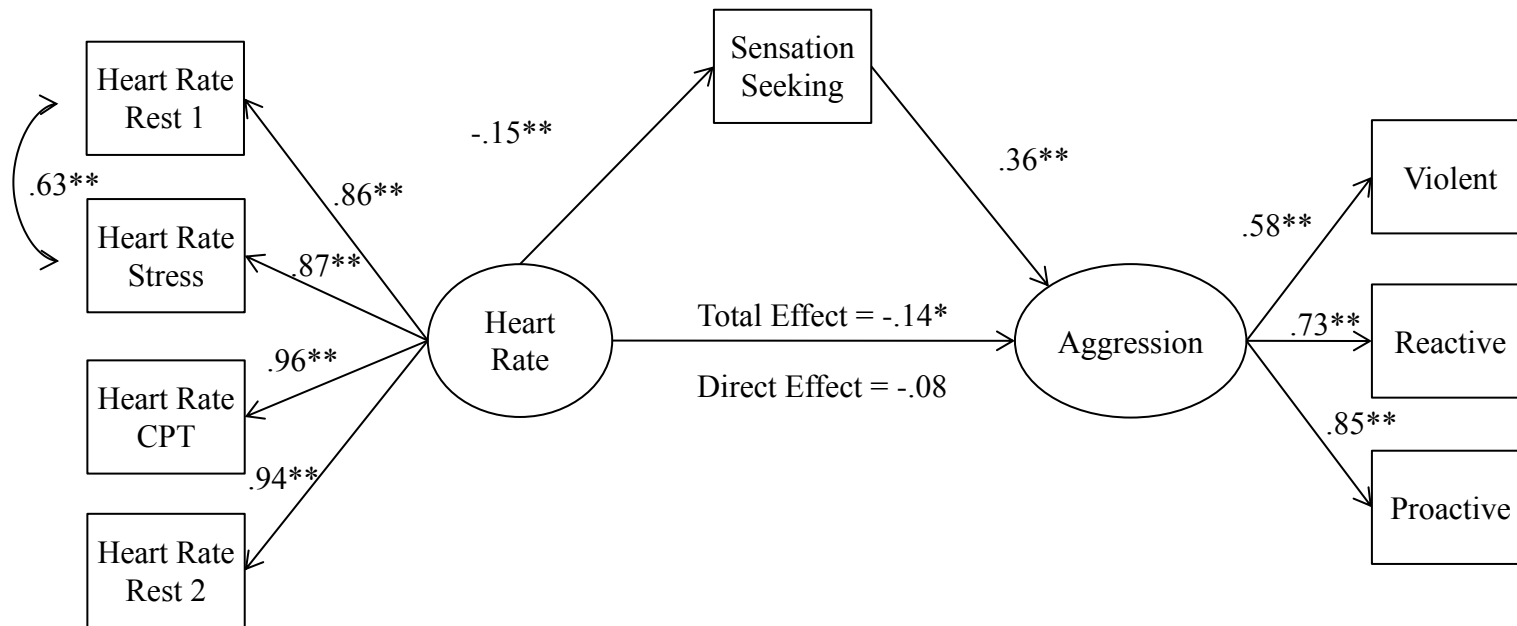
Table 1.2. Bivariate Correlations Between Observed Study Variables and Covariates ($N = 301-335$)

	Physical Activity	SES	Teen Mother	BMI	Race
Heart rate rest 1	-.22*	.08	-.06	.04	.22**
Heart rate CPT	-.25**	.09	-.06	-.02	.21**
Heart rate stress	-.24**	.11	-.06	.06	.30**
Heart rate rest 2	-.25**	.09	-.06	.02	.22**
Reactive	.16**	-.06	.02	-.07	-.05
Proactive	.15**	-.16**	.11	-.08	-.13*
Violent	.19**	-.04	.02	-.05	-.08
Nonviolent	-.08	-.08	.05	-.05	.01
Psychopathy	-.01	-.06	.03	.00	-.02
Impulsive sensation seeking	.09	-.01	-.02	-.05	.20**
Fear	.01	.06	.01	-.05	.13*
<i>Mean</i>	47.84	35.31	.21	23.45	.41
<i>SD</i>	32.58	13.40	.41	5.19	.49

Notes: Heart rate rest 1 = heart rate during first rest; Heart rate stress = heart rate during stressor; Heart rate CPT = heart rate during the Continuous Performance Task, Heart rate rest 2 = heart rate during the final rest; Reactive = reactive aggression; Proactive = proactive aggression; Violent = violent delinquency; Nonviolent = nonviolent delinquency; Impulsive sensation seeking = score on the impulsive sensation seeking scale of the Zuckerman-Kuhlman Personality Questionnaire; Fear = Positive and Negative Affect Schedule state fear score; Physical activity = number of times participated in physical activity during past month; Teen mother = 1 if mother was younger than age 20 years when boy was born; BMI = body mass index; Race = 0 if African American.

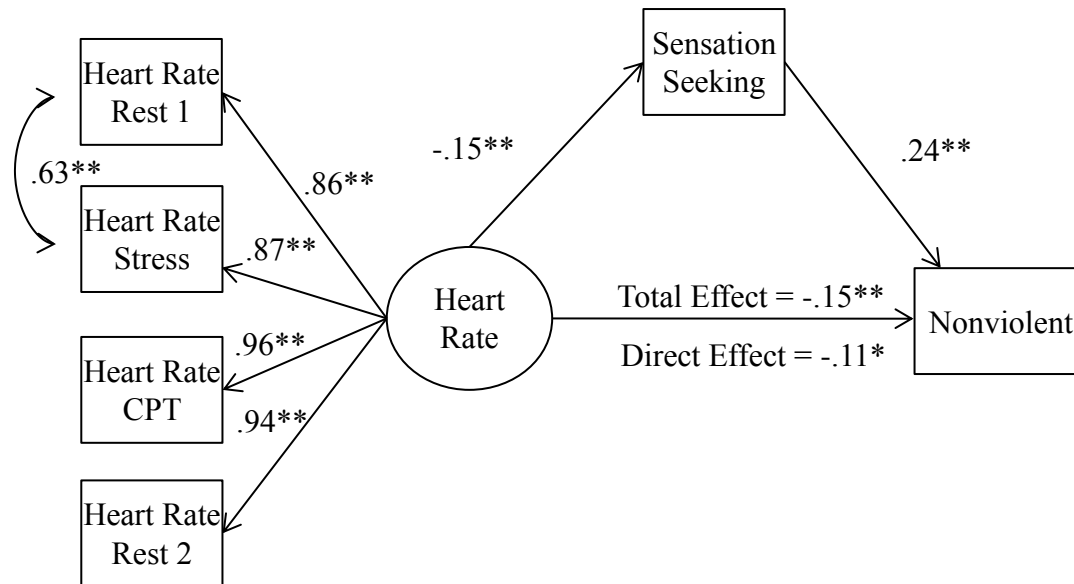
* $p < .05$. ** $p < .01$.

Figure 1.1
Mediation Model Predicting Aggression ($N = 335$)



Notes: Rectangles denote observed variables and circles denote latent variables. Standardized parameter estimates are shown. Curved lines represent correlations between variables' error terms. For ease of presentation, physical activity and race are not shown, although they were included as covariates in the model. Heart rate rest 1 = heart rate during first rest; Heart rate stress = heart rate during stressor; Heart rate CPT = heart rate during the Continuous Performance Task, Heart rate rest 2 = heart rate during the final rest; Violent = violent delinquency; Reactive = reactive aggression; Proactive = proactive aggression; Sensation seeking = score on the impulsive sensation seeking scale of the Zuckerman-Kuhlman Personality Questionnaire.

Figure 1.2.
Mediation Model Predicting Nonviolent Delinquency ($N = 335$)



Notes: Rectangles denote observed variables and circles denote latent variables. Standardized parameter estimates are shown. Curved lines represent correlations between variables' error terms. For ease of presentation, physical activity and race are not shown, although they were included as covariates in the model. Heart rate rest 1 = heart rate during first rest; Heart rate stress = heart rate during stressor; Heart rate CPT = heart rate during the Continuous Performance Task, Heart rate rest 2 = heart rate during the final rest; Sensation seeking = score on the impulsive sensation seeking scale of the Zuckerman-Kuhlman Personality Questionnaire; Nonviolent = nonviolent delinquency.
* $p < .05$; ** $p < .001$.

PAPER 2: HEART RATE STRESS REACTIVITY MODERATES THE RELATIONSHIP BETWEEN NEIGHBORHOOD DISADVANTAGE AND ANTISOCIAL BEHAVIOR

Abstract

Although criminology has a long-standing interest in neighborhood disadvantage, little is known about how biological functioning may moderate the impact of neighborhood disadvantage on antisocial behavior. This paper addressed this limitation by examining whether resting heart rate and heart rate reactivity to stress moderate the relationship between neighborhood disadvantage and antisocial behavior. Antisocial behavior was assessed in a community sample of 445 males and females (mean age = 11.92 years) using respondent and parent measures of externalizing behavior, aggression, and rule-breaking. Heart rate was measured during rest and stress tasks. Heart rate reactivity to stress interacted with neighborhood disadvantage to predict antisocial behavior, with a stronger association between neighborhood disadvantage and antisocial behavior amongst subjects with low heart rate reactivity. In contrast, high heart rate reactivity *protected* individuals living in disadvantaged neighborhoods from engaging in antisocial behavior. This study is one of the few to document a biosocial interaction involving a neighborhood-level risk factor, and is the first to find that heart rate reactivity to stress interacts with the neighborhood environment to predict antisocial behavior. These findings demonstrate the importance of examining biological factors in conjunction with the broader environmental context in order to understand the development of antisocial behavior.

Background

A growing body of research shows that family risk factors interact with biological factors to predict crime and antisocial behavior (Raine, 2002b, 2013). A surprising gap in this literature is a lack of research on biosocial interactions involving neighborhood factors. This is despite a long history of sociological and criminological research which shows that crime and other antisocial behaviors cluster in economically disadvantaged neighborhoods (Sampson, 2012). Some studies indicate that the association between neighborhood disadvantage and antisocial behavior exists even after controlling for demographic, individual, and family factors (e.g., Seidman et al., 1998; Simcha-Fagan & Schwartz, 1986). Nonetheless, it is also known that not all individuals living in disadvantaged neighborhoods will become delinquent or antisocial. Researchers have attempted to identify sources of this heterogeneity; for instance, some studies have found that the individuals in disadvantaged neighborhoods who are most likely to become antisocial are those who are also at high family risk (Roche & Leventhal, 2009). Despite the growing body of biosocial criminological research, it is not yet known if biological risk also heightens the negative impact of a disadvantaged neighborhood on antisocial behavior. The purpose of this paper will be to examine whether biological risk factors moderate the relationship between neighborhood disadvantage and antisocial behavior in a sample of young adolescents.

Neighborhood Effects on Crime and Antisocial Behavior

Sociological researchers have a long-standing interest in how neighborhood features affect behavior (e.g., Shaw & McKay, 1942). Neighborhood effects are thought to be particularly important in explaining adolescent antisocial behavior, because adolescence is a period when individuals tend to spend more time in their neighborhoods and less time in the home with their families (Cleveland, 2003). Adolescence is also a period when antisocial behavior increases dramatically in many individuals (Moffitt, 1993). In addition to the obvious social costs of adolescent delinquency, individuals who are antisocial as youth continue to impose significant financial costs to society throughout their lives and into adulthood (Cohen, 1998; Scott, Knapp, Henderson, & Maughan, 2001). Therefore, research into neighborhood effects on adolescent behavior may have especially important implications for the prevention of antisocial behavior and the reduction of its associated social and financial costs.

Research examining neighborhoods and antisocial behavior often rely on measures that capture overall levels of structural neighborhood disadvantage. These measures capture sociodemographic and compositional features of neighborhoods (Chung & Steinberg, 2006), and often consist of indicators, such as percent single mother homes, percent of households receiving public assistance, percent of adults without a high school education, percent vacant housing units, and percent of population living in poverty in the neighborhood (Brenner, Zimmerman, Bauermeister, & Caldwell, 2013; Hackman, Bentancourt, Brodsky, Hurt, & Farah, 2012; Sampson, Raudenbush, & Earls, 1997; Wright & Fagan, 2013). Theories that attempt to explain the effect of structural neighborhood disadvantage on crime and antisocial behavior often focus on concepts, such as social disorganization (Bursik, 1988; Shaw & McKay, 1942) and collective

efficacy (Sampson et al., 1997). In particular, structurally disadvantaged neighborhoods are thought to lack the community structure and social ties needed to maintain informal social control and achieve residents' common goals (Sampson & Groves, 1989). Likely in part due to this lack of informal social control in disadvantaged neighborhoods, adolescents living in disadvantaged neighborhoods tend to have increased access to delinquent peers (Chung & Steinberg, 2006; Leventhal & Brooks-Gunn, 2000), which is known to increase their own likelihood of engaging in antisocial behavior (Warr, 2002). Disadvantaged neighborhoods also provide more opportunities for criminal behavior and easier access to illicit activities, including illegal drug and alcohol use (Leventhal & Brooks-Gunn, 2000). Together, this increased opportunity and access to deviant peers is thought to increase the likelihood of antisocial behavior among adolescents in disadvantaged neighborhoods.

Nonetheless, not all adolescents who live in disadvantaged neighborhoods will become antisocial, despite exposure to similar environmental risks (Anderson, 1999). In order to understand this heterogeneity, it may be necessary to adopt a multidisciplinary approach that takes into account the neighborhood context, as well as family and individual factors, including biological factors. Although prior research has attempted to explain heterogeneity in antisocial behavior within neighborhoods by examining adolescents' family context (Roche & Leventhal, 2009), it is largely unknown whether biological functioning could also moderate the impact of neighborhood disadvantage on antisocial behavior.

Heart Rate and Antisocial Behavior

Criminologists are increasingly interested in biological factors and the interactions that take place between biological and social systems (Beaver, Gibson, DeLisi, Vaughn, & Wright, 2012; Cullen, 2011). Over the past several years, studies that examine interactions between biological factors and the environment have become more common in sociological and criminological outlets (Beaver et al., 2012; Rowe & Osgood, 1984). This paper examines resting heart rate and heart rate reactivity to stress as putative moderators of the harmful effects of neighborhood disadvantage on antisocial behavior. This study examines these factors, because the mechanisms by which these biological processes are thought to influence behavior may be especially relevant in the disadvantaged neighborhood context.

Heart rate is a psychophysiological index of autonomic nervous system activity controlled by the sympathetic (acceleratory) and parasympathetic (deceleratory) branches of the autonomic nervous system. Heart rate can be measured at rest or in response to a laboratory stimulus, such as a stress task. A meta-analysis of child and adolescent studies reported that reduced heart rate during a stressor was associated with increased levels of antisocial behavior ($d = -.76, p < .0001$; Ortiz & Raine, 2004). Reduced heart rate reactivity during a laboratory stressor is thought to indicate reduced sensitivity to stress. Therefore, it is not surprising that reduced heart rate reactivity to a stressor is associated with higher levels of antisocial behavior, given that reduced sensitivity to stress across multiple biological systems is thought to be characteristic of antisocial individuals (van Goozen & Fairchild, 2008). Several theoretical frameworks have been introduced to attempt to explain the blunted stress reactivity observed in antisocial individuals. Damasio's (1994) somatic marker hypothesis, for instance, argues that individuals with

reduced physiological reactivity to stressors are less likely to make appropriate decisions that minimize risk. Given the increased exposure to criminal opportunities and delinquent peers in disadvantaged neighborhoods, reduced sensitivity to stress may be especially problematic for those individuals living in structurally disadvantaged neighborhood.

Like reduced heart rate reactivity to stress, low *resting* heart rate is also associated with higher levels of antisocial behavior. A meta-analysis of 45 independent effect sizes concluded that low resting heart rate is likely the best-replicated correlate of antisocial behavior in children and adolescents ($d = -.44, p < .001$; Ortiz & Raine, 2004). There are several proposed explanations for this well-replicated finding. According to sensation-seeking theory, low autonomic nervous system arousal—as indexed by a resting low heart rate—is argued to be an unpleasant physiological state, leading those with low resting heart rates to seek stimulating behaviors, including antisocial behaviors, in order to increase their level of physiological arousal to a more optimal level (Quay, 1965; Raine, 2002a). In support of this theory, recent studies found that sensation seeking mediated the relationship between low heart rate and antisocial behavior (Portnoy et al., 2014; Sijtsema et al., 2010; see paper 1 in this dissertation). In light of these findings, low resting heart rate may be especially risky in disadvantaged neighborhoods, given that there are more opportunities to engage in sensation-seeking behaviors that are illegal or antisocial.

Biosocial Interactions in a Neighborhood Context

The most common theory of biosocial interactions is the long standing, dual-hazard model of antisocial behavior (Brennan & Raine, 1997; Raine, 2002b). According to this framework, the presence of *both* biological and social risk factors disproportionately increases the likelihood of antisocial behavior. Under this framework, therefore, it might be expected that antisocial behavior would be most common amongst those individuals with both low heart rate and a high level of neighborhood disadvantage. This would be consistent with the growing body of research which has documented that having both biological and social risk factors increases the likelihood of antisocial behavior (Raine, 2002b, 2013). However, there is a scarcity of research investigating whether this is true for neighborhood environments as it is for family environments.

A complementary perspective on this pattern of interaction focuses on *protective*, rather than *risk* factors for antisocial behavior. This increasingly popular approach attempts to identify protective factors that decrease the likelihood of antisocial and criminal behavior in individuals that would otherwise be at high risk of engaging in these behaviors (Cicchetti, 2010; Lösel & Farrington, 2012; Rutter, 2012; Ttofi & Farrington, 2012). Although there has been a large body of research on social protective factors, there has been a striking lack of exploration into biological protective factors. Although empirical research is currently limited, it has been suggested that increased autonomic nervous system activity may act as a biological protective factor for antisocial behavior in individuals from high-risk social environments (Lösel & Farrington, 2012; Portnoy, Chen, & Raine, 2013). From this theoretical approach, it is possible that *increased* heart rate *protects* individuals living in disadvantaged neighborhoods from engaging in antisocial behavior, because they may more prone to avoid stressful, criminal situations

or may be less prone to sensation-seeking behavior. There is preliminary support for this possibility. Farrington (1997) found that amongst males with high heart rates at age 18, large family size—which was normally a risk factor for violence—was no longer associated with violent convictions. Other studies have shown that amongst high risk adolescents, those with high resting heart rates are less likely to engage in antisocial (Lösel & Bender, 1997) and aggressive behavior (Kindlon et al., 1995), and they are also more likely to desist from criminal behavior in adulthood (Raine, Venables, & Williams, 1995). It remains to be seen whether increased heart rate could also protect against a disadvantaged neighborhood environment.

To date, remarkably little research has examined interactions between biological and neighborhood variables, although there are some exceptions. These very few studies have generally found that genetic risk factors are more strongly associated with offending and antisocial behavior in disadvantaged neighborhoods (Barnes & Jacobs, 2013; Beaver et al., 2012), findings which are consistent with the dual-hazard model, though other studies detected a more complex pattern of interaction effects (Barnes, 2013; Hart & Marmorstein, 2009). Relatedly, other research has shown that early pubertal timing, as well as other hormonal and neuropsychological risk factors for antisocial behavior, have more pronounced effects in disadvantaged neighborhoods (Foshee et al., 2007; Lynam et al., 2000; Obeidallah, Brennan, Brooks-Gunn, & Earls, 2004). Very few studies have examined the interaction between autonomic functioning and neighborhood factors in predicting antisocial behavior (Bubier, Drabick, & Breiner, 2009; Scarpa & Ollendick, 2003; Scarpa, Tanaka, & Haden, 2008), and these studies have had important limitations that preclude firm conclusions. For instance, existing studies all had small sample sizes

($N = 40-57$). Importantly, these studies also used self-report measures of neighborhood features, rather than aggregate, official neighborhood data. These measures, therefore, likely reflected respondent characteristics, rather than neighborhood features alone. This is an especially relevant limitation given that these studies did not adequately control for individual- and family-level variables in order to isolate neighborhood effects. Bubier et al. (2009) included only sex and family income as covariates, while the other studies did not control for covariates in order to capture neighborhood effects (Scarpa & Ollendick, 2003; Scarpa et al., 2008). These prior studies also did not separately examine aggressive and non-aggressive sub-types of antisocial behavior. This is an important limitation given that responses to social stressors are thought to be differentially related to aggressive and non-aggressive forms of antisocial behavior (Burt & Larson, 2007).

In light of these limitations, this paper examines whether heart rate reactivity to stress and resting heart rate moderate the relationship between neighborhood disadvantage and antisocial behavior in a sample of young adolescents. I hypothesize that reduced resting heart rate and heart rate reactivity will be associated with increased levels of externalizing behavior. I also hypothesize that neighborhood disadvantage will be associated with increased externalizing behavior, and that this relationship will be strongest amongst those with reduced resting heart rate and heart rate reactivity to stress.

Methods

Participants

Data for this study come from the Healthy Brains and Behavior study (Liu et al., 2013). The sample consisted of 11 and 12-year old boys and girls living in Philadelphia County, PA or suburbs of Philadelphia. Within the study area, fliers soliciting enrollment were placed in recreation centers, libraries, health clinics, and other community centers. Targeted mailings were also sent to parents of 11 to 12 year old children living in the geographic catchment area. Youths with diagnosed psychosis, mental retardation, or a pervasive developmental disorder were excluded. More information about subject recruitment and exclusionary criteria can be found in Liu et al. (2013). The original sample consisted of 454 subjects. Of this original group, 8 subjects were later deemed ineligible or withdrew. One subject that did not reside in Pennsylvania was not included in the analyses that follow, resulting in a sample of 445 subjects. The sample was 49.4% female, 11.9% white, and 79.7% African American. The mean age of the sample was 11.92 years ($SD = .59$). All subjects were accompanied to the laboratory with a caregiver, who also completed questionnaires about the child's behavior, demographics, and living circumstances.

Psychophysiological Testing Procedure

Heart rate for youth study subjects was recorded continuously during a resting period and a stress task. During the rest task, subjects were told that for the next few minutes nothing would happen and that they should sit with their eyes open. During the social stressor task (Raine, Lencz, Bihrlle, LaCasse, & Colletti, 2000), subjects were instructed to spend two minutes thinking about the worst or most stressful thing that had ever happened to them. After two minutes, they were told to describe the event to an

experimenter for an additional two minutes. In order to increase the level of stress experienced by subjects, a researcher remained in the room with the subject and the task was video recorded. Heart rate data was analyzed for the thinking period of the stress task only, because the act of speaking may interfere with the measurement of cardiovascular activity (Lynch, Long, Thomas, Malinow, Honori, 1981).

Cardiovascular Recording and Data Reduction

Electrocardiograph (ECG) was recorded axially on the left and right ribs at the level of the heart using silver/silver chloride (Ag/AgCl) adhesive disposable electrodes. Prior to attaching electrodes, skin was prepared using NuPrep abrasive skin prepping paste. Biopac isotonic recording gel was used as the electrolyte medium. Impedance for ECG was kept below 10 k Ω . Data were recorded using a bandpass of 0.5-35 Hz and a 60 Hz notch filter, and the recording was digitized at 1000 Hz. ECG data were cleaned for artifacts manually after using *AcqKnowledge* analytic tools to identify unusually large changes in heart rate. Heart rate was then quantified using *AcqKnowledge* analytic tools. Average heart rate for the rest task and the thinking phase of the speech task were calculated by averaging heart rate over four 30-second epochs in each task.

Heart rate reactivity was calculated by subtracting average heart rate during rest from average heart rate during the stress task, with higher scores indicating a larger cardiovascular response to the stressor. This operationalization of heart rate reactivity is used in many studies of cardiovascular reactivity to a laboratory stimulus (Bubier et al., 2009; El-Sheikh, Hinnant, & Erath, 2011; Gottmann et al., 1995). As in prior psychophysiological studies (El-Sheikh et al., 2011), in regression analyses that included

the heart rate reactivity score, I also controlled for resting heart rate. This better captures heart rate reactivity to stress because the magnitude of psychophysiological responses to stimuli are known to be affected by baseline psychophysiological level (Berntson, Uchino, & Cacioppo, 1994).

Antisocial Behavior Measures

Self-reported antisocial behavior was assessed using the externalizing behavior scale of the Youth Self-Report (Achenbach & Rescorla, 2001). The externalizing behavior scale consists of rule-breaking and aggression sub-scales, which were also analyzed separately. Parent-reported antisocial behavior was assessed using the rule-breaking and aggression sub-scales of the Child Behavior Checklist, as well as the overall externalizing behavior score (Achenbach & Rescorla, 2001). The CBCL externalizing scale has 35 items in total. Seventeen of the items measure rule-breaking (e.g., “lie or cheat”) and eighteen are aggression items (e.g., “gets in many fights”) that are rated by the parent on a 3-point Likert scale, with higher scores indicating higher levels of externalizing behavior. The Cronbach’s alpha of both the CBCL rule-breaking and aggression sub-scales in this sample were .97. The YSR has 32 items in total. Fifteen items measure rule-breaking and seventeen are aggression items that are rated by the child on 3-point Likert scale, with higher scores indicating higher levels of externalizing behavior. The Cronbach’s alpha of the YSR rule-breaking and aggression sub-scales in this sample were .88 and .85 respectively.

Neighborhood Measures

Measures of neighborhood disadvantage were based on the census block-group in which a household resided. Block groups are sub-units of census tracts that contain between 600 and 3,000 residents and tend to be relatively economically and socially homogenous (Krieger, Williams, & Moss, 1997). Subjects' addresses were geocoded and assigned to their corresponding block group. Subjects lived in a total of 330 block groups, with an average of 1.35 subjects living in each of these block groups.

Neighborhood disadvantage was assessed using data from the most temporally proximate available American Community Survey 5-year estimate (2005-2009; U.S. Census Bureau). Items similar to those frequently used in prior research to capture structural neighborhood disadvantage (e.g., Sampson et al., 1997; Wright & Fagan, 2013) were subjected to principal components analysis. Eight items were captured as measured by their correlation with the first principal component: percent of female headed family households with children under age 18 years ($M = 22.95\%$, $SD = 14.85$), percent of population that is 25 years or over that has less than a high school education ($M = 22.95\%$, $SD = 14.85$), percent of population that is less than 18 years ($M = 26.45\%$, $SD = 11.25$), percent of households receiving public assistance income ($M = 10.11\%$, $SD = 11.02$), percent African American ($M = 66.41\%$, $SD = 35.82$), percent of occupied housing units that are renter occupied ($M = 42.77\%$, $SD = 23.28$), percent vacant housing units ($M = 16.21\%$, $SD = 14.77$), and percent of population living below the poverty level ($M = 27.66\%$, $SD = 19.71$). Scores were standardized and summed to create a neighborhood disadvantage index, with higher scores indicating higher levels of neighborhood disadvantage.

Covariates

In order to better isolate neighborhood effects, analyses controlled for individual- and family-level covariates. Caregivers reported on whether the mother had ever been arrested (0 = never arrested; 1 = arrested once or more [20.9%]), whether the child lived in government housing (0 = no; 1 = yes [21.1%]), whether the child lived in a non-intact home (0 = child lived with both biological parents; 1 = child lived in some other arrangement [72.1%]), teenage mother (0 = mother was 20 years or older when child born; 1 = mother 19 years or younger when child born [19.6%]), early separation from mother (0 = mother not separated from child from 6 months-2.5 years; 1 = mother separated from child [10.8%]), maternal mental illness (0 = mother did not have mental illness that impaired her functioning during child's lifetime; 1 = mother had mental illness that impaired her functioning during child's lifetime [14.8%]), maternal physical illness (0 = mother did not have physical illness that impaired her functioning during child's lifetime; 1 = mother had physical illness that impaired her functioning during child's lifetime [22.0%]), and child physical illness (0 = child has not had serious physical illness; 1 = child has suffered from serious physical illness [5.4%]). The child's sex was coded as 0 for male and 1 for female (49.4%), and race was coded as 0 for white and 1 for non-white (87.9%).

This study also controlled by body mass index (BMI; $M = 21.85$; $SD = 5.76$), because body size has been associated with heart rate (Shekharappa, Johncy, Mallikarjuna, Vedvathi, & Jayarajan, 2011) and has also been found to be associated with antisocial behavior, although the direction of association is inconsistent across studies (Farrington, 1997; Raine, Reynolds, Venables, Mednick, & Farrington, 1998). BMI was

calculated as kilograms/m² and was derived from measurements in the laboratory of the subject's height and weight on the day of the study visit.

Statistical Analyses

Statistical analyses were performed using Mplus Version 7 (Muthén & Muthén, Los Angeles, CA). Because there were few subjects in each block group (average of only 1.35 subjects/block group), multilevel modeling was not appropriate (Hox, 1998). However, to ensure that standard errors were not biased, parameter estimates were obtained using maximum likelihood with robust standard errors that accounted for clustering at the block group-level (Asparouhov, 2005). In order to test for interaction effects, several regression analyses were conducted with the externalizing, rule-breaking, and aggression as outcome variables. The first models included only individual and family covariates as predictors of outcomes. The main effects of neighborhood disadvantage and heart rate reactivity were added to the second models, and the interaction term (neighborhood disadvantage X heart rate reactivity) was added to the third models (variables were not centered). Significant interactions were probed using the Johnson-Neyman technique (Hayes & Matthes, 2009; Johnson & Fay, 1950; Johnson & Neyman, 1936). This technique is used to determine the exact values along the full continuum of the moderator for which the relationship between the predictor and outcome variable transitions from statistically significant to nonsignificant. The Johnson-Neyman technique has recently re-gained popularity due its advantages over other more commonly used approaches to probing interactions; most importantly, the Johnson-Neyman technique avoids the arbitrariness of selecting discrete points at which the

interaction is probed (Hayes & Matthes, 2009). For ease of interpretation, significant interactions were also plotted using the procedures described in Aiken and West (1991). Analyses were then repeated in order to examine the interaction between neighborhood disadvantage and resting heart rate.

Missing data on the study variables ranged from 0% for child's sex and teenage mother to 5.8% for heart rate reactivity to stress. Independent samples t-tests showed that subjects who were missing data on one or more independent variables did not significantly differ in their scores on aggression, rule-breaking, or externalizing scales of the YSR or CBCL from subjects who were not missing data ($p > .10$). Statistical analyses were performed using the 385 subjects who had complete data.

Results

Bivariate correlations between the key observed study variables are shown in Table 2.1. As expected, high levels of neighborhood disadvantage were associated with increased levels of externalizing behavior ($p < .05$). Overall, there was a significant within-subject increase in heart rate from the resting task ($M = 81.61$, $SD = 10.12$) to the stress task ($M = 83.03$, $SD = 10.56$), $F(1, 420) = 25.62$, $p < .001$. Reduced heart rate reactivity and resting heart rate were significantly associated with CBCL externalizing behavior scores ($p < .05$), indicating that blunted stress reactivity and reduced heart rate at rest were associated with increased levels of parent-reported antisocial behavior.

I first examined whether heart rate reactivity moderated the relationship between neighborhood disadvantage and parent-reported and child-reported antisocial behavior. As shown in Table 2.2, heart rate reactivity and neighborhood disadvantage interacted to

predict parent-reported scores on the externalizing behavior, aggression, and rule-breaking outcomes ($p < .05$). On the other hand, the interaction between neighborhood disadvantage and heart rate reactivity did not significantly predict child-reported antisocial behavior outcomes ($p > .05$; see Table 2.3).

Significant interactions were probed using the Johnson-Neyman technique. The range of values of heart rate reactivity for which the relationships between parent-reported externalizing scores and neighborhood disadvantage were statistically significant are illustrated in Figure 2.1. For subjects with low heart rate reactivity, increased neighborhood disadvantage was associated with higher levels of aggression, rule-breaking, and externalizing behavior. Additionally, as heart rate reactivity decreased, the relationship between neighborhood disadvantage and externalizing behavior scores increased in strength. On the other hand, for subjects with higher levels of heart rate reactivity, neighborhood disadvantage was not significantly associated with externalizing behavior ($p < .05$). These interactions are further illustrated in Figure 2.2 and Table 2.4. These results suggest that having both low heart rate reactivity to stress and neighborhood risk factor increases the likelihood of parent-reported antisocial behavior.

I then examined whether resting heart rate interacted with neighborhood disadvantage to predict parent- and child-reported antisocial behavior. Contrary to initial predictions, the interaction between resting heart rate and neighborhood disadvantage did not significantly predict any of the externalizing behavior outcomes ($p > .05$).

Discussion

The purpose of this paper was to examine whether resting heart rate and heart rate reactivity to stress moderate the relationship between neighborhood disadvantage and antisocial behavior. The current study found that neighborhood disadvantage was more strongly associated with higher levels of antisocial behavior among individuals with reduced heart rate reactivity to stress. This paper is one of the few to examine interactions between neighborhood and biological risk factors and is the first to show that heart rate reactivity to stress moderates the relationship between neighborhood disadvantage and externalizing behavior. Results demonstrate the importance of considering biological factors in conjunction with the larger neighborhood environment, and the study provides a new biological lens through which to view classical social risk factors for antisocial behavior.

Biosocial Theories of Antisocial Behavior

The current study found that for subjects with blunted heart rate reactivity to stress, the relationship between neighborhood disadvantage and antisocial behavior was potentiated. This finding is consistent with the dual-hazard model of antisocial behavior, given that having both a social risk combined with a biological risk factor increased the likelihood of antisocial behavior. More specifically, results are in line with those of other studies that have shown that low heart rate combined with social adversity increases the likelihood of antisocial behavior (Farrington, 1997; Raine, Fung, Portnoy, Choy, & Spring, 2014). This study built upon this prior research by documenting a biosocial interaction involving a neighborhood-level risk factor.

Results were also consistent with a protective factors model of antisocial behavior. In particular, *high* heart rate reactivity appeared to protect against antisocial behavior amongst adolescents living in high-risk neighborhoods. This finding is important given the renewed interest across multiple intellectual disciplines in identifying factors that protect against antisocial and other adverse outcomes in the context of environmental risk (Cicchetti, 2010; Lösel & Farrington, 2012; Rutter, 2012). This line of research is based on the often overlooked observation that many individuals who are at high-risk of offending either do not become criminal or desist from offending (Loeber & Stouthamer-Loeber, 1998). Non-biological putative protective factors include intensive parental supervision, support and supervision by teachers, and emotionally positive relationships between parents and their children (reviewed in Lösel & Farrington, 2012). Although there has very limited research into biological protective factors for antisocial behavior, possible biological protective factors include strong executive functioning and genetic polymorphisms (reviewed in Lösel & Farrington, 2012; Portnoy, Chen, & Raine, 2013). In addition, increased autonomic nervous system arousal and reactivity have also been identified as possible protective factors (Lösel & Farrington, 2012; Portnoy, Chen, & Raine, 2013; Raine, Venables, & Williams, 1995, 1996). Studies in high risk samples have shown that adolescents with high resting heart rates are less likely to engage in antisocial and aggressive behaviors (Kindlon et al., 1995; Lösel & Bender, 1997). Other research found that high-risk males who did not become criminal displayed increased heart rate and skin conductance (an index of sympathetic nervous system activation) responses as compared to both criminals and low-risk non-criminal controls (Brennan et al., 1997). Together, and in conjunction with the current results, these findings suggest

that increased autonomic nervous system activity may protect against the development of antisocial behavior in otherwise high-risk individuals.

It should be noted that heart rate reactivity, but not resting heart rate, interacted with neighborhood disadvantage to predict antisocial behavior. This suggests that reduced sensitivity to stress, rather than reduced physiological arousal in general, interacts with the neighborhood environment. The risk of antisocial behavior may be heightened among adolescents with reduced stress reactivity because these individuals are less influenced by the negative consequences of engaging in antisocial behavior, which could include police contact, arrest, or even physical injury. Reduced sensitivity to these risks could be particularly problematic in disadvantaged neighborhoods where there may be increased opportunities to engage in antisocial behavior.

On the other side of the coin, individuals with high heart rate reactivity to stress may be able to avoid engaging in delinquent opportunities that may be more common in disadvantaged neighborhoods. Consistent with this, a recent study found that youth with a stronger fear of crime were less likely to be involved in violence and also less likely to engage in routine activities that brought them into contact with delinquent peers (Melde, Berg, & Esbensen, 2014). Other research has shown that young offenders are aware of the physical dangers of offending—which include personal injury as a result of victim retaliation and police encounters—and that increased perceptions of dangerousness decrease the likelihood that an individual will offend (McCarthy & Hagan, 2005). Together, these findings suggest that reduced stress sensitivity may be especially harmful in social contexts that provide opportunities for antisocial behavior and association with delinquent peers. There are additional social processes that could potentially underlie the

observed interactions. For instance, high heart rate reactivity to a social stressor may be reflective of a high level of social anxiety. Socially anxious adolescents may spend less time outside of the home with peers, thus making them less likely to engage in delinquent behaviors. Further search into this possibility and other social mechanisms that may be driving the observed interactions is needed.

Contributions, Limitations, and Future Directions

There are some limitations to the current study that should be noted. First, this study was not longitudinal, which precluded the conclusion that low heart rate stress reactivity preceded the onset of externalizing behavior. However, it should be noted that numerous studies have found that low heart rate prospectively predicts future levels of antisocial behavior (Farrington, 1997; Jennings, Piquero, & Farrington, 2013; Raine, Venables, & Williams, 1990; Sijtsema et al., 2010), suggesting that this issue may not be a major concern.

It is also important to mention that reduced heart rate reactivity to stress was significantly associated with higher levels of neighborhood disadvantage. There are several possible explanations for this relationship. One possibility is due to selection effects of antisocial parents into disadvantaged neighborhoods. A genetically informative design—such as a twin study—would be able to rule out the possibility of genetic confounding underlying any observed relationships (Beaver, Ferguson, & Lynn-Whaley, 2010). The use of a household design could also partly address this limitation through the comparison of levels of antisocial behavior across siblings in the same

household who differ on heart rate reactivity. Because this study did not use this type of design, it is not possible to rule out selection biases.

It should also be noted that disadvantaged neighborhoods are chronically stressful places. Individuals living in disadvantaged neighborhoods are exposed to higher levels of numerous chronic stressors, including community violence, poor housing conditions, and social disorder. Children living in disadvantaged neighborhoods report higher levels of perceived stress (Roosa et al., 2005) and experience more stressful life events (Attar, Guerra, & Tolan 1994). Chronic stress is thought to affect the body's biological stress response; over time, chronic stress is hypothesized to result in the down-regulation of the body's stress response system as a way for individuals to cope with chronically threatening environments without constantly evoking hormonal and cardiovascular stress responses (Susman, 2006). Therefore, an additional possibility that cannot be ruled out in this study is that individuals who were characterized by *both* reduced stress reactivity *and* disadvantaged neighborhoods, were exposed to particularly stressful early life circumstances that predisposed them to engage in antisocial behavior.

We should also mention that this study only examined antisocial behavior as the outcome variable of interest. Although high heart rate reactivity was protective for antisocial behavior, it is possible that high heart rate may serve as a *risk* factor for other adverse psychological and health outcomes. High heart rate has been associated with anxiety (Weems, Zakem, Costa, Cannon, & Watts, 2005) and is also associated with a host of physical health problems, including cardiovascular disease and coronary mortality (Cooney et al., 2010). Future research that includes a more comprehensive measure of

well-being is necessary in order to determine how high heart rate reactivity to stress affects adolescents' overall functioning.

Finally, findings only applied to parent-reported externalizing behavior, and no significant interactions were found for respondent reported behavior. However, the magnitude and patterns of interaction for child-reported outcomes were similar to those of the parent-reported outcomes, suggesting that the lack of exact convergence across raters is not a major concern.

These limitations should be viewed in light of several strengths of this study. Importantly, this study took our current understanding of biosocial interactions a step further by documenting for the first time an interaction between neighborhood disadvantage and heart rate reactivity to stress in predicting antisocial behavior. Of note, the current study used objective biological measures, official government data, as well as parent-report and child self-report. Therefore, bias due to shared informant variance is unlikely to have affected results. Additionally, the interaction effects were significant after taking into account some of the best-known correlates of antisocial behavior, including living in a broken home and maternal criminality. The large sample size, examination of multiple types of antisocial behavior, and extensive controls for individual and family covariates were also strengths that addressed important limitations of prior research. Taken together, the strengths of this study lend support to the robustness of the current findings.

Above all, the current study suggests the importance of future criminological research that integrates multiple levels of measurement to understand the etiology of externalizing behavior. Longitudinal research that examines changes in biological

functioning, neighborhood characteristics, and behavior over time will be especially useful in elucidating the development of antisocial behavior over the life-course. Even without this research, however, it is clear that to best understand both biological and neighborhood effects on externalizing behavior it is necessary to examine interactions between these domains. Research that examines biological and social factors in conjunction with one another will be a crucial next step in improving our understanding of the etiology of antisocial behavior (Choy et al., 2015).

For sociological and criminological researchers who may not be trained in biological methods, heart rate could be an especially useful biomarker to incorporate into this type of research agenda given that heart rate tends to be relatively less expensive and simpler to measure than other biological measures (Gao et al., 2012). In light of the current findings, heart rate may help us to develop a better understanding of why certain subgroups of individuals living in disadvantaged neighborhoods are more likely to become antisocial. Investigations into the way in which biomarkers interact with the larger neighborhood and social structure will be a crucial step in bridging academic disciplines and developing a more complete understanding of the complex, multilevel processes responsible for antisocial behavior.

Paper 2 Tables and Figures

Table 2.1. Bivariate Correlations Between Key Study Variables ($N = 385$)

	1	2	3	4	5	6	7	8	9
1. Neighborhood Disadvantage	1.00								
2. Heart rate reactivity	-.17**	1.00							
3. Resting heart rate	.00	-.22**	1.00						
<i>Self-Reported Externalizing Behavior</i>									
4. YSR Externalizing	.15**	-.08	-.07	1.00					
5. YSR Aggression	.12*	-.08	-.06	.96**	1.00				
6. YSR Rule-breaking	.19**	-.08	-.09	.86**	.67**	1.00			
<i>Parent-Reported Externalizing Behavior</i>									
7. CBCL Externalizing	.20**	-.12*	-.11*	.39**	.33**	.36**	1.00		
8. CBCL Aggression	.20**	-.10*	-.11*	.38**	.36**	.32**	.98**	1.00	
9. CBCL Rule-breaking	.19**	-.12*	-.11*	.35**	.32**	.32**	.91**	.79**	1.00
<i>Mean</i>	-.01	1.40	81.64	10.89	7.44	3.43	9.82	6.67	3.16
<i>SD</i>	5.07	5.55	10.06	7.91	5.43	3.07	9.05	6.27	3.24
<i>Minimum-Maximum</i>	-9.98- 14.31	-12.18- 21.46	56.31- 118.69	0.00- 40.00	0.00- 26.00	0.00- 17.00	0.00- 45.00	0.00- 28.00	0.00- 20.00

Notes: YSR = Youth Self-Report; CBCL = Child Behavior Checklist (parent-report).

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

Table 2.2 Regressions Predicting Parent-Reported Outcomes ($N = 385$)

	Externalizing			Aggression			Rule-Breaking		
	Model 1 β (SE)	Model 2 β (SE)	Model 3 β (SE)	Model 1 β (SE)	Model 2 β (SE)	Model 3 β (SE)	Model 1 β (SE)	Model 2 β (SE)	Model 3 β (SE)
Non-intact Family	.15 (.05)**	.10 (.05)	.10 (.05)*	.14 (.05)**	.08 (.05)	.09 (.05)	.15 (.05)**	.11 (.05)*	.11 (.05)*
Sex	-.11 (.05)*	-.09 (.05)	-.11 (.05)*	-.09 (.05)	-.07 (.05)	-.08 (.05)	-.14 (.05)**	-.13 (.05)*	-.14 (.05)**
Mother arrested	.13 (.05)*	.16 (.05)**	.16 (.05)**	.12 (.05)*	.15 (.05)**	.14 (.05)**	.15 (.05)**	.16 (.05)**	.16 (.05)**
Race	.05 (.05)	-.02 (.06)	.01 (.05)	.03 (.05)	-.05 (.06)	-.02 (.06)	.10 (.04)*	.03 (.05)	.07 (.05)
BMI	.08 (.06)	.05 (.06)	.03 (.05)	.07 (.06)	.04 (.05)	.03 (.05)	.08 (.07)	.06 (.07)	.04 (.06)
Public Housing	.01 (.06)	.01 (.05)	-.02 (.05)	.01 (.06)	-.01 (.06)	-.02 (.05)	.01 (.05)	-.01 (.05)	-.02 (.05)
Teenage Mother	-.05 (.05)	-.06 (.05)	-.07 (.05)	-.06 (.05)	-.07 (.05)	-.08 (.05)	-.03 (.05)	-.04 (.06)	-.05 (.05)
Early Separation from Mother	-.00 (.05)	-.01 (.05)	-.01 (.05)	.01 (.05)	.01 (.05)	.00 (.05)	-.02 (.05)	-.03 (.05)	-.04 (.05)
Mother Mental Illness	.05 (.05)	.05 (.05)	.04 (.05)	.05 (.05)	.05 (.05)	.04 (.05)	.04 (.05)	.03 (.05)	.02 (.05)
Mother Physical Illness	.08 (.05)	.10 (.05)	.09 (.05)	.07 (.05)	.08 (.05)	.08 (.05)	.10 (.05)	.11 (.05)*	.11 (.05)*
Child Serious Illness	.01 (.04)	.01 (.04)	.00 (.04)	-.00 (.05)	.00 (.05)	-.01 (.05)	.03 (.04)	.02 (.04)	.01 (.04)
Heart rate rest		-.10 (.05)*	-.11 (.05)*		-.10 (.05)	-.10 (.05)*		-.09 (.05)	-.10 (.05)*
Heart rate reactivity		-.09	-.12		-.07	-.11		-.10	-.13

Neighborhood disadvantage	(.05) .20 (.07)*	(.05)* .23 (.07)**	(.05) .21 (.08)**	(.05)* .24 (.07)**	(.05) .15 (.06)*	(.05)* .19 (.06)**			
HR reactivity X neighborhood disadvantage		-.19 (.06)**		-.18 (.06)**		-.17 (.05)**			
Total R ²	.08	.13	.16	.06	.11	.14	.10	.14	.16

NoteS: Model 1 includes only the covariates as predictors of the latent variables. Model 2 includes covariates and the main effects of heart rate reactivity and neighborhood disadvantage. Model 3 includes all variables in models 1 and 2, as well as the interaction between neighborhood disadvantage and heart rate reactivity. All coefficients are standardized. Non-intact family = 0 if child lived with both biological parents; Sex = 0 if male; Mother arrested = 0 if mother never arrested; Race = 0 if white; BMI = body mass index; Public housing = 0 if child did not live in government housing; Teenage mother = 0 if mother was 20 years or older when child was born; Early separation from mother = 0 if child was not separated from the mother from 6 months-2.5 years; Mother mental illness = 0 if mother did not have a mental illness that impaired her functioning during child's lifetime; Mother physical illness = 0 if mother did not have physical illness that impaired her functioning during child's lifetime; Child serious illness = 0 if child has not had serious illness.

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

Table 2.3. Regressions Predicting Child-Reported Outcomes ($N = 385$)

	Externalizing			Aggression			Rule-Breaking		
	Model 1 β (SE)	Model 2 β (SE)	Model 3 β (SE)	Model 1 β (SE)	Model 2 β (SE)	Model 3 β (SE)	Model 1 β (SE)	Model 2 β (SE)	Model 3 β (SE)
Non-intact Family	.06 (.05)	.05 (.05)	.06 (.05)	.07 (.05)	.06 (.05)	.07 (.05)	.03 (.05)	.02 (.05)	.03 (.05)
Sex	-.04 (.05)	-.02 (.05)	-.03 (.05)	.01 (.05)	.03 (.05)	.02 (.05)	-.09 (.05)*	-.08 (.05)	-.09 (.05)
Mother arrested	.02 (.05)	.04 (.06)	.04 (.06)	.01 (.05)	.03 (.06)	.03 (.06)	.05 (.05)	.07 (.06)	.06 (.06)
Race	.05 (.05)	.00 (.06)	.02 (.06)	.01 (.05)	-.01 (.06)	.01 (.06)	.09 (.04)*	.04 (.05)	.06 (.05)
BMI	.08 (.05)	.06 (.06)	.05 (.06)	.06 (.05)	.04 (.06)	.03 (.06)	.07 (.05)	.05 (.06)	.05 (.06)
Public Housing	.08 (.06)	.03 (.05)	.02 (.05)	.05 (.05)	.01 (.05)	.01 (.05)	.11 (.06)	.06 (.06)	.05 (.06)
Teenage Mother	.04 (.05)	-.00 (.05)	-.01 (.04)	.07 (.05)	.03 (.05)	.03 (.05)	-.03 (.04)	-.07 (.04)	-.08 (.04)*
Early Separation from Mother	.05 (.06)	.08 (.05)	.07 (.05)	.05 (.05)	.07 (.05)	.08 (.05)	.05 (.06)	.07 (.06)	.07 (.06)
Mother Mental Illness	.05 (.06)	.06 (.05)	.06 (.05)	.02 (.05)	.04 (.05)	.03 (.05)	.04 (.06)	.06 (.06)	.05 (.06)
Mother Physical Illness	.09 (.05)	.10 (.06)	.10 (.05)	.08 (.05)	.09 (.05)	.09 (.05)	.06 (.05)	.07 (.05)	.07 (.05)
Child Serious Illness	-.05 (.05)	-.10 (.04)*	-.11 (.04)*	-.03 (.05)	-.09 (.04)*	-.09 (.04)*	-.05 (.05)	-.11 (.04)*	-.11 (.04)*
Heart rate rest		-.06 (.05)	-.06 (.05)		-.05 (.05)	-.05 (.05)		-.08 (.05)	-.08 (.05)
Heart rate reactivity		-.06 (.05)	-.08 (.06)		-.05 (.06)	-.07 (.06)		-.04 (.06)	-.06 (.06)

Neighborhood disadvantage	.13 (.07)	.15 (.08)*			.09 (.08)	.11 (.08)			.13 (.06)*	.15 (.07)*
HR reactivity X neighborhood disadvantage		-.11 (.07)				-.08 (.07)				-.10 (.06)
Total R ²	.04	.08	.09	.03	.05	.06	.06	.09	.10	

Notes: Model 1 includes only the covariates as predictors of the latent variables. Model 2 includes covariates and the main effects of heart rate reactivity and neighborhood disadvantage. Model 3 includes all variables in models 1 and 2, as well as the interaction between neighborhood disadvantage and heart rate reactivity. All coefficients are standardized. Non-intact Family = 0 if child lived with both biological parents; Sex = 0 if male; Mother arrested = 0 if mother never arrested; Race = 0 if white; BMI = body mass index; Public Housing = 0 if child did not live in government housing; Teenage mother = 0 if mother was 20 years or older when child was born; Early separation from mother = 0 if child was not separated from the mother from 6 months-2.5 years; Mother mental illness = 0 if mother did not have a mental illness that impaired her functioning during child's lifetime; Mother physical illness = 0 if mother did not have physical illness that impaired her functioning during child's lifetime; Child serious illness = 0 if child has not had serious illness.

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

Table 2.4a. Parent-Reported Externalizing Behavior for Subjects with High (+ 1 SD) and Low Levels (-1 SD) of Neighborhood Disadvantage and Heart Rate Reactivity

	Low Neighborhood Disadvantage	High Neighborhood Disadvantage
High Heart Rate Reactivity	7.33 (8.34) <i>n</i> = 21	9.14 (6.61) <i>n</i> = 7
Low Heart Rate Reactivity	6.50 (4.73) <i>n</i> = 4	22.27 (11.50) <i>n</i> = 11

Notes: Child Behavior Checklist externalizing scale means and standard deviations are shown in each cell.

Table 2.4b. Parent-Reported Aggression for Subjects with High (+ 1 SD) and Low Levels (-1 SD) of Neighborhood Disadvantage and Heart Rate Reactivity

	Low Neighborhood Disadvantage	High Neighborhood Disadvantage
High Heart Rate Reactivity	5.43 (5.94) <i>n</i> = 21	6.29 (7.32) <i>n</i> = 7
Low Heart Rate Reactivity	5.00 (2.45) <i>n</i> = 4	15.45 (8.96) <i>n</i> = 11

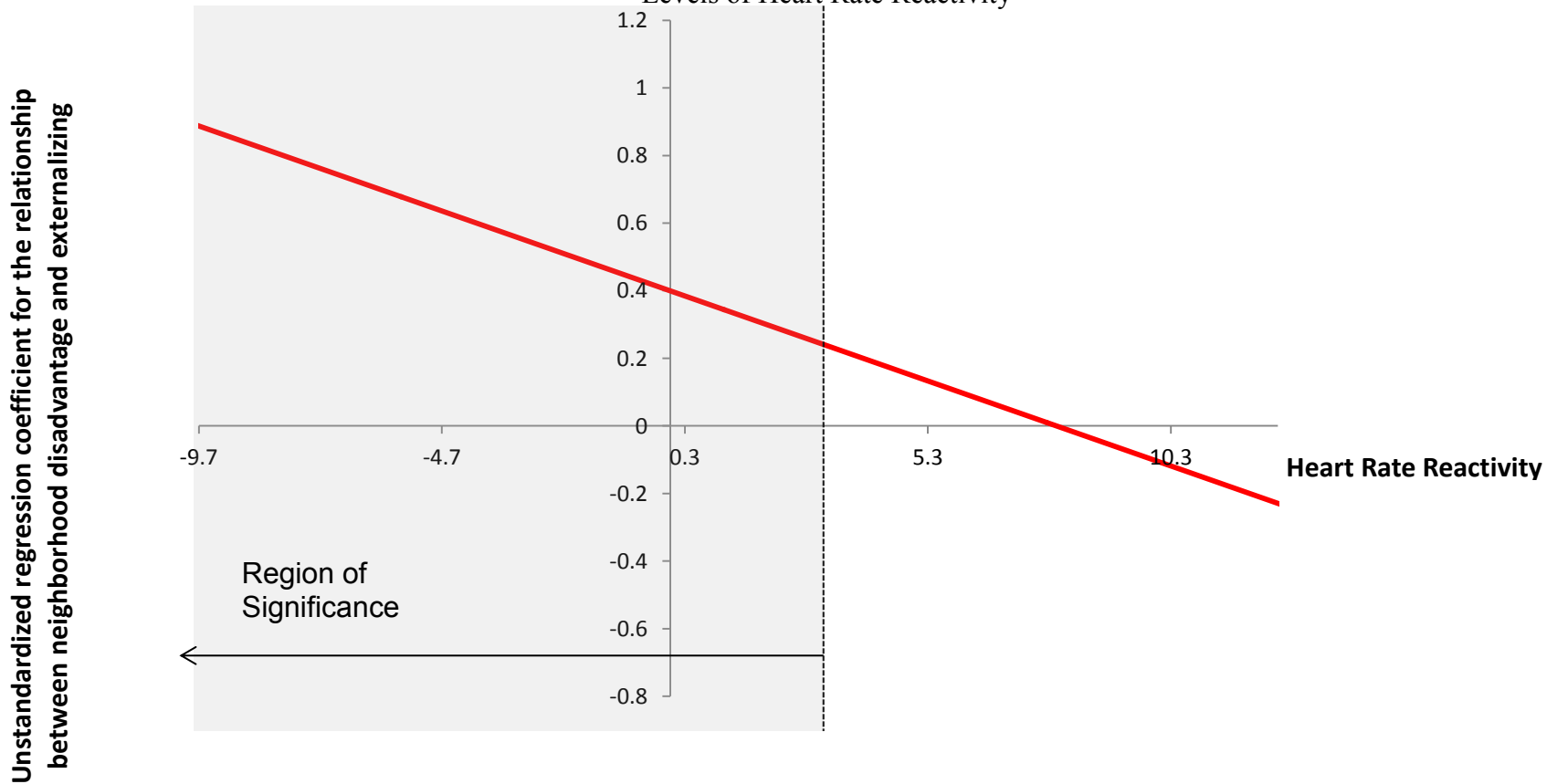
Notes: Child Behavior Checklist aggression means and standard deviations are shown in each cell.

Table 2.4c. Parent-Reported Rule-Breaking for Subjects with High (+ 1 SD) and Low Levels (-1 SD) of Neighborhood Disadvantage and Heart Rate Reactivity

	Low Neighborhood Disadvantage	High Neighborhood Disadvantage
High Heart Rate Reactivity	1.90 (2.72) <i>n</i> = 21	2.86 (1.68) <i>n</i> = 7
Low Heart Rate Reactivity	1.50 (2.38) <i>n</i> = 4	5.40 (3.89) <i>n</i> = 11

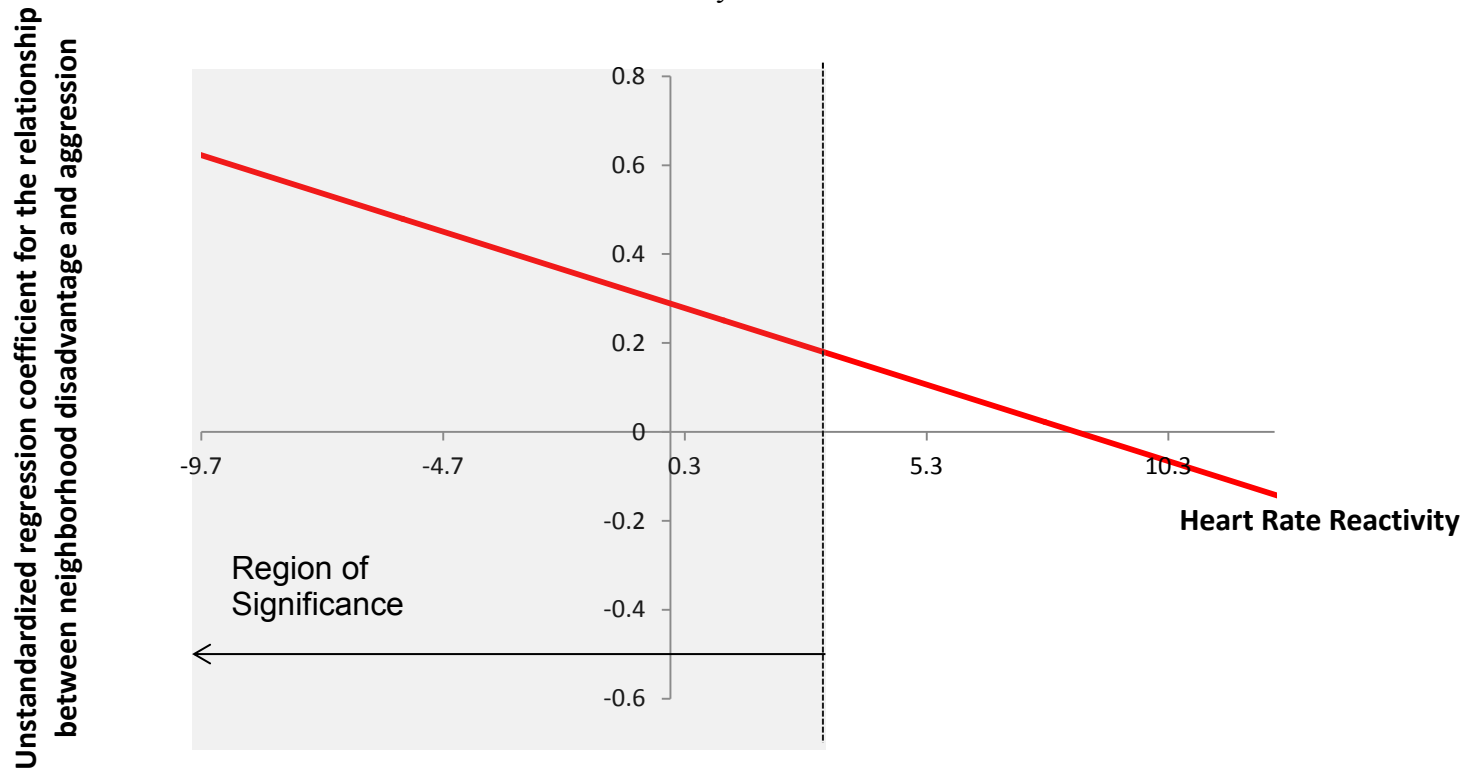
Notes: Child Behavior Checklist rule-breaking means and standard deviation are shown in each cell.

Figure 2.1a.
 Relationship Between Externalizing Behavior and Neighborhood Disadvantage at Different
 Levels of Heart Rate Reactivity



Notes: Regions of heart rate reactivity for which the relationship between externalizing behavior and neighborhood disadvantage is significant ($p < .05$, 2-tailed) are shown in gray. $N = 385$.

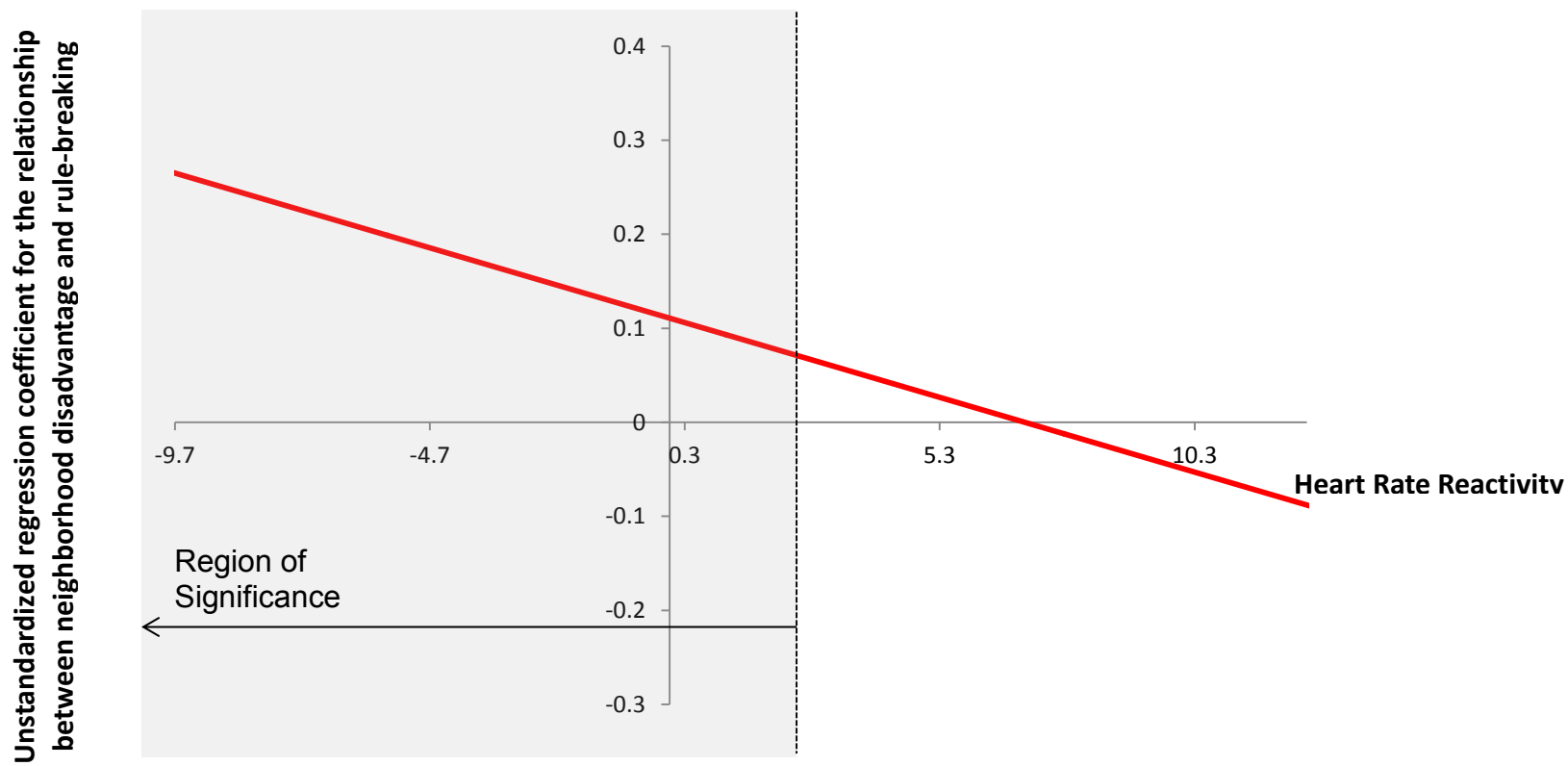
Figure 2.1b.
Relationship Between Aggression and Neighborhood Disadvantage at Different Levels of Heart Rate Reactivity



Notes: Regions of heart rate reactivity for which the relationship between aggression and neighborhood disadvantage is significant ($p < .05$, 2-tailed) are shown in gray. $N = 385$.

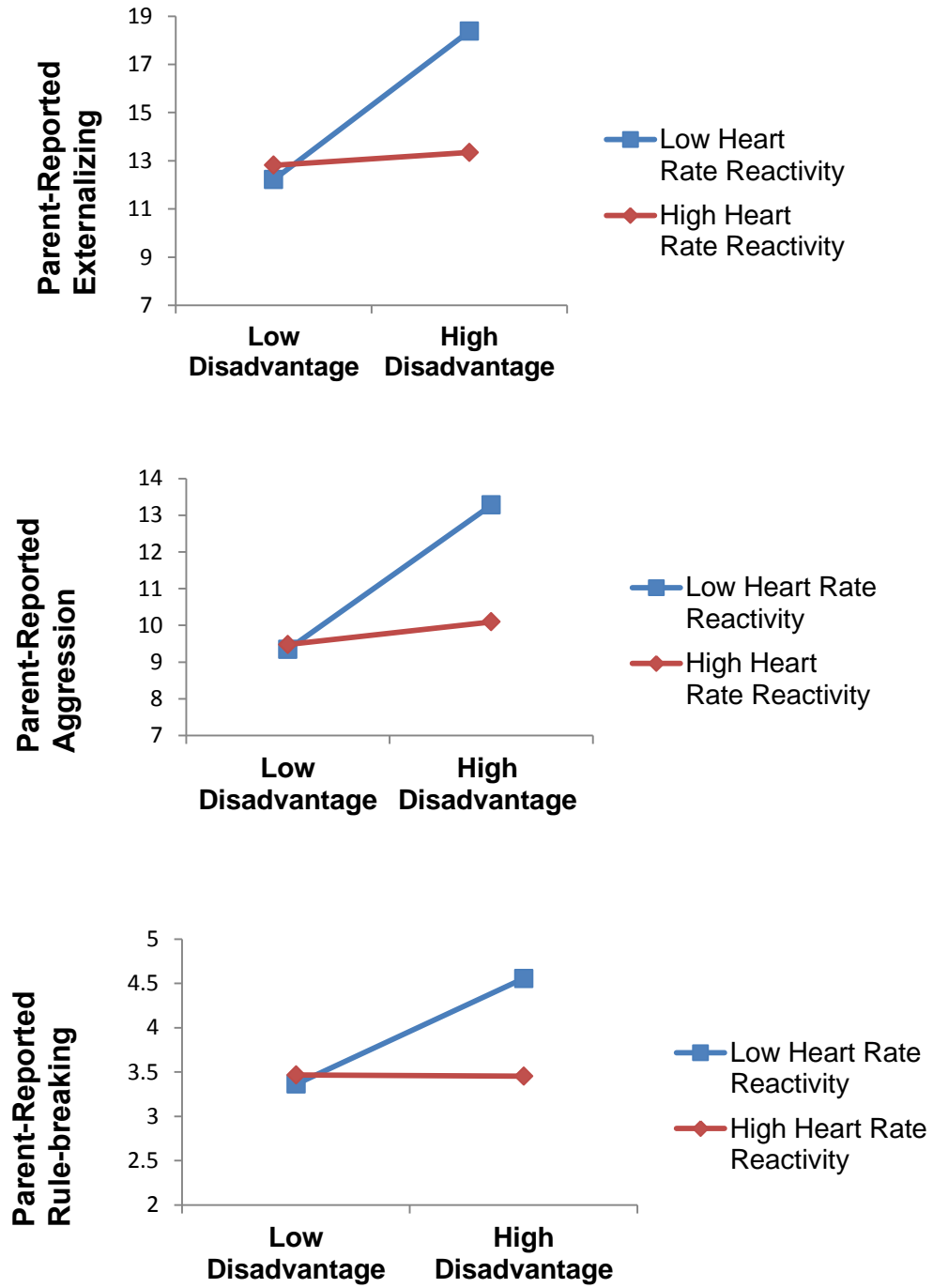
Figure 2.1c.

Relationship Between Rule-breaking and Neighborhood Disadvantage at Different Levels of Heart Rate Reactivity



Notes: Regions of heart rate reactivity for which the relationship between rule-breaking and neighborhood disadvantage is significant ($p < .05$, 2-tailed) are shown in gray. $N = 385$.

Figure 2.2. Simple Slopes of Parent-reported Externalizing Behavior, Aggression, and Rule-Breaking on Neighborhood Disadvantage at High (+1 SD) and Low (-1 SD) Levels of Heart Rate Reactivity



**PAPER 3: PRENATAL TESTOSTERONE MARKER MODERATES THE
RELATIONSHIP BETWEEN CORTISOL REACTIVITY AND SELF-
REPORTED EXTERNALIZING BEHAVIOR IN YOUNG ADOLESCENT
MALES**

Abstract

Although reduced cortisol reactivity to stress and increased circulating testosterone level are hypothesized to be associated with higher levels of externalizing behavior, empirical findings are inconsistent. One factor that may account for the heterogeneity in these relationships is prenatal testosterone exposure. This study examined whether the second-to-fourth digit ratio (2D:4D), a marker of prenatal testosterone exposure, moderated the relationships of testosterone and cortisol reactivity with externalizing behavior. Left and right hand 2D:4D and self-reported externalizing behavior were measured in a sample of 353 young adolescents (*M* age = 11.92 years; 178 females; 79.7% African American). Saliva samples were collected before and after a stress task and later assayed for cortisol. Testosterone levels were determined from an AM saliva sample. 2D:4D interacted with cortisol reactivity in males to predict externalizing behavior. In males, low cortisol reactivity was associated with higher levels of aggression and rule-breaking behavior, but only among subjects with low 2D:4D (i.e., high prenatal testosterone). Findings suggest the importance of a multi-systems approach in which interactions between multiple hormones are taken into account. Furthermore, results demonstrate the importance of considering the organizational influence of prenatal testosterone in order to understand the activational influence of circulating hormones during adolescence.

Background

Hormones, including testosterone and cortisol, are frequently studied in relation to externalizing problem behavior (Archer, 1991; Susman et al., 1987, 2010). However, the findings of studies that examine main effects of cortisol and testosterone on behavior problems are somewhat inconsistent. A meta-analysis of child and adolescent studies reported no association between cortisol reactivity and externalizing behavior ($r = -.04, p > .05$) and only a small relationship between basal cortisol and externalizing behavior ($r = -.05, p < .05$; Alink et al., 2008). Although a meta-analysis showed a stronger association between testosterone and aggression ($r = .13, p < .01$), there was significant heterogeneity in effect sizes across studies (Book, Starzyk, & Quinsey, 2001; Book & Quinsey, 2005), suggesting that there may be factors that moderate this relationship. A large body of research has examined social context, including family and peer relationships, as moderators of the relationship between hormones and behavior problems (Booth, Johnson, Granger, Crouter, & McHale, 2003; Rowe, Maughan, Worthman, Costello, & Angold, 2004). Less research has been conducted on non-social, biological factors as moderators, although there is an increasing interest among researchers in incorporating a multi-systems approach to behavior that takes into account multiple biological processes (Mehta & Josephs, 2010; Montoya et al., 2012; Terburg, Morgan, & van Honk, 2009). This article examines prenatal testosterone as a putative biological moderator of the cortisol-externalizing behavior and testosterone-externalizing behavior relationships.

This paper examines prenatal testosterone as a moderator because of its hypothesized organizational influences on the developing fetus. In addition, in contrast

to environmental moderators, to my knowledge, no prior research has examined prenatal testosterone as a moderator of the effect of cortisol on behavior. Organizational effects were first discovered through animal research; a seminal study found that female rats who were treated prenatally with testosterone were more likely to exhibit male-typical behaviors than untreated rats, and that this effect persisted even after the termination of testosterone treatment (Phoenix, Goy, Gerall, & Young, 1959). This finding suggested that prenatal testosterone played a role in the masculinization of the brain. Since the publication of Phoenix et al. (1959), evidence has mounted that prenatal testosterone plays a role in the masculinization of the developing brain and nervous system and affects brain structure during critical periods of development (Arnold, 2009; Breedlove, 1994). Prenatal testosterone is thought to contribute to the masculinization of the brain by influencing cells in sexually dimorphic areas of the brain. For instance, androgens in rodents have been found to prevent cell death in neural regions that are larger in adult males than adult females. On the other hand, androgens promote cell death in neural regions that are larger in rodent females than in males (Hines, 2004; McCarthy, 2010). Given the organizational role of testosterone during prenatal developmental, the purpose of this article is to determine whether the extent of exposure to prenatal testosterone moderates the effects of circulating hormones on behavior during early adolescence.

Testosterone

Testosterone is the end product of the hypothalamic-pituitary-gonadal (HPG) axis and is the primary androgen, the group of steroid hormones responsible for the development and maintenance of masculine traits (Mazur & Booth, 1998). Testosterone

is released prenatally by the gonads and is secreted in much higher levels in males, contributing to the masculinization of the central nervous system (Hines, 2004).

Testosterone is thought to have both organizational effects on behavior—through its effects on neurodevelopment during gestation—and activational effects that occur through the influence of postnatal circulating testosterone (Breedlove, 2010; Mazur & Booth, 1998).

Research on prenatal testosterone is often conducted using indirect biological markers due to the difficulty of measuring hormones prenatally. The second-to-fourth digit ratio of the hand (2D:4D) is thought to be a marker of prenatal testosterone levels, with a lower 2D:4D indicating higher exposure to prenatal testosterone relative to estrogen (Manning, Scutt, Wilson, & Lewis-Jones, 1998; Manning, Kilduff, Cook, Crewther, & Fink, 2014). Several indirect findings are often used to support the validity of 2D:4D as a marker of prenatal testosterone exposure. These include (1) 2D:4D is a sexually dimorphic trait; males tend to have lower 2D:4D than females (Hönekopp & Watson, 2010), and this sex difference is already present during gestation (Galis, Broek, Van Dongen, & Wijnaendts, 2010), (2) females with congenital adrenal hyperplasia (CAH), a disorder that results in increased in utero androgen production, have lower 2D:4D ratios than females without CAH (Brown, Hines, Fane, & Breedlove, 2002; Okten, Kalyoncu, & Yaris, 2002), and (3) a correlational study of routine amniocentesis samples taken during the second trimester of pregnancy found that 2D:4D ratios were negatively associated with the prenatal testosterone / estrogen ratio at age two years (Lutchmaya, Baron-Cohen, Raggatt, Knickmeyer, & Manning, 2004). In addition to this indirect and correlational evidence, a recent experimental study in mice found that

inactivation of the androgen receptor during gestation resulted in more feminized digit ratios in mice, while inactivation of the estrogen receptor resulted in more masculinized digit ratios (Zheng & Cohn, 2011). Conversely, postnatal doses of androgen and estrogen had no effect on digit ratios, a finding which suggests that there is a critical prenatal period for the determination of digit ratios.

As would be expected based on prenatal testosterone's hypothesized organizational effects, low 2D:4D (indicating high prenatal testosterone) has been associated with higher levels of male-typical traits, including spatial abilities (Csathó et al., 2003) and sensation-seeking (Hampson, Ellis, & Tenk, 2008). Low 2D:4D has also been associated with aggression, (Hampson et al. 2008), dating violence (Cousins, Fugère, & Franklin, 2009), and traffic violations (Schwerdtfeger, Heims, & Heer, 2010), although some results have been inconsistent (Austin, Manning, McInroy, & Matthews, 2002). A recent meta-analysis found a small negative association between 2D:4D and aggression in males (Hönekopp & Watson, 2011). The presence of only a small, negative relationship between 2D:4D and aggression in males leaves open the possibility that other hormonal factors could account for heterogeneity in this relationship.

Circulating Testosterone

Following a dramatic rise in testosterone production in males during gestation, as well as a brief surge in testosterone beginning shortly after birth and lasting until about the sixth month of infancy, testosterone levels return to low levels in both males and females until puberty (Hines, 2004). In males, testosterone levels remain at low levels until the transition to Tanner Stage 3, when testosterone levels begin to increase

dramatically. In males, testosterone reaches adult levels by Tanner Stage 4 or 5, which occurs around age 16 years (Kushnir et al., 2010; Sato, Scuhlz, Sisk, & Wood, 2008). In females, the greatest increase in testosterone occurs earlier in life, during the transition to Tanner Stage 2, and adult levels are reached by Tanner Stage 3. Because the brain is a target organ for steroid hormones (Sisk & Zehr, 2005), hormones during puberty are thought to activate steroid receptors in the brain that contribute to behavioral change in adolescents (Sato et al., 2008). Adolescence is also a period when risk-taking behaviors become more frequent (Sato et al., 2008) and offending begins to increase dramatically (Moffitt, 1993). Because of this, it has been hypothesized that the hormonal surges during puberty may in some form contribute to the higher levels of externalizing behavior observed in adolescents. Consistent with this, higher circulating testosterone has been associated with externalizing behavior among older male children transitioning to puberty (ages 9 to 11 years; Chance, Brown, Dabbs, & Casey, 2000) and adolescent males (ages 11-14 years; Fang et al., 2009). Some results, however, have varied (Granger et al., 2003). In light of this, it should be noted that some researchers argue that the social context surrounding the timing of puberty relative to an adolescent's peers, rather than biological changes themselves, may predispose early maturing adolescents to engage in risky behaviors (Haynie & Piquero, 2006).

Postnatal testosterone is thought to influence antisocial behavior by activating the hormone structures established prenatally (Mazur & Booth, 1998). It is possible, therefore, that examining *both* prenatal and circulating testosterone is necessary in order to understand the etiology of antisocial behavior. Experimental research in women has shown that the effect of an administered dose of testosterone on cognitive empathy (van

Honk et al., 2011) is dependent on the 2D:4D ratio. In particular, high prenatal testosterone (low 2D:4D) amplified the harmful effect of administered testosterone on cognitive empathy. The effect of administered doses of testosterone on cooperation (van Honk, Montoya, Bos, van Vugt, & Terburg, 2012) and moral decision-making (Montoya et al., 2013) have also been found to be dependent on the 2D:4D ratio, although patterns of interaction differ from those observed in van Honk et al. (2011). These studies suggest that the prenatal exposure to sex steroids could play an important role in influencing sensitivity to the activational effects of testosterone later in life. To my knowledge, however, no research has examined whether 2D:4D also moderates the effect of circulating testosterone on aggressive and externalizing behavior.

Cortisol

The release of cortisol is regulated by the hypothalamic-pituitary-adrenocortical (HPA) axis, which is activated by psychological stressors (Dickerson & Kemeny, 2004). Reduced stress reactivity is thought to be characteristic of individuals with high levels of antisocial behavior (van Goozen & Fairchild, 2008); reduced stress reactivity may make individuals less fearful of the negative consequences of their actions, which could increase the likelihood of externalizing behavior (Raine, 1993; 2002a). Consistent with this, low basal cortisol has been associated with conduct disorder (Pajer, Gardner, Rubin, Perel, & Neal, 2001) and aggression in adolescents (McBurnett, Lahey, Rathouz, & Loeber, 2000). However, many studies have found no relationship between externalizing behavior and both basal cortisol and cortisol reactivity to stress (Alink et al., 2008).

In order to better understand the effect of cortisol on behavior, it may be necessary to examine interactions between hormone systems. Cortisol, which is the end product of the HPA axis, inhibits the activity of the HPG axis, of which testosterone is the end product. Therefore, the balance between cortisol and postnatal testosterone may be crucial to understanding behavior (Glenn, Raine, Schug, Gao, & Granger, 2011; Mehta & Josephs, 2010; Montoya et al., 2012; Terburg et al., 2009). One study, for instance, found that psychopathy was associated with a higher circulating testosterone-to-cortisol reactivity ratio (Glenn et al., 2011).

Similarly, it may be possible that prenatal testosterone and cortisol interact to predict antisocial behavior. Animal studies examining corticosterone (the end product of the HPA axis in rats) suggest an important connection between prenatal testosterone and cortisol secretion. These studies find that prenatal testosterone contributes to the masculinization of the HPA axis, as reflected by decreased postnatal corticosterone production (Seale, Wood, Atkinson, Lightman, & Harbuz, 2005a, 2005b). It has been hypothesized that the combination of high prenatal testosterone and reduced cortisol may predispose individuals toward aggressive, reward-driven behavior (Yildirim & Derksen, 2012). However, to our knowledge, no study has empirically tested whether cortisol and 2D:4D interact to predict antisocial behavior.

Sex Differences

Testosterone levels are dramatically higher during adolescence in males than in females (Kushnir et al., 2010), making it important to examine sex differences in the relationship between testosterone and externalizing behavior. Studies examining

testosterone in relation to externalizing behavior in males and female adolescents have detected sex differences in this relationship, with higher testosterone tending to show more consistent associations with increased externalizing behavior in males than in females (Booth et al., 2003; Granger et al., 2003; Susman et al., 1987). This is somewhat unsurprising given that there are important sex differences in the production of androgens in males and females (Burger, 2002). However, many prior studies have not adequately controlled for gender, age, and pubertal development (Granger et al., 2003), which may obscure the nature of the relationship between testosterone and externalizing behavior in females. Meta-analytic results suggest that the effects of 2D:4D on behavior may only be present amongst males (Hönekopp & Watson, 2011), a possibility that is consistent with a more recent study that found that 2D:4D was related to externalizing behavior problems in male, but not in female children (Liu, Portnoy, & Raine, 2012).

Current Study

The purpose of this paper is to examine whether 2D:4D interacts with cortisol and adolescent testosterone level to predict externalizing behavior in late childhood/early adolescence. I hypothesize that lower cortisol reactivity will be associated with higher levels of externalizing behavior, and that this effect will also be strongest amongst subjects with low 2D:4D. Similarly, I predict that higher adolescent testosterone will be associated with higher levels of externalizing behavior and that this effect will be strongest amongst subjects with low 2D:4D (indicating high prenatal testosterone). Hypotheses are examined separately for males and females in order to determine whether there are any sex differences in these relationships. I predict that any observed effects

will be stronger in males than in females because of prior research showing stronger effects of testosterone on behavior in males. Hypotheses are also examined separately for aggressive and non-aggressive forms of antisocial behavior. This is important given that responses to social stressors like the one used in this study are thought to be differentially related to aggressive and non-aggressive forms of externalizing behavior (Burt & Larson, 2007). This study also controls for a number of covariates that are thought to be associated with both hormone levels and externalizing behavior.

Methods

Participants

Data for this study come from the Healthy Brains and Behavior study (Liu et al. 2013). The sample for this study consisted of 11 and 12-year old boys and girls living in Philadelphia County, PA or suburbs of Philadelphia. Within the study area, fliers soliciting enrollment were placed in recreation centers, libraries, health clinics, and other community centers. Targeted mailings were also sent to parents of 11 to 12 year old children living in the geographic catchment area. Youths with a diagnosed psychotic disorder, mental retardation, or a pervasive developmental disorder were excluded. More information about subject recruitment and exclusionary criteria can be found in Liu et al. (2013). The original sample consisted of 454 subjects. Of this original group, 8 subjects were later deemed ineligible or withdrew, resulting in a sample of 446 subjects. The sample was 50.6% male, 11.9% white, and 79.7% African American. The mean age of the sample was 11.92 years ($SD = .59$). 14.2% of subjects had a lifetime diagnosis of

conduct disorder and 19.1% had a lifetime diagnosis of oppositional defiant disorder (Liu et al., 2013). All subjects were accompanied to the laboratory with a caregiver, who also completed questionnaires about the child's behavior and demographics.

Externalizing Behavior Measures

Self-reported antisocial behavior was assessed using the externalizing behavior scale of the Youth Self-Report (Achenbach & Rescorla, 2001). The externalizing behavior scale consists of rule-breaking and aggression sub-scales, which were also analyzed separately. Parent-reported antisocial behavior was assessed using the rule-breaking and aggression sub-scales of the Child Behavior Checklist, as well as the overall externalizing behavior score (Achenbach & Rescorla, 2001). The CBCL externalizing scale has 35 items in total. Seventeen of the items measure rule-breaking (e.g., "lie or cheat") and eighteen are aggression items (e.g., "gets in many fights") that are rated by the parent on a 3-point Likert scale, with higher scores indicating higher levels of externalizing behavior. The Cronbach's alpha of both the CBCL rule-breaking and aggression sub-scales in this sample were .97. The YSR has 32 items in total. Fifteen items measure rule-breaking and seventeen are aggression items that are rated by the child on 3-point Likert scale, with higher scores indicating higher levels of externalizing behavior. The Cronbach's alpha of the YSR rule-breaking and aggression sub-scales in this sample were .88 and .85 respectively.

Digit Ratio (2D:4D)

The second and fourth finger digit of each participant was measured directly, as the size of fat pads in the fingers is believed to affect the measurements of 2D:4D when using scanned pictures of the hand (Manning, Fink, Neave, & Caswell, 2005). Ultratech digital calipers (General Tools & Instruments Co., New York), which are reliable to .001 millimeters, were used to measure the digits. Researchers instructed participants to fully flex their fingers. The second and fourth digits of the right hand were then measured from the finger's basal crease (crease closest to the palm) to the most distal point of the finger. The second and fourth digits of the right hand were measured twice according to this protocol. The same process was then employed to measure the digits of the left hand. The 2D:4D ratio for each hand was calculated by dividing the average length of the second digit by the average length of the fourth digit. This procedure has been utilized in several digit ratio studies (e.g. Benderlioglu & Nelson, 2004). Subjects' digits were measured at the child's initial visit, a 3-month follow-up, a 6-month follow-up, and a 12-month follow-up. In order to minimize missing data, the average 2D:4D across the available time points was calculated for each subject. Digit measurements across the time points were highly correlated; the reliability (Cronbach's alpha) for the four left 2D:4D measurements was .99 and the reliability for the right 2D:4D measurements was .94.

Stress Task Procedure

Subjects completed a modified version of the Trier Social Stress Test, which consists of speech and arithmetic tasks (Kirschbaum, Pirke, & Helhammer, 1993). During the speech task (Raine, Lencz, Bihrlé, LaCasse, & Colletti, 2000), subjects were

instructed to spend two minutes thinking about the worst or most stressful thing that had ever happened to them. After two minutes, they were told to describe the event to an experimenter for an additional two minutes. In order to increase the level of stress experienced by subjects, a researcher remained in the room with the subject and the task was video recorded. After completing the speech task, subjects completed a cognitive stress task. During the cognitive task, subjects were instructed to count backward from 758 in 7's as quickly as possible without making mistakes. Subjects were given verbal prompts at standard intervals throughout the task to increase the uncontrollability of the task. The combination of a short public speaking task and a cognitive task with elements of uncontrollability and social evaluative threat has been shown to be a reliable way in which to induce a substantial cortisol response in the laboratory (Dickerson & Kemeny, 2004). These stress tasks were embedded in a series of other laboratory tasks; stress tasks were preceded by a resting period, conditioning task, the "oddball" target detection task, and an empathy task. The stress tasks were then followed by a final resting period.

Collection and Determination of Salivary Analytes

Saliva samples were collected across a single day for each participant. Participants were instructed to refrain from food and drink (except water) prior to sample donation (Granger et al., 2012). Whole un-stimulated saliva was collected by passive drool. A morning saliva sample was collected at an average time of 9:18 AM. Between sample collections, subjects completed behavioral questionnaires. In the afternoon, four saliva samples were collected to assess cortisol reactivity to the stressor at the following times: (1) Immediately prior to the laboratory tasks (mean time = 12:36 PM), (2) 5

minutes after the end of the stress task (mean time = 1:27 PM), (3) 20 minutes after the end of the stress task (mean time = 1:42 PM), and (4) 40 minutes after the end of the stress task (mean time = 2:02 PM). Following collection, samples were stored and frozen at -80°C until assay. Cortisol stress reactivity for each subject was measured by calculating area under curve with respect to ground (AUC_G) using the following formula (Pruessner, Kirschbaum, Meinlschmid, & Helhammer, 2003),

$$AUC_G = \sum_{i=1}^{n-1} \frac{(m_{(i+1)} + m_i) \times t_i}{2}$$

where m_i denotes cortisol level of sample i , n denotes the total number of samples, and t_i denotes the time interval between samples i and $i + 1$ (t_i will be specific to each participant). AUC_G , which captures cortisol reactivity and baseline cortisol, is useful because it combines information from repeated measurements into a single index, which increases statistical power and reduces the need for multiple comparisons, which can lead to type I error (Pruessner, Kirschbaum, Meinlschmid, & Helhammer, 2003).

Testosterone was assayed using the morning saliva sample, and cortisol was assayed using the four samples collected throughout the stress task. On the day of testing, all samples were centrifuged at 3,000 r.p.m. for 15 minutes to remove mucins. Samples were assayed for salivary cortisol using a commercially available enzyme immunoassay (Salimetrics, State College, PA). The test used 25 μ l of saliva for singlet determinations and had a range of sensitivity of .007 to 3 μ g/dl. Samples were assayed in duplicate and the averages of cortisol concentrations were used in the current analysis. Coefficient of variation is less than 5% for intra-assay and less than 10% for inter-assay.

All samples were assayed for salivary testosterone in duplicate using a highly-sensitive enzyme immunoassay (Cat. No. 1-2402, Salimetrics LLC, State College, PA).

The test used 25 μ l of saliva per determination, has a lower limit of sensitivity of 1.0 pg/mL, standard curve range from 6.1 pg/mL to 600 pg/mL, an average intra-assay coefficient of variation of 4.6% and an average inter-assay coefficient of variation of 8.25%.

Covariates

In regression analyses, I controlled for the time of the saliva sample collection, race (0 = black; 1 = not black), social adversity, body mass index (BMI), age (in years), and pubertal timing. The time of collection of the first morning sample was used for calculations involving adolescent circulating testosterone level. For calculations involving cortisol, I controlled for the time of the first stress sample. Analyses controlled for a social adversity index based on 18 demographic items completed by the parents (e.g., parents unemployed, parents arrested, problems with living accommodation). Each item was coded as 0 (low adversity) or 1 (high adversity). Item scores were summed with higher scores indicating a higher level of social adversity. More information about this measure can be found in Choy et al. (2015). Pubertal development was measured using the Tanner Stages of Development (Morris & Udry, 1980). Subjects were shown two sets of drawings of five stages of pubertal development (stage 1 = preadolescent, stage 5= adult appearance). Males rated their development in genitalia and pubic hair growth, and females rated their development in breast and pubic hair growth. The scores were averaged for each subject. As in prior studies, in order to calculate a measure of pubertal timing, I regressed pubertal development score on age separately for males and females and used the saved residuals as a measure of pubertal timing (Dorn, Susman, &

Ponirakis, 2003; Susman et al., 2010). A higher residual indicates that the subject was further along in pubertal development than same-aged peers.

Statistical Analyses

All analyses that follow were conducted separately for males and females, as recommended by Breedlove (2010) when conducting 2D:4D research. I first examined zero-order correlations between 2D:4D, testosterone, cortisol reactivity, and externalizing behavior. I then used the PROCESS SPSS macro to test whether 2D:4D significantly interacted with cortisol to predict child- and parent-reported externalizing behavior (Hayes, 2013). The OLS regression analyses conducted by the PROCESS macro included the covariates specified above. Significant interactions were plotted using the procedures described in Aiken and West (1991) at 1 standard deviation above and below the mean of the moderator and independent variable. I then determined the significance of the simple slopes at these points using PROCESS, which reports the significance of the simple slopes across different levels of the moderator when the Johnson-Neyman technique is invoked. These analyses were repeated to test whether 2D:4D interacted with morning testosterone to predict antisocial behavior.

As in prior cortisol and testosterone research (Gordis, Granger, Susman, & Trickett, 2006; Granger et al., 2003), cortisol reactivity and circulating testosterone outliers three standard deviations or greater from the mean were removed, resulting in the exclusion of 7 testosterone scores and 3 AUC_G scores. Complete data were available for 175 males and 178 females. Among the male and female groups, subjects with missing

data did not differ from subjects with complete data on demographic variables, including age, race, and social adversity ($p > .05$).

Results

Bivariate Correlations

Descriptive statistics for males and females are shown in Table 3.1, and bivariate correlations between the study variables are shown in Table 3.2. In bivariate correlations, adolescent testosterone and cortisol were not associated with externalizing behavior in males or females ($p > .05$). In females, left and right 2D:4D were not associated with externalizing behavior ($p > .05$). In males, only right 2D:4D was associated with externalizing behavior and aggression ($p < .05$), although these relationships were in the unexpected positive direction. In general, most bivariate correlations between the biological variables and behavioral outcomes were not significant.

Interactions

Self-Reported Externalizing Behavior

Analyses were first performed to examine whether 2D:4D interacted with cortisol reactivity to predict self-reported externalizing behavior. In boys, left 2D:4D interacted with cortisol reactivity to predict self-reported externalizing behavior ($B = 7.92, p < .05$), aggression ($B = 5.32, p < .05$), and rule-breaking ($B = 2.87, p < .05$). In boys right 2D:4D also interacted with cortisol reactivity to predict self-reported externalizing behavior ($B =$

7.60, $p < .05$), aggression ($B = 4.56$, $p < .05$), and rule-breaking ($B = 3.03$, $p < .05$). The interactions were probed as shown in Figures 3.1 and 3.2. For subjects with low 2D:4D (indicating higher prenatal testosterone), low cortisol reactivity was associated with higher levels of externalizing behavior. However, for subjects with high 2D:4D (indicating lower prenatal testosterone), there was no relationship between cortisol reactivity and externalizing behavior. Therefore, the expected relationship between low cortisol and increased levels of externalizing behavior was only present in subjects with low 2D:4D. In females, neither left nor right 2D:4D interacted with cortisol reactivity to predict aggression, rule-breaking, or externalizing ($p < .05$).

I then examined whether 2D:4D and circulating adolescent testosterone interacted to predict child-reported externalizing behavior. In males and females, neither left nor right 2D:4D interacted with testosterone to externalizing behavior outcomes ($p > .05$).

Parent-Reported Externalizing Behavior

In both males and females, left and right 2D:4D did not significantly interact with cortisol reactivity to predicting parent-reported externalizing behavior ($p > .05$). The interactions between left and right 2D:4D and adolescent testosterone were also non-significant in predicting parent-reported externalizing behavior in males and females ($p > .05$).

Discussion

The purpose of this article was to examine whether 2D:4D, a marker of prenatal testosterone, interacts with adolescent circulating testosterone level and cortisol reactivity

to predict externalizing behavior in a sample of young adolescents. The current study found that 2D:4D moderated the relationship between cortisol reactivity and self-reported externalizing behavior in males. Specifically, the expected negative relationship between cortisol reactivity and self-reported externalizing behavior was significant only for male subjects with a low 2D:4D. On the other hand, 2D:4D did not moderate the relationship between adolescent testosterone and either parent- or child-reported externalizing behavior. To my knowledge, this is the first study to find that 2D:4D interacts with cortisol reactivity to predict antisocial behavior. Results suggest the need to examine interactions between multiple hormone systems in order to understand externalizing behavior (Terburg et al., 2009). Because bivariate correlations between testosterone and cortisol with externalizing behavior were not significant, these findings also suggest that 2D:4D could help to explain heterogeneity in the findings of studies that examine the independent effects of hormones on externalizing behavior.

This study examined a marker of prenatal testosterone exposure as a moderator of the cortisol-externalizing behavior relationship. Although a growing body of prior research has found that adolescent and adult circulating testosterone and cortisol interact to predict violent and antisocial behavior (Dabbs & Jurkovic, 1991; Glenn et al., 2011; Mehta & Josephs, 2010; Popma et al., 2007), this study is the first to find that prenatal testosterone also interacts with cortisol to predict these behaviors. Findings are consistent with the pattern of interactions observed in these prior studies; in particular, low cortisol was associated with higher levels of antisocial behavior, but only for subjects with low 2D:4D (high prenatal testosterone). The current study extended prior findings by documenting this interaction prenatally.

There have been several proposed explanations as to why postnatal testosterone may interact with cortisol to predict externalizing behavior (reviewed in Terburg et al., 2009). For instance, it has been argued that an increased level of testosterone relative to cortisol may reflect an imbalance in reward and punishment sensitivity that increases the likelihood of reward motivated antisocial behavior (Terburg et al., 2009). This model is based on the finding that high testosterone is associated with increased reward sensitivity and decreased punishment sensitivity (van Honk et al., 2004), while low cortisol is associated with reduced punishment sensitivity (van Honk, Schutter, Hermans, & Putman, 2003).

Although existing theories of the cortisol-testosterone imbalance focus on postnatal testosterone, the current results also suggest the need to consider the influence of prenatal testosterone in determining the effect of cortisol on behavior. Animal studies that examine corticosterone—the end product of the HPA axis in rats—could help to guide our understanding of the interrelationship between cortisol and prenatal testosterone in humans. In particular, female rats exposed to testosterone prenatally were found to experience masculinization of the HPA axis, as indicated by lower corticosterone secretion in adulthood (Seale et al., 2005a). On the other hand, male rats deprived of prenatal testosterone had increased adult secretion of corticosterone, a more feminine pattern of HPA axis activation (Seale et al., 2005b). This suggests that prenatal testosterone likely plays some role in the masculinization of the HPA axis in rats, although this remains to be seen in human research.

Contrary to initial expectations, 2D:4D did not interact with adolescent testosterone level to predict antisocial behavior. One possible reason for this null finding

relates to the outcome measure used in this study. It is thought that aggression itself is not related to testosterone, but rather that testosterone is associated with increased social dominance, which may or may not take the form of aggressive behavior (Mazur & Booth, 1998; Rowe et al., 2004; Schaal, Tremblay, Soussignan, & Susman, 1996). Thus, the externalizing behavior measures used in this study may not have captured the social dominance construct that is thought to be most directly related to circulating testosterone. Alternatively, the null findings may be related to the developmental period of the subjects in this study. Male subjects were on average between Tanner Stages 3 and 4. This is a period of large hormonal fluctuations, which could have affected results. On the other hand, the findings of this study are suggestive that the organizational influence of prenatal testosterone may have a more important impact than circulating testosterone on the behavior of early adolescents transitioning to puberty.

Sex Differences

Although the interaction between 2D:4D and cortisol reactivity significantly predicted self-reported externalizing behavior in males, this interaction was not significant in females. While it is not possible to identify the exact source of the null finding in females, there are several potential explanations. For instance, it is possible that amongst adolescents, externalizing and aggressive behavior are less reflective of social dominance in females than in males. Consistent with this, de Bruyn (2012) found that physical aggression was characteristic of social dominance in male, but not in female adolescents. This suggests that testosterone, which is thought to be indicative of social dominance, may be less strongly associated with physical aggression in adolescent

females. Alternatively, sex differences observed in this study may be related to sex differences in androgen production (Montoya et al., 2012). Testosterone is produced in much smaller levels in females than in males both prenatally and in adolescence (Hines, 2004; Kushnir et al., 2010), suggesting that testosterone could have a less important influence on female behavior than on male behavior. Consistent with this possibility, a prior-meta-analysis found that 2D:4D had a small relationship in males, not in females (Hönekopp & Watson, 2010). On the other hand, markers of prenatal testosterone exposure have been associated with other sexually dimorphic traits in females, including sensation seeking (Austin et al., 2002) and male-typical childhood play (Auyeung et al., 2009), leaving unknown the exact source of the null results in the current study.

Limitations, Contributions, and Future Directions

There are several limitations to this study that should be highlighted. One limitation relates to the marker of prenatal testosterone used in the current study, as 2D:4D is an imperfect marker of prenatal testosterone. However, given the risks of performing medically unnecessary amniocentesis to assay prenatal hormones and the clear ethical concerns of manipulating in-utero hormone levels, 2D:4D is widely used and accepted as a method of retrospectively estimating prenatal androgen exposure (Breedlove, 2010; Manning et al., 1998; 2014).

Also, findings only applied to self-reported externalizing behavior, and no significant interactions were found for parent-reported behavior. It is not uncommon for parent and child ratings of behavior to differ (Achenbach & Rescorla, 2001), and given differences in the sample of behaviors observed by different informants, it is possible that

different raters may capture somewhat different behavioral constructs. Because of this, results would not necessarily be expected to converge across raters. Nonetheless, given this lack of convergence, findings should be interpreted with some caution.

A strength of the current study was that it examined both rule-breaking and aggressive sub-types of externalizing behavior, which may have distinct etiologies (Burt & Klump, 2012). The current study, however, did not examine reactive and proactive sub-types of aggression. Some researchers have argued that there may be distinct correlates of reactive aggression, which is emotionally-driven and perpetrated in response to real or imagined provocation, and proactive aggression, which is instrumental in nature (Dodge, Lochman, Harnish, Bates, & Petit, 1997). Consistent with this, one study found that reactive aggression was associated with *increased* cortisol in response to a stressor, while there was no association of cortisol with proactive aggression. (Lopez-Duran, Olson, Hajal, Felt, & Vazquez, 2009). In addition to differentiating between aggressive and non-aggressive antisocial behavior, future research should consider whether the interactions observed in the current study also predict reactive aggression, which is more “hot-blooded” and emotionally driven in nature.

In spite of these limitations, it is believed that the current study has significant strengths. Importantly, this study extended our understanding of the relationship between cortisol and externalizing behavior in males by demonstrating for the first time that the expected negative relationship between cortisol reactivity and externalizing behavior was only present in subjects with low 2D:4D (high prenatal testosterone). This could partly explain why findings on cortisol reactivity and externalizing behavior are inconsistent (Alink et al., 2008). Interestingly, prenatal testosterone interacted with adolescent

cortisol reactivity. This finding suggests the importance of early developmental processes in shaping behavior later in life. This study was also conducted in a relatively large sample at a critical point in development when both testosterone and behavior are beginning to change dramatically. Therefore, this is a particularly important developmental period to examine the effect of hormones on behavior.

This study provides support for the need to examine interactions between multiple hormones in order to understand behavior. Taken together, the findings of this study provides further support for a partial hormonal basis to antisocial behavior and point to the critical need to examine biological processes in conjunction with one another in order to understand the etiology of externalizing behavior

Paper 3 Tables and Figures

Table 3.1. Descriptive Statistics by Sex

	Males Mean (SD)	Females Mean (SD)	<i>t</i>
Cortisol AUC _G	9.9 (7.01)	10.64 (8.36)	-.93
Morning Testosterone (pg/mL)	53.27 (26.22)	48.13 (21.97)	2.22*
Left 2d:4d	.95 (.03)	.96 (.03)	-2.62**
Right 2d:4d	.96 (.03)	.97 (.03)	-1.14
YSR externalizing	11.01 (8.03)	10.75 (7.78)	.35
YSR aggression	7.31 (5.45)	7.31 (5.45)	-.48
YSR rule-breaking	3.65 (3.21)	3.19 (2.90)	1.60
CBCL externalizing	10.75 (8.64)	8.88 (9.36)	2.16*
CBCL aggression	7.20 (5.96)	6.12 (6.53)	1.80
CBCL rule-breaking	3.55 (3.16)	2.76 (3.28)	2.55*
Puberty Stage	3.07 (1.01)	3.48 (.93)	-4.30**
Social Adversity	4.07 (2.38)	3.99 (2.44)	.40
Age	11.91 (.62)	11.92 (.57)	-.13
Race	.20 (.40)	.19 (.39)	.24
BMI	21.00 (5.18)	22.70 (6.19)	-1.92

Note: Cortisol AUC_G = cortisol area under the curve with respect to ground. YSR = Youth Self Report. CBCL = Child Behavior Checklist (parent-report). BMI = body mass index. *n* = 201-220 for females. *n* = 206-226 for males.

Table 3.2. Bivariate Correlations. Correlations for males ($n = 195-221$) shown above the diagonal. Correlations for females ($n = 190-216$) shown below the diagonal.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Cortisol AUC _G	--	.10	-.03	.06	-.09	-.07	-.11	.03	-.01	-.07	.08	-.02	.07	.03	-.08
2. Morning Testosterone (pg/mL)	.11	--	-.09	-.04	-.02	-.03	.03	-.08	-.09	-.04	.32**	-.04	.47**	-.17**	.08
3. Left 2D:4D	-.15*	-.07	--	.63**	.06	.07	.03	.04	.03	.05	-.03	-.00	.05	-.05	.05
4. Right 2d:4d	-.07	-.02	.61**	--	.15*	.17*	.09	-.04	-.03	-.04	.00	-.02	.02	.01	.06
5. YSR externalizing	.01	-.01	.04	.04	--	.95**	.85**	.35**	.36**	.29**	-.01	.05	-.04	.05	.04
6. YSR aggression	-.01	-.01	.04	.04	.97**	--	.65**	.31**	.31**	.24**	-.01	.00	-.07	.10	.00
7. YSR rule-breaking	.06	-.00	.02	.03	.88**	.73**	--	.30**	.30**	.26**	.06	.08	.04	-.03	.04
8. CBCL externalizing	-.03	-.06	.06	.01	.42**	.42**	.36**	--	.97**	.90**	-.09	.21**	-.01	-.05	-.01
9. CBCL aggression	-.04	-.06	.06	.01	.40**	.40**	.32**	.98**	--	.78**	-.11	.18*	-.03	.01	-.00
10. CBCL rule-breaking	-.00	-.04	.07	.00	.41**	.40**	.37**	.91**	.80**	--	-.03	.23**	.01	-.15*	-.02
11. Pubertal Timing	.05	.23**	.00	.07	.14*	.14*	.10	.01	-.03	.09	--	.00	.00	-.27**	.04
12. Social Adversity	.04	.04	.01	.05	.32**	.33**	.25**	.35**	.34**	.32**	.09	--	-.08	-.22**	-.05
13. Age	-.11	.10	.26**	.22**	.06	.02	.11	.02	.01	.04	.00	.02	--	-.09	.17**
14. Race	.01	-.20**	.14*	.09	-.20**	-.17*	-.20**	-.13	-.11	-.15*	-.33**	-.12	-.03	--	-.08
15. BMI	-.03	.09	.02	.07	.13	.11	.14*	.11	.09	.14	.30**	.12	.04	-.13	--

Note: Cortisol AUC_G = Cortisol area under the curve with respect to ground. YSR = Youth Self Report. CBCL= Child Behavior Checklist (parent-report). BMI = Body Mass Index.

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

Figure 3.1 Simple Slopes of Self-Reported Externalizing Behavior, Aggression, and Rule-Breaking on Cortisol Reactivity at High (+1 SD) and Low (-1 SD) Levels of Left 2D:4D in Males

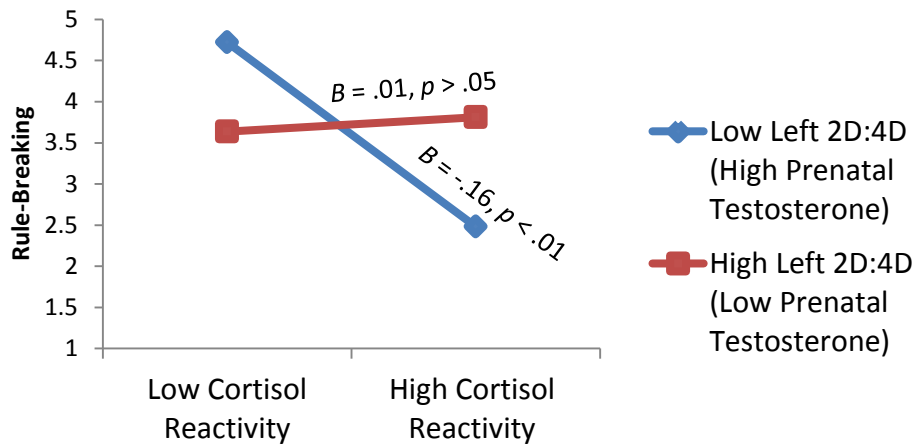
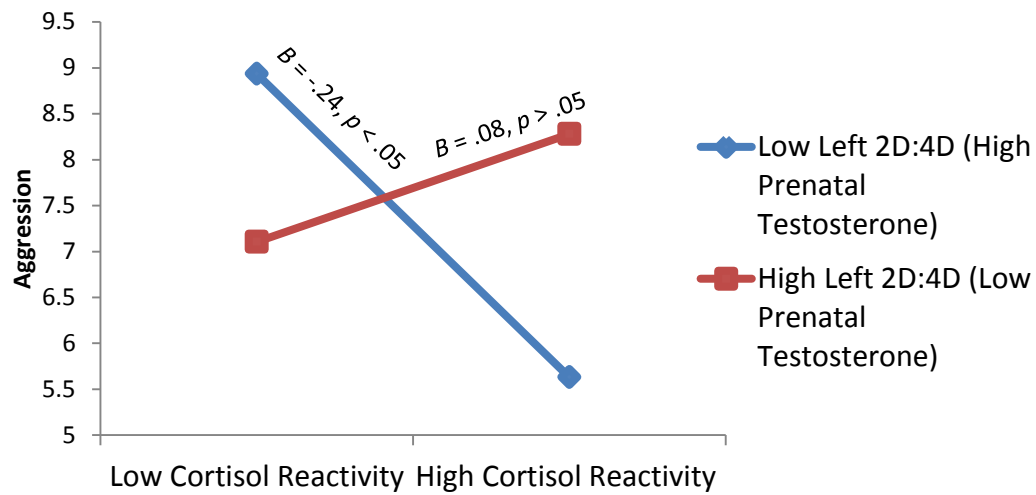
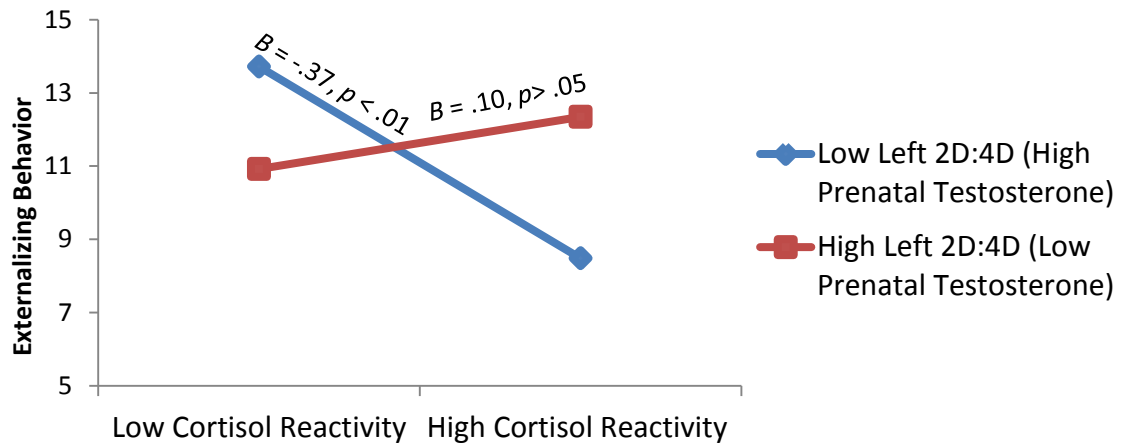
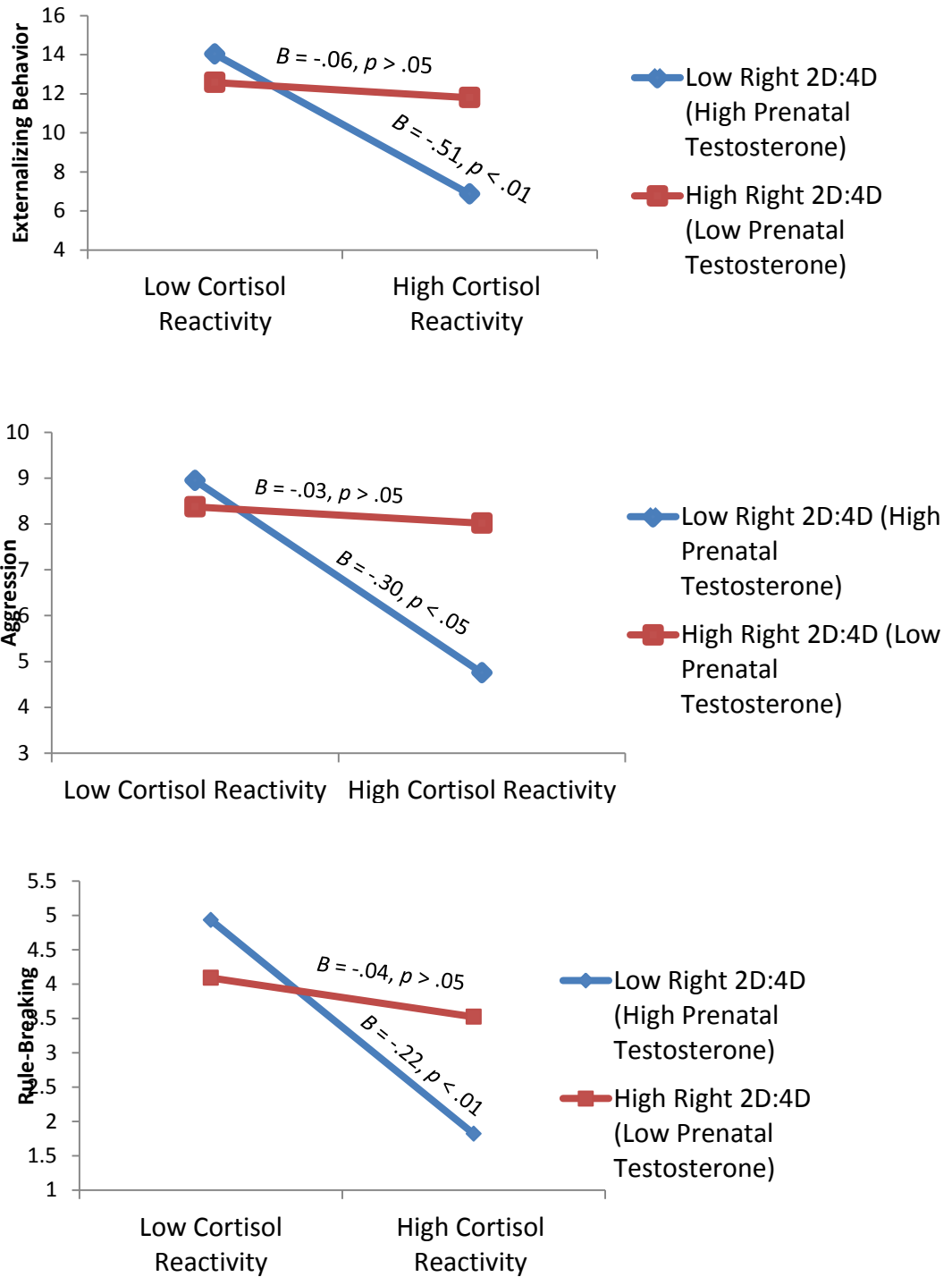


Figure 3.2. Simple Slopes of Self-Reported Externalizing Behavior, Aggression, and Rule-Breaking on Cortisol Reactivity at High (+1 SD) and Low (-1 SD) Levels of Right 2D:4D in Males



GENERAL DISCUSSION

The purpose of this dissertation was to examine biological risk factors for antisocial behavior in youths. Findings provided support for a multidisciplinary model of antisocial behavior (Beauchaine & Gatzke-Kopp, 2012; Burnette & Cicchetti, 2012; Cicchetti, 2010) in which biological, social, and psychological factors contribute to the etiology of antisocial behavior, both individually and in interaction with one another. The first paper of this dissertation found that adolescent males who displayed high levels of violent and non-violent antisocial behavior had low heart rates, and that high levels of impulsive sensation seeking partly accounted for these associations. The second paper of this dissertation examined whether heart rate reactivity to stress interacted with the neighborhood environment to predict antisocial behavior in male and female young adolescents. This study found that adolescents who had *both* reduced reactivity to stress *and* lived in disadvantaged neighborhoods displayed the highest levels of aggression and rule-breaking behavior. On the other hand, amongst individuals with heightened heart rate reactivity to stress, neighborhood disadvantage was not associated with antisocial behavior. The third paper examined interactions between biological systems in male and female young adolescents. Among males, reduced cortisol reactivity to stress was only associated with higher levels of antisocial behavior amongst those who also had low 2D:4D (i.e., high prenatal testosterone). While examining interactions between biological and social factors is increasingly accepted as a research priority (Beaver, Gibson, DeLisi, Vaughn, & Wright, 2012; Raine, 2013), results of this study also suggest the critical need to examine interactions between multiple biological systems in order to

best understand the etiology of antisocial behavior processes (Mehta & Josephs, 2010; Terburg, Morgan, & van Honk, 2009).

The papers in this dissertation provide support for the need to examine biological risk factors for antisocial behavior, both in interaction with one another, and in interaction with the broader social context. Many important questions, however, remain unresolved. Perhaps most importantly, longitudinal research is needed that examines whether within-in individual changes in biological functioning predict within-individual changes in antisocial behavior over time (Baker et al., 2009). Furthermore, it is becoming increasingly clear that the social environment likely affects biological functioning (Susman, 2006). Therefore, it is necessary to examine changes in *both* biological and social risk factors over time in order to understand the complex relationship between biological functioning and the social environment and the way in which these factors contribute to the etiology of delinquency over time.

Even without this research, the findings of this dissertation suggest the need to consider how the early identification of biological risk factors for antisocial behavior could contribute to the development of interventions for delinquent behavior. Findings of this dissertation could contribute to risk focused prevention efforts, which target evidence-based risk factors for antisocial behavior in order to achieve behavioral change (Farrington, 2000, 2007). Results of the first paper, for instance, suggest that interventions for children with reduced autonomic arousal may be most effective when aimed at encouraging children to participate in prosocial, stimulating behaviors that can partly fulfill the need for stimulation that underlies their delinquent behavior. Research that evaluates interventions in the context of biological functioning will be an important

next step for criminological researchers, given the mounting evidence that certain interventions may affect physiological functioning associated with antisocial behavior. One study, for instance, found that an educational and nutrition enrichment program between ages three to five years was associated with increased autonomic nervous system arousal at age eleven years (Raine et al., 2001), as well as reduced levels of behavior problems at age 17 years and less criminal offending at age 23 years (Raine, Mellingen, Liu, Venables, & Mednick, 2003). Other research found that a family intervention in preschoolers affected cortisol response to a social challenge in high-risk children, and that this biological change mediated the intervention's observed effect on aggression (O'Neal et al., 2010). These findings are suggestive that certain behavioral and cognitive interventions could affect biological functioning, which may in turn reduce levels of antisocial behavior.

The papers in this dissertation advance our understanding of the development of antisocial behavior in youth by identifying ways in which biological factors both in interaction with the social environment and in interaction with one another contribute to the etiology of delinquency. Future research efforts that examine biological functioning in longitudinal studies and in the context of behavioral interventions will be critical to advancing our understanding of the etiology of childhood and adolescent antisocial behavior. This research could have important implications in the future for the prevention of antisocial behavior across the life course.

BIBLIOGRAPHY

- Achenbach, T. M., & Edelbrock, C. (1983). *Manual for the Child Behavior Checklist and revised behavior profile*. Burlington, VT: University of Vermont.
- Achenbach, T. M., & Rescorla, L.A. (2001). *Manual for the ASEBA school-age forms & profiles*. Burlington, VT: University of Vermont, Research Center for Children, Youth, & Families.
- Aiken, L. S., & West, S. G. (1991). *Multiple regression: Testing and interpreting interactions*. Newbury Park, CA: SAGE Publications, Inc.
- Alink, L. R., van Ijzendoorn, M. H., Bakermans-Kranenburg, M. J., Mesman, J., Juffer, F., & Koot, H. M. (2008). Cortisol and externalizing behavior in children and adolescents: Mixed meta-analytic evidence for the inverse relation of basal cortisol and cortisol reactivity with externalizing behavior. *Development and Psychobiology, 50*, 427-450.
- American Psychiatric Association (2000). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, D.C.: Author.
- Anderson, E. (1999). *Code of the street: Decency, violence, and the moral life of the inner city*. New York, NY: W. W. Norton & Company.
- Archer, J. (1991). The influence of testosterone on human aggression. *British Journal of Psychology, 82*, 1-28.
- Armstrong, T. A., & Boutwell, B. B. (2012). Low resting heart rate and rational choice: Integrating biological correlates of crime in criminological theories. *Journal of Criminal Justice, 40*, 31-39.

- Armstrong, T. A., Keller, S., Franklin, T. W., & Macmillan, S. N. (2009). Low resting heart rate and antisocial behavior: A brief review of evidence and preliminary results from a new test. *Criminal Justice and Behavior, 36*, 1125-1140.
- Arnold, A. P. (2009). The organizational-activational hypothesis as the foundation for a unified theory of sexual differentiation in mammalian tissues. *Hormones and Behavior, 55*, 570-578.
- Asparouhov, T. (2005). Sampling weights in latent variable modeling. *Structural Equation Modeling, 12*, 411-434.
- Attar, B. K., Guerra, N. G., & Tolan, P. H. (1994). Neighborhood disadvantage, stressful life events, and adjustment in urban elementary-school children. *Journal of Clinical Child Psychology, 23*, 391-400.
- Auyeung, B., Baron-Cohen, S., Ashwin, E., Knickmeyer, R., Taylor, K., Hackett, G. & Hines, M. (2009). Fetal testosterone predicts sexually differentiated childhood behavior in girls and in boys. *Psychological Science, 20*, 144-148.
- Austin, E. J., Manning, J. T., McInroy, K., & Matthews, E. (2002). A preliminary investigation of the association between personality, cognitive ability and digit ratio. *Personality and Individual Differences, 33*, 1115-1124.
- Baker, L. A., Raine, A., Liu, J., & Jacobson, K. C. (2008). Differential genetic and environmental influences on reactive and proactive aggression in children. *Journal of Abnormal Child Psychology, 36*, 1265-1278.
- Baker, L. A., Tuvblad, C., Reynolds, C., Zheng, M., Lozano, D. I., & Raine, A. (2009). Resting heart rate and the development of antisocial behavior from age 9 to 14:

- Genetic and environmental influences. *Development and Psychopathology* 21, 939-960.
- Barnes, J. C. (2013). Analyzing the origins of life-course-persistent offending: A consideration of environmental and genetic influences. *Criminal Justice and Behavior*, 40, 519-540.
- Barnes, J. C., & Jacobs, B. A. (2013). Genetic risk for violent behavior and environmental exposure to disadvantage and violent crime: The case for gene-environment interaction. *Journal of Interpersonal Violence*, 28, 92-120.
- Barron, S. A., Rogovski, Z., & Hemli, J. (1994). Autonomic consequences of cerebral hemisphere infarction. *Stroke*, 25, 113-116.
- Beauchaine, T. P., & Gatzke-Kopp, L. M. (2012). Instantiating the multiple levels of analysis perspective in a program of study on externalizing behavior. *Development and Psychopathology*, 24, 1003-1018.
- Beaver, K. M., Ferguson, C. J., & Lynn-Whaley, J. (2010). The association between parenting and levels of self-control. *Criminal Justice and Behavior*, 37, 1045-1065.
- Beaver, K. M., Gibson, C. L., DeLisi, M., Vaughn, M. G., & Wright, J. P. (2012). The interaction between neighborhood disadvantage and genetic factors in the prediction of antisocial outcomes. *Youth Violence and Juvenile Justice*, 10, 25-40.
- Benderlioglu, Z., & Nelson, R. J. (2004). Digit length ratios predict reactive aggression in women, but not in men. *Hormones and Behavior*, 46, 558-564.

- Bendixen, M., Endresen, I. M., & Olweus, D. (2003). Variety and frequency scales of antisocial involvement: Which one is better? *Legal and Criminological Psychology, 8*, 135-50.
- Berntson, G. G., Uchino, B. N., & Cacioppo, J. T. (1994). Origins of baseline variance and the Law of Initial Values. *Psychophysiology, 31*, 204-210.
- Book, A. S., & Quinsey, V. L. (2005). Re-examining the issues: A response to Archer et al. *Aggression and Violent Behavior, 10*, 637-646.
- Book, A. S., Starzyk, K. B., & Quinsey, V. L. (2001). The relationship between testosterone and aggression: A meta-analysis. *Aggression and Violent Behavior, 6*, 579-599.
- Booth, A., Johnson, D. R., Granger, D. G., Crouter, A. C., & McHale, S. (2003). Testosterone and child and adolescent adjustment: The moderating role of parent-child relationships. *Developmental Psychology, 1*, 85-98.
- Breedlove, S. M. (1994). Sexual differentiation of the human nervous system. *Annual Review of Psychology, 45*, 389-418.
- Breedlove, S. M. (2010). Minireview: Organizational hypothesis: Instances of the fingerpost. *Endocrinology, 151*, 4116-4122.
- Brennan, P. A., Raine, A., Schulsinger, F., Kirkegaard-Sorenson, L., Knop, J., ... Mednick, S. A. (1997). Psychophysiological protective factors for male subjects at high risk for criminal behavior. *American Journal of Psychiatry, 154*, 853-855.
- Brennan, P. A., & Raine, A. (1997). Biosocial bases of antisocial behavior: Psychophysiological, neurological, and cognitive factors. *Clinical Psychology Review, 17*, 589-604.

- Brenner, A. B., Zimmerman, M. A., Bauermeister, J. A., & Caldwell, C. H. (2013). The physiological expression of living in disadvantaged neighborhoods for youth. *Journal of Youth and Adolescence, 42*, 792-806.
- Brown, W. M., Hines, M., Fane, B. A., & Breedlove, S. M. (2002). Masculinized finger length patterns in human males and females with congenital adrenal hyperplasia. *Hormones and Behavior, 42*, 380-386.
- Bubier, J. L., Drabick, D. A., & Breiner, T. (2009). Autonomic functioning moderates the relations between contextual factors and externalizing behaviors among inner-city children. *Journal of Family Psychology, 23*, 500-510.
- Burnette, M. L., & Cicchetti, D. (2012). Multilevel approaches toward understanding antisocial behavior: Current research and future directions. *Development and Psychopathology, 24*, 703-704.
- Bursik, R. J. (1988). Social disorganization and theories of crime and delinquency: Problems and prospects. *Criminology, 26*, 519-551.
- Burger, H. G. (2002). Androgen production in women. *Fertility and Sterility, 77*, 83-85.
- Burt, S. A., & Klump, K. L. (2012). Etiological distinctions between aggressive and non-aggressive antisocial behavior: Results from a nuclear twin family model. *Journal of Abnormal Child Psychology, 40*, 1059-1071.
- Burt, S. A., & Larson, C. L. (2007). Differential affective responses in those with aggressive versus non-aggressive antisocial behaviors. *Personality and Individual Differences, 43*, 1481-1492.

- Cauffman, E., Steinberg, L., & Piquero, A. R. (2005). Psychological, neuropsychological, and physiological correlates of serious antisocial behavior in adolescence: The role of self-control. *Criminology*, *43*, 133-176.
- Centers for Disease Control and Prevention. (2012). *Ten leading causes of death and injury*. Retrieved from <http://www.cdc.gov/injury/wisqars/leadingcauses.html>
- Chance, S. E., Brown, R. T., Dabbs, J. M., & Casey, R. (2000). Testosterone, intelligence and behavior disorders in young boys. *Personality and Individual Differences*, *28*, 437-445.
- Choy, O., Raine, A., Portnoy, J., Rudo-Hutt, A., Gao, Y., & Soyfer, L. (2015). The mediating role of heart rate on the social adversity-antisocial behavior relationship: A social neurocriminology perspective. *Journal of Research in Crime and Delinquency*. doi: 0022427814565905
- Chung, H. L., & Steinberg, L. (2006). Relations between neighborhood factors, parenting behaviors, peer deviance, and delinquency among serious juvenile offenders. *Developmental Psychology*, *42*, 319-331.
- Cicchetti, D. (2010). Resilience under conditions of extreme stress: A multilevel perspective. *World Psychiatry*, *9*, 145-154.
- Cleveland, H. H. (2003). Disadvantaged neighborhoods and adolescent aggression: Behavioral genetic evidence of contextual effects. *Journal of Research on Adolescence*, *13*, 211-238.
- Cohen, M. A. (1998). The monetary value of saving a high-risk youth. *Journal of Quantitative Criminology*, *14*, 5-33.

- Cousins, A. J., Fugère, M. A., & Franklin, M. (2009). Digit ratio (2D:4D), mate guarding, and physical aggression in dating couples. *Personality and Individual Differences*, *46*, 709-713.
- Csathó, Á., Osváth, A., Karádi, K., Bicsák, É., Manning, J., & Kállai, J. (2003). Spatial navigation related to the ratio of second to fourth digit length in women. *Learning and Individual Differences*, *13*, 239-249.
- Cullen, F. T. (2011). Beyond adolescence-limited criminology: Choosing our future—The American Society of Criminology 2010 Sutherland Address. *Criminology* *49*, 287-330.
- Dabbs, J. M. & Jurkovic, G. J. (1991). Salivary testosterone and cortisol among late adolescent male offenders. *Journal of Abnormal Child Psychology*, *19*, 469-478.
- Damasio, A. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York, NY: Penguin Books.
- Davies, J. G. V., & Maliphant, R. (1971). Autonomic responses of male adolescents exhibiting refractory behaviour in school. *Journal of Child Psychology and Psychiatry*, *12*, 115-127.
- de Bruyn, E. H. (2012). Dominance-popularity status, behavior, and the emergence of sexual activity in young adolescents. *Evolutionary Psychology*, *10*, 296-319.
- Dickerson, S. S., & Kemeny, M. E. (2004). Acute stressors and cortisol responses: A theoretical integration and synthesis of laboratory research. *Psychological Bulletin*, *130*, 355-391.

- Dodge, K. A., Lochman, J. E., Harnish, J. D., Bates, J. E., & Petit, G. S. (1997). Reactive and proactive aggression in school children and psychiatrically impaired chronically assaultive youth. *Journal of Abnormal Psychology, 106*, 37-51.
- Dorn, L. D., Susman, E. J., Ponirakis, A. (2003). Pubertal timing and adolescent adjustment and behavior: Conclusions differ by rater. *Journal of Youth and Adolescence, 32*, 157-167.
- El-Sheikh, M. J., Hinnant, B., & Erath, S. (2011). Developmental trajectories of delinquency symptoms in childhood: The role of marital conflict and autonomic nervous system activity. *Journal of Abnormal Psychology, 120*, 16-32.
- Eysenck, H. J. (1993). The nature of impulsivity. In W. G., McCown, J. L. Johnson, & M. B. Shure (Eds.), *The Impulsive Client: Theory, Research, and Treatment* (pp. 57-69). Washington, D.C.: American Psychological Association.
- Falkenbach, D. M., Poythress, N. G., & Heide, K. M. (2003). Psychopathic features in a juvenile diversion population: Reliability and predictive validity of two self-report measures. *Behavioral Sciences and the Law, 21*, 787-805.
- Fang, C. Y., Egleston, B. L., Brown, K. M., Lavigne, J. V., Stevens, V. J., Barton, B. A., . . . Dorgan, J. F. (2009). Family cohesion moderates the relation between free testosterone and delinquent behaviors in adolescent boys and girls. *Journal of Adolescent Health, 44*, 590-597.
- Farrington, D. P. (1990). Age, period, cohort and offending. In D. M. Gottfredson, & R. V. Clarke (Eds.). *Policy and theory in criminal justice: Contributions in honour of Leslie T. Wilkins* (pp. 51-75). Brookfield, VT: Avebury.

- Farrington, D. P. (1997). The relationship between low resting heart rate and violence. In A. Raine, P. A. Brennan, D. P. Farrington, & S. A. Mednick (Eds.), *Biosocial bases of violence* (pp. 89-105). New York: Plenum Press.
- Farrington, D. P. (2000). Explaining and preventing crime: The globalization of knowledge- The American Society of Criminology 1999 Presidential Address. *Criminology*, 38, 1-24.
- Farrington, D. P. (2007). Childhood risk factors and risk-focused prevention. In M. Maguire, R. Morgan, & R. Reiner (Eds.), *The Oxford handbook of criminology* (4th ed.) (pp. 602-640). Oxford, UK: Oxford University Press.
- Farrington, D. P., Coid, J. W., Harnett, L. M., Jolliffe, D., Soteriou, N., Turner, R. E., & West, D. J. (2006). *Criminal careers up to age 50 and life success up to age 48: New findings from the Cambridge Study in Delinquent Development* (2nd ed.). London, UK: Home Office Research, Development and Statistics Directorate.
- Foshee, V. A., Ennett, S. T., Bauman, K. E., Granger, D. A., Benfield, T., Suchindran, C., ... Durant, R. H. (2007). A Test of biosocial models of adolescent cigarette and alcohol involvement. *Journal of Early Adolescence*, 27, 4-39.
- Fossati, A., Raine, A., Borroni, S., Bizzozero, A., Volpi, E., Santalucia, I., & Maffei, C. (2009). A cross-cultural study of the psychometric properties of the Reactive-Proactive Aggression Questionnaire among Italian nonclinical adolescents. *Psychological Assessment*, 21, 131-135.
- Frick, P. J., & White, S. F. (2008). Research review: The importance of callous-unemotional traits for developmental models of aggressive and antisocial behavior. *Journal of Child Psychology and Psychiatry*, 49, 359-375.

- Fung, A. L., Raine, A., & Gao, Y. (2009). Cross-cultural generalizability of the Reactive-Proactive Aggression Questionnaire (RPQ). *Journal of Personality Assessment*, *91*, 473-479.
- Galis, F., Ten Broek, C. M., Van Dongen, S., & Wijnaendts, L. C. (2010). Sexual dimorphism in the prenatal digit ratio (2d:4d). *Archives of Sexual Behavior*, *39*, 57-62.
- Gao, Y., Glenn, A. L., Peskin, M., Rudo-Hutt, A., Schug, R. A., Yang, Y., & Raine, A. (2012). Neurocriminological approaches. In D. Gadd, S. Karstedt, & S. F. Messner (Eds.), *The SAGE handbook of criminological research methods* (pp. 63-75). Los Angeles, CA: SAGE
- Gao, Y., Raine, A., Venables, P. H., Dawson, M. E., & Mednick. S. A. (2010). Association of poor childhood fear conditioning and adult crime. *American Journal of Psychiatry*, *167*, 56-60.
- Gaudreau, P., Sanchez, X., & Blondin, J. (2006). Positive and negative affective states in a performance-related setting. *European Journal of Psychological Assessment*, *22*, 240-249.
- Glenn, A. L., Raine, A., Schug, R. A., Gao, Y., & Granger, D. A. (2011). Increased testosterone-to-cortisol ratio in psychopathy. *Journal of Abnormal Psychology*, *120*, 389-399.
- Gordis, E. B., Granger, D. A., Susman, E. J., & Trickett, P. K. (2006). Asymmetry between salivary cortisol and alpha-amylase reactivity to stress: Relation to aggressive behavior in adolescents. *Psychoneuroendocrinology*, *31*, 976-987.

- Gottfredson, M. R., & Hirschi, T. (1990). *A general theory of crime*. Stanford, CA: Stanford University Press.
- Gottman, J. M., Jacobson, N. S., Rushe, R. H., Shortt, J. W., Babcock, J., La Taillade, J. J., & Waltz, J. (1995). The relationship between heart rate reactivity, emotionally aggressive behavior, and general violence in batterers. *Journal of Family Psychology, 9*, 227-248.
- Granger, D. A., Fortunato, C. K., Beltzer, E. K., Virag, M., Bright, M. A., & Out, D. (2012). Focus on methodology: Salivary bioscience and research on adolescence: An integrated perspective. *Journal of Adolescence, 35*, 1081-1095.
- Granger, D. A., Shirtcliff, E. A., Zahn-Waxler, C., Usher, B. A., Klimes-Dougan, B., & Hastings, P. (2003). Salivary testosterone diurnal variation and psychopathology in adolescent males and females: Individual differences and developmental effects. *Development and Psychopathology, 15*, 431-449.
- Hackman, D. A., Betancourt, L. M., Brodsky, N. L., Hurt, H., & Farah, M. J. (2012). Neighborhood disadvantage and adolescent stress reactivity. *Frontiers in Human Neuroscience, 6*, 1-11.
- Hampson, E., Ellis, C. L., & Tenk, C. M. (2008). On the relation between 2D:4D and sex-dimorphic personality traits. *Archives of Sexual Behavior, 37*, 133-144.
- Hanson, B., Tuna, N., Bouchard, T., Heston, L., Eckert, E., Lykken, D., ... Rich, S. (1989). Genetic factors in the electrocardiogram and heart rate of twins reared apart and together. *American Journal of Cardiology, 63*, 606-609.
- Hare, R. D. (1968). Psychopathy, autonomic functioning, and the orienting response. *Journal of Abnormal Psychology Monograph Supplement, 73*, 1-24.

- Hare, R. D. (1991). *The Hare Psychopathy Checklist-Revised*. Canada: Multi-Health Systems, Inc.
- Hart, D., & Marmorstein, N. M. (2009). Neighborhoods and genes and everything in between: understanding adolescent aggression in social and biological contexts. *Development and Psychopathology, 21*, 961-973.
- Hayes, A. F. (2013). *Introduction to mediation, moderation, and conditional process analysis*. New York: Guilford Press.
- Hayes, A. F., and Matthes, J. (2009). Computational procedures for probing interactions in OLS and logistic regression: SPSS and SAS implementations. *Behavior Research Methods, 41*, 924-936.
- Haynie, D. L., & Piquero, A. R. (2006). Pubertal development and physical victimization in adolescence. *Journal of Research in Crime and Delinquency, 43*, 3-35.
- Hines, M. (2004). *Brain gender*. Oxford, UK: Oxford University Press.
- Hollingshead, A.B. (1975). Four factor index of social status. New Haven, CT.
- Hönekopp, J., & Watson, S. (2010). Meta-analysis of digit ratio 2D:4D shows greater sex difference in the right hand. *American Journal of Human Biology, 22*, 619-630.
- Hönekopp, J., & Watson, S. (2011). Meta-analysis of the relationship between digit-ratio 2D:4D and aggression. *Personality and Individual Differences, 51*, 381-386.
- Hox, J. (1998). Multilevel modeling: When and why. In I. Balderjahn, R. Mathar, and M. Schader (Eds.), *Classification, data analysis, and data highways* (pp. 147-154). New York: Springer Verlag.
- Jennings, W. G., Piquero, A. R., & Farrington, D.P. (2013). Does resting heart rate at age 18 distinguish general and violent offending up to age 50? Findings from the

- Cambridge Study in Delinquent Development. *Journal of Criminal Justice*, 41, 213-219.
- Johnson, P. O., & Fay, L. C. (1950). The Johnson–Neyman technique, its theory and application. *Psychometrika*, 15, 349-367.
- Johnson, P. O., & Neyman, J. (1936). Tests of certain linear hypotheses and their application to some educational problems. *Statistical Research Memoirs*, 1, 57-93.
- Killgore, W. D. (2000). Evidence for a third factor on the Positive and Negative Affect Schedule in a college student sample. *Perceptual and Motor Skills*, 90, 147-152.
- Kindlon, D. J., Tremblay, R. E., Mezzacappa, E., Earls, F., Laurent, D., & Schaal, B. (1995). Longitudinal patterns of heart rate and fighting behavior in 9- through 12-year-old boys. *Journal of the American Academy of Child and Adolescent Psychiatry*, 34, 371-377.
- Kirschbaum, C., Pirke, K., & Hellhammer, D. H. (1993). The ‘Trier Social Stress Test’- a tool for investigating psychobiological stress. *Neuropsychobiology*, 28, 76-81.
- Krieger, N., Williams, D. R., & Mossm N. E. (1997). Measuring social class in US public health research: Concepts, methodologies, and guidelines. *Annual Review of Public Health*, 18, 341-378.
- Kushnir, M. M., Blamiers, T., Rockwood, A. L., Roberts, W. L., Yue, B., Erdogan, E., ...Meikle, A.W. (2010). Liquid chromatography-tandem mass spectrometry assay for androstenedione, dehydroepiandrosterone, and testosterone with pediatric and adult reference intervals. *Clinical Chemistry*, 56, 1138-1147.

- Leventhal, T., & Brooks-Gunn, J. (2000). The neighborhoods they live in: The effects of neighborhood residence on child and adolescent outcomes. *Psychological Bulletin, 126*, 309-337.
- Liu, J., Portnoy, J., & Raine, A. (2012). Association between a marker for prenatal testosterone exposure and externalizing behavior problems in children. *Development and Psychopathology, 24*, 771-782.
- Liu, J., Richmond, T. S., Raine, A., Cheney, R., Brodtkin, E. S., Gur, R. C., & Gur, R. E. (2013). The Healthy Brains and Behavior Study: Objectives, design, recruitment, and population coverage. *International Journal of Methods in Psychiatric Research, 22*, 204-216.
- Loeber, R., Farrington, D. P., Stouthamer-Loeber, M., & Van Kammen, W. B. (1998). *Antisocial behavior and mental health problems: Exploratory factors in childhood and adolescence*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
- Loeber, R., & Stouthamer-Loeber, M. (1998). Development of juvenile aggression and violence: Some common misconceptions and controversies. *American Psychologist, 55*, 242-259.
- Lopez-Duran, N. L., Olson, S. L., Hajal, N. J., Felt, B. T., Vazquez, D. M. (2009). Hypothalamic pituitary adrenal axis functioning in reactive and proactive aggression in children. *Journal of Abnormal Child Psychology, 37*, 169-182.
- Lorber, M. F. (2004). Psychophysiology of aggression, psychopathy, and conduct problems: A meta-analysis. *Psychological Bulletin, 130*, 531-552.

- Lösel, Friedrich, & Farrington, D. P. (2012). Direct protective and buffering protective factors in the development of youth violence. *American Journal of Preventive Medicine, 43*, S8-23.
- Lösel, Friedrich, & Bender, D. (1997). Heart rate and psychosocial correlates of antisocial behavior in high-risk adolescents. In A. Raine, P. A. Brennan, D. P. Farrington, & S. A. Mednick (Eds.), *Biosocial bases of violence* (pp. 321-325). New York: Plenum Press.
- Lutchmaya, S., Baron-Cohen, S., Raggatt, P., Knickmeyer, R., & Manning, J. T. (2004). 2nd to 4th digit ratios, fetal testosterone and estradiol. *Early Human Development, 77*, 23-28.
- Lynam, D. R. (1997). Pursuing the psychopath: Capturing the fledgling psychopath in a nomological net. *Journal of Abnormal Psychology, 106*, 425-438.
- Lynam, D. R., Caspi, A., Moffitt, T. E., Wikstrom, P. H., Loeber, R. & Novak, S. (2000). The interaction between impulsivity and neighborhood context on offending: The effects of impulsivity are stronger in poorer neighborhoods. *Journal of Abnormal Psychology, 109*, 563-574.
- Lynch, J. L., Long, J. M., Thomas, S. A., Malinow, K. L., & Katcher, A. H. (1981). The effects of talking on the blood pressure of hypertensive and normotensive individuals. *Psychosomatic Medicine, 43*, 25-33.
- Mackinnon, D. P., Lockwood, C. M., & Williams, J. (2004). Confidence limits for the indirect effect: Distribution of the product and resampling methods. *Multivariate Behavioral Research, 39*, 99-128.

- Manning, J. T., Fink, B., Neave, N., & Caswell, N. (2005). Photocopies yield lower digit ratios (2d:4d) than direct finger measurements. *Archives of Sexual Behavior*, *34*, 329-333.
- Manning, J., Kilduff, L., Cook, C., Crewther, B., & Fink, B. (2014). Digit ratio (2D:4D): A biomarker for prenatal sex steroids and adult sex steroids in challenge situations. *Frontiers in Endocrinology*, *5*, 1-5.
- Manning, J. T., Scutt, D., Wilson, J., & Lewis-Jones, D. I. (1998). The ratio of 2nd to 4th digit length: A predictor of sperm numbers and concentrations of testosterone, luteinizing hormone and oestrogen. *Human Reproduction*, *13*, 3000-3004.
- Marmorstein, N. R. (2007). Relationships between anxiety and externalizing disorders in youth: The influences of age and gender. *Journal of Anxiety Disorders*, *21*, 420-432.
- Mathias, C. W., & Stanford, M. S. (2003). Impulsiveness and arousal: Heart rate under conditions of rest and challenge in healthy males. *Personality and Individual Differences*, *35*, 355-371.
- Mazur, A., & Booth, A. (1998). Testosterone and dominance in men. *Behavioral and Brain Sciences*, *21*, 353-397.
- McBurnett, K., Lahey, B. B., Rathouz, P. J., & Loeber, R. (2000). Low salivary cortisol and persistent aggression in boys referred for disruptive behavior. *Archives of General Psychiatry*, *57*, 38-43.
- McCarthy, M. M. (2010). How it's made: Organisational effects of hormones on the developing brain. *Journal of Neuroendocrinology*, *22*, 736-742.

- McCarthy, B., & Hagan, J. (2005). Danger and the decision to offend. *Social Force* 83, 1065-1096.
- Mehrabian, A. (1997). Comparison of the PAD and PANAS as models for describing emotions and for differentiating anxiety from depression. *Journal of Psychopathology and Behavioral Assessment*, 19, 331-357.
- Mehta, P. H., & Josephs, R. A. (2010). Testosterone and cortisol jointly regulate dominance: Evidence for a dual-hormone hypothesis. *Hormones and Behavior*, 58, 898-906.
- Melde, C., Berg, M. T., & Esbensen, F. (2014). Fear, social interactions, and violence mitigation. *Justice Quarterly*. doi: 10.1080/07418825.2014.928348
- Mercy, J. A., Rosenberg, M. L., Powell, K. E., Broome, C. V., & Roper, W. L. (1993). Public health policy for preventing violence. *Health Affairs*, 12, 7-29.
- Moffitt, T. E. (1993). Adolescence-limited and life-course-persistent antisocial behavior: A developmental taxonomy. *Psychological Review*, 100, 674-701.
- Moffitt, T. E., Arseneault, L., Jaffee, S. R., Kim-Cohen, J., Koenen, K. C., Odgers, C. L., ... Viding, E. (2008). Research review: DSM-V conduct disorder: Research needs for an evidence base. *Journal of Child Psychology and Psychiatry*, 49, 3-33.
- Montoya, E. R., Terburg, D., Bos, P. A., & van Honk, J. (2012). Testosterone, cortisol, and serotonin as key regulators of social aggression: A review and theoretical perspective. *Motivation and Emotion*, 36, 65-73.
- Montoya, E. R., Terburg, D., Bos, P. A., Will, G. J., Buskens, V., Raub, W., & van Honk, J. (2013). Testosterone administration modulates moral judgments depending on second-to-fourth digit ratio. *Psychoneuroendocrinology*, 38, 1362-1369.

- Morris, N. M., & Udry, J. R. (1980). Validation of a self-administered instrument to assess stage of adolescent development. *Journal of Youth and Adolescence*, 9, 271-280.
- Nagai, M., Hoshide, S., & Kario, K. (2010). The insular cortex and cardiovascular system: A new insight into the brain-heart axis. *Journal of the American Society of Hypertension*, 4, 174-182.
- Narayan, V. M., Narr, K. L., Kumari, V., Woods, R. P., Thompson, P. M., Toga, A. W., & Sharma, T. (2007). Regional cortical thinning in subjects with violent antisocial personality disorder or schizophrenia. *American Journal of Psychiatry*, 164, 1418-1427.
- Nuechterlein, K. H., Parasuraman, R., & Jiang, Q. (1983). Visual sustained attention: Image degradation produces rapid sensitivity decrement over time. *Science*, 220, 327-329.
- Obeidallah, D., Brennan, R. T., Brooks-Gunn, J., & Earls, F. (2004). Links between pubertal timing and neighborhood contexts: Implications for girls' violent behavior. *Journal of the American Academy of Child and Adolescent Psychiatry*, 43, 1460-1468.
- Okten, A., Kalyoncu, M., & Yaris, N. (2002). The ratio of second- and fourth-digit lengths and congenital adrenal hyperplasia due to 21-hydroxylase deficiency. *Early Human Development*, 70, 47-54.
- Olinsky, A., Chen, S., & Harlow, L. (2003). The comparative efficacy of imputation methods for missing data in structural equation modeling. *European Journal of Operational Research*, 151, 53-79.

- O'Neal, C. R., Brotman, L. M., Huang, K., Gouley, K. K., Kamboukos, D., Calzada, E. J., & Pine, D. S. (2010). Understanding relations among early family environment, cortisol response, and child aggression via a prevention experiment. *Child Development, 81*, 290-305.
- 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.
- Pajer, K., Gardner, W., Rubin, R. T., Perel, J., & Neal, S. (2001). Decreased cortisol levels in adolescent girls with conduct disorder. *Archives of General Psychiatry, 58*, 297-302.
- Phoenix, C. H., Goy, R. W., Gerall, A. A., & Young, W. C. (1959). Organizing action of prenatally administered testosterone propionate on the tissues mediating mating behavior in the female guinea pig. *Endocrinology, 65*, 369-382.
- Popma, A., Vermeiren, R., Geluk, C. A. M. L., Rinne, T., van den Brink, W., ... Doreleijers, T. A. H. (2007). Cortisol moderates the relationship between testosterone and aggression in delinquent male adolescents. *Biological Psychiatry, 61*, 405-411.
- Porter, S., & Woodworth, M. (2006). Psychopathy and aggression. In C. J. Patrick (Ed.), *Handbook of psychopathy* (pp. 481-494). New York, NY: Guilford Press.
- Portnoy, J., Chen, F. R., & Raine, A. (2013). Biological protective factors for antisocial and criminal behavior. *Journal of Criminal Justice 41*, 292-299.

- Portnoy, J., & Farrington, D. P. (2015). Resting heart rate and antisocial behavior: An updated systematic review and meta-analysis. *Aggression and Violent Behavior*. doi:10.1016/j.avb.2015.02.004
- Portnoy, J., Gao, Y., Glenn, A. L., Niv, S., Peskin, M., Rudo-Hutt, A., ... Raine, A. (2013). In C. L. Gibson & M. D. Krohn (Eds.), *Handbook of life-course criminology* (pp. 21-42). New York: Springer.
- Portnoy, J., Raine, A., Chen, F. R., Pardini, D., Loeber, R., & Jennings, J. R. (2014). Heart rate and antisocial behavior: The mediating role of impulsive sensation seeking. *Criminology*, 52, 292-311.
- Pruessner, J. C., Kirschbaum, C., Meinlschmid, G., & Hellhammer, D. H. (2003). Two formulas for computation of the area under the curve represent measures of total hormone concentration versus time-dependent change. *Psychoneuroendocrinology*, 28, 916-931.
- Quay, H. C. (1965). Psychopathic personality as pathological stimulation-seeking. *American Journal of Psychiatry* 122, 180-183.
- Raine, A. (1993). *The psychopathology of crime*. San Diego, CA: Academic Press Inc.
- Raine, A. (2002a). Annotation: The role of prefrontal deficits, low autonomic arousal, and early health factors in the development of antisocial and aggressive behavior in children. *Journal of Child Psychology and Psychiatry*, 43, 417-434.
- Raine, A. (2002b). Biosocial studies of antisocial and violent behavior in children and adults: A review. *Journal of Abnormal Child Psychology*, 30, 311-326.
- Raine, A. (2013). *The anatomy of violence*. New York, NY: Pantheon Books.

- Raine, A., Dodge, K., Loeber, R., Gatzke-Kopp, L., Lynam, D., Reynolds, C., ... Liu, J. (2006). The Reactive-Proactive Aggression Questionnaire: Differential correlates of reactive and proactive aggression in adolescent boys. *Aggressive Behavior*, 32, 159-71.
- Raine, A., Fung, A. L., Portnoy, J., Choy, O., & Spring, V.L. (2014). Low heart rate as a risk factor for child and adolescent proactive aggressive and impulsive psychopathic behavior. *Aggressive Behavior* 40, 290-299.
- Raine, A., Lencz, T., Bihrlé, S., LaCasse, L., & Colletti, P. (2000). Reduced prefrontal gray matter volume and reduced autonomic activity in antisocial personality disorder. *Archives of General Psychiatry*, 57, 119-27.
- Raine, A., Mellinger, K., Liu, J., Venables, P. H., & Mednick, S. A. (2003). Effects of environmental enrichment at ages 3-5 years on schizotypal personality and antisocial behavior at ages 17 and 23 years. *American Journal of Psychiatry*, 160, 1627-1635.
- Raine, A., Moffitt, T. E., Caspi, A., Loeber, R., Stouthamer-Loeber, M., & Lynam, D. (2005). Neurocognitive impairments in boys on the life-course persistent antisocial path. *Journal of Abnormal Psychology*, 114, 38-49.
- Raine, A., Reynolds, C., Venables, P. H., Mednick, S. A., & Farrington, D. P. (1998). Fearlessness, stimulation-seeking, and large body size at age 3 years as early predispositions to childhood aggression at age 11 years. *Archives of General Psychiatry* 55, 745-751.
- Raine, A., Venables, P. H., Dalais, C., Mellinger, K., Reynolds, C., & Mednick, S. A. (2001). Early educational and health enrichment at age 3-5 years is associated

- with increased autonomic and central nervous system arousal and orienting at age 11 years: Evidence from the Mauritius Child Health Project. *Psychophysiology*, 38, 254-266.
- Raine, A., Venables, P. H., & Mednick, S. A. (1997). Low resting heart rate at age 3 years predisposes to aggression at age 11 years: Evidence from the Mauritius Child Health Project. *Journal of the American Academy of Child and Adolescent Psychiatry*, 36, 1457-1464.
- Raine, A., Venables, P. H., & Williams, M. (1990). 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. (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.
- Raine, A., Venables, P. H., & Williams, M. (1996). Better autonomic conditioning and faster electrodermal half-recovery time at age 15 years as possible protective factors against crime at age 29 years. *Developmental Psychology*, 32, 624-630.
- Raine, A., Yaralian, P. S., Reynolds, C., Venables, P. H., & Mednick, S. A. (2002). Spatial but not verbal cognitive deficits at age 3 years in persistently antisocial individuals. *Development and Psychopathology*, 14, 25-44.
- Reiss, A. J. & Roth, J. A. (Eds.). (1993). *Understanding and preventing violence*. Washington, D.C.: National Academy Press.

- Rhee, S. H., & Waldman, I. D. (2002). Genetic and environmental influences on antisocial behavior: A meta-analysis of twin and adoption studies. *Psychological Bulletin*, 128, 490-529.
- Roche, K. M. & Leventhal, T. (2009). Beyond neighborhood poverty: Family management, neighborhood disorder, and adolescents' early sexual onset. *Journal of Family Psychology*, 23, 819-827.
- Roosa, M. W., Deng, S., Ryu, E., Burrell, G. L., Tein, J., Jones, S., ... Crowder, S. (2005). Family and child characteristics linking neighborhood context and child externalizing behavior. *Journal of Marriage and Family*, 67, 512-529.
- Rowe, D. C., & Osgood, D. W. (1984). Heredity and sociological theories of delinquency: A reconsideration. *American Sociological Review* 49, 526-540.
- Rowe, R., Maughan, B., Worthman, C. M., Costello, E. J., & Angold, A. (2004). Testosterone, antisocial behavior, and social dominance in boys: Pubertal development and biosocial interaction. *Biological Psychiatry*, 55, 546-552.
- Rutter, M. (2012). Resilience as a dynamic concept. *Development and Psychopathology*, 24, 335-344.
- Sallis, J. F., Buono, M. J., Roby, J. J., Micale, F. G. G., & Nelson, J. A. (1993). Seven-day recall and other physical activity self-reports in children and adolescents. *Medicine and Science in Sports and Exercise*, 25, 99-108.
- Sampson, R. J. (2012). *Great American city: Chicago and the enduring neighborhood effect*. Chicago, IL: The University of Chicago Press.
- Sampson, R. J., & Groves, W. B. (1989). Community structure and crime: Testing social-disorganization theory. *American Journal of Sociology*, 94, 774-802.

- Sampson, R. J., Raudenbush, S. W., & Earls, F. (1997). Neighborhoods and violent crime: A multilevel study of collective efficacy. *Science*, *277*, 918-924.
- Sareen, J., Stein, M. B., Cox, B. J., & Hassard, S. T. (2004). Understanding comorbidity of anxiety disorders with antisocial behavior. *The Journal of Nervous and Mental Disease*, *192*, 178-186.
- Sato, S. M., Schulz, K. M., Sisk, C. L., & Wood, R. I. (2008). Adolescents and androgens, receptors, and rewards. *Hormones and Behavior*, *53*, 647-658.
- Scarpa, A., & Ollendick, T. H. (2003). Community violence exposure in a young adult sample: III. Psychophysiology and victimization interact to affect risk for aggression. *Journal of Community Psychology*, *31*, 321-338.
- Scarpa, A., Tanaka, A., & Haden, S. C. (2008). Biosocial bases of reactive and proactive aggression: The roles of community violence exposure and heart rate. *Journal of Community Psychology*, *36*, 969-988.
- Schaal, B., Tremblay, R. E., Soussignan, R., & Susman, E. J. (1996). Male testosterone linked to high social dominance but low physical aggression in early adolescence. *Journal of the American Academy of Child and Adolescent Psychiatry*, *34*, 1322-1330.
- Schwerdtfeger, A., Heims, R., & Heer, J. (2010). Digit ratio (2D:4D) is associated with traffic violations for male frequent car drivers. *Accident Analysis and Prevention*, *42*, 269-274.
- Scott, S., Knapp, M., Henderson, J., & Maughan, B. (2001). Financial cost of social exclusion: Follow up study of antisocial children into adulthood. *British Medical Journal*, *323*, 1-5.

- Seale, J. V., Wood, S.A., Atkinson, C., Harbuz, M. S., & Lightman, S. L. (2005a).
Postnatal masculinization alters the HPA axis phenotype in the adult female rat.
Journal of Physiology, *563*, 265-274.
- Seale, J. V., Wood, S. A., Atkinson, C., Lightman, S. L., & Harbuz, M. S. (2005b).
Organizational role for testosterone and estrogen on adult hypothalamic-pituitary-
adrenal axis activity in the male rat. *Endocrinology*, *146*, 1973-1982.
- Seidman, E., Yoshikawa, H., Roberts, A., Chesir-Teran, D., Allen, L., Friedman, J. L., &
Aber, J. L. (1998). Structural and experiential neighborhood contexts,
developmental stage, and antisocial behavior among urban adolescents in poverty.
Development and Psychopathology, *10*, 259-281.
- Shaw, C. R., & McKay, H. D. (1942). *Juvenile delinquency and urban areas*. Chicago,
IL: The University of Chicago Press.
- Shekharappa, K. R., Johncy, S. S., Mallikarjuna, P. T., Vedavathi, K. J., & Jayarajan, M.
P. (2011). Correlation between body mass index and cardiovascular parameters in
obese and non-obese in different age groups. *International Journal of Biological
and Medical Research* *2*, 551-555.
- Shepherd, J. P., & Farrington, D. P. (1993). Assault as a public health problem:
Discussion paper. *Journal of the Royal Society of Medicine*, *86*, 89-92.
- Sijtsema, J. J., Veenstra, R., Lindenberg, S., van Roon, A. M., Verhulst, F. C., Ormel, J.,
& Riese, H. (2010). Mediation of sensation seeking and behavioral inhibition on
the relationship between heart rate and antisocial behavior: The TRAILS study.
Journal of the American Academy of Child and Adolescent Psychiatry, *49*, 493-
502.

- Simcha-Fagan, O., & Schwartz, J. E. (1986). Neighborhood and delinquency: An assessment of contextual effects. *Criminology*, *24*, 667-703.
- Sisk, C. L., & Zehr, J. L. (2005). Pubertal hormones organize the adolescent brain and behavior. *Frontiers in Neuroendocrinology*, *26*, 163-174.
- Smith, D. J. (2007). Crime and the life course. In M. Maguire, R. Morgan, & R. Reiner (Eds.), *The Oxford handbook of criminology* (4th ed.) (pp. 641-683). Oxford, UK: Oxford University Press.
- Spielberger, C. D., Gorusch, R. L., & Lushene, R. E. (1970). *Manual for the State-Trait Anxiety Inventory*. Palo Alto, CA: Consulting Psychologists Press.
- Stadler, C., Grasmann, D., Fegert, J. M., Holtmann, M., Poustka, F., & Schmeck, K. (2008). Heart rate and treatment effect in children with disruptive behavior disorders. *Child Psychiatry and Human Development*, *39*, 299-309.
- Stouthamer-Loeber, M., & Stallings, R. (2008). Measurement instruments and constructs. In R. Loeber, D. P. Farrington, M. Stouthamer-Loeber, & H. R. White (Eds.) *Violence and serious theft: Development and prediction from childhood to adulthood* (pp. 39-73). New York, NY: Routledge.
- Susman, E. J. (2006). Psychobiology of persistent antisocial behavior: Stress, early vulnerabilities and the attenuation hypothesis. *Neuroscience and Biobehavioral Reviews*, *30*, 376-389.
- Susman, E. J., Dockray, S., Granger, D. A., Blades, K. T., Randazzo, W., Heaton, J. A., & Dorn, L. D. (2010). Cortisol and alpha-amylase reactivity and timing of puberty: Vulnerabilities for antisocial behaviour in young adolescents. *Psychoneuroendocrinology*, *35*, 557-569.

- Susman, E. J., Inoff-Germain, G., Nottelmann, E. D., Loriaux, D. L., Cutler, G. B., & Chrousos, G. P. (1987). Hormones, emotional dispositions, and aggressive attributes in young adolescents. *Child Development, 58*, 1114-1134.
- Sylvers, P., Lilienfeld, S. O., & LaPrairie, J. L. (2011). Differences between trait fear and trait anxiety: Implications for psychopathology. *Clinical Psychology Review, 31*, 122-137.
- Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed.). Boston, MA: Pearson.
- Terburg, D., Morgan, B., & van Honk, J. (2009). The testosterone-cortisol ratio: A hormonal marker for proneness to social aggression. *International Journal of Law and Psychiatry, 32*, 216-223.
- Tonry, M., & Farrington, D. P. (1995). Strategic approaches to crime prevention. *Crime and Justice, 19*, 1-20.
- Ttofi, M. M., & Farrington, D. P. (2012). Risk and protective factors, longitudinal research and bullying prevention. *New Directions for Youth Development, 133*, 85-98.
- U.S. Census Bureau. American Community Survey 2005-2009. Social Explorer.
- van Goozen, S. H.M., & Fairchild, G. (2008). How can the study of biological processes help design new interventions for children with severe antisocial behavior? *Development and Psychopathology 20*, 941-973.
- van Goozen, S. H. M., Snoek, H., Matthys, W., van Rossum, I., & van Engeland, H. (2004). Evidence of fearlessness in behaviourally disordered children: A study on

- startle reflex modulation. *Journal of Child Psychology and Psychiatry*, 45, 884-892.
- van Honk, J., Montoya, E. R., Bos, P. A., van Vugt, M., & Terburg, D. (2012). New evidence on testosterone and cooperation. *Nature*, 485, 356-359.
- van Honk, J., Schutter, D. J., Bos, P. A., Kruijt, A. W., Lentjes, E. G., & Baron-Cohen, S. (2011). Testosterone administration impairs cognitive empathy in women depending on second-to-fourth digit ratio. *Proceedings of the National Academy of Sciences*, 108, 3448-3452.
- van Honk, J., Schutter, D. J., Hermans, E. J., & Putman, P. (2003). Low cortisol levels and the balance between punishment sensitivity and reward dependency. *Neuroreport*, 14, 1993-1996.
- van Honk, J., Schutter, D. J., Hermans, E. J., Putman, P., Tuiten, A., & Koppeschaar, H. (2004). Testosterone shifts the balance between sensitivity for punishment and reward in healthy young women. *Psychoneuroendocrinology*, 29, 937-943.
- Venables, P. H. (1987). Autonomic and central nervous system factors in criminal behavior. In S. A. Mednick, T. E. Moffitt, & S. A. Stack (Eds.), *The causes of crime: New biological approaches* (pp. 110-136). New York, NY: Cambridge University Press.
- Warr, M. (2002). *Companions in crime: The social aspects of criminal conduct*. Cambridge, UK: Cambridge University Press.
- Watson, D., Clark, L. E., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, 54, 1063-1070.

- Weber, E. J.M., Molenaar, P. C. M., & van der Molen, M. W. (1992). A nonstationarity test for the spectral analysis of physiological time series with an application to respiratory sinus arrhythmia. *Psychophysiology*, *29*, 55-65.
- Whiteside, S. P, & Lynam, D. R.. (2001). The Five Factor Model and impulsivity: Using a structural model of personality to understand impulsivity. *Personality and Individual Differences*, *30*, 669-689.
- Wilson, L. C., & Scarpa, A. (2011). The link between sensation seeking and aggression: A meta-analytic review. *Aggressive Behavior*, *37*, 81-90.
- Wilson, L. C., & Scarpa, A. (2013). Baseline heart rate, sensation seeking, and aggression in young adult women: A two-sample examination. *Aggressive Behavior*, *39*, 280-289.
- Wright, E. M., & Fagan, A. A. (2013). The cycle of violence in context: Exploring the moderating roles of neighborhood disadvantage and cultural norms. *Criminology*, *51*, 217-249.
- Yildirim, B. O., & Derksen, J. J. L. (2012). A review on the relationship between testosterone and the interpersonal/affective facet of psychopathy. *Psychiatry Research*, *197*, 181-198.
- Yoon, B., Morillo, C. A., Cechetto, D. F., & Hachinski, V. (1997). Cerebral hemispheric lateralization in cardiac autonomic control. *Archives of Neurology*, *54*, 741-744.
- Zheng, Z., & Cohn, M. J. (2011). Developmental basis of sexually dimorphic digit ratios. *Proceedings of the National Academy of Sciences*, *108*, 16289-16294.
- Zuckerman, M. (1993). Sensation seeking and impulsivity: A marriage of traits made in biology? In W. G. McCown, J. L. Johnson, & M. B. Shure (Eds.), *The Impulsive*

client: Theory, research, and treatment (pp. 71-91). Washington, D.C.: American Psychological Association

Zuckerman, M. (2007). *Sensation seeking and risky behavior*. Washington, D.C.: American Psychological Association.

Zuckerman, M., & Kuhlman, D. M. (2000). Personality and risk-taking: Common biosocial factors. *Journal of Personality*, 68, 999-1029.

Zuckerman, M., Kuhlman, D. M., Joireman, J., Teta, P., & Kraft, M. (1993). A comparison of three structural models for personality: The Big Three, the Big Five, and the Alternative Five. *Journal of Personality and Social Psychology*, 65, 757-768.