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A Within-Person Approach to Understanding Daily Experiences and Well-Being among Adolescents in Socioeconomic Disadvantage: Vulnerability and Opportunity *in vivo*

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY
in Psychology and Social Behavior

by

Michael A. Russell

Dissertation Committee:
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2014

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DEDICATION

To my family and friends,

For all the love and support they've given me over the years;

I am truly grateful.

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Dissertation Committee and Members

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Robins, S., Odgers, C. L., & **Russell, M. A.** (2011). Incarcerated girls' physical health: Can the juvenile justice system help to reduce long-term costs? *Court Review, 46,* 30-35.

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Book Chapters

Russell, M. A., & Odgers, C. L. (**in press**). Antisocial Behavior among Children in Poverty: Understanding Environmental Effects in Daily Life. In Pietz, C. A., & Mattson, C. A. (eds.). *Violent Offenders: Understanding and Assessment*. Oxford, UK: Oxford University Press.

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ABSTRACT OF THE DISSERTATION

A Within-Person Approach to Understanding Daily Experiences and Well-Being among Adolescents in Socioeconomic Disadvantage: Vulnerability and Opportunity *in vivo*

By

Michael A. Russell

Doctor of Philosophy in Psychology and Social Behavior

University of California, Irvine, 2014

Professor Carol K. Whalen, Chair

For many children and adolescents growing up in socioeconomic disadvantage, the conditions of everyday life are characterized by persistent exposure to risks and stressors, such as family turmoil, deviant peer groups, and unsafe neighborhoods. However, there has been little research that has directly examined such experiences in the everyday lives of low-income youth. As such, little is known about the effects of daily stressors, both in-the-moment and across developmental time, as well as which youth may be most susceptible to positive and negative experiences in daily life. This dissertation has two overarching aims: (1) to better understand how daily experiences affect adolescents' health and behavior, and (2) to test for characteristics that may help identify adolescents who are more sensitive to their daily environments than others. Chapter 1 reviews theory and research on the everyday environments of children living in socioeconomic disadvantage. It articulates a within-person framework for understanding how youth change in relation to themselves across changing environmental contexts, and discusses how mobile technologies may help researchers better understand the daily lives of low-income youth. Chapters 2 and 3 provide empirical examples informed by the within-person framework

presented in Chapter 1, using mobile phones to repeatedly measure contextual triggers, daily stressors, affect, and behavior in the daily lives of 151 adolescents from low-socioeconomic status neighborhoods. Chapter 2 shows that adolescents were more likely to engage in problem behavior (antisocial behavior and substance use) on days when they did versus did not witness others using substances. Adolescents were especially likely to engage in problem behavior if exposure to others' substance use occurred in outside the home (i.e. in their schools, neighborhoods, or other contexts) versus inside the home. The effects of substance use exposure were stronger for adolescents with the *DRD4*-7R gene, suggesting a gene-environment interaction occurring in daily life. Chapter 3 shows that adolescents with genetic and behavioral markers (*DRD4*-7R and low levels of self-control) showed greater day-to-day variability in their affect and behavior as well as greater sensitivity to positive and negative experiences in daily life. The implications of these findings for research, theory, and intervention are discussed.

PREFACE

Children and adolescents who are exposed to extreme forms of adversity early in life are at risk for a wide range of poor outcomes. Decades of research has shown that exposure to abuse, maltreatment, and major stressful life events can have lasting influences on health and behavior (Felitti et al., 1998; Miller, Chen, & Parker, 2011; Widom, Czaja, Bentley, & Johnson, 2012). Less is known, however, about how the more "mundane" stressful experiences of everyday life affect child and adolescent health and behavior, both in-the-moment and across developmental time. Although, emerging evidence suggests that repeated, daily exposure to negative experiences may have effects that are as large, if not *larger*, than the effects of major adversity on health and well-being among both adolescents and adults (Hertzman & Boyce, 2010; Odgers & Jaffee, 2013).

For children and adolescents living in socioeconomic disadvantage, the conditions of daily life tend to be characterized by persistent and pervasive exposure to risky and stressful situations (see Evans, 2004). Continual exposure to stressors such as tensions in the home, peer pressures at school, and dangerous situations in the neighborhood are thought to account for a large share of poverty's negative effects on children's emotional and behavioral development (Evans, 2004; McLoyd, 2011; Repetti, Taylor, & Seeman, 2002). Over time, the effects of everyday environments can accumulate, adding up to large, meaningful, and lasting differences in the life chances of low- versus high-income children (see Hart & Risley, 1995 for a striking example).

Studying the ways in which everyday environments affect child and adolescent development, however, presents a number of significant methodological challenges to

researchers. I highlight three of these challenges in the current document. First, most research in this area has relied on retrospective reports of interactions, experiences and reactions to environmental stressors; it is difficult for researchers to observe transactions between youth and their environments *as they occur*, at the pace of everyday life. Methods allowing continual assessment of adolescents in their naturalistic environments, with minimal intrusion on the part of the researcher, are needed to trace the effects of daily exposures on health and well-being "in the moment" and over time. Second, youth bring a host of preexisting characteristics to every situation they encounter. Unless careful methodological controls are used to account for the effects of these preexisting characteristics, we cannot be sure that what appear to be "environmental" effects are not actually driven by the characteristics of youth themselves. Third, even when "true" environmental effects are present, we cannot expect them to operate in the same way or at the same magnitude for all youth. Some youth will be more sensitive to their environments than others, and a better understanding of the factors that characterize sensitive youth will be needed to inform theory and intervention efforts concerned with child and adolescent development in low-income environments.

In this document, I present a trio of papers addressing these challenges. In each of these papers, I emphasize the use of mobile technologies – such as mobile phones, wireless sensors, and mobile tablets – as valuable research tools for examining environmental effects of daily triggers, stressors and adversities on low-income adolescents' health and development *in context*, with a careful eye toward the characteristics that mark youth who may be most sensitive to the ups and downs of daily life. Chapter 1 provides a conceptual review of past theory and research in this area, highlighting the use of mobile technologies in low-income adolescents' daily lives as a promising future research direction. Chapters 2 and 3 present findings from the miLife study,

in which 151 adolescents (ages 11-15) from low-SES neighborhoods responded to assessments about their environments, health, and behavior 3 times daily over a one month period. I conclude with a discussion of findings across the three papers, and suggest future directions for the study of adolescent wellbeing in context and in "real time". Below, I provide a brief synopsis for each chapter in this document.

Chapter 1 is a conceptual review on how context influences the development and expression of antisocial behavior among low-income children and adolescents. I begin by reviewing research and theory suggesting how the everyday environments of the home, peer group, and neighborhood might play a causal role in the developmental outcomes of low-income children, with a focus on research supporting environmentally mediated causal effects of poverty-related environments on children's antisocial behavior. Next, I discuss the ways in which diary research using mobile technologies may help researchers understand the effects that poverty-related environments may have on children's behavior and well-being. Specifically, I highlight the ability of these methods to (1) document the contexts that low-income children experience on a daily basis through the use of photo, video, and global positioning systems; (2) obtain real-time information on the patterning of environmental exposures, the interplay between context and behavior, and the unique environment-behavior signatures that describe each adolescent's daily life; and (3) enhance internal validity of environment-behavior relationships by using each person as his or her own comparison across time and context, helping to account for all stable selection factors that may confound environmental effects. I close with a discussion of how these methodological features augment our ability to test longstanding models of person-environment interaction (such as diathesis-stress and differential susceptibility) and deliver intervention content at the times and places low-income children may need it most.

Chapter 2 is an empirical piece demonstrating a gene-environment interaction in the daily lives of adolescents in the miLife study. In this chapter, I present evidence that adolescents with versus without the *DRD4*-7R allele were more reactive to contextual triggers for problem behavior (antisocial behavior and substance use). Specifically, 7R versus non-7R carriers showed larger increases in their odds of problem behavior on days when they witnessed others using substances, compared to themselves when they did not witness others' substance use. I found no evidence that adolescents with versus without the *DRD4*-7R allele witnessed others' substance use more often, thus helping to rule out gene-environment correlation as a potential counter-explanation for these results. Because these results are based on within-person comparisons obtained through repeated naturalistic measurement of the same individuals, they cannot be explained away by stable individual difference factors (e.g., sex, ethnicity, current family socioeconomic status) that serve as potential confounds in studies relying on between-person comparisons. As such, these results facilitate causal inferences regarding how adolescents' everyday experiences interact with their pre-existing characteristics to influence their risk for psychopathology.

Chapter 3 is an empirical piece, in which I adopt a novel within-person approach to testing differential susceptibility theory in the daily lives of adolescents in the miLife study. Differential susceptibility suggests that some adolescents will be more sensitive to both the positive and negative features of their environments, and that these adolescents can be identified by an assortment of genetic and behavioral characteristics (Ellis, Boyce, Belsky, Bakermans-Kranenburg, & van Ijzendoorn, 2011). Using the extensive within-person information obtained in the miLife study, I test whether adolescents with theoretically specified differential susceptibility markers show (1) higher levels of *lability*, operationalized by high within-person

variability on affective and behavioral dimensions, indicating a greater range of phenotypic possibility in these dimensions and (2) higher levels of within-person change in affect (or affective reactivity) to both positive and negative experiences in their everyday lives. I find some evidence that two markers – the *DRD4*-7R and low self-control – are associated with greater lability and reactivity in adolescents' daily lives. I then discuss these findings in light of the claims made by differential susceptibility theory that highly sensitive youth may be those who, although most vulnerable to the effects of harsh environments, may be most likely to benefit from targeted intervention.

CHAPTER 1

Antisocial Behavior Among Children in Poverty: Understanding Environmental Effects in Daily Life*

*Citation:

Russell, M. A., & Odgers, C. L. (in press). Antisocial Behavior Among Children in Poverty: Understanding Environmental Effects in Daily Life. In Pietz, C. A., & Mattson, C. A. (eds.). Violent Offenders: Understanding and Assessment. Oxford, UK: Oxford University Press.

Abstract

Children living in poverty are at increased risk for antisocial behavior, and a large portion of this risk appears to operate through chronic exposure to stressful events in daily life. The difficulty of measuring daily stressors in-the-moment, however, presents a challenge for researchers attempting to characterize low-income children's daily environments and their effects on antisocial behavior. In this chapter, we review research and theory supporting the idea that everyday environments may play a causal role in low-income children's antisocial development. Then, we discuss how mobile technologies may help researchers achieve a better understanding of (a) the everyday environments experienced by low-income children, (b) the effects of these environments on their behavior and well-being, and (c) whether some children are more sensitive to their environments than others, as suggested by theories of person-by-environment interaction. We conclude with a discussion of future directions that emerge from our review.

Keywords: antisocial behavior, environmental effects, mobile technologies, diary methods, daily stressors, differential susceptibility

Introduction

Children who grow up in poverty are more likely to engage in antisocial behavior – such as aggression, rule-breaking behavior, and delinquency – than children who grow up in better-off circumstances (see reviews by Bradley & Corwyn, 2002; Brooks-Gunn & Duncan, 1997; McLoyd, 1998). The strength and consistency of this relationship have led many to question whether poverty *causes* antisocial development in children, or whether the relationship is better explained by preexisting characteristics shared among children and families who live in poverty (e.g., family history of aggression, personality features, or genetic liability; see Jaffee, Strait, & Odgers, 2012 for a discussion). Answering this question is important for a number of reasons. First, childhood poverty has been shown to predict antisocial behavior at multiple points in the life course. Children from low socioeconomic status (SES) backgrounds are more likely to show chronic aggression during the first 4 years of life (Tremblay et al., 2004), are more likely to engage in serious crime and violence during adolescence (Bjerk, 2007; Elliott & Ageton, 1980; Jarjoura, Triplett, & Brinker, 2002), and are more likely to continue their involvement in antisocial behavior as adults (Fergusson & Horwood, 2002; Lahey et al., 2006; Odgers, Moffitt, et al., 2008). Second, child and adolescent antisocial behavior is known to predict a broad range of poor adult outcomes, including physical health problems (Odgers et al., 2007), broad spectrum psychiatric disorder (Kim-Cohen et al., 2003), economic/occupational difficulties (Moffitt, Caspi, Harrington, & Milne, 2002; Odgers, Moffitt, et al., 2008), and involvement in crime and violence (Farrington, 1989; Moffitt, Caspi, Rutter, & Silva, 2001; Theobald & Farrington, 2012). Third, the societal costs associated with antisocial behavior are staggering, as estimates place the aggregate burden of crime in the United States between $1 and $2 trillion *per year* (Anderson, 1999; Ludwig, 2006, 2010).

Taken together, this evidence makes it clear that childhood poverty is a powerful risk factor for the development of antisocial behavior, an important and pressing societal problem. But how does living in poverty increase children's risk for developing antisocial behavior? Theory and research suggest that poverty may be bad for children because low-income youth are embedded in home, school, and neighborhood environments where they are chronically exposed to stressful events in daily life. These stressors include harsh parenting, family turmoil, exposure to violence, low quality living conditions, and family chaos, to name just a few (Evans, 2004). Exposure to chronic stressors in everyday life results in prolonged activation of the stress response systems, which is thought to impair children's development of self-regulation abilities (e.g., attention and impulse control, delay of gratification, and working memory; Blair & Raver, 2012; Evans & Kim, 2013). Additionally, chronic exposure to aggressive, hostile, or coercive "role" models may train children to engage in aggression themselves via social modeling processes (Patterson, 1982; Patterson, Reid, & Dishion, 1992).

As such, the environment of childhood poverty – particularly the quality of children's everyday experiences – may be a principal source of risk for antisocial development. However, it is challenging to examine the causal effects of poverty on children's antisocial development because obtaining accurate "fly-on-the-wall" measurements of everyday events has been difficult with traditional assessment methods. Thus, there is little evidence on which of these events is most prominent in low-income children's daily lives, which types of stressful events have the most deleterious effects "in the moment", and which children may be the most susceptible to the effects of daily stressors. Given the structural barriers to lifting children out of impoverished conditions, it is imperative that researchers begin to identify factors that could protect children from the adverse effects of poverty-related daily stressors. By doing so, these efforts could have

a reasonable shot at improving low-income children's life chances. In this chapter, we discuss how mobile technology can be leveraged to help us characterize the environments of children[1] in poverty and to better understand the effects that these environments may have on the development of antisocial behavior. Because mobile technologies (such as smartphones, tablets, and iPads) provide researchers with enhanced capabilities for assessing social and physical environments, mood, self-regulation, and behavior as people live their everyday lives, these tools seem naturally suited to studying how exposure to relatively minor, yet meaningful stressors in everyday life may increase risk for antisocial behavior among children in poverty.

The chapter is organized into the following sections. In the first section, we discuss the concept of "environment" in children's development and follow with a review of evidence for how the environment of childhood poverty may lead to antisocial behavior problems in children. We focus primarily on the social environment, as the majority of environmental conditions associated with both poverty and antisocial behavior are social in nature (e.g. parental conflict, low parental support, deviant peer affiliation, exposure to violence; cf. Dodge, Coie, & Lynam, 2006; Evans, 2004). Next, we discuss how mobile technologies may help researchers meet the challenges of measuring children's everyday environments and understanding the effects of these environments for children's antisocial behavior. Then, given that not all children exposed to negative environments will develop antisocial behavior, we discuss theory and research suggesting that some children may be more sensitive to their environmental surroundings than others, such that they are at greatest risk when environments are bad but at lowest risk when environments are good (Ellis et al., 2011). We conclude with a discussion of future research directions that emerge from our review.

[1] Throughout, we use the term *children* to refer to both childhood and adolescence, and distinguish between the two developmental periods when necessary.

What Is the Environment of Childhood Poverty?

Imagine a child living in poverty. His home feels crowded; he has little privacy and he feels as though family members are always intruding into his space. His parents are exhausted and short tempered from working long hours, leading to frequent bouts of conflict at home. His school is underfunded and understaffed; his teachers seem constantly stressed and overburdened. He feels pressured to do bad things – like smoking and stealing – by kids at his school. He feels unsafe in his neighborhood, as high levels of crime and disorder characterize the streets surrounding his home. Continuous exposure to these stressful conditions takes its toll over time, as he struggles to keep his focus at school, soothe his seemingly constant anxiety and irritation amid the chaos at home and on the streets, and somehow plan for a future that becomes increasingly uncertain with each passing year.

As this vignette illustrates, the daily lives of children in poverty, are in a word, stressful. Not only do low-income children experience a greater number of major stressful life events (such as parental divorce or residential instability; Attar, Guerra, & Tolan, 1994; Gad & Johnson, 1980; Pryor-Brown, Cowen, Hightower, & Lotyczewski, 1986), but their everyday lives are simply more risky. Their homes, schools, and neighborhoods are more chaotic, unsafe, and conflictual than those of children from middle- to upper-class backgrounds (Evans, 2004). Their daily lives are more likely to be characterized by greater levels of family turmoil, exposure to violence, harsh parenting, low levels of social support, and crowded, chaotic living conditions compared to children who are not poor (Evans, Gonnella, Marcynyszyn, Gentile, & Salpekar, 2005; Grant et al., 2003; Repetti et al., 2002). While an impressive body of research shows that major stressful life events have profound effects on health and antisocial behavior (see e.g. Attar et al., 1994; Danese et al., 2009; Felitti et al., 1998; Whitfield, Anda, Dube, & Felitti, 2003),

evidence from adults suggests that chronic, accumulating exposure to more "mundane" hassles or stressors in everyday life may have effects that are just as strong, if not *stronger* (Almeida, 2005; Kanner, Coyne, Schaefer, & Lazarus, 1981; see review by Odgers & Jaffee, 2013). When combined with evidence that exposure to negative social conditions explains *over 50%* of poverty's effect on child antisocial behavior (Dodge, Pettit, & Bates, 1994), it seems likely that the everyday environment may be a principal source of risk for antisocial behavior in low-income children, as well as an important target for interventions.

How Can We Better Characterize and Understand Environmental Effects?

To obtain a better understanding of how everyday environments affect low-income children's development, it is necessary to start with a clear definition of what is meant by the environment. To this end, it is helpful to consider two complementary perspectives of what environment is. The first invokes the concept of environment as a *context* that consists of the structural and social characteristics of a person's surroundings. The environment-as-context perspective often serves a descriptive function, enhancing knowledge on environment by characterizing the specific exposures faced by individuals across different types of environmental settings, as well as how these exposures are associated with intellectual, behavioral, and physical outcomes. For example, studies that document the characteristics of low-income households (i.e., number of books on the shelf, cleanliness of the home; Bradley, Corwyn, McAdoo, & Coll, 2001), the specific types of daily stressors experienced by adolescents in poverty (Evans, Vermeylen, Barash, Lefkowitz, & Hutt, 2009) or the levels of aircraft noise in metropolitan neighborhoods (Cohen, Krantz, Evans, Stokols, & Kelly, 1981; Haines, Stansfeld, Head, & Job, 2002) provide a better understanding of environment as context.

The second perspective invokes the concept of the environment as a *causal agent*. The environment-as-agent perspective is rooted in behavioral genetics and developmental psychology, and it focuses on determining the causal (read "nongenetic") effects of both measured and unmeasured environmental factors. Studies in this tradition aim to understand whether environments have any effects when children's genes or genetically influenced characteristics are effectively held constant, through natural experiments, twin or adoption designs, and randomized controlled interventions (Moffitt, 2005; Rutter, 2005). This is important to do because prior to Bell's (1968) seminal argument on how children affect their environments (rather than the reverse), few studies had tested the hypothesis that children's genetically influenced characteristics could in truth be the causal agents behind what appeared to be environmental effects. This was followed by convincing arguments, buttressed by behavioral genetic research, that the effect of parental rearing environments was essentially null; children's genetically influenced characteristics were believed to elicit or otherwise account for much of the observed parental rearing effects (Harris, 1995; Scarr, 1992). More recent evidence has shown that parental environments do have potentially causal effects on children's development after all (e.g., Caspi et al., 2004; Jaffee, Caspi, Moffitt, & Taylor, 2004), but the lesson learned here is that in order to determine with any confidence that an effect is environmentally driven, one must first address – and at least partially rule out – preexisting characteristics of children and families that may serve as the primary source of the association between an environmental risk factor and children's behavior (Moffitt, 2005; Rutter, 2005; Rutter, Pickles, Murray, & Eaves, 2001).

Does Poverty Have an Environmental Effect on Children's Antisocial Behavior?

Jaffee, Strait, and Odgers (2012) reviewed evidence from experimental and quasi-experimental studies that could facilitate causal inferences – including natural experiments,

randomized controlled intervention trials, and twin/adoption studies – and found evidence that poverty has effects on children's antisocial behavior that are above and beyond genetic liability or other preexisting child and family characteristics. One of the studies they reviewed was a natural experiment that occurred during an ongoing longitudinal study of the development of psychiatric illness in children (Costello, Compton, Keeler, & Angold, 2003). Four years after the start of the study, a casino opened on a Native American reservation and provided all families in the study with a recurring income supplement that increased in value each year. For some of these families (14%), the income supplements moved them out of poverty, whereas 53% of families remained in poverty despite the supplements and 32% were never poor. Children in families who moved out of poverty showed significant decreases in antisocial behavior during the 4 years following the casino opening. The reduction was so pronounced that, after 4 years of income supplements, children whose families moved out of poverty had levels of antisocial behavior resembling those of the youth who were never poor. Conversely, American Indian children whose families remained poor despite the income supplements did not decrease their antisocial behavior. Because income supplements were delivered to an entire community of Native American families, this study provides a strong natural control for any preexisting characteristics of children and families that may confound the relationship between family income and children's antisocial behavior. As such, this study provides strong evidence that poverty plays a potentially causal role in the development of children's antisocial behavior.

Other studies reviewed by Jaffee and colleagues (2012) relied on quasi-experimental methods to identify whether poverty has environmental effects on children's antisocial behavior. For example, Strohschein (2005), in a study that compared children to themselves across time, showed that children engaged in more antisocial behavior when family income decreased and

less antisocial behavior when family income increased. Because this study compares each child's antisocial behavior to that of himself or herself at different points in time, it provides evidence that the effect of poverty on antisocial behavior cannot be explained by factors that remain unchanged, such as sex, ethnicity, and genetic makeup (Allison, 2005). In another quasi-experimental study of over 2000 twin pairs (50% of twin pairs were monozygotic), Caspi, Taylor, Moffitt, and Plomin (2000) showed that children in socioeconomically deprived neighborhoods had greater emotional and behavioral problems than children living in relatively advantaged neighborhoods, and that neighborhood deprivation had effects on children that were above and beyond the effects of genetic liability—thus evincing an environmentally mediated effect.

How Poverty Affects Children: The Role of Everyday Experience

Taken together, the aforementioned studies provide evidence that the effect of poverty on children's antisocial behavior is partly explained by environmental factors. These studies have answered the question of *whether* the environment of poverty affects children's antisocial behavior—the next step, therefore, is to determine *how*. In many of the explanations for how poverty affects children's antisocial behavior, the everyday environment takes center stage. In their *risky families model*, Repetti et al. (2002) suggest that everyday family interactions characterized as cold, unsupportive, and neglectful represent an important pathway through which poverty can affect child and adolescent well-being. Similarly, Hertzman and Boyce (2010, p. 331) argue that it is the "mundane, rather than [the] exceptional, exposures" that often have the largest effects by altering children's developmental pathways and leaving lasting imprints on adult outcomes. Predictions such as these have been borne out in studies of adults, which have shown that everyday stressors or "hassles" have stronger effects on physical and mental health

than major stressful life events (Almeida, 2005; DeLongis, Coyne, Dakof, Folkman, & Lazarus, 1982). Through their frequent, pervasive, and chronic nature, the effects of daily environmental conditions accumulate with continued exposure, sometimes leading to profound and long-lasting effects on well-being.

A striking example comes from the work of Hart and Risley (1995), who conducted monthly observational visits with 42 families, starting when children were 7-9 months old and ending at 3 years of age. In observed interactions with their parents, children from professional families (high SES) heard an average of 2,153 words an hour, whereas children from working-class families heard 1,251 and children from welfare families heard 616. This difference in language exposure was not inconsequential. By approximately age three, children from professional families had a vocabulary of around 1,100 words, whereas children from welfare families had less than half; that is, a vocabulary of around 500 words. From their data, Hart and Risley estimated that each year, children in professional families hear 11 million words whereas children in welfare families hear 3 million. One can clearly see that as the years go by, the gap in language exposure between high- and low-SES children will increase exponentially. Extrapolating to age 4, Hart and Risley estimated that children from welfare families will have heard *32 million* fewer words than children from professional families, which they dubbed *the 30 million word gap* (see Hart & Risley, 2003, p. 8). This ever-increasing gap in language exposure may be expected to produce an ever-increasing gap in cumulative vocabulary and, with it, a substantial decrease in life chances for low-SES children.

The work of Hart and Risley (1995) provides a compelling example of how children's everyday conditions can produce meaningful differences in their developmental outcomes. The accumulating nature of everyday environmental exposures (exposure to language in the Hart and

Risley study) may be expected to create ever-widening gaps in academic, behavioral, and physical outcomes for children across socioeconomic strata. In the same way that differential exposure to language led to ever-increasing vocabulary differences among children, it is likely that differential exposure to *stressful events* may produce ever-widening differences in antisocial behavior between low- and high-SES children and thus suggest one reason why antisocial behavior problems are so much more common in low-income youth. The multiple stressors indigenous to poverty, and the reactions these stressors evoke, are central to numerous models describing how poverty affects children's development (McLoyd, 2011). Two prominent examples include family stress (Conger et al., 1992; Elder, 1974) and cumulative stress models (Evans, Kim, Ting, Tesher, & Shannis, 2007), both of which emphasize the damaging effects of repeated stressor exposure and the frequent psychological and physiological reactivity that results. We describe the relevance of these perspectives for low-income children's antisocial behavioral development next.

The Family Stress Model

The family stress model suggests that economic hardship increases children's risk for emotional and behavioral problems by increasing tension, conflict, and hostility in the daily interactions of parents and children. Stress associated with life in poverty compromises parents' ability to respond supportively to their children and often results in more harsh and punitive parenting and family conflict (Bradley et al., 2001; McLoyd, 2011). High levels of family conflict, tension, and hostility increase children's risk for antisocial behavior because the home effectively becomes a training ground in which aggressive, angry, and hostile behavior is modeled, learned, reinforced, and further elaborated (Patterson, 1982; Patterson et al., 1992). The family stress model was originally informed by the classic work of Elder and colleagues (Elder,

1974; Elder, van Nguyen, & Caspi, 1985) following children of the Great Depression. Elder and his colleagues showed that economic hardship had negative effects on parents (primarily fathers), making them more rejecting, indifferent, and less supportive, which in turn had downstream negative effects on children's socioemotional development. Studies since have shown that negative parenting mediates the relationship between economic hardship and children's externalizing or antisocial behavior (Conger, Ge, Elder, Lorenz, & Simons, 1994; Grant et al., 2003).

The Cumulative Stress Model

The cumulative stress model suggests that frequent stressor exposure and prolonged stress reactivity play a key role in the development of socioemotional and behavioral difficulties among children in poverty. This view has been most strongly associated with the work of Gary Evans, who emphasizes the role of poverty-related stress in fostering difficulties in children's self-regulation and in promoting *allostatic load* (Evans & English, 2002; Evans et al., 2007), a physiological marker of wear and tear on bodily systems stemming from frequent activation of the stress response (McEwen, 1998; McEwen & Lasley, 2002). In a study of 8- to 10-year olds, Evans and English (2002) showed that low-income children experience a multitude of environmental stressors, including physical stressors such as higher levels of crowding, noise, and poorer housing quality, as well as psychosocial stressors including greater levels of family turmoil, family separation, and exposure to violence. For each of the stressors in this study, a child was classified as *exposed* if his or her score was greater than one standard deviation above the sample mean (with the exception of violence, for which any exposure was considered stressful). Not only was exposure to each of these stressors more common in the lives of low- versus middle-income children, but low-income children were also more likely to be exposed to

multiple stressors in their lifetime. In fact, 54% of low-income children in the study were exposed to three or more of these stressors in their lifetimes, whereas this was true for only 14% of middle-income children. Multiple-stressor exposure predicted poor psychological outcomes such as impaired self-regulation and poor mental health (including higher conduct problems), as well as poor physiological outcomes such as higher resting blood pressure and higher overnight urinary stress hormone levels (cortisol and epinephrine). Moreover, multiple stressor exposure was shown to mediate the relationship between poverty and children's psychological and physiological outcomes, supporting the idea that exposure to multiple, accumulating stressors may be an important pathway through which poverty increases children's risk for poor psychological outcomes such as antisocial behavior.

Next Steps: Can Mobile Technologies Help Identify Environmental Effects on Antisocial Behavior?

Based on this evidence, it seems clear that highly stressful everyday environments play an important role in the development of antisocial behavior for low-income children. A promising strategy for improving the lives of low-income children may be to gain a better understanding of how stressful everyday environments affect low-income children's day-to-day adjustment and risk for antisocial behavior. In doing so, researchers could identify specific environmental factors likely to play a causal role in promoting low-income children's antisocial behavior and thereby inform prevention and intervention efforts aimed at reducing their effects.

However, obtaining accurate and comprehensive measures of children's everyday environments remains a persistent methodological challenge. Although observational studies (e.g. Hart & Risley, 1995; Patterson, 1982; Patterson et al., 1992) provide enormous depth of observation and objectivity in measurement, they cannot well capture the *range* of exposures that

a child has in a given day because observers cannot follow the child everywhere he or she goes. Moreover, observational methods by their nature are restricted to measuring observables (i.e., emotional expression, instances of behavior) and may not be well suited toward measuring internal states such as affect and self-regulation, both of which (a) constitute important dimensions of how one reacts to experience and (b) may serve as momentary markers for emotional and behavioral problems or disorders (Larson, Richards, Raffaelli, Ham, & Jewell, 1990; Silk, Steinberg, & Morris, 2003; Whalen, Jamner, Henker, & Delfino, 2001).

Diary methods, also known as experience sampling methodologies (ESMs; Csikszentmihalyi, Larson, & Prescott, 1977) or ecological momentary assessment (EMA; Shiffman, Stone, & Hufford, 2008) strategies, may help researchers better meet the challenge of measuring everyday environments and their effects. Diary methods are assessment strategies that use pagers, handheld computers (Palm pilots), cellular phones, tablets such as the iPad, or paper-and-pencil entries to obtain repeated self-reports on individuals' contexts, social interactions, affect, motivations, self-regulation, and behavior at the tempo of daily life (Bolger, Davis, & Rafaeli, 2003). Because they allow near real-time measurement in people's natural environments, diary measures provide high levels of ecological validity and permit comprehensive reports of context, experience, and well-being. Moreover, diary methods have been effectively used across a wide range of age groups, demonstrating feasibility among children as young as 8 years (Whalen et al., 2009) to adults of oldest old age (Keller-Cohen, Fiori, Toler, & Bybee, 2006). As such, they may be fruitfully applied to measuring relationships between everyday environment and antisocial behavior among low-income children.

Of course, diary methods are not without their limitations. First, these methods often rely solely on self-reports of both exposure and outcome, which may create shared method variance

and artificially inflate associations between study variables. Second, the low frequency of severely aggressive or antisocial behaviors may make it difficult to observe environmental effects in daily life. However, researchers may limit assessments to conceptually related but less severe antisocial behaviors, such as bullying, lying, stealing, or vandalism, which are more likely to occur with sufficient frequency at the daily level. Third, because the intensive assessment procedures may become burdensome for children and adolescents, researchers may benefit from designing incentive strategies to keep youth engaged and responsive to diary assessments, especially if the assessments are particularly frequent or the duration of diary data collection is long (see Conner Christensen, Barrett, Bliss-Moreau, Lebo, & Kaschub, 2003 for an excellent review of these and other practical considerations inherent in diary research).

Despite these limitations, however, we believe that diary methods have unique features to contribute to the study of environmental effects on low-income children's antisocial behavior and, as discussed later in this chapter, we believe these methods may be especially promising when combined with the enhanced technological features of mobile phones and other newly emerging technologies. Next, we discuss three potential contributions that diary methods may make in this area. First, by assessing experiences close to when they occur, diary methods allow researchers to better measure the *environment as experienced*, rather than the environment *as remembered*. Second, diary methods allow researchers to appreciate that every child is different. Through repeated measurement of experiences *within* a person, diary methods allow us to appreciate (and measure) the specific constellation of experiences, emotions, behaviors, as well as the unique interrelations between these constructs, *for each child.* Third, the intensive within-person measurement of diary measures allows examinations of within-person processes that may help identify environmental effects. We discuss each of these features in more detail next.

Feature 1: Diary Methods Can Measure the Environment As *Experienced*, Rather than As *Remembered*

The first feature offered by diary methods is the ability to measure the environment *as it is experienced*, because reports of environmental exposures can be obtained within minutes to hours of when the child experiences them. This type of assessment differs from the more typical mode of measurement, which focuses on the *environment as remembered*. Here participants are asked to recall "how much", "how often", or "whether" specific things have happened over a longer time frame, often over the past 6-12 months. The environment-as-remembered measurement strategy is less than ideal if the goal is to accurately measure the routine environmental conditions of a person's daily life. This is because routine experiences are not as easily recalled over long time spans as are unusual events, leaving retrospective reports of daily events more susceptible to heuristic biases that may reduce reporting accuracy (Bradburn, Rips, & Shevell, 1987; Shiffman et al., 2008). This evidence suggests that as time passes, individuals may be increasingly likely to misremember or even forget routine stressful occurrences, leaving researchers with an incomplete understanding of how frequent and impairing these routine stressors can be. Other factors such as the participant's mood at the time of assessment can also affect the accuracy of recall (Shiffman et al., 2008). Diary methods may help researchers to minimize (but not eliminate) retrospective recall biases by shortening the window of recall to minutes or hours, a strategy that has been empirically shown to produce more accurate self-reports (see, e.g.,Shiffman, 2009).

One example among low-income children is provided by Evans et al. (2009). Evans and his colleagues used experience sampling methodology (ESM) to obtain hourly reports of daily hassles – minor stressors in everyday life – among both low- and middle-income rural

adolescents. The hourly assessment strategy stands in marked contrast to prior research on children's self-reported stressful events, which has typically relied on recall periods ranging from a month to a year (see, e.g., Attar et al., 1994; Compas, Davis, Forsythe, & Wagner, 1987; Kanner, Feldman, Weinberger, & Ford, 1987; Shahar, Henrich, Reiner, & Little, 2003), and because of this, it was able to provide an unprecedented look at the frequency, domain, and content of the daily events that characterize the everyday lives of low- versus middle-income adolescents. For example, Evans and colleagues corroborated prior research findings (e.g., Attar et al., 1994; Gad & Johnson, 1980; Pryor-Brown et al., 1986) by showing that low-income adolescents experienced a greater number of stressful events compared to middle-income adolescents. However, Evans and colleagues provided a more nuanced picture by showing that the source of this difference was primarily in the family context, as negative social interactions (e.g., nagging and activity prohibition from parents), chaotic living conditions, and lack of privacy at home were especially salient stressors for adolescents living in poverty, whereas low- and middle-income adolescents experienced a similar number of stressors in both school and peer domains. In short, the hourly assessment strategy used in this study was able to provide a richer picture of adolescents' daily contexts than had been achieved before, and it allowed for a better understanding of both the similarities and the differences in the daily experiences of low- versus middle-income youths.

In addition to momentary self-reports, the experienced environment can also be measured more objectively through the recording (photo, video, and voice) and global positioning system (GPS) capabilities of the latest generation of mobile devices (i.e., smartphones and tablets). Using these objective features allows researchers to get closer to measuring the *exposome*: the full catalog of an individual's environmental exposures (Borrell, 2011). For example, voice and

photo capture on mobile phones is being used to more objectively obtain dietary information from individuals in their everyday lives (see the Food Intake Visual and voice Recognizer or FIVR; Weiss, Stumbo, & Divakaran, 2010). Similarly, mobile phones' photo and video capture capabilities could be used to document the daily contexts and activities of children living in poverty. For example, as part of their daily assessments, youth could be asked to take pictures of "where they are right now" in addition to providing self-reported information about what they are doing. These images could be directly uploaded to the researchers' data files, circumventing privacy and confidentiality concerns. These photos could be coded on dimensions such as disorder (e.g., messiness of the home, quality of housing, vandalism present) and dangerousness (e.g., observer impressions of safety in the home, school, or neighborhood; see Odgers, Caspi, Bates, Sampson, & Moffitt, 2012 for an example of such coding using images from Google Street View). Combined with daily self-reports, these in-the-field photos of contexts could help researchers obtain a richer picture of the types of contexts that children in poverty actually experience in their daily lives.

Similarly, GPS now comes standard on the majority of mobile technologies, and can provide researchers with another means of acquiring objective measures of children's experienced environments. Using GPS, researchers can get a glimpse of the locations in which children spend their time, as well as the distances they travel in a given day around central locations (such as homes or schools). Wiehe and colleagues (2008) provided evidence that GPS-enabled mobile phones can accurately measure the travel patterns of adolescents in daily life, while at the same time allowing researchers to collect self-reports of adolescents' daily activities. Combined with objective information about the neighborhoods children frequent, researchers

could derive a measure of each child's exposure to disordered or dangerous contexts over the course of a day.

Feature 2: Diary Methods Allow Us to Relax the Assumption That Everyone Is the Same

Diary methods allow us to avoid what Conner, Barrett, Tugade, and Tennen (2007) have called the *nomothetic fallacy*: "assuming what is true for the 'average' person is also true for each and every person" (p. 81). The term *nomothetic* was first used by the philosopher Wilhelm Windelband (1894/1998), who broadly dichotomized academic disciplines into (a) those that sought to identify general laws and principles (e.g. natural sciences such as biology) and (b) those that focused on understanding the peculiarities and idiosyncrasies of specific individuals, events, or time periods (e.g. humanities such as history). The former he called *nomothetic*; the latter, *idiographic*. In his book *Personality: A Psychological Interpretation*, Gordon Allport (1937) introduced Windelband's dichotomy to psychologists. Allport suggested that with its nearly exclusive focus on discovering general laws that could apply to everyone, psychology was too entrenched in nomothetic inquiry and should make a greater effort to integrate idiographic inquiry (i.e. case studies or biographies of individual people) into its methodological armamentarium. His argument was that by relying primarily on nomothetic methods to obtain general laws about people, what psychologists were getting in their results described a "hypothetical average" person that in one sense represented everyone and yet in another sense represented no one.

Allport's urging for idiographic inquiry is highly relevant to research on how poverty-related stress influences children's development, because the majority of research in this area has been nomothetic in nature. Nomothetic designs are essentially between-subjects designs, seeking to uncover natural laws about how, for example, poverty-related stress increases risk for

antisocial behavior among *all* low-income children. These studies sample large numbers of people, assess them on static measures, and calculate correlations. Thus, nomothetic designs can tell us that among a large sample of children living in poverty, those with higher-than-average daily stressor exposure also typically have higher-than-average levels of antisocial behavior. These designs *cannot* tell us, however, that stress and antisocial behavior are related *within* a person over time. That is, a finding that children with higher-than-average stressor exposure tend to have higher-than-average antisocial behavior (a between-person effect) is not the same as a finding that children are more likely to engage in antisocial behavior compared to themselves on high- versus low-stress days (a within-person effect; see Bolger & Laurenceau, 2013; Curran & Bauer, 2011; Nesselroade & Ram, 2004 for further discussion of between- versus within-person variability and effects).

In fact, for most psychological processes, between- and within-person effects are likely to be independent, a fact that can be supported on both conceptual and empirical grounds (Bolger & Laurenceau, 2013; Hoffman & Stawski, 2009; Molenaar, 2004; Nezlek, 2001). At a conceptual level, between- and within-person effects are separate entities that most likely result from separate causal processes (Molenaar, 2004; Molenaar & Campbell, 2009). Take aggression as an example. Aggression can vary both between people (in terms of how aggressive each person is on average) and within a person over time (in terms of how much each person's aggression varies day by day). The causal processes explaining between-child differences in children's average levels of aggression are not likely to be the same as those explaining within-child differences in aggression from one day to the next. Why is this so? For one thing, stable factors that differ only between people, such as sex, ethnicity, family history, and genetic makeup, cannot logically explain why a single child was more aggressive on Monday than he was on

Tuesday (a within-person effect; see Allison, 2005; Bolger & Laurenceau, 2013). For another, it is seems highly unlikely that a single negative event (such as an argument with a friend) could explain why a child shows a higher mean level of aggression than his peers, whereas this single negative event could easily explain why a single child was more aggressive on one day versus another. At an empirical level, the size, direction, and significance of between- versus within-person effects routinely differ and may even suggest opposite conclusions (see Bolger & Laurenceau, 2013; Nezlek, 2001).

The conceptual and empirical independence of between- and within-person effects makes it clear that we need designs capable of capturing both. Through intensive measurement of children in their natural environments, diary methods represent a "modern idiographic approach" (Conner, Tennen, Fleeson, & Barrett, 2009, p. 292) allowing researchers to better understand both the constellation of environmental exposures as well as the specific environment-behavior relationships that together determine where and with whom each individual child is most like likely to display antisocial or aggressive behavior. These methods are not strictly idiographic, however; aggregating these person-specific results to the group level allows researchers to draw valid group-level inferences that are directly informed by in-depth person-level information (see Nesselroade & Molenaar, 1999 for an example). As such, diary methods allow researchers to answer Allport's call to idiographic arms while still allowing researchers to draw nomothetic inferences. Next, we discuss how diary methods may be applied to study both environments and environmental effects on low-income children's antisocial behavior, in a way that is sensitive to the idiosyncracies of each individual child.

The Structure of Exposure. Although children in poverty, on average, are more likely to experience stressors of all types compared to children not in poverty, each child in poverty is

likely to experience his or her own unique constellation of stressors in daily life. For example, some children in low-income circumstances may face stressors that predominantly relate to chaos in their home environments. Others may face stressors relating primarily to neighborhood safety, family conflict, or school bullying. Still others will confront an array of stressors that elude researchers' a priori attempts to neatly categorize them. Combining the intensive time-series measurement of diary studies with empirically driven statistical clustering techniques (i.e., factor and latent class analysis) offers new ways forward for measuring the specific constellation of stressor experiences that characterize each child's daily life.

Cross-sectional research by Seidman et al. (1999) provides an empirical foundation for identifying the constellation of stress exposures unique to each child. Using survey responses, Seidman and colleagues (1999) applied empirical clustering techniques (k-means and hierarchical clustering methods, see Hartigan, 1975; Rapkin & Luke, 1993) to identify different constellations of family and peer social interactions among adolescents in poverty. In both family and peer domains, they identified six clusters of social experience in family and peer groups. Example clusters from the family domain included *dysfunctional* (high hassles, low support, low involvement), *hassling* (high hassles, near average support and involvement), and *enmeshing* (high hassles, low support, high involvement); examples from the peer domain included *rejecting* (high hassles, low acceptance, low involvement and support), *entangling* (high hassles, high involvement and support), and *antisocial-engaging* (high antisocial peer values, high involvement and support). Importantly, membership in these clusters was associated with antisocial behavior in adolescents. In the family domain, adolescents in either the dysfunctional, hassling, or enmeshing clusters showed the highest levels of antisocial behavior. In the peer domain, adolescents in the antisocial-engaging cluster showed the most antisocial behavior.

The clusters identified by Seidman and colleagues (1999) are a grouping of youths who share similar experiences on average. They are not, however, a clustering of *experiences* within each youth. The difference is subtle but important. Empirical clustering of at the *group level* provides the profile, constellation, or factor structure of experiences that best explains the regularities of experiential reports for a group of individuals. It does *not* provide the specific constellation of experiences unique to each *person*. Instead, it takes what may be called a top-down approach, assuming that the group-level solution explains the regularities of experience for each group member. In contrast, by collecting repeated measurements of experience from each person, researchers can employ a *bottom-up* approach, obtaining a profile of experiences unique to each child in the study and then generalizing to the group level by identifying individuals who share similar profiles of experiences. Mapping the regularities of experience for each child in poverty would lead researchers to identify natural clusters of children who can be empirically shown (rather than assumed) to have the same constellation of experiences, and it would lead to stronger group-level inferences regarding the specific constellation of experiences that an actual child in poverty might encounter (see Molenaar & Campbell, 2009; Nesselroade & Molenaar, 1999; Nesselroade & Ram, 2004 for discussion).

The usefulness of the person-based approach has been clearly shown in the emotion literature. For example, in a 90-day diary study, Barrett (1998) obtained university students' reports on their positive and negative emotions three times a day (morning, afternoon, and evening). She then factor analyzed each person's multiple emotion reports separately (a method known as P-technique factor analysis; see Cattell, Cattell, & Rhymer, 1947) and found that some individuals tended to report "clustered" emotional experiences. In other words, when these individuals reported happiness, they were also more likely to report other positive emotions such

as joy and cheerfulness *at the same time* (the same was true for negative emotions). Others, however, showed greater differentiation in their real-time emotional reports, such that reports of happiness were less likely to be temporally coupled with other positive emotions (same for negatives as well). These results differ from those obtained using more traditional factor analytic approaches (R-technique; see Cattell, 1952), which would provide information regarding whether a person who reports more happiness on average also reports more joy on average—not whether people experience these emotions at the same time. From this more person-centered approach, Barrett (1998) concluded that a single theory of emotion is unlikely to apply to everyone, as people differed substantially in the complexity of their moment-to-moment (rather than average) emotional experiences. Another study (Carstensen, Pasupathi, Mayr, & Nesselroade, 2000) showed that some adults had a greater tendency to report positive and negative emotions simultaneously in their daily lives than others (which they termed *poignancy*), and that the tendency to experience mixed emotional states was higher among older versus younger adults (age range of the study was 19 to 94 years). Importantly, the type of information gained in the Barrett (1998) and Carstensen et al. (2000) studies can only be obtained through intensive within-person measurement, such as what diary methods can offer (Conner et al., 2009). A similar approach could be fruitfully applied to obtain a more idiosyncratic understanding of the environmental experiences that characterize a day in the life of a child living in poverty.

Environment-Behavior Signatures. Suppose we find two children who are equal in age, gender, and ethnicity, both of whom have spent their entire lives living in impoverished homes and communities. Suppose we observe these children further and find that they both show high levels of antisocial behavior relative to their same-age peers. Given their similarities, should we

assume that these children engage in antisocial behavior for the same reasons and in the same situations? According to personality theorists Walter Mischel and Yuichi Shoda (1995), the answer to this question is "no". It has been clearly shown that even between people who engage in similar levels of behavior on average (such as aggression), there will be important differences between them in terms of *where*, *with whom*, and *in which situations* each person will engage in aggression.

A classic example comes from a summer treatment camp study of children with self-regulatory and aggressive behavior problems (Shoda, Mischel, & Wright, 1994). Over 6 weeks, these children's behaviors were observed and recorded across a variety of situations. Shoda and colleagues found that children's levels of aggression were not constant across situations, as trait theories of personality would predict. Instead, children's aggression varied greatly across situations. However, Shoda and colleagues found that some situations reliably predicted aggression for some children, but not for others. In other words, some children may reliably show aggression when teased by peers but show no such aggression when scolded by adults. Other children may show the reverse pattern, engaging in aggression when scolded by adults but not when teased by peers. The significance of this finding is perhaps best articulated by Mischel (2004):

> Collectively, the results showed that when closely observed, individuals are characterized by stable, distinctive, and highly meaningful patterns of variability in their actions, thoughts, and feelings across different types of situations. These *if … then …* situation-behavior relationships provide a kind of "behavioral signature of personality" that identifies the individual and maps on to the impressions formed by observers about what they are like. (p. 8)

Evidence for predictable patterns of variability, or behavioral signatures, has been found across numerous independent investigations using a variety of methodologies (Leikas, Lonnqvist, & Verkasalo, 2012; Smith, Shoda, Cumming, & Smoll, 2009; Vansteelandt & Van Mechelen, 1998), including studies using diary methods (e.g., Fournier, Moskowitz, & Zuroff, 2008), which seem naturally poised to answer such questions. Using such methods among children in poverty, researchers could examine the particular environmental exposures or situations that reliably predict antisocial behavior in some children versus others. Using diary measures and multilevel modeling statistical techniques (Raudenbush & Bryk, 2002), a separate effect of each hassle (e.g., family conflict, chaotic home, school stressors) on momentary antisocial behavior can be obtained for each child. The strength of the association between daily hassles and antisocial behavior can be quantified as a regression coefficient for each child. This regression coefficient can then serve as an individual difference variable, characterizing each child's likelihood of engaging in various types of antisocial behaviors (e.g., verbal or physical aggression, anger, and hostility) across these specific situations (see Fleeson, 2007 for an example of this type of approach with personality). As predicted, one may find a group of children who show a strong likelihood of engaging in antisocial behavior when peer hassles are experienced, whereas another group of children shows a strong likelihood of antisocial behavior when parent hassles occur. Using other child or family characteristics, such as the child's previous level of stressful life events, history of antisocial behavior, and parental monitoring, one can then attempt to characterize children who show aggression in response to peer versus parent hassles in daily life.

Feature 3: Diary Methods Allow the Study of Within-Person Processes, Facilitating Causal Inference and Discovery of Environmentally Mediated Effects

Perhaps one of the strongest features of diary methods is their ability to capture processes that occur within a person in response to changing environments. This approach allows the researcher to control for a whole host of characteristics that remain stable over time, measured or unmeasured, by using each person as his or her own control across a range of situations or stressors. This design feature of diary studies gets researchers a step closer to causal inferences about environmental effects because in this within-person framework, stable characteristics such as genetic makeup, biological sex, and ethnicity are effectively held constant (Allison, 2005; Bolger & Laurenceau, 2013).

This within-person focus provides a novel way to facilitate causal inferences regarding the role of stressor exposure in children's antisocial development in a nonexperimental context. If it could be shown that change in stressor exposure correlates with change in antisocial outcomes *within the same child*, this could facilitate causal inferences regarding environmental effects because stable "selection" factors such as genetic makeup, sex, and ethnicity have been held constant. Causal inferences regarding the role of stressors can be further facilitated by adding statistical controls for other potential confounds that do vary over time, such as previous negative mood, sleep quality from the previous night, or even the passage of time itself. Moreover, diary methods allow the estimation of temporal patterns, allowing researchers to test whether stress exposure predicts antisocial behaviors, or vice versa.

A recent example of this type of approach in daily life comes from work by Stadler, Snyder, Horn, Shrout, and Bolger (2012). Using daily diaries in the lives of male-female couples, they found that within-person increases in physical intimacy between partners predicted within-person decreases in self-reported physical symptoms (e.g., headache, upset stomach, back/muscle ache). Stadler and colleagues (2012) further strengthened this result by showing that

previous increases in physical intimacy (from 2 days ago to yesterday) predicted *current* decreases in physical symptoms (from yesterday to today). They found no evidence for the reverse effect: Previous symptom change did not significantly predict current change in intimacy. All of their models controlled for the effects of elapsed time, following the rationale that this represents a proxy for unmeasured third variables (i.e., fatigue caused by duration of the study; a shared growth process that creates a spurious association between the two variables of interest; see Bolger & Laurenceau, 2013). Taken together, their results provide strong evidence for a causal effect of intimacy on physical symptoms because (a) their focus on within-person change ruled out stable selection factors, (b) they found no evidence for reverse causation, and (c) they statistically controlled for unmeasured time-varying processes that could confound the effects. Although they cannot completely rule out lurking selection effects because physical intimacy was not randomly assigned, the combined use of these methods in a daily life framework nonetheless provides a strong basis for facilitating causal inference.

This within-person process approach could be applied to the question of whether stressful events have environmentally mediated effects on low-income children's antisocial behavior. For instance, by using diary methods to test for the within-person effects of daily stressors on negative affect and aggressive behavior in daily life, each child is used as his or her own "control". If within-person effects are found, they cannot be explained by stable factors that differ between individuals but do not vary over time, such as sex, ethnicity, or genetic makeup. Additionally, information obtained through diary methods can be paired with real-time physiological measures of stress reactivity, such as heart-rate variability, which can now be obtained in children's natural contexts through the newest generation of ambulatory sensors. One

of these, the Zephyr Bioharness™ 3[2], allows real-time remote monitoring of parameters such as heart rate and breathing rate, and can wirelessly stream this information to mobile devices or to the researcher's desktop computer. By synching this information with children's diary reports of stressful events, researchers could obtain a more objective measure stress reactivity that does not rely exclusively on self-report. If daily stressors were found to predict within-person changes in negative affect, antisocial behavior, and physiological stress markers alike, this evidence would provide yet another step toward causal inferences because the effects cannot be explained away by shared method variance. By offering researchers the ability to examine the within-person effects of daily stressors on affect, behavior, and physiology, diary methods allow researchers to get closer to causality regarding whether everyday stressors affect children's antisocial behavior through environmental pathways.

In short, diary methods, delivered through the latest generation of mobile technologies, provide numerous opportunities to improve our current understanding of environmental effects on children's antisocial behavior, while allowing us to appreciate that not every child responds to adversity in the same way. Currently, we are in a unique position to pair the methodological advances offered by diary methods with exciting new theories about why some children may be more reactive to their daily events than others, and whether this increased reactivity can help explain their risk for poor outcomes (such as antisocial behavior) or their receptiveness to targeted intervention efforts. In the next section, we discuss how the within-person power of diary methods can provide novel ways to test theories of person-environment interaction, such as diathesis-stress (Monroe & Simons, 1991) and differential susceptibility (Ellis et al., 2011).

[2] http://www.zephyranywhere.com/products/bioharness-3/

Individual Differences in Environmental Effects: Why Are Some Children More Reactive to Experience Than Others?

On average, children in poverty are more likely to engage in antisocial behavior than children from higher income backgrounds. Not every child in poverty, however, will engage in antisocial behavior. This fact naturally leads to questions about why some children exposed to high poverty-related stress will develop antisocial behavior and others will not. An exciting idea known as differential susceptibility theory (DST; Ellis et al., 2011) suggests that some children may be, by nature, more sensitive to their environments, both positive and negative, than others. These "sensitive" children may be at greatest risk when environments are chronically stressful but at lowest risk when environments are consistently supportive (Belsky, Bakermans-Kranenburg, & van Ijzendoorn, 2007; Ellis et al., 2011). "Sensitive" or "susceptible" children may be distinguished by genes, physiological parameters, and behavioral phenotypes thought to be under high genetic influence such as early temperaments (Belsky & Pluess, 2009). DST suggests that children with one or more of these sensitivity markers may be more likely to develop negative outcomes (such as antisocial behavior) when exposed to negative contexts (such as disadvantaged homes and neighborhoods), but they may also be more likely to show positive developmental outcomes (i.e. good self-regulation, empathy, prosocial behavior) when exposed to positive contexts (such as supportive home environments and socially cohesive neighborhoods). This is an exciting possibility because it suggests that youth who were previously considered to be highly vulnerable may in fact be more validly considered highly *susceptible* to the good and the bad of whichever environments they are in. As a result, these vulnerable youth may be the ones who will benefit most from targeted interventions.

Here again, diary methods offer a novel and potentially powerful way to test the core assertion of differential susceptibility: that environmental effects are stronger for some children versus others. Differential susceptibility theory falls into a broader class of person-by-environment theories, such as the diathesis-stress model (Monroe & Simons, 1991). The diathesis-stress model suggests that some children possess genetic or temperamental characteristics that make them more vulnerable to bad environments, but not more responsive to good environments, as the differential susceptibility perspective suggests. The majority of research testing person-by-environment interaction theories has tested whether children with *both* an individual sensitivity marker and a negative environment have higher levels of antisocial behavior (for example) than children without the sensitivity marker, negative environment, or either (see, for example, Caspi et al., 2002; Lengua, Wolchik, Sandler, & West, 2000). This type of test is inherently between people, because it compares children to each other on their average levels of antisocial behavior and tests whether children with the most antisocial behavior are more likely to have *both* an individual vulnerability and an environmental risk. A complementary approach to testing person-by-environment theories is to ask whether "sensitive" children are more *reactive* to changing environments. In other words, do sensitive children show more behavior problems in stressful situations compared to themselves in nonstressful situations? This is essentially a within-person question, one which diary methods are well suited to answer. Using a within-person perspective may be particularly important for research on the differential susceptibility theory, because this theory suggests that sensitive children should both be more reactive to negative events *and* more responsive to positive events.

Figure 1.1 illustrates that the use of within-person changes in environments and behaviors could provide strong evidence for whether differential susceptibility operates in the daily lives of

youth. As children go through their daily lives, they experience both stressful and positive events. However, some children will be more sensitive to these events than others. Highly sensitive children (the dashed trajectory in Figure 1.1) will be more responsive to both stressful and positive events in daily life than typically sensitive children (the solid trajectory). As such, highly sensitive children are predicted to show greater increases in positive outcomes (e.g., prosocial behaviors and positive affect) when experiencing positive events *and* greater increases in negative outcomes (e.g., problem behaviors and negative affect) following negative events, such as daily stressors. Because diary methods allow us to (a) obtain true-to-life or ecologically valid reports of both positive and negative events in daily life, (b) test the effects of these events within each child, and (c) test whether within-person effects are stronger for youth with sensitivity markers, they allow a strong and direct test of the differential susceptibility model's key hypothesis that some children are more sensitive to their environments than others—for better *and* for worse (Belsky et al., 2007).

Which markers may help identify children who are differentially susceptible to environmental effects on behavior? To date, some of the strongest evidence points to the 7-repeat allele of the dopamine receptor D4 gene (*DRD4*-7R), a gene that has been previously associated with novelty/sensation seeking (Laucht, Becker, El-Faddagh, Hohm, & Schmidt, 2005), impulsivity (Congdon, Lesch, & Canli, 2008), anger and delinquency (Dmitrieva, Chen, Greenberger, Ogunseitan, & Ding, 2011), and attention-deficit/hyperactivity disorder (ADHD; Faraone et al., 2005). Rather than being solely a risk allele, the *DRD4*-7R gene may function more like a "plasticity allele", conferring increased sensitivity to whatever environment a child is in (Belsky et al., 2009). This increased sensitivity is thought to provide an evolutionary advantage when environments are positive, which may explain why genes and traits associated

with risk have nonetheless been preserved in the human species (Belsky, 2005). In support of this, a recent meta-analysis showed that children with "risky" dopamine genes such as the 7R allele showed *the most* externalizing (or antisocial) behavior in negative rearing environments, but children with these genes in positive rearing environments showed *the least* externalizing behavior (Bakermans-Kranenburg & van Ijzendoorn, 2011).

Particularly compelling support for the *DRD4*-7R gene comes from two experimental studies showing that an intervention designed to promote parent-child attachment was more effective in reducing externalizing behavior problems for children with versus without *DRD4*-7R (Bakermans-Kranenburg, van Ijzendoorn, Mesman, Alink, & Juffer, 2008; Bakermans-Kranenburg, van Ijzendoorn, Pijlman, Mesman, & Juffer, 2008). By conferring increased susceptibility to environmental influence, the *DRD4*-7R gene may identify children who are most sensitive to positive and negative events in their everyday lives. This hypothesis could be tested using diary methods that allow researchers to examine whether daily events have stronger within-person effects on behavior—for better and for worse—among low-income children with versus without the *DRD4*-7R gene. If low-income children with this gene are more sensitive to both positive *and* negative daily events, this evidence may suggest that these children, although at higher risk in their current environments, may be more likely to benefit from intervention strategies targeting the link between daily stressors and antisocial behavior.

Future Directions

Diary methods provide tremendous flexibility in the measurement of daily experiences, and their effects, on low-income youth. The most exciting future directions for these methods may lie in their combination with more "traditional" research designs, as well as interventions of known efficacy.

Diary Measurement Bursts: Combining Diary Methods and Longitudinal Designs

Antisocial behavior is a developmental phenomenon. Because of this, longitudinal study designs that follow children over key developmental periods (such as childhood and the transition to adolescence) are necessary in order to truly understand its causes. Although traditional longitudinal designs have provided us with much valuable information about how antisocial behavior develops over years (see e.g., Moffitt et al., 2001; NICHD Early Child Care Research Network, 2004; Sampson & Laub, 2005; Thornberry & Krohn, 2003; Tremblay, 2010), these designs may miss the micro-level processes that affect whether a child will engage in antisocial behavior on one day versus another – such as a provocation from a peer or harsh discipline from a parent (Dodge, 2006; Patterson et al., 1992). Diary methods are especially useful for understanding this type of micro-level change and may be powerfully combined with traditional longitudinal studies to better understand the interaction between short-term and long-term processes in the development of antisocial behavior.

Measurement burst studies embed daily-life measurement bursts into more traditional longitudinal studies that follow people over years (Nesselroade, 1991; Sliwinski, 2008). Despite their potential, these designs have not yet been applied to the study of antisocial behavior. These powerful designs could allow researchers to examine the interplay between short-term processes and long-term changes, and thereby improve our understanding of the causal pathways through which environmental conditions affect antisocial development. For example, measurement burst designs could provide investigators with a means for (a) examining how the relationship between stressor exposure and antisocial behavior changes over time and (b) learning how changes in these micro-level processes feed into developmental "turning points" (Sampson & Laub, 2005), such as desistence or escalation in antisocial behavior during key developmental transitions (such

as early adolescence). Moreover, these designs could offer better insight into the *timescale* of environmental effects. For example, with regard to the differential susceptibility hypothesis mentioned earlier, it is not yet known whether "sensitive" children (such as youth with *DRD4*-7R) will be more responsive to environments *in the moment* or whether this sensitivity will only manifest itself over years. In other words, should we expect that a single day of high support will predict less antisocial behavior the next day among youth with the *DRD4*-7R gene? Or does this relationship take years to manifest, such that we will only see larger decreases in antisocial behavior among youth with versus without *DRD4*-7R if they experience a home environment that remains supportive over longer time spans? Through their ability to separate empirically both short- and long-term processes of change, measurement burst designs could provide powerful and unique information regarding the role of environment in low-income children's antisocial development.

Interventions at the Right Time, in the Right Place

Mobile technologies are also providing researchers and health professionals with new opportunities for assessment and intervention among previously hard-to-access high-risk groups, such as children living in poverty. The movement toward using mobile technologies to administer assessments and deliver intervention has been dubbed *mobile health* (or mHealth) by the National Institutes of Health (National Institutes of Health, 2013) and includes diary measurement techniques such as those described earlier. Among children living in poverty, diary methods could be used to test – and eventually disseminate – message-based interventions focused on fostering positive coping strategies, triggered when youth report experiencing a stressful event. These approaches may offer promise, as evidence suggests that youth who use active coping strategies, such as problem solving, emotion regulation, and positive thinking may

be less likely to display emotional, behavioral, and physical health problems than youth who rely on avoidant coping strategies (Chen & Miller, 2012; Wadsworth, 2012). For example, mobile phone delivery of intervention content could be used as a supplement to cognitive-behavioral therapy (CBT; Beck, 1991), an intervention of known efficacy among youth with antisocial behavior (McCart, Priester, Davies, & Azen, 2006). Mobile devices could be used to reinforce intervention content by sending coping intervention-related messages, reminding children to use positive coping strategies when stressful events occur. In this way, mobile messaging may help clinical professionals with the daunting task of delivering time-tested interventions to high-risk groups, at the times and places they are needed most.

Summary

Children growing up in poverty are at risk for developing antisocial behavior, a significant and costly societal problem. Evidence suggests that the association between poverty and antisocial behavior is consistent with a causal interpretation, and emerging theoretical perspectives argue that the effect of poverty on antisocial development may be driven by the chronically stressful conditions of low-income children's everyday environments. However, accurate measurement of daily events remains a persistent methodological challenge, which limits the field's understanding of causal processes. Diary methods may help by allowing researchers to measure children's everyday experiences, emotion, self-regulation, and behavior as they go through their daily lives, in their natural environments, and in a way that is sensitive to the idiosyncrasies of each individual child. The latest generation of mobile technologies, through their ability to measure within-person change and capture more objective measures of context and physiology, provide added flexibility and can get researchers one step closer to a causal understanding of environmental effects on children's antisocial behavior. Moreover, these

mobile technologies are opening up exciting possibilities for the delivery of intervention to high-risk populations, at the times and places they are needed most. In sum, the stage is set for mobile methods to improve our understanding of environmental effects on children's antisocial behavior and to open up new opportunities for interventions aimed at improving the lives of low-income children and their families.

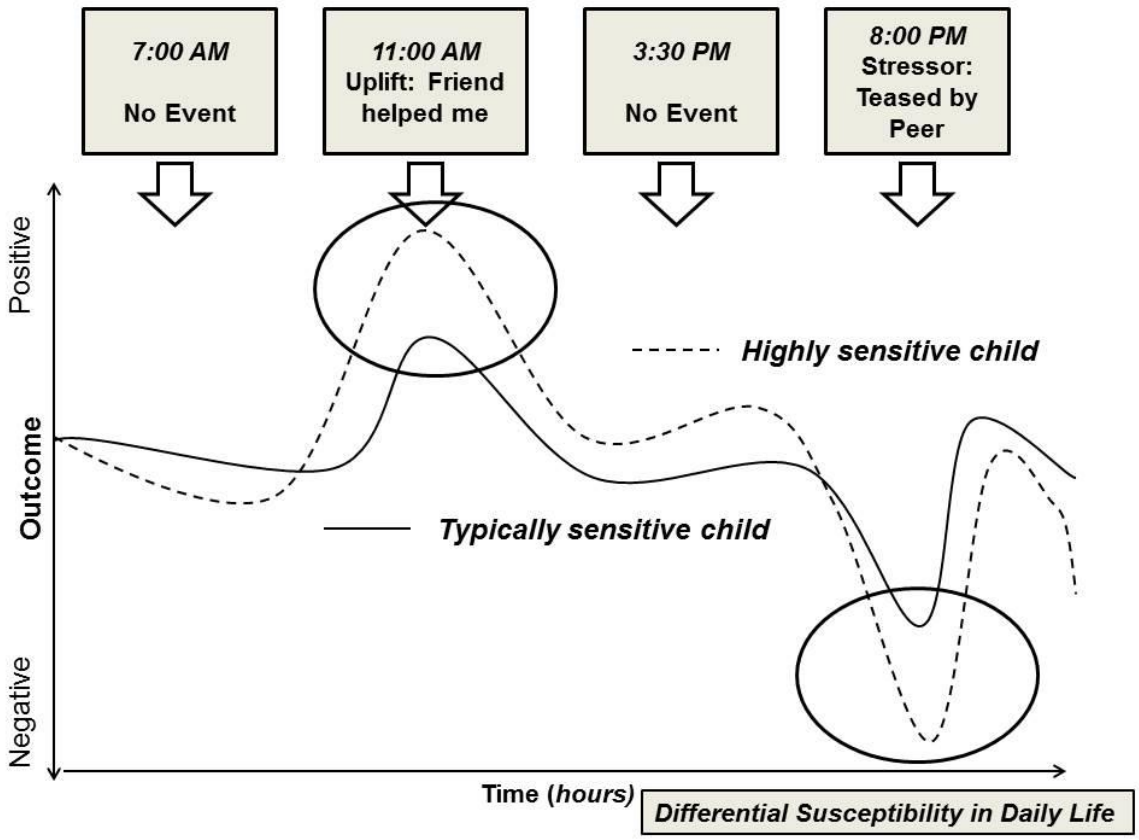


Figure 1.1. A hypothetical illustration of differential susceptibility to the environment in daily life.

CHAPTER 2

Adolescents with, versus without, the DRD4-7R Allele are More Reactive to Substance Use Exposure: Evidence for a Gene-Environment Interaction in Daily Life*

***Citation:**

Russell, M.A., Wang, V., & Odgers, C.L. (in preparation). Adolescents with, versus without, the DRD4-7R allele are more reactive to substance use exposure: Evidence for a gene-environment interaction in daily life.

Abstract

This study provides evidence that (a) adolescents are more likely to show problem behavior (i.e., antisocial behavior and substance use) on days when they witness others using substances and (b) adolescents with versus without the *DRD4*-7R allele are more behaviorally reactive across days when they do versus do not witness others' substance use. Participants were 141 adolescents from the miLife study (ages 11-15) who provided daily reports of contexts and problem behavior across 38 consecutive days using mobile devices. Results from multilevel models indicated that adolescents were more likely to engage in problem behavior on days when they witnessed, versus did not witness, others using substances. A significant gene-by-environment interaction illustrated that adolescents with, versus without, the *DRD4*-7R allele showed a greater increase in their odds of engaging in problem behavior across witnessing versus non-witnessing days. These effects were more pronounced when adolescents witnessed substance use *outside the home* (at school, in the neighborhood, or somewhere else) compared to when they witnessed substance use in the home. Adolescents with versus without the *DRD4*-7R allele were no more likely to witness others' substance use in their daily lives, suggesting the absence of a gene-environment correlation. The implications of our findings for theory and prevention of adolescent problem behavior are discussed.

Introduction

During early adolescence, the prevalence of antisocial behaviors such as fighting, stealing, and vandalism peaks (Moffitt et al., 2001), and a substantial number of youth begin experimenting with substance use (Johnston, O'Malley, Miech, Bachman, & Schulenberg, 2014). These facts are unsettling given that both antisocial behavior and early substance use (particularly substance use before age 15) are well-known predictors of poor adult outcomes, including substance dependence, physical health problems, crime and violence, and economic/occupational hardship (Grant & Dawson, 1997; Odgers, Caspi, et al., 2008; Odgers, Moffitt, et al., 2008; Theobald & Farrington, 2012).

What causes adolescents to engage in these problem behaviors? Evidence suggests that the etiology of problem behavior is complex and multifactorial, involving transactions between environmental circumstances and individual characteristics at both behavioral and genetic levels (see reviews by Dodge & Pettit, 2003; Iacono, Malone, & McGue, 2008), with conceptual models emphasizing that these transactions occur in the flow of everyday life (e.g., Granic & Patterson, 2006). However, the majority of research in this area has not been designed to test the fine-grained, momentary relationships these etiological models hypothesize, as most research designs do not directly measure adolescents' daily lives. Although there is a large amount of high-quality longitudinal research on the development of child and adolescent problem behavior (see for example Bierman et al., 1992; Farrington, 1989; Jaffee et al., 2004; Tremblay, 2010), the long gaps between assessment periods in these studies do not allow for a more fine-grained examination of the specific environments that facilitate problem behavior both "in the moment"

and over time, thus preventing a complete understanding of the development and expression of problem behavior among youth.

In the current study, we address these issues by using mobile phone surveys to examine the interplay between contexts, characteristics, and behavior in the daily lives of adolescents. Specifically, we tested whether adolescents were more likely to engage in problem behavior on days when they witnessed others using substances, including alcohol and other drugs, hereafter referred to as *exposure to substance use* (ETS). Next, we test whether adolescents with versus without the 7-repeat allele of the dopamine receptor D4 gene (*DRD4*-7R), a marker of genetic risk, show greater increases in the odds of problem behavior (compared to themselves) across exposure versus non-exposure days. We focus on ETS because it may engender a "facilitating context" where adolescent problem behavior is more likely to occur. That is, ETS in one's immediate contexts may signify the occurrence of concurrent antisocial or deviant activities, and may facilitate the adolescents' own involvement in antisocial activities or substance use through social modeling and influence processes (Bandura & Walters, 1963; Dishion, McCord, & Poulin, 1999). Because this is a naturalistic process that occurs in adolescents' daily lives, we used mobile phone surveys to obtain repeated measures of both ETS and problem behavior in adolescents' everyday environments, a measurement technique known as ecological momentary assessment (EMA; Shiffman et al., 2008), experience sampling methodology (ESM; Csikszentmihalyi et al., 1977) or diary methodology (Bolger et al., 2003). Using diary methods via mobile phone surveys allowed us to (1) obtain measurements of adolescents' contexts and behaviors in-the-moment or shortly after they occurred, thus reducing recall biases; (2) test the *within*-person relationship between ETS and problem behavior using each adolescent as his or

her own "control" across time, and (3) test whether ETS was a stronger predictor of problem behavior among adolescents with the *DRD4*-7R allele versus those without.

Environmental Risk, *DRD4* Genotype, and Adolescent Problem Behavior

Numerous studies have shown that children and adolescents who are exposed to substance use in their immediate contexts, such as with parents at home and or with peers in their schools or communities, are at increased risk for antisocial behavior and substance use (e.g., Chassin, Rogosch, & Barrera, 1991; Hawkins, Catalano, & Miller, 1992; Loukas, Zucker, Fitzgerald, & Krull, 2003). However, it is not clear that exposure to others' substance use *per se* has a causal effect on the development and expression of adolescent problem behavior. For example, the relationship between parental substance use in the home and adolescent problem behavior may be explained by *familial or genetic confounding*—a shared liability (genetic or otherwise) that predicts both the exposure (witnessing others' substance use) and the outcome (problem behavior), which has been evidenced in genetically informative studies on the relationship between parental substance use and offspring antisocial behavior (see e.g. Haber, Jacob, & Heath, 2005; Waldron, Martin, & Heath, 2009). Similarly, studies of the relationship between deviant peer affiliation and adolescent problem behavior have shown that this relationship is partly driven by a process known as *social selection*, whereby adolescents who are prone to antisocial behavior selectively affiliate with peers who engage in deviant behaviors such as substance use (Burt, McGue, & Iacono, 2009; Kendler, Jacobson, Myers, & Eaves, 2008).

In their recent review of experimental and quasi-experimental studies aimed at understanding the causes of children's antisocial behavior, Jaffee et al. (2012) provide evidence for both environmental causation and social selection/genetic confounding across studies that

examined parental substance use and peer deviance as predictors of antisocial behavior. They note that evidence for environmental causation is stronger in studies of peer deviance. In addition, they suggest that an understanding of the causal pathways leading to antisocial behavior in children and adolescents may benefit from studies that measure youth's contexts and behaviors with a higher resolution, such as daily diary designs that can examine the relationship between ETS and problem behavior *within* individuals in their daily lives, using each adolescent as his or her own "control" to hold genetic influences and stable selection factors (such as sex and ethnicity) constant. Although random assignment of exposures is needed to truly establish environmental causation, research relying on within-individual change to rule out genetic influences and stable selection factors can allow researchers to get one step closer to causal inferences in this area while maintaining a high level of ecological validity.

If ETS has environmentally mediated effects on adolescents' problem behaviors, how might these effects be transmitted? Mechanisms of transmission may differ based on the contexts in which exposure occurs. In the home environment, witnessing substance use may lead to adolescent problem behavior via increased familial-environmental stress and disruption (Chassin et al., 1991) and less effective parental monitoring, a known protective factor against the development of problem behavior (Dishion & McMahon, 1998). With peers or others outside the home, exposure to substances may lead adolescents to engage in antisocial behavior and substance use through a process of deviancy training (Dishion et al., 1999), whereby adolescents who do versus do not affiliate with deviant and substance using peers learn and are reinforced for problem behaviors more readily. Risky, deviant, and antisocial behaviors often occur in conjunction with substance use, such that some have argued these behaviors form a coherent "problem behavior syndrome" (Donovan & Jessor, 1985) with shared etiological factors

promoting their development over time (Curcio, Mak, & George, 2013) and perhaps even their expression in daily life. Thus, adolescents spending time with siblings, peers, or others who are using substances may be more likely to use substances themselves and/or may be more likely to engage in deviant or risky behavior that might accompany others' substance use. In the current study, we are able to test whether witnessing others' substance use influences the same-day behavior of youth by leveraging repeated observations of both ETS and antisocial behavior within individuals over one month period.

The *DRD4*-7R allele and Increased Vulnerability to Substance Use Exposure

Of course, not every adolescent who encounters substance use in his or her everyday contexts will be persuaded or enticed to engage in problem behavior. In fact, there will be wide variation in the effect that substance use exposure has on whether an adolescent will engage in antisocial behavior themselves. Traits that may confer vulnerability are many (Ingram & Price, 2010), and include genetic makeup, as prominently featured in studies of gene-environment interaction or G x E (see reviews by Belsky et al., 2009; Caspi & Moffitt, 2006; Dick, 2011).

A gene that has received particular attention for its role as a vulnerability factor for substance use and problem behavior is the *DRD4*-7R allele. The *DRD4* gene is located on chromosome 11 and is highly polymorphic in the human population, displaying a variable number of tandem repeats of a 48-base pair (bp) sequence located in exon 3 (Ding et al., 2002; Vantol et al., 1992). This 48-bp sequence ranges from 2 to 11 repeats, with the 4-repeat (4R) and the 7-repeat (7R) versions being the most common (Ding et al., 2002). Compared to shorter alleles (6R and below), the 7R allele has been associated with reduced dopamine reception efficiency, through mechanisms such as decreased ligand binding (Asghari et al., 1994) and reduced inhibition of intracellular cyclic AMP when dopamine binds to the receptor (Asghari et

al., 1995). Behaviorally, the *DRD4*-7R allele is associated with numerous externalizing spectrum outcomes, including novelty/sensation-seeking (Benjamin et al., 1996; Ebstein et al., 1996; Laucht et al., 2005), delinquency and anger (Dmitrieva et al., 2011), poor inhibitory control (Congdon et al., 2008), and attention-deficit/hyperactivity disorder (ADHD; Faraone et al., 2005).

Individuals with versus without the *DRD4*-7R allele may also be more sensitive to their environmental circumstances, suggesting a G x E. For example, experimental studies suggest that individuals with the *DRD4*-7R allele may be more sensitive to contexts where substance use cues are present, and may be more likely to crave or use substances as a result. These studies have shown that individuals with versus without the "long" *DRD4* allele (7 or more bp repeats) are more likely to crave cigarettes and alcohol in response to experimentally induced cues for smoking (Hutchison, LaChance, Niaura, Bryan, & Smolen, 2002) and "priming" doses of alcohol (Hutchison, McGeary, Smolen, Bryan, & Swift, 2002) in the laboratory. It has also been shown experimentally that young adults with versus without the *DRD4*-7R allele were more likely to consume alcohol in the presence of heavy-drinking peers (Larsen et al., 2010), providing evidence that individuals with the 7R allele may be more susceptible to social influence processes leading to substance abuse in daily life. Experimental and meta-analytic evidence also suggests that youth with versus without the *DRD4*-7R allele may be more susceptible to their social environments, displaying higher levels of externalizing behavior when environments are risky and lower levels of externalizing behavior when environments are secure and supportive (Bakermans-Kranenburg & van Ijzendoorn, 2011; Bakermans-Kranenburg, van Ijzendoorn, Pijlman, et al., 2008). Taken together, this evidence suggests that adolescents with

DRD4-7R may be more susceptible to environmental risks, of which exposure to others' substance use is one, and may be more likely to engage in problem behavior as a result.

Studying G x E in Daily Life via Mobile Technology

Although there have been many studies testing gene-environment interaction for problem behavior outcomes (see meta-analyses by Bakermans-Kranenburg & van Ijzendoorn, 2011; Kim-Cohen et al., 2006), the majority of research in this area has relied on has relied on between-person comparisons, testing whether adolescents with *both* a risk genotype and a risky environment show more problem behavior, on average, than adolescents who have only the risk genotype, the environment, or neither. Studies utilizing between-person comparisons in this way cannot test an important implication of person-environment interaction models: that "vulnerable" individuals (such those with the *DRD4*-7R allele) will be more *reactive* to risky versus non-risky environments as they experience them in their daily lives. That is, theoretical models of person-environment interaction (e.g. Ellis et al., 2011; Monroe & Simons, 1991) implicitly cast the relationship between environmental risks and behavioral outcomes as a *within-person*, naturalistic processes, describing how a person reacts or changes in response to experiences as they happen. Therefore, research designs such as diary methods, which can repeatedly measure the same individuals over time and in their natural contexts, are needed to (a) document this within-person process and (b) test whether this within-person process differs between those with vulnerability factors such as *DRD4*-7R and those without.

Moreover, diary methods offer important methodological strengths that could be well used in G x E studies. First, the near real-time, naturalistic measurement of emotion, behavior and environment in adolescents' daily lives shortens the recall window from days to hours,

enhancing ecological validity of environmental exposure measures and reducing recall biases (Bradburn et al., 1987; Shiffman et al., 2008). Second, these studies allow us to test genes as moderators of *within-person processes*, which more closely maps onto theories of person-environment interaction (Ellis et al., 2011; Monroe & Simons, 1991) than studies that do not directly measure within-person processes. Third, within-person comparisons offer a natural control for passive gene-environment correlation (*r*GE), whereby genes operate as "third variables" explaining the association between the environment and the behavioral outcome (Jaffee & Price, 2007). In G x E models, it is assumed that the environment exerts a causal effect on behavior, and that this environmental effect differs by genotype (Moffitt, Caspi, & Rutter, 2006). Passive *r*GE confounds this interpretation because it suggests that a common genetic liability explains why the environment and the behavior are correlated, and in so doing, potentially renders the environment-behavior relationship spurious. Diary methods offer a natural control for passive *r*GE by allowing researchers to rule out all stable individual differences, including genetic makeup, through within-person comparisons. These methods do not, however, control for active *r*GE, which describes a process through which a person's genes or genetically influenced characteristics lead them to select into risky environments or evoke risky behavior from others (the latter is referred to as evocative rGE; Jaffee & Price, 2007). In the present study, we test for active *r*GE by testing whether adolescents with versus without the *DRD4*-7R gene show higher levels of substance use exposure across the study period.

The Current Study

This study takes a novel approach to the study of gene-environment interaction in adolescents' daily lives. Using mobile phone surveys in adolescents' natural contexts, we (1)

obtained ecologically valid measures of substance use exposure, when and where they occurred, (2) tested whether adolescents were more likely to engage in problem behavior on days when they were versus were not exposed to substance use, and (3) tested whether adolescents with versus without the *DRD4*-7R showed greater increases in the odds of problem behavior across exposure versus non-exposure days. The current study is also novel in that it examines the daily interplay between ETS and problem behavior during early adolescence, a unique window of vulnerability for the development of these problems. Moreover, by focusing on processes that occur within a person, each adolescent is used as his or her own "control" over time, thus facilitating causal inferences.

Method

Participants

The miLife Study used EMA via mobile phones to track the daily experiences, behaviors and emotions of a sample of adolescents (n = 151) at heightened risk for both substance use exposure and problem behavior for an average of 38 consecutive days (*SD*=13.5). Participants ranged in age from 11 to 15 years (M = 13.0, SD = 0.90), with males and females equally represented in the sample (48.9% female) and 41.8% of the participants identifying as belonging to an ethnic minority group. Parents (90% biological mothers) of the adolescents (n = 141) also participated in the study and provided information on their family's health, socio-economic status, and relationship quality. Parents gave informed consent and the adolescents gave assent. The University of California Irvine Institutional Review Board approved all measures and procedures in the study.

Procedure

Adolescents from low SES neighborhoods were targeted and recruited via telephone screening. To determine eligibility for the study, parents completed a brief screen that recorded whether their child had experienced learning or behavioral difficulties at school, inattention or hyperactivity problems, substance use and/or exposure to alcohol or drugs by family members or peers. Adolescents for whom the parent reported the presence of 3 or more of the above risk factors were invited to participate in the study. Following a description of the study procedures, parents provided informed consent for their own and their child's participation in the study and adolescents provided assent. In private interview rooms, both the parent and the adolescent completed a battery of self-report inventories on laptop computers.

The adolescent assessment gathered information on school performance and experiences, stressful life events, perceived socio-economic status, substance use and exposure, mental health, connectedness with family and friends and diet and exercise. The parent assessment involved both structured self-report inventories as well as a qualitative interview. Parents reported on the child's use of substances, mental health, pubertal development, sleep, diet, exercise and behavior. Parents also provided information on the economic status of the family, educational and employment history, living conditions, family history of mental health problems, neighborhood problems and resources. Parents and adolescents each received a $20 gift card for their participation in the baseline component of the study.

Following the baseline assessments, adolescents were provided with smart phones that were programmed to "beep" the participant three times a day for 30 consecutive days. Alarms were individually programmed to be compatible with each adolescent's normal waking hours as well as their school schedules and other activities. The morning survey was scheduled between

the times of 7 and 10 am, and took approximately 2.3 minutes to complete. The afternoon survey was scheduled between the hours of 2 and 5PM, and took on average 3.8 minutes to complete. Finally, the PM survey was scheduled between the hours of 5PM and midnight, and took on average 8.3 minutes to complete. Each study participant was assigned a "case manager" who monitored the incoming data, tracked response rates and sent a text message reminder when adolescents had missed two or more sessions in a row. The average response rate across the mobile assessment period was 92%. Adolescents were paid $25 for each of the four study weeks that they completed.

Approximately 18 months following the initial assessments, adolescents were again interviewed to assess mental health, behavioral and educational status. During this follow-up visit, adolescents were also asked to provide a saliva sample for the purpose of DNA extraction and genotyping of selected alleles, including the *DRD4*-7R allele. One-hundred and forty-one adolescents provided saliva samples either during this follow-up visit or via mail; *analyses for the present report are restricted to these 141 youth.*

DNA Collection and Extraction. Saliva samples were collected from adolescents using Oragene OG-500 collection tubes. Samples were stored at room temperature and transferred to a genomic facility for extraction and analysis. Genomic DNA was extracted from saliva samples using the prepIT L2P procedure (DNA Genotek). All samples were RNase treated for 15 minutes at 37ºC before DNA precipitation. The DNA precipitate was washed with 70% ethanol, then air dried. DNA pellet was dissolved in a nuclease-free distilled water (Qiagen). The DNA concentration was determined using a GE Nanovue Spectrophotometer.

Genotyping for the DRD4 exon 3 VNTR polymorphism was performed using polymerase chain reaction (PCR) combined with band size analysis. The forward primer sequence is (5'-ACCGCGACTACGTGGTCTACTCGTC-3') and the reverse (5'-CCCGCCCCTCAGGACAGGA-3'). This amplifies a 517 base pair product for the 4 repeat (4) allele and a 661 base pair product for the 7 repeat (7) allele. PCR products were separated on 2% agarose gel supplemented with ethidium bromide and visualized by ultraviolet transillumination. Digital images of the gels were taken, and band size was determined based on comparisons to 100 bp ladder molecular weight standards (Hyperladder IV, Bioline). From these digital images, adolescents' *DRD4* genotype was determined. *Consistent with previous studies, we split adolescents into two groups: (1) those who possessed at least one copy of the 7R allele on either chromosome versus (2) those who did not possess the 7R allele.* Among the 141 adolescents who provided saliva samples, 35% carried at least one copy of the 7R allele (n=50). The prevalence of the 7R allele did not differ by gender (34.7% of males, 36.2% of females, χ^2=0.04, p=0.85) nor by ethnicity (39.0% of non-whites, 32.9% of whites, χ^2=0.55, p=0.46).

Measures

Exposure to substances in daily life was measured using four items asking adolescents to report whether they saw anyone drinking or using drugs (1) at home, (2) in school, (3) in their neighborhoods, or (4) "somewhere else" using "Yes" or "No" responses. From these, we created a single indicator of exposure to substance use in *any* of these contexts by summing these "Yes" responses and dichotomizing the variable, so that "1" meant the adolescent reported substance use exposure in at least one of the four contexts, and "0" meaning the adolescent was not exposed. Item-level information was also used to test for context-specific effects of ETS. The

intraclass correlation (ICC) for exposure to substance use, calculated using an empty multilevel logistic model with a random intercept, was 0.37, indicating that 37% of the variance in substance use exposure in daily life is between adolescents, whereas the remaining 63% is within adolescents over time. Sixty-two percent of adolescents (n=87) reported ETS at least once, reporting ETS on an average of 15.0% of days (Min=1.9%, Max=80.0%). By context, 28% of adolescents (n=40) reported being exposed to substances in their homes (M=9.9% of days, Min=2.3%, Max=54.5%), 34% of adolescents (n=48) reported ETS in their neighborhoods (M=8.9% of days, Min=1.9%, Max=69.0%), 14% of adolescents (n=20) reported ETS in school (M=6.2% of days, Min=2.9%, Max=23.3%), and 51% of adolescents (n=72) reported ETS "somewhere else" (M=10.3% of days, Min=2.4%, Max=48.5%).

Problem behavior in daily life was measured using 8 Yes or No items asked during the evening diary. Six items asked about antisocial behaviors, such as aggression (Today did you hit or hurt someone?), vandalism (Today did you damage someone else's property?), and theft (Today did you steal something that did not belong to you?). Two of the items asked about substance use, including one item asking about alcohol or drug use that day and one item asking about cigarette smoking. These 8 items were summed to create a problem behavior score for each day. This score was then dichotomized so that 1=adolescent engaged in at least one of these behaviors and 0=the adolescent did not engage in any of these. The ICC for problem behavior was 0.44, indicating that 44% of its variance was between adolescents, whereas 56% of its variance was within adolescents. Fifty-three percent of adolescents (n=75) reported engaging in problem behavior at least once (M=17.5% of days, Min=2.0%, Max=100.0%).

Analytic Strategy and Statistical Model

Participants included 141 adolescents who provided reports over 38 consecutive days on average (*SD*=13.6). Because the daily reports are nested within individuals, two levels of analysis are utilized: the within-person level (Level 1) and the between-person level (Level 2). At the within-person level, we tested whether adolescents were more likely to engage in problem behavior compared to themselves on days when they were versus were not exposed to others using substances. At the between-person level, we tested whether the within-person relationship between substance use exposure and problem behavior was greater for adolescents with versus without the *DRD4*-7R allele, as hypothesized.

To obtain within-person effects of ETS on problem behavior and account for the nesting of daily observations within adolescents, we conducted our analyses in a multilevel modeling framework (Raudenbush & Bryk, 2002) using SAS PROC GLIMMIX. We used the following model to estimate the within-person relationship between ETS and problem behavior in daily life, as well test whether carriers of the *DRD4*-7R allele were more behaviorally reactive when exposed to substances in their daily lives (the *DRD4*-7R x ETS interaction):

$$PRB_{ij} = \beta_0 + \beta_1(ETS_day_{ij}) + \beta_2(DRD4\text{-}7R_i) + \beta_3(DRD4\text{-}7R_i \times ETS_day_{ij}) + \beta_4(ETS_person_i) + u_{0i} + u_{1i}(ETS_day_{ij}) + \rho + e_{ij} \quad (1)$$

In this model, PRB_{ij} is the log odds of problem behavior for adolescent *i* on day *j*. Because the PRB_{ij} outcome was dichotomous, models were specified in PROC GLIMMIX using a binomial distribution and a logit link. The ETS_day_{ij} variable is a dichotomous marker of whether ETS was reported by adolescent *i* on day *j*, where 1=exposed and 0=not exposed, and the *DRD4*-$7R_i$

variable is a dichotomous marker of whether adolescent *i* carries at least one copy of the 7R allele. *DRD4*-$7R_i$ x ETS_day_{ij} represents the G x E, testing whether the within-person relationship between ETS_day_{ij} and PRB_{ij} differs between adolescents with versus without the 7R allele. The ETS_person_i variable is the average level of ETS for each adolescent across all days of the study, and is the proportion of days each adolescent reported witnessing others use substances in their immediate contexts. The ETS_person_i variable was multiplied by 100 so that it represented the % of days each adolescent was exposed to substance use during the study period, and then centered around its sample mean (M=9.25%). When this variable is included in the model, it removes all between-person variation in the ETS_day_{ij} variable, thereby allowing the estimation of a purely within-person relationship between ETS_day_{ij} and problem behavior, as well as a test of whether the within-person relationship between daily ETS and problem behavior differs between adolescents with versus without the *DRD4*-7R allele (the G x E).

The random effects in Equation 1 include the following. The Level 1 residual e_{ij}, represents the amount of daily within-person variation in the log odds of problem behavior that remains unexplained by the model. To account for the fact that problem behavior values closer together in time were more highly correlated than those farther apart, we included residual autocorrelation parameter ρ in the model, which modeled the autocorrelation using a spatial power structure SP(POW). SP(POW), like a first-order autoregressive AR(1) structure, assumes an exponential decay in the correlation between residuals, such that problem behavior residuals 1 day apart are assumed to be correlated ρ, those 2 days apart are assumed to be correlated ρ^2, and those 3 days apart are assumed to be correlated ρ^3. SP(POW) differs from AR(1), however, because it adjusts for unequal time intervals between adjacent observations, which often arise in

daily diary designs as a result of missing data (Bolger & Laurenceau, 2013). That is, SP(POW) estimates the autocorrelation between time-adjacent observations using the exact distance between them (e.g., 2 days, 3 days, et cetera), and uses these estimates to calculate what the autocorrelation might have been if observations were only 1 day apart, producing a single autocorrelation parameter ρ for the entire sample. Two random effects at Level 2 were also included in the model, random intercept u_{0i} and random ETS_day slope u_{1i}, which estimate between-person differences in adolescents' log odds of externalizing on non-exposure days (the random intercept) as well as in the strength of the daily ETS- problem behavior relationship (the random ETS_day slope).

Results

Descriptive Results

Table 2.1 compares the mean proportion of days that adolescents with versus without the *DRD4*-7R allele reported ETS and problem behavior and illustrates two main findings. First, we found no evidence that adolescents with versus without the *DRD4*-7R allele experienced ETS on a higher proportion of study days, providing some evidence against the presence of an active gene-environment correlation. Second, for both 7R and non-7R carriers, ETS was higher outside the home (approximately 8% for both groups across neighborhood, school, and other contexts) than inside the home (approximately 3% for both groups).

Are adolescents reactive to ETS in daily life, and are those with versus without the *DRD4*-7R allele more reactive when exposed to substances in their homes, schools and communities?

Table 2.2 shows results from two multilevel logistic models, the first testing the main effects of ETS and *DRD4* genotype (the Main Effects model), and the second testing whether adolescents with versus without the *DRD4*-7R allele showed larger increases in the odds of problem behavior across exposure versus non-exposure days (the G x E model). Table 2.2 illustrates four main findings. First, in the Main Effects model, there was a significant main effect for daily ETS, suggesting that on average, adolescents were significantly more likely to engage in problem behavior on days when they witnessed others using substances compared to themselves on days when they did not witness substance use. Second, the significant effect for Person-Mean ETS suggests that adolescents with higher versus lower mean levels of ETS were significantly more likely to engage in problem behavior during the study period. Third, there was no evidence for a main effect of *DRD4*-7R, suggesting that adolescents with the *DRD4*-7R allele are no more likely to engage in problem behavior across the study period than adolescents without the 7R allele. Fourth, Table 2.2 also provides evidence of a gene-environment interaction (see the G x E model). The significant *DRD4*-7R x Daily ETS interaction effect suggests that the within-person relationship between ETS and problem behavior differed by *DRD4* genotype. The daily ETS effect on problem behavior was considerably stronger for adolescents with the *DRD4*-7R allele (OR=6.14, $p<0.001$, 95% CI: 3.44, 10.95) compared to adolescents without the 7R allele (OR=2.04, $p=0.011$, 95% CI: 1.18, 3.53). This interaction effect is displayed in **Figure 2.1**.

Next, we tested whether adolescents with the *DRD4*-7R allele were more reactive to substance use exposure in specific contexts, such as inside the home versus outside the home. To do this, we repeated the Main Effect and G x E models shown in Table 2.2 twice; once using a marker of substance use exposure in the home (Home ETS, Table 2.3), and once using a marker of substance use exposure *outside the home*, which included reports of whether adolescents

reported ETS in their neighborhoods, schools, or other contexts (Outside Home ETS, Table 2.4). **Table 2.3** shows results from multilevel logistic models testing home ETS and *DRD4*-7R main effects as well as their interaction effect on daily problem behavior. Three findings are noteworthy. First, the Main Effects model shows that although adolescents were more likely to engage in problem behavior on days when they witnessed versus did not witness substance use at home, this relationship was only marginally significant ($p<0.10$). Second, adolescents with higher versus lower mean levels of home ETS were more likely to engage in problem behavior during the study period, as evidenced by a significant effect for person-mean home ETS. Third, the G x E Model in Table 2.3 shows that the interaction between *DRD4*-7R and Home ETS is not significant, meaning there is little evidence to support that adolescents with versus without *DRD4*-7R were more behaviorally reactive to home ETS. Adolescents with the *DRD4*-7R allele showed marginally significant elevations in the odds of problem behavior on days they were exposed substance use at home (OR=2.76, $p=0.071$, 95% CI: 0.92, 8.28) whereas adolescents without the 7R allele did not (OR=1.60, $p=0.479$, 95% CI: 0.43, 5.91). However, the nonsignificant interaction term suggests that adolescents with versus without the *DRD4*-7R allele do not differ in their behavioral reactivity to ETS at home.

Table 2.4 shows main effects for *DRD4*-7R and ETS *outside the home* as well as their interaction, and displays three main findings. First, the Main Effects model shows a significant effect for daily ETS outside the home, suggesting that on average, adolescents were considerably more likely to engage in problem behavior on days when they witnessed others using substances outside the home compared to themselves on days when they did not witness others using substances outside the home. Second, we found that adolescents with higher versus lower mean levels of ETS outside the home were more likely to engage in problem behavior during the study

period, as evidenced by a significant effect for person-mean ETS outside the home. Third, the G x E model shows a significant interaction between *DRD4*-7R and ETS outside the home. Adolescents with the *DRD4*-7R allele showed a greater increase in the odds of problem behavior when they witnessed substance use outside the home (OR=6.65, p<0.001, 95% CI: 3.52, 12.56) compared to adolescents without the 7R allele (OR=2.01, p=0.020, 95% CI: 1.12, 3.60). **Figure 2.2** displays the *DRD4*-7R x Home ETS and *DRD4*-7R x Outside Home ETS interactions detailed in Tables 2.3 and 2.4.

We also tested whether the size and direction of G x E effects presented in Tables 2.2, 2.3, and 2.4 differed between boys (*n*=72) and girls (*n*=69) using models containing Gender x *DRD4*-7R x ETS interaction terms, as well as all lower-order interactions (Gender x *DRD4*-7R, Gender x ETS, *DRD4*-7R x ETS). We found no evidence that *DRD4*-7R x Daily ETS interaction effects presented in Tables 2.2-2.4 differed between boys and girls.

Sensitivity analyses. A possible counter-interpretation of our results is that the effect of witnessing others' substance use is driven by adolescents' own substance use. That is, if our model effects are rendered nonsignificant after dropping substance use from the outcome, this leaves open the possibility that our results might generated by a process beginning with adolescents' own substance use, rather than an environmentally mediated effect of exposure to others' substance use facilitating adolescent problem behavior. To test this possibility, we reran all Main Effect and G x E models in Tables 2.2, 2.3, and 2.4 after dropping substance use items from the problem behavior outcome. The pattern of results presented in Tables 2.2-2.4 did not change, suggesting that our results are not driven by adolescents' own substance use.

Does ethnic stratification explain away the *DRD4*-7R x Daily ETS interaction?

Ethnic stratification suggests that observed genetic effects may actually be due to the ethnic or ancestral background of individuals, rather than their genotypes per se. Ethnic stratification is essentially a problem of confounding, when ethnicity serves as a third variable confounding observed relationships between genes, environments, and behavior (Cardon & Palmer, 2003; Wacholder, Rothman, & Caporaso, 2000). A simple illustration of this problem is presented in Wacholder et al. (2000): any gene that is more prevalent in Asian versus Caucasian populations will be highly associated with chopstick use; however, it is most likely ethnicity and its associated cultural factors driving such a relationship, rather than genetics.

In the current set of results, ethnic stratification may be present in the following ways. First, ethnicity may confound the main effect of *DRD4*-7R on problem behavior if both the allele frequency and the outcome differ between ethnic groups. Second, ethnicity may confound the gene-environment interaction effect, if the effect of *DRD4*-7R on problem behavior differs by ethnicity, or if ethnicity (as opposed to the *DRD4*-7R gene) is the true moderator of within-person ETS- problem behavior relationships. In other words, if *DRD4*-7R x ETS effects are rendered nonsignificant after *DRD4*-7R x Ethnicity and Ethnicity x ETS interaction terms are added to our models, this suggests that our findings may be due to ethnic stratification.

The ethnic distribution of the sample was 58.2% White (*n*=82), 22.0% Latino (*n*=31), 5.0% Native American (*n*=7), 4.3% African-American (*n*=6), 3.6% Asian or Pacific Islander (*n*=5), and 7.1% "Other" (*n*=10). To test the effect of ethnicity, we split the sample using a marker of White (*n*=82, 58.2% of sample) versus non-White ethnicity (*n*=59, 41.8% of sample). Next, we tested whether the prevalence rates of problem behavior and the *DRD4*-7R genotype differed between White and non-White adolescents. Finally, we tested whether ethnicity

confounded G x E effects by adding *DRD4*-7R x Ethnicity and Ethnicity x ETS interaction terms to our models.

Table 2.5 shows ethnic comparisons in the prevalence rates of *DRD4*-7R, ETS, and problem behavior. We found no evidence for ethnic group differences in any of these measures.

Table 2.6 shows the results of multilevel models that included the main effect of Ethnicity, as well as Ethnicity x ETS and Ethnicity x *DRD4*-7R interactions. Two findings in **Table 2.6** are noteworthy. First, we found no evidence for a main effect of ethnicity on the daily problem behavior outcome, nor did we find evidence for Ethnicity x *DRD4*-7R or Ethnicity x Daily ETS interaction effects. Second, even after including Ethnicity x Daily ETS and Ethnicity x *DRD4*-7R interactions in our models, *DRD4*-7R x Any ETS and *DRD4*-7R x Any ETS Outside the home interactions remained significant, providing evidence against an ethnic stratification confound in our G x E effects.

Discussion

The current study used mobile phone surveys in adolescents' daily lives to test (1) whether adolescents were more likely to engage in problem behavior on days when they witnessed others using substances and (2) whether adolescents with versus without the *DRD4*-7R allele showed greater problem behavior reactivity to others' substance use in their immediate contexts. We found that adolescents were more likely to engage in problem behavior on days when they witnessed, versus did not witness, others using substances. This was particularly true when exposure to substance use occurred outside the home, such as in adolescents' schools and neighborhoods. Additionally, we found that adolescents with versus without the *DRD4*-7R allele

were more behaviorally reactive to substance use exposures, showing greater increases in the odds of problem behavior across exposure versus non-exposure days. The G x E effect was also particularly strong when substance use exposure occurred outside the home, as 7R carriers showed greater behavioral reactivity when exposed to substances outside the home but did not show increased reactivity when exposed to substances in the home.

The study findings represent a novel contribution for two reasons. First, they provide evidence supporting an environmentally mediated relationship between substance use exposure and problem behavior in adolescents' daily lives. Because we examined this relationship within adolescents, using each adolescent as his or her own "control", our results cannot be explained away by stable selection factors such as biological sex, ethnicity, or genetic makeup. Second, the current study supports and extends experimental findings suggesting that youth with *DRD4*-7R are more sensitive to their environments (e.g. Bakermans-Kranenburg, van Ijzendoorn, Mesman, et al., 2008; Larsen et al., 2010) by showing that adolescents with versus without the *DRD4*-7R allele are more behaviorally reactive to contextual triggers, such as witnessing substance use, in their everyday, real-life contexts.

How might the *DRD4*-7R gene increase vulnerability to contexts, such as those in which youth witness others' substance use? Evidence suggests that the *DRD4*-7R allele is associated with both increased impulsivity and higher levels of reward-related reactivity. The *DRD4* gene has been shown to be related to a number of impulsive phenotypes, including reduced inhibitory control (Congdon et al., 2008), novelty seeking (Benjamin et al., 1996; Ebstein et al., 1996) and ADHD (Swanson et al., 2001). Laboratory evidence also suggests that youth with the *DRD4*-7R allele show greater ventral striatal reactivity in response to reward-related cues (Forbes et al.,

2009), which might suggest that these youth experience a higher drive for engaging in exciting or potentially reinforcing activities such as antisocial behavior and substance use. Thus, when confronted with contexts in which risky, exciting, and reinforcing behavior such as substance use is occurring, decreased impulse control and increased reward-related reactivity may combine to confer a "double whammy" of vulnerability for problem behavior among youth with the *DRD4*-7R allele. However, the exact mechanisms for this increased vulnerability are not yet known; future research that specifically examines *DRD4*-related vulnerability mechanisms explaining environmental effects on problem behavior is needed.

Importantly, we found that exposure to substance use was particularly strong when it was experienced outside the home, as opposed to inside the home. There are a number of potential reasons explaining why this pattern of findings might have emerged. First, when adolescents are with others outside the home, it seems most likely for them to be in the company of their peers. Increasing amounts of time are spent in the company of peers during adolescence (Brown, 2004; Csikszentmihalyi, 1984) and the importance of satisfying peer expectations and approval is increased during the adolescent years (Brown & Larson, 2009). Moreover, time outside the home with peers is also a time of reduced parental monitoring and control. The combination of peer influence and lack of parental oversight may explain why exposure to substance use outside the home had such strong effects on adolescents' propensity to engage in problem behavior. Second, the lack of significant findings relating home ETS to problem behavior may be due to shared heritability factors that account for both (see e.g. Haber et al., 2010; Waldron et al., 2009). Therefore, when stable between-person factors are held constant – as was done in our analyses – there may be little evidence for an environmentally mediated effect. Third, if an environmentally mediated effect between home ETS and problem behavior exists, it may be through mechanisms

such as increased stress, family disruption, and reduced parental monitoring (see for example Chassin et al., 1991), and these effects may take longer to manifest than peer influence processes on antisocial and substance use behavior, or they may manifest as other problems (e.g., depression, anxiety). However, this is not to say that exposure to substance use at home does not have daily-level effects on adolescent problem behavior; the current study may have lacked the statistical power to detect these effects. Future research should continue to test the relative importance of substance use exposure in home versus outside the home as well as the potential mechanisms connecting these exposures to adolescent problem behavior.

It is important to acknowledge the study's limitations. First, substance use exposure in adolescents' daily lives was naturally occurring, meaning we could not completely rule out selection effects or gene-environment correlation in the same way that an experimental study with randomly assigned exposures could. We therefore echo the call of van Ijzendoorn et al. (2011) for continued gene-environment experimental studies, which could offer a greater degree of experimental control in testing hypotheses of gene-by-environment interaction. Second, although we found no evidence that adolescents with versus without the *DRD4*-7R allele experienced greater levels of daily ETS, suggesting the absence of a gene-environment correlation, our study may have lacked the statistical power to detect it. Third, we present same-day associations between substance use exposure and problem behavior, and therefore cannot fully rule out the possibility that problem behavior precedes and leads adolescents to engage with others who are using substances. Future research with more careful attention to the timing and patterning of substance use exposure and behavior *within a day* may be able to better address this issue of temporality. Fourth, it is important to note that the current G x E finding should be regarded as preliminary until it is replicated in an independent sample. As previously mentioned,

our findings support and extend previous correlational and experimental work suggesting that individuals with the *DRD4*-7R allele are more reactive to their surrounding contexts (e.g. Bakermans-Kranenburg & van Ijzendoorn, 2011; Larsen et al., 2010), offering confidence that these effects may exist. Nonetheless, replication is required. Fifth, the age range of the sample (ages 11-15) and the concomitant low base rate of daily substance use (approximately 1% of observations) prevented us from separately examining the effects of substance use exposure on adolescents' own substance use. Future research should examine these relationships among older adolescents – roughly ages 14-17 – as rates of substance use increase during late versus middle adolescence (National Institute on Drug Abuse, 2010).

With these limitations in mind, the implications of these findings for theory and practice can be noted. The findings of the current study provide support for theories of person-environment interaction, such as the diathesis-stress model of psychopathology (Monroe & Simons, 1991) and the stress-vulnerability models of substance use (Sinha, 2001), which suggest that individuals with genetic or dispositional vulnerabilities are more sensitive to their contexts. These models are primarily tested using between-subjects designs, which cannot well demonstrate that individuals with dispositional risk factors are more reactive to changes in their environments as they experience them. By demonstrating that adolescents with the *DRD4*-7R allele show greater increases in problem behavior on days when they are, versus are not, exposed to substances, the current study adds strong support for person-environment interaction models of problem behavior.

These results may also have implications for the design of interventions aimed at preventing adolescent antisocial behavior and substance use. Our results suggest that

interventions should continue to focus on the interaction between at-risk individuals and risky contexts in order to target interventions toward those at the highest risk for involvement in antisocial behavior and substance use. Although our study tested only one marker of vulnerability (the *DRD4*-7R allele), the consistency of our findings and the methodological rigor of our approach adds strong support to the idea that context may matter for some individuals more than others, and that these individuals may be most in need of intervention.

Table 2.1. *Descriptives by DRD4 genotype*

	DRD4-7R+ (*n*=50)	*DRD4*-7R- (*n*=91)	b (SE)	95% CI	*p*	β
	M (SD)	M (SD)				
Exposures						
Any Exposure to Substances (ETS)	0.09 (0.13)	0.09 (0.16)	0.00 (0.03)	-0.05, 0.05	0.945	0.01
ETS at Home	0.03 (0.08)	0.03 (0.08)	0.01 (0.01)	-0.02, 0.03	0.701	0.03
ETS Outside Home	0.08 (0.11)	0.08 (0.13)	-0.00 (0.02)	-0.04, 0.04	0.954	-0.00
in Neighborhood	0.03 (0.06)	0.03 (0.08)	-0.00 (0.01)	-0.03, 0.03	0.991	-0.00
in School	0.01 (0.04)	0.01 (0.02)	0.01 (0.01)	-0.00, 0.02	0.268	0.09
"Somewhere Else"	0.06 (0.10)	0.05 (0.09)	0.00 (0.02)	-0.03, 0.04	0.791	0.02

M=mean proportion of days adolescents reported exposure to substance use. SD=standard deviation. *DRD4*-7R+: 7R present; *DRD4*-7R-: 7R absent. OLS regressions were used to test genotype group differences (7R versus no 7R) in the proportion of days exposed to substances. b=unstandardized regression coefficient, representing the difference in mean proportions of exposures between genotype groups. SE=standard error for b. β = standardized regression coefficient. 95% CI: 95% confidence interval for b estimate.

Table 2.2. *Multilevel Logistic Models Testing Effects of DRD4-7R, Daily ETS, and DRD4-7R X Daily ETS interactions on* ***Problem Behavior in Daily Life***

	Main Effects Model		G x E Model	
Fixed Effects (intercepts, slopes)	OR	95% CI	OR	95% CI
Daily ETS	**3.36*** **	2.23, 5.06	**2.04***	1.18, 3.53
DRD4-7R	1.46	0.75, 2.84	1.12	0.56, 2.24
DRD4-7R X Daily ETS	--	--	**3.01****	1.37, 6.62
Person-Mean ETS	**1.04*** **	1.02, 1.06	**1.05*** **	1.02, 1.07
Intercept	**0.03*** **	0.02, 0.04	**0.03*** **	0.02, 0.05
Random Effects (variances, covariances)	Estimate	SE	Estimate	SE
Between person				
VAR(Intercept)	**2.78*** **	0.48	**2.76*** **	0.48
VAR(Daily ETS Effect)	**1.13***	0.51	**0.99***	0.48
COV(Intercept, Daily ETS Effect)	-0.57	0.42	-0.55	0.39
CORR (Intercept, Daily ETS Effect)	-0.32		-0.33	
Within person				
Autocorrelation	**0.09*** **	0.02	**0.09*** **	0.02
Residual	**0.55*** **	0.01	**0.55*** **	0.01

Table 2.2 Notes:

***p<0.001, **p<0.01, *p<0.05, ^{+}p<0.10. OR=Odds ratio from a multilevel logistic model. 95% CI=95% Confidence interval. VAR=Variance parameter, COV=Covariance parameter. SE=Standard error of random effect estimate. Significant estimates are presented in **bold** type.

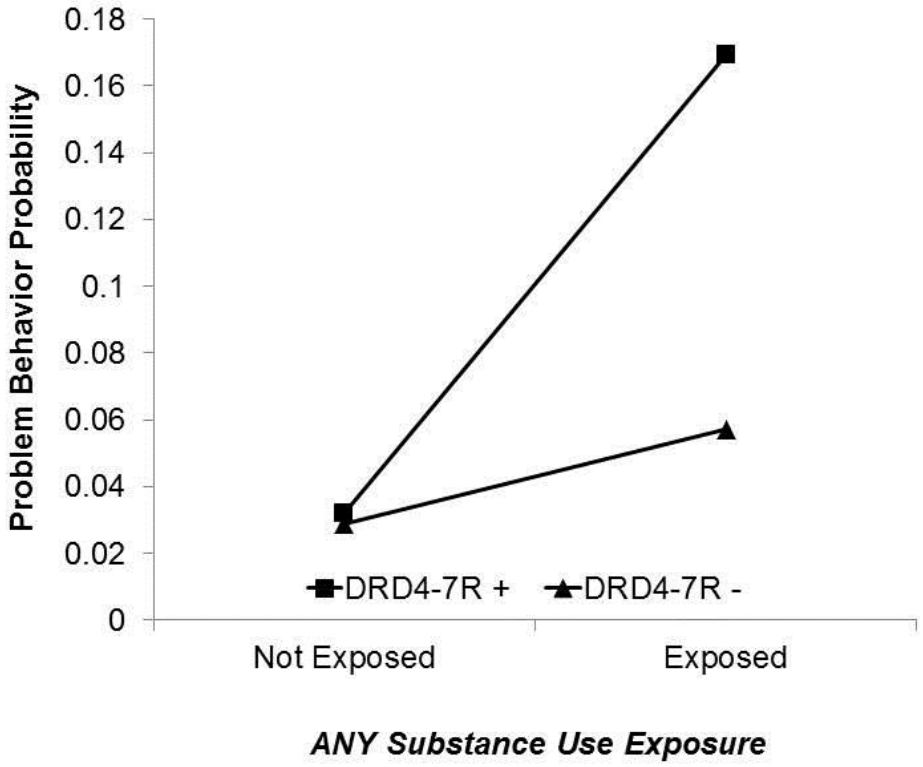


Figure 2.1. *DRD4*-7R x Daily ETS interaction predicting problem behavior. *DRD4*-7R+: 7R allele present; *DRD4*-7R-: 7R allele absent. On days when adolescents were exposed to substance use, adolescents with the *DRD4*-7R allele show greater increases in problem behavior odds compared to adolescents without the 7R allele.

Table 2.3. *Multilevel Logistic Models Testing Effects of DRD4-7R, Daily Home ETS, and DRD4-7R X Daily Home ETS interactions on* ***Problem Behavior in Daily Life***

	Main Effects Model		G X E Model	
Fixed Effects (intercepts, slopes)	OR	95% CI	OR	95% CI
Daily Home ETS	2.16^{+}	0.95, 4.93	1.60	0.43, 5.91
DRD4-7R	1.26	0.62, 2.55	1.25	0.61, 2.54
DRD4-7R X Daily Home ETS	--	---	1.72	0.31, 9.50
Person-Mean Home ETS	**1.06****	1.02, 1.11	**1.06****	1.02, 1.10
Intercept	**0.03*****	0.02, 0.05	**0.03*****	0.02, 0.05
Random Effects (variances, covariances)	Estimate	SE	Estimate	SE
Between person				
VAR(Intercept)	**3.05*****	0.50	**3.05*****	0.50
VAR(Daily Home ETS Effect)	**2.60***	1.35	**2.75***	1.43
COV(Intercept, Daily Home ETS Effect)	0.18	0.76	0.12	0.78
CORR (Intercept, Daily Home ETS Effect)	0.07		0.04	
Within person				
Autocorrelation	**0.10*****	0.02	**0.10*****	0.02
Residual	**0.55*****	0.01	**0.55*****	0.01

Table 2.3 Notes:

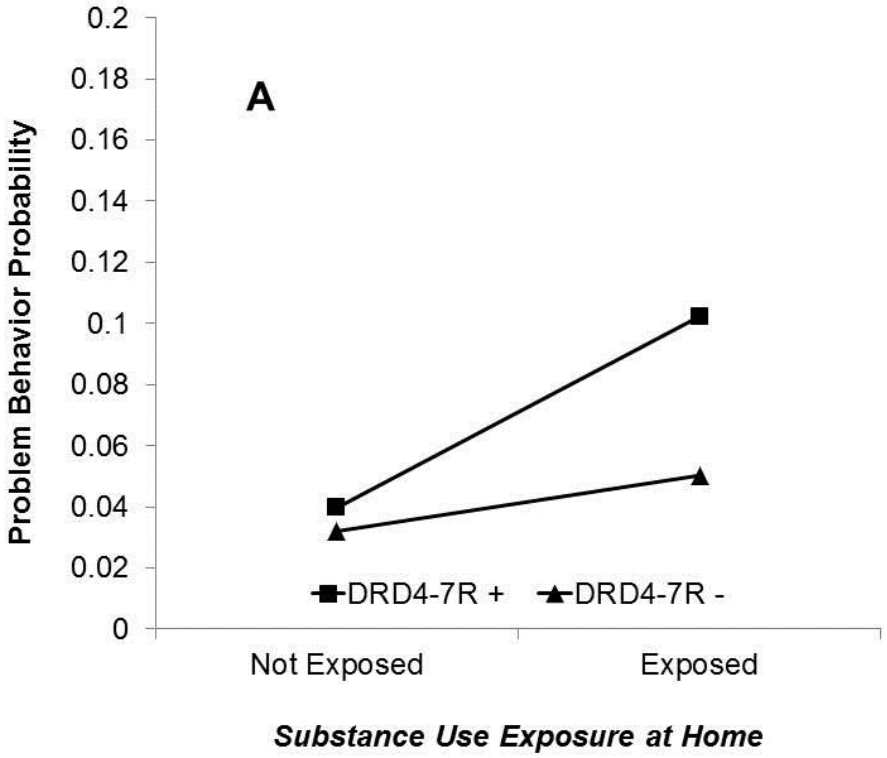
***p<0.001, **p<0.01, *p<0.05, ^{+}p<0.10. OR=Odds ratio from a multilevel logistic model. 95% CI=95% Confidence interval. VAR=Variance parameter, COV=Covariance parameter. SE=Standard error of random effect estimate. Significant estimates are presented in **bold** type.

Table 2.4. *Multilevel Logistic Models Testing Effects of DRD4-7R, Daily Outside ETS, and DRD4-7R X Daily Outside ETS interactions on* ***Problem Behavior in Daily Life***

	Main Effects Model		G X E Model	
Fixed Effects (intercepts, slopes)	OR	95% CI	OR	95% CI
Daily Outside Home ETS	**3.40*** **	2.17, 5.33	**2.01***	1.12, 3.60
DRD4-7R	1.52	0.79, 2.92	1.16	0.59, 2.30
DRD4-7R X Daily Outside Home ETS	--	--	**3.31****	1.41, 7.80
Person-Mean Outside Home ETS	**1.06*** **	1.03, 1.08	**1.06*** **	1.03, 1.08
Intercept	**0.03*** **	0.02, 0.04	**0.03*** **	0.02, 0.05
Random Effects (variances, covariances)	Estimate	SE	Estimate	SE
Between person				
VAR(Intercept)	**2.68*** **	0.46	**2.66*** **	0.45
VAR(Daily Outside Home ETS Effect)	**1.46****	0.62	**1.23***	0.57
COV(Intercept, Daily Outside Home ETS Effect)	-0.70	0.46	-0.63	0.43
CORR (Intercept, Daily Outside Home ETS Effect)	-0.35		-0.35	
Within person				
Autocorrelation	**0.09*** **	0.02	**0.09*** **	0.02
Residual	**0.55*** **	0.01	**0.55*** **	0.01

Table 2.4 Notes:

***p<0.001, **p<0.01, *p<0.05, ^{+}p<0.10. OR=Odds ratio from a multilevel logistic model. 95% CI=95% Confidence interval. VAR=Variance parameter, COV=Covariance parameter. SE=Standard error of random effect estimate. Significant estimates are presented in **bold** type.


A
Problem Behavior Probability
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
DRD4-7R +
DRD4-7R -
Not Exposed
Exposed
Substance Use Exposure at Home

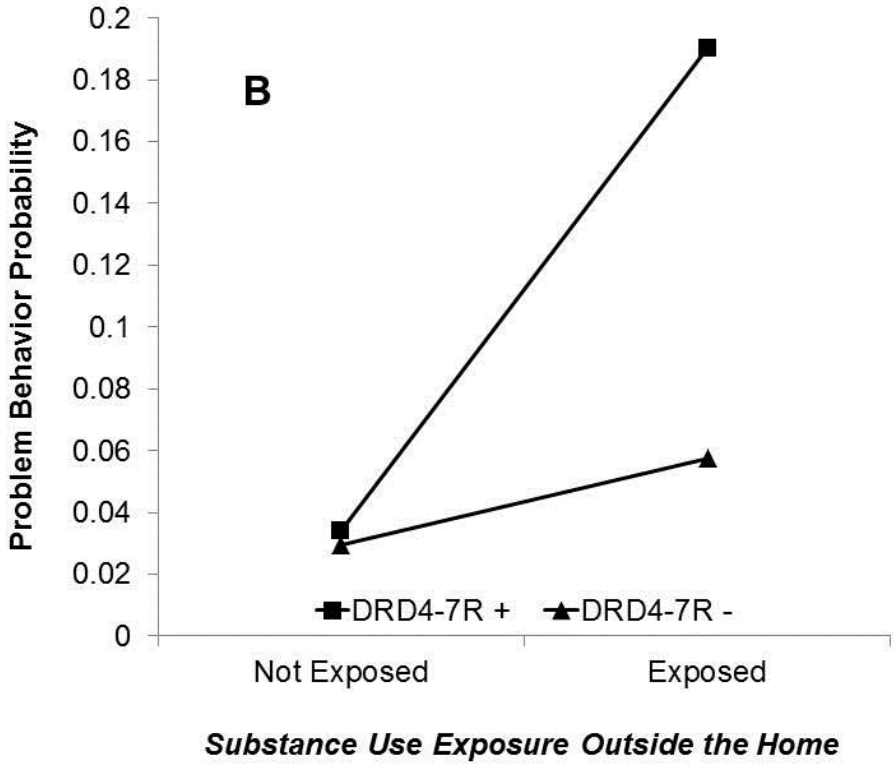


Figure 2.2: *DRD4*-7R x Home ETS interaction (panel A) and *DRD4*-7R x Outside Home interaction (panel B) predicting problem behavior in adolescents' daily lives.

Table 2.5. *Descriptives by Ethnicity*

	White (*n*=82)	Non-White (*n*=59)	Ethnicity Comparisons			
	M (SD)	M (SD)	b (SE)	95% CI	*p*	*β*
Exposures						
Any Exposure to Substances (ETS)	0.09 (0.16)	0.09 (0.14)	-0.00 (0.03)	-0.05, 0.05	0.919	-0.01
ETS at Home	0.03 (0.09)	0.03 (0.08)	0.00 (0.01)	-0.02, 0.03	0.747	0.03
ETS Outside Home	0.07 (0.13)	0.08 (0.10)	-0.00 (0.02)	-0.05, 0.04	0.855	-0.02
in Neighborhood	0.03 (0.09)	0.03 (0.04)	0.01 (0.01)	-0.02, 0.03	0.645	0.04
in School	0.01 (0.02)	0.01 (0.04)	-0.01 (0.01)	-0.02, 0.00	0.189	-0.11
"Somewhere Else"	0.05 (0.10)	0.05 (0.09)	-0.00 (0.02)	-0.03, 0.03	0.853	-0.02
	%	%	OR	95% CI	p	
DRD4-7R	32.93%	38.98%	0.77	0.38, 1.54	0.459	--
Outcomes	M (SD)	M (SD)	b (SE)	95% CI	*p*	*β*
Problem Behavior	0.09 (0.17)	0.09 (0.17)	0.00 (0.03)	-0.06, 0.06	0.947	0.01

Table 2.5 Notes:

Ethnicity is a dichotomous marker of White (n=82, 58.2% of sample) versus non-White (n=59, 41.8% of sample).

M=mean proportion of days adolescents reported exposure to substance use or engagement in problem behavior, SD=standard deviation. OLS regressions were used to test ethnic-group differences (White versus Non-White) in the proportion of days exposed to substances and proportion of days engaged in problem behavior. b=unstandardized regression coefficient, representing the difference in mean proportions of exposures and outcomes between ethnicity groups. β = standardized regression coefficient. OR= odds ratio. SE=standard error for b. 95% CI: 95% confidence interval for b and OR estimates.

Table 2.6. *Multilevel Models Testing DRD4-7R x Exposure to Substances (ETS) Interactions Predicting Problem Behavior**, with Ethnicity Controls***

	Exposure: Any ETS		Exposure: Home ETS		Exposure: Outside Home ETS	
Fixed Effects (intercepts, slopes)	OR	95% CI	OR	95% CI	OR	95% CI
Daily ETS	**2.62****	1.31, 5.22	1.33	0.24, 7.56	**2.22***	1.06, 4.67
DRD4-7R	1.05	0.38, 2.94	1.19	0.41, 3.46	1.02	0.37, 2.79
DRD4-7R X Daily ETS	**3.04****	1.38, 6.70	1.70	0.29, 9.84	**3.37****	1.42, 8.00
Ethnicity	0.91	0.39, 2.12	0.79	0.33, 1.92	0.85	0.37, 1.96
Ethnicity X *DRD4*-7R	1.10	0.28, 4.33	1.07	0.25, 4.57	1.25	0.33, 4.78
Ethnicity X Daily ETS	0.60	0.27, 1.33	1.34	0.23, 7.93	0.80	0.34, 1.89
Person-Mean ETS	**1.05*****	1.02, 1.07	**1.06****	1.02, 1.10	**1.06*****	1.03, 1.09
Intercept	**0.03*****	0.02, 0.06	**0.04*****	0.02, 0.07	**0.03*****	0.02, 0.06

Table 2.6., Continued: *Multilevel Models Testing DRD4-7R x Exposure to Substances (ETS) Interactions Predicting Problem Behavior**, with Ethnicity Controls***

Random Effects (variances, covariances)	Estimate	SE	Estimate	SE	Estimate	SE
Between person						
VAR(Intercept)	**2.86*** **	0.49	**3.14*** **	0.51	**2.75*** **	0.47
VAR(Daily ETS Effect)	**0.96***	0.49	**2.97***	1.55	**1.26***	0.60
COV(Intercept, Daily ETS Effect)	-0.49	0.40	0.13	0.83	-0.61	0.45
CORR (Intercept, Daily ETS Effect)	-0.30		0.04		-0.33	
Within person						
Autocorrelation	**0.09*** **	0.02	**0.10*** **	0.02	**0.09*** **	0.02
Residual	**0.55*** **	0.01	**0.55*** **	0.01	**0.55*** **	0.01

Table 2.6 Notes:

Ethnicity is a dichotomous marker of White (n=82, 58.2% of sample) versus non-White (n=59, 41.8% of sample).

OR=Odds ratio from multilevel logistic regression. *DRD4*-7R+: 7R allele present; *DRD4*-7R-:

7R allele absent. Significant estimates are presented in **bold** type, *p<.05, **p<.01, ***p<.001.

Estimates marginally significant at the p<0.10 level are marked with $^{+}$.

CHAPTER 3

Vulnerability and Opportunity *in vivo*: A Within-Person Approach to Testing Differential Susceptibility in Adolescents' Daily Lives*

Citation:

Russell, M.A., Wang, V., & Odgers, C.L. (in preparation). Vulnerability and opportunity *in vivo*: A within-person approach to testing differential susceptibility in adolescents' daily lives.

Abstract

Adolescence has been called a time of both "vulnerability and opportunity" (Dahl, 2004), and for some adolescents, this characterization may be more true than for others. Differential susceptibility theory suggests that some adolescents will be more sensitive to both the positive and negative features of their environments, and that these adolescents can be characterized by various genetic, endophenotypic, or behavioral markers. The current study adopted a novel within-person approach to testing differential susceptibility in adolescents' daily lives using mobile phones to repeatedly measure adolescents' contexts, affect, and behavior across 38 consecutive days. Three findings emerged. First, adolescents with either the *DRD4*-7R allele or low levels of trait self-control showed greater lability (operationalized by higher intraindividual standard deviations) in daily affect and behavior ($p=0.06$ for the effect of low self-control on risky behavior lability). Second, adolescents who showed high reactivity to both positive and negative events in daily life tended to display lower levels of self-control ($p=0.05$), whereas adolescents who showed high versus low reactivity to negative events only were somewhat more likely to be carriers of the *DRD4*-7R allele ($p=0.06$). Third, 5-HTTLPR s/s did not characterize any of our reactivity groups. We discuss these findings in the context of differential susceptibility theory, highlighting the potential of a within-person approach for advancing research, theory, and prevention efforts in this area.

Introduction

Children and adolescents differ greatly in how they respond to their environments. Some youth may seem unaffected by stressful experiences such as conflict, rejection, or exposure to violence, whereas others may seem highly sensitive to even the most minor of these experiences. Similarly, some youth thrive exceptionally in response to the attention and care offered within highly supportive environments, whereas others may seem impervious to such conditions. Children and adolescents who appear more sensitive to their environmental surroundings have long captured the imaginations of theorists in developmental and clinical psychology, who have focused on the interaction between children's inherent characteristics (such as genes or personality factors) and those of their surrounding environments (stress versus support) in determining their current adjustment as well as their later life outcomes (e.g., Bronfenbrenner & Ceci, 1994; Monroe & Simons, 1991).

Historically, these ideas of person-environment interaction have predominantly accentuated the negative. For example, the diathesis-stress model (Monroe & Simons, 1991) posits that some children, by virtue of their genotypes or their genetically influenced temperaments, are more *vulnerable* to the negative conditions they encounter, manifesting higher rates of affective and behavioral psychopathology as a result. Recently, however, theorists have advanced an idea known as *differential susceptibility* (Belsky & Pluess, 2009; Boyce & Ellis, 2005), which emphasizes the "bright side" of so-called vulnerability markers. Differential susceptibility theory suggests that these markers may function in a more *susceptibility*-like fashion, making children more sensitive to *both* positive and negative environmental experiences as opposed to more *vulnerable* to negative experiences only (see Belsky & Pluess, 2009 for a

review and cataloguing of these factors). The differential susceptibility perspective argues that these "plasticity" factors (Belsky et al., 2009) allow a greater range of developmental phenotypes as well as a greater sensitivity to environments, conferring high levels of risk when environments are negative, while also conferring great benefits when environments are supportive (Ellis et al., 2011).

Characteristics of these sensitive/susceptible children and adolescents include a diverse array of factors spanning genetic, endophenotypic, and behavioral levels (Bakermans-Kranenburg & van Ijzendoorn, 2011; Belsky & Pluess, 2009; Ellis et al., 2011). This diverse array of factors is thought to index a unitary neurobiological process conferring greater sensitivity/reactivity to both risky and beneficial environments when such environments are encountered. Ellis and colleagues (2011) describe this sensitivity as such: "Susceptibility to the environment is instantiated in the biology of the nervous system; it is *neurobiological* susceptibility. Genetic susceptibility factors operate through neurobiological processes and behavioral indicators of susceptibility are grounded in neurobiology" (pp. 7-8, emphasis in original). It is estimated that ~15% of youth will show this pattern of increased neurobiological susceptibility to their environments (Hertzman & Boyce, 2010). Although the exact mechanism for this neurobiological susceptibility is not yet provided, differential susceptibility theories (Belsky & Pluess, 2009; Boyce & Ellis, 2005) converge on the assertion that sensitivity markers across multiple levels of analysis (e.g., genetic, endophenotypic, and behavioral) are similarly underpinned by a common neurobiological process that is operative all across the life span, from childhood to adulthood (Ellis et al., 2011).

In the current study, we focus on three markers of differential susceptibility (two genetic markers and one behavioral marker), including: (1) the 7-repeat allele of the dopamine receptor D4 gene (*DRD4*-7R); (2) the homozygous short allele (s/s) of the serotonin-transporter-linked polymorphic region (5-HTTLPR) of the SLC6A4 gene; and (3) impulsivity/low self-control. These factors were chosen given evidence suggesting their association with differential susceptibility effects in children and adolescents, which we briefly review below.

Markers of Susceptibility: Review of Evidence

***DRD4*-7R.** The *DRD4* gene is located on chromosome 11 and is highly polymorphic, with the 4-repeat (4R) and 7-repeat (7R) versions of the 48-base pair sequence being most common (Ding et al., 2002). The 7R allele of this gene has been associated with a range of affective and behavioral outcomes, including novelty/sensation-seeking (Benjamin et al., 1996; Ebstein et al., 1996; Laucht et al., 2005), delinquency and anger (Dmitrieva et al., 2011), poor inhibitory control (Congdon et al., 2008) and attention attention-deficit/hyperactivity disorder (ADHD; Faraone et al., 2005). Both experimental (e.g. Bakermans-Kranenburg, van Ijzendoorn, Mesman, et al., 2008; Bakermans-Kranenburg, van Ijzendoorn, Pijlman, et al., 2008) and correlational studies (e.g. Sheese, Voelker, Rothbart, & Posner, 2007) have shown that children with versus without the *DRD4*-7R allele show the greatest levels of problem behavior when parenting environments are hostile or insensitive, and the lowest levels of problem behavior when parenting environments are sensitive and supportive.

5-HTTLPR s/s. The serotonin-transporter-linked polymorphic region (5-HTTLPR) is a polymorphic region located in the SLC6A4 gene, which codes for the serotonin transporter. The short/short allele of the 5-HTTLPR polymorphism (5-HTTLPR s/s) was one of the first genetic

markers examined in studies of gene-environment interactions. In a landmark study, Caspi and colleagues (2003) showed that individuals with the 5-HTTLPR s/s allele were at the highest risk for depression if exposed to childhood maltreatment and a high number of recent stressful life events. Since this initial study, there have been numerous replications of this initial finding (see review by Caspi, Hariri, Holmes, Uher, & Moffitt, 2010), including one study showing that individuals with the 5-HTTLPR s/s allele display more anxious reactivity to daily stressors (Gunthert et al., 2007). Recent evidence also suggests that individuals with the 5-HTTLPR s/s allele may be more sensitive to their environments in a manner suggested by differential susceptibility—for better *and* for worse (see Belsky et al., 2007). A prominent example is provided by Taylor and colleagues (2006), who showed that adult carriers of the 5-HTTLPR s/s allele displayed the highest levels of depressive symptomatology when exposed to early adversity and recent negative life events, whereas 5-HTTLPR s/s carriers who experienced a supportive early environment and recent positive events showed the *fewest* depressive symptoms.

Low Self-Control. Self-control entails the effortful regulation of attention, emotion, and behavior in the service of a socially or personally valued goal (Duckworth, Tsukayama, & Geier, 2010), and is a multifaceted construct encompassing concepts from several disciplines, including inattention, hyperactivity, impulsivity, conscientiousness, sensation/novelty seeking, and delay of gratification (Moffitt et al., 2011). Individual differences in self-control have been shown to predict a wide array of poor outcomes, including antisocial behavior and violence (Moffitt et al., 2011), depression/anxiety (Tangney, Baumeister, & Boone, 2004), and risky health behavior (i.e. risky sex and substance abuse; Bogg & Roberts, 2004). Evidence abounds for the role of low self-control as an agent of vulnerability to risky environments (see for example Lengua et al.,

2000; Lynam et al., 2000). However, emerging evidence also suggests that low self-control may provide benefits in positive environments as well. For example, Leve, Kim, and Pears (2005) showed that adolescent girls with high versus low impulsivity showed steeper growth in externalizing behavior problems if they experienced high levels of harsh parental discipline, whereas adolescent girls with high impulsivity whose parents did not use harsh discipline showed the steepest *declines* in externalizing behavior as they aged.

The Need for a Within-Person Perspective in Differential Susceptibility Research

Studies such as those described above have provided considerable evidence supporting the existence of genetic and behavioral factors that moderate children and adolescents' sensitivity to environments in a "for better and for worse" manner (Belsky et al., 2007). The majority of this work, however, has examined the differential susceptibility hypothesis using between-person comparisons, meaning that these studies predominantly test whether individuals with a differential susceptibility factor *and* exposure to a high-risk environment have the worst outcomes, while individuals with the same differential susceptibility factor but exposure to a highly beneficial environment have the best outcomes. In suggesting directions for future research, Ellis and colleagues (2011) have discussed the need for within-person information in assessing differential susceptibility. Specifically, they suggest the use of experimentally manipulated environments (such as Trier Social Stress tasks with positive and negative experimenter feedback) to provide evidence showing that the *same* individuals react more negatively when environments are stressful, as well as more positively when environments are supportive or beneficial (see pp. 21-22 in Ellis et al., 2011).

Although the study designs suggested by Ellis and colleagues (2011) are experimental in nature, similar within-person investigations can be performed using naturalistic investigations of youths' daily lives. These naturalistic studies could examine whether children and adolescents with differential susceptibility markers are more reactive to the naturally occurring positive and negative experiences that characterize their real, everyday lives. Diary methods, also known as ecological momentary assessment (EMA; Shiffman et al., 2008) or experience sampling methodology (ESM; Csikszentmihalyi et al., 1977), allow repeated measurement of adolescents' experiences, affect, and behavior over time and in their natural environments. Increasingly, these studies are being conducted via electronic devices such as mobile phones, which allow measurements to be obtained in-the-moment. As such, diary methods via mobile technologies can measure within-person changes in affect and behavior as positive experiences and daily stressors are encountered. By examining environment-behavior relationships within each individual over time, diary methods allow researchers to use each adolescent as his or her own "control", thereby holding constant all stable characteristics such as sex and ethnicity and facilitating causal inferences regarding naturally occurring environmental effects.

In the current study, we test the differential susceptibility hypothesis in the daily lives of 151 adolescents. We focus on adolescence because it is a time of both vulnerability and opportunity (Dahl, 2004), suggested by the high rates of problems such as depression, antisocial behavior, and substance use during this time (Johnston, O'Malley, Bachman, & Schulenberg, 2011; Lewinsohn, Hops, Roberts, Seeley, & Andrews, 1993; Moffitt et al., 2001) as well as the high potential for positive change suggested by experts in child and adolescent development (Steinberg, 2013). Adolescents in our study provided momentary reports of their environments,

behaviors, and affect three times daily using mobile phones across 38 consecutive days. Using this extensive within-person information from adolescents' daily lives allows us to test two important concepts related to differential susceptibility in a novel way. First, we tested whether adolescents with differential susceptibility factors (including *DRD4*-7R, 5-HTTLPR s/s, and low self-control) show higher levels of behavioral and affective *lability*, operationalized by the amount of within-person variability shown in behavior and affect for each adolescent over the course of the 30-day measurement period (see Nesselroade, 1991 for an application of this approach). We focus on behavioral-affective lability in the current study given assertions in the differential susceptibility literature that sensitive youth should show a greater range of phenotypic possibility in their developmental phenotypes (Belsky & Pluess, 2009), which in daily life might manifest as a higher level of lability, flexibility, or variability in affective and behavioral outcomes across days. Second, we tested whether adolescents with differential susceptibility markers show greater *affective reactivity*, defined by within-person changes in affect, to both positive and negative events, as they occur in their daily lives (see Charles, Piazza, Mogle, Sliwinski, & Almeida, 2013 for a recent example of affective reactivity). We focus on affective reactivity because (a) daily affect is known to be a sensitive indicator of both affective and behavioral psychopathology (Axelson et al., 2003; Larson et al., 1990; Whalen et al., 2001), (b) affective reactivity has been postulated as a mechanism through which differential sensitivity may operate (Belsky & Pluess, 2009), and (c) affect as a general construct includes both positive and negative dimensions, both of which are necessary in order to fully test hypotheses of differential susceptibility (Belsky & Pluess, 2009; Ellis et al., 2011).

Method

Participants

The miLife Study used EMA via mobile phones to track the daily experiences, behaviors and emotions of a sample of adolescents (n = 151) at heightened risk for both substance use exposure and externalizing behavior for 38 consecutive days on average (*SD*=13.5). Participants ranged in age from 11 to 15 years (M = 13.0, SD = 0.90), with males and females equally represented in the sample (48.9% female) and 41.8% of the participants identifying as belonging to an ethnic minority group. The ethnic breakdown of the sample (*n*=150 with ethnicity information) was 57.3% White (*n*=86), 23.3% Latino (*n*=35), 4.7% Native American (*n*=7), 4.0% African-American (*n*=6), 4.0% Asian or Pacific Islander (*n*=6), and 6.7% identified as "Other" (*n*=10). Parents (90% biological mothers) of the adolescents (n = 141) also participated in the study and provided information on their family's health, socio-economic status, and relationship quality. Parents gave informed consent and the adolescents gave assent. The University of California Irvine Institutional Review Board approved all measures and procedures in the study.

Procedure

Adolescents from low SES neighborhoods were targeted and recruited via telephone screening. To determine eligibility for the study, parents completed a brief screen that recorded whether their child had experienced learning or behavioral difficulties at school, inattention or hyperactivity problems, substance use and/or exposure to alcohol or drugs by family members or peers. Adolescents for whom the parent reported the presence of 3 or more of the above risk

factors were invited to participate in the study. Following a description of the study procedures, parents provided informed consent for their own and their child's participation in the study and adolescents provided assent. In private interview rooms, both the parent and the adolescent completed a battery of self-report inventories on laptop computers.

The adolescent assessment gathered information on school performance and experiences, stressful life events, perceived socio-economic status, substance use and exposure, mental health, connectedness with family and friends and diet and exercise. The parent assessment involved both structured self-report inventories as well as a qualitative interview. Parents reported on the child's use of substances, mental health, pubertal development, sleep, diet, exercise and behavior. Parents also provided information on the economic status of the family, educational and employment history, living conditions, family history of mental health problems, neighborhood problems and resources. Parents and adolescents each received a $20 gift card for their participation in the baseline component of the study.

Following the baseline assessments, adolescents were provided with smart phones that were programmed to "beep" the participant three times a day for 30 consecutive days. Alarms were individually programmed to be compatible with each adolescent's normal waking hours as well as their school schedules and other activities. The morning survey was scheduled between the times of 7 and 10 am, and took approximately 2.3 minutes to complete. The afternoon survey was scheduled between the hours of 2 and 5PM, and took on average 3.8 minutes to complete. Finally, the PM survey was scheduled between the hours of 5PM and midnight, and took on average 8.3 minutes to complete. Each study participant was assigned a "case manager" who

monitored the incoming data, tracked response rates and sent a text message reminder when adolescents had missed 2 or more sessions in a row. The average response rate across the mobile assessment period was 92%. Adolescents were paid $25 for each of the four study weeks that they completed.

Approximately 18 months following the initial assessments, 140 adolescents were again interviewed to assess mental health, behavioral and educational status. During this follow-up visit, adolescents were also asked to provide a saliva sample for the purpose of DNA extraction and genotyping of selected alleles, including the *DRD4*-7R and 5-HTTLPR s/s alleles. One-hundred and forty-one adolescents provided saliva samples either during this follow-up visit or via mail.

Behavioral-Affective Measures in Daily Life

Risky behavior in daily life included two measures assessed during the evening diary. The first measure, *problem behavior*, was measured using 6 Yes or No items that asked about antisocial behaviors such as aggression (Today did you hit or hurt someone?), vandalism (Today did you damage someone else's property?), and theft (Today did you steal something that did not belong to you?) as well as 2 items that asked about substance use (1 item for cigarette use; 1 item for use of alcohol, marijuana, or other drugs). The second measure, *injury-risk behavior*, was measured using 4 Yes or No items intended to cover risk-taking behaviors or activities that could have caused serious injury. Items included "Today did you…(a) ride a bike without wearing a helmet, (b) ride in a car without wearing a seatbelt, (c) ride in the car with a drunk driver, and (d) skateboard without a helmet?" A daily *risky behavior* measure was created by combining the 8

antisocial behavior and 4 injury-risk items into a single prorated composite (M=0.23, SD=0.60, Min=0.00, Max=8.33, ICC=0.34). Scores were set to missing if the adolescent was missing responses for more than 6 of the 12 risky behavior measure items for that day (23 out of 4338, or 0.53%, of observations were missing more than 6 items and were set to missing).

Affect in daily life was measured using dichotomous items from the Positive and Negative Affect Scale for Children (PANAS-C; Laurent et al., 1999). Affect items began with the stem "Right now I feel…" and ended with an affective mood state descriptor. Affect items were measured three times daily (morning, afternoon, and evening). *Negative affect* items included *mad, sad, bad about myself, lonely, hopeless (or like nothing matters), guilty for no reason, afraid, worried, nervous, sick to my stomach,* and an additional item tapping *irritability*: "Even little things are getting on my nerves". These 11 items were assessed 3 times a day, yielding 33 negative affect items in total for each day. A daily negative affect score was created by taking the mean of these 33 items for each day (M=0.06, SD=0.11, Min=0.00, Max=0.97, ICC=0.45); this score represents the proportion of negative affect items the adolescent endorsed each day. Negative affect scores were set to missing if the adolescent was missing more than 16 of the 33 negative affect items for that day (762 out of 5189, or 14.7%, of observations were missing more than 16 items and were set to missing). *Positive affect* items included 4 descriptors: *happy, excited, proud,* and *full of energy,* assessed 3 times a day. For each day, the 12 positive affect items (the above 4 items assessed 3 times each day) were averaged to create a daily positive affect score that represented the proportion of positive affect items each adolescent endorsed in a day (M=0.35, SD=0.27, Min=0.00, Max=1.00, ICC=0.58). Positive affect scores were set to missing if the adolescent was missing responses for more than 6 of the 12 positive affect items

(763 out of 5193, or 14.7%, of observations were missing more than 6 items and were set to missing). Finally, a daily *Affect Balance* score was created by taking the difference between equally weighted positive and negative affect proportion scores for each day (Diener & Seligman, 2002). A positive sign on the affect balance means that positive affect predominated affect for the day; a negative sign indicates that negative affect predominated affect for the day (M=0.29, SD=0.30, Min=-0.97, Max=1.00, ICC=0.54).

Environmental Measures in Daily Life

Exposure to Violence in daily life served as our measure of negative environments, given the powerful adverse effects of violence exposure on many aspects of child and adolescent development (Buka, Stichick, Birdthistle, & Earls, 2001; Holt, Buckley, & Whelan, 2008). Exposure to violence was indexed by four items asking adolescents to report on whether they saw anyone fighting at home, at school, in their neighborhoods, or somewhere else, using "Yes" (=1) or "No" (=0) responses. A response of "1" on any of the above items resulted in the day being counted as a violence exposure day. Of the 151 adolescents in our sample, 113 (74.8%) reported violence exposure on at least one of the study days. These 113 adolescents reported exposure to violence on 13.8% of days, on average (Min=1.9%, Max=100.0%, ICC=0.31).

Positive Events in daily life were assessed using a single item in the evening diary: "Did something really good happen to you today?" Adolescents responded to this question with either a "Yes" (coded 1) or "No" (coded 0). One-hundred and forty-one adolescents (93.4% of the sample) reported experiencing at least one positive event during the study period, and these

adolescents reported a positive experience on 19.0% of days on average (Min=2.7%, Max=100.0%, ICC=0.20).

Markers of Differential Susceptibility

DNA Collection and Extraction. Saliva samples were collected from adolescents using Oragene OG-500 collection tubes. Samples were stored at room temperature and transferred to a genomic facility for extraction and analysis. Genomic DNA was extracted from saliva samples using the prepIT L2P procedure (DNA Genotek). All samples were RNase treated for 15 minutes at 37ºC before DNA precipitation. The DNA precipitate was washed with 70% ethanol, then air dried. DNA pellet was dissolved in a nuclease-free distilled water (Qiagen). The DNA concentration was determined using a GE Nanovue Spectrophotometer.

DRD4 exon 3 VNTR polymorphism genotyping was performed using polymerase chain reaction (PCR) combined with band size analysis. The forward primer sequence is (5'-ACCGCGACTACGTGGTCTACTCGTC-3') and the reverse (5'-CCCGCCCCTCAGGACAGGA-3'). This amplifies a 517 base pair product for the 4 repeat (4) allele and a 661 base pair product for the 7 repeat (7) allele. PCR products were separated on 2% agarose gel supplemented with ethidium bromide and visualized by ultraviolet transillumination. Digital images of the gels were taken, and band size was determined based on comparisons to 100 bp ladder molecular weight standards (Hyperladder IV, Bioline). From these digital images, adolescents' *DRD4* genotype was determined. *Consistent with previous studies, we split adolescents into two groups: (1) those who possessed at least one copy of the 7R allele on either chromosome versus (2) those who did not possess the 7R allele.* Among the 141 adolescents who

provided saliva samples, 35% carried at least one copy of the 7R allele (n=50). The prevalence of the 7R allele did not differ by gender (36.2% of females, 34.7% of males, N=141, χ^2=0.04, p=0.85) nor by ethnicity (32.9% of Whites, 39.0% of Non-Whites, N=141, χ^2=0.55, p=0.46).

5-HTTLPR polymorphism was genotyped by agarose gel size fractionation of PCR products. PCR Primer sequences for 5-HTTLPR are as described by Gelernter, Kranzler, and Cubells (1997); the forward primer having the sequence (5'-ATGCCAGCACCTAACCCCTAATGT-3') and the reverse (5'-GGACCGCAAGGTGGGCGGGA-3'). This amplifies a 419 base pair product for the 16 repeat (L) allele and a 375 base pair product for the 14 repeat (S) allele. PCR products were separated on 2 % agarose gel supplemented with ethidium bromide and visualized by ultraviolet transillumination. Digital images of the gels were taken, and band size was determined based on comparisons to 100 bp ladder molecular weight standards (Hyperladder IV, Bioline). The 5HTT promoter Alleles are designated according to their relative size: Short "S" (14 repeats), long "L" (16 repeats), or Extra Long "XL" (20 repeats). Only one subject had one "XL". We created a count of the number of "S" alleles present for each adolescent across the two copies of chromosome 17, ranging naturally from 0 (no "S" alleles present on either copy of chromosome 17) to 2 (both copies of chromosome 11 contained an "S" allele). In the sample of 141 adolescents who provided saliva samples, 51.1% (n=72) carried one copy of the "S" allele; 20.6% (n=29) carried two copies of the "S" allele. *For the current analyses, we compared youth with two copies of the "S" allele (20.6%, n=29) to youth with 0 or 1 copies of the "S" allele (79.4%, n=112).* Although the prevalence of the s/s allele was higher in females (26.1% of

females, 15.3% of males, χ^2=2.52, N=141, p=0.11) and in White adolescents (24.4% of Whites, 15.3% of Non-Whites, χ^2=1.75, N=141, p=0.19), these differences were not statistically significant.

Low Self-Control was measured at the follow-up using a modified version of the 13-item Brief Self-Control Scale (BSCS; Tangney et al., 2004). The BSCS was created for adults but has face validity for adolescents (Duckworth et al., 2010). The BSCS includes items such as "I have trouble concentrating", "I often act without thinking", and "I have a hard time breaking bad habits", each of which were scored on a 3-point scale where 0=*not true*, 1=*somewhat or sometimes true*, and 2=*very true or often true.* A prorated sum of these items was created for use in analyses, including all adolescents who completed at least 50% of the items in the scale (n=137, M=10.62, SD=4.77, Min=2.00, Max=23.00, α=0.80).

Analytic Strategy

Analyses proceeded in three steps, each corresponding to a primary aim of the study.

***Question 1*: Do Adolescents with Differential Susceptibility Markers Show More Affective-Behavioral Lability in Daily Life?**

Lability on daily behavioral and affective measures was operationalized using intraindividual standard deviations (iSDs). iSDs measure within-person variability by taking the standard deviation across each adolescent's distribution of scores on a given dimension over time (e.g. risky behavior or positive/negative affect). As such, the iSD represents the amount of day-to-day variability around each adolescent's own mean score (aka the intraindividual mean or

iMean) for affective and behavioral dimensions. High iSD values indicate a wide range of behavioral-affective lability; low iSD values indicate a narrow range of lability (Baltes & Nesselroade, 1973; Nesselroade, 1991; Ram & Gerstorf, 2009). To test the hypothesis that adolescents with differential susceptibility markers will show greater behavioral-affective lability in daily life, we used a series of ordinary least squares (OLS) regression models to test whether behavioral-affective iSDs were higher for youth with versus without theoretically specified differential susceptibility markers (*DRD4*-7R, 5-HTTLPR s/s, and low self-control).

Question 2: Are Adolescents with Differential Susceptibility Markers More Reactive to Positive and Negative Daily Events?

We used multilevel modeling with random slopes in SAS PROC MIXED to identify adolescents who were most reactive to positive and negative experiences in daily life. Two separate multilevel models were specified: (1) a positive exposure model and (2) a negative exposure model. The positive exposure model estimated each adolescent's change in positive affect across days when he or she did versus did not experience a positive event. The negative exposure model estimated each adolescent's change in negative affect across days when he or she was versus was not exposed to violence. Reactivity was measured using a Level 1 (within-person) slope coefficient, representing the within-person change in affect on days when individuals did versus did not experience a positive or negative event. Reactivity slopes were allowed to vary across adolescents in the study via random effects. These models also included each person's iMean level of exposure as a Level 2 (between-person) predictor in order to remove all between-person variability from within-person exposure-affect slopes (Bolger &

Laurenceau, 2013). Residual autocorrelation was modeled using an autoregressive spatial power structure via a REPEATED statement in PROC MIXED. Slopes representing affective reactivity for each adolescent were output from both the positive and negative exposure models.

Once positive and negative exposure slopes were exported, we used a 66th percentile cutoff, marking adolescents in the upper third of positive and negative reactivity slope distributions as showing "high" reactivity on either. Based on these cutoffs, adolescents were then grouped based on whether they showed low reactivity (low negative reactivity and low positive reactivity, 44.9% of sample), predominantly positive reactivity (low negative reactivity but high positive reactivity, 20.6% of sample), predominantly negative reactivity (high negative reactivity but low positive reactivity, 20.6% of sample), or differential reactivity profiles (high negative reactivity and high positive reactivity, 14.0% of sample). We then used a series of logistic and OLS regressions to test our hypothesis that adolescents showing a differential reactivity profile (aka differential susceptibility in daily life) would be characterized by a higher prevalence of differential susceptibility factors (*DRD4*-7R, 5-HTTLPR s/s, and low self-control) compared to those in the low reactivity group.

Results

Descriptive Statistics for Daily Behavioral-Affective Measures

Table 3.1 shows iSDs and person-level means (iMeans) for daily behavioral-affective measures, as well as the correlations between iSDs and iMeans for each measure. With the exception of affect balance (r =0.01), iSDs and iMeans were positively and significantly correlated for each behavioral-affective dimension, suggesting that adolescents with higher

levels of lability were also more likely to show higher individual-level means for risky behavior and positive/negative affect across the study period. This was especially true for negative affect (r =0.90, p<0.001) and risky behavior (r = 0.77, p<0.001).

Question 1: Do Adolescents with Differential Susceptibility Markers Show More Emotional-Behavioral Lability in Daily Life?

Table 3.2 tests whether adolescents with versus without differential susceptibility factors show higher levels of behavioral-affective lability in daily life, as measured by the iSD. **Table 3.2** shows three main findings. First, the unadjusted models show that adolescents with versus without the *DRD4*-7R allele show higher levels of lability across all four behavioral and affective measures; however, only two of these differences are significant (negative affect and affect balance) and one is marginally significant (positive affect, p<0.10). When effects are adjusted for adolescents' individual-level means (Adjusted for iMeans models in Table 3.2), a significant effect emerges showing that adolescents with versus without the *DRD4*-7R allele display greater lability in risky behavior, whereas *DRD4*-7R effects on positive and negative affective lability are rendered nonsignificant. Adolescents with the *DRD4*-7R allele continue to show higher lability in daily affective balance, however, even after adjusting for individual-level means. Second, the unadjusted models also show that adolescents with low self-control display significantly higher levels of lability in risky behavior, negative affect, and affective balance. Even after models are adjusted for individual-level means, adolescents with low self-control continue to show higher levels of lability in risky behavior (p=0.06) and affect balance, whereas the effect of low self-control on negative affective lability is rendered nonsignificant. Third,

although adolescents with versus without the 5-HTTLPR s/s allele showed marginally higher levels of lability in risky behavior in the unadjusted model, this effect disappeared when models were adjusted for individual means. No other effects were found for adolescents with versus without the 5-HTTLPR s/s allele.

Question 2: Are Adolescents with Differential Susceptibility Markers More Reactive to Positive and Negative Daily Events?

Adolescents who were not exposed to violence during the study period were excluded from negative affective reactivity calculation (n excluded=38), just as adolescents who were not exposed to positive experiences during the study period were excluded from positive affective reactivity calculation (n excluded=10). **Table 3.3** shows estimates from multilevel models testing positive and negative reactivity in adolescents' daily lives. Fixed effects estimates from these models suggested that on average, adolescents showed significant elevations in negative affect on days were they were exposed to violence versus days when no violence occurred (b=0.02, SE=0.01, p=0.004) as well as significant elevations in positive affect on days with versus without a positive experience (b=0.11, SE=0.01, p<0.001). A marginally significant random effect for the violence exposure slope (variance estimate=0.0006, SE=0.0004, p=0.05) and a significant effect for the positive experience slope (variance estimate=0.004, SE=0.001, p=0.002) provided evidence that adolescents differed from one another in their reactivity to both positive and negative events in daily life. From these models, reactivity slopes unique to each adolescent were estimated and exported as separate variables. Adolescents were categorized as high in negative reactivity if their reactivity slope scored in the upper third of the distribution for

negative reactivity slopes (b>0.02) and high in positive reactivity if their positive reactivity slope scored in the upper third of the distribution for positive reactivity slopes (b>0.13).

Of the 151 adolescents in our sample, 107 (70.9%) experienced both violence exposure and positive events. Of these 107 adolescents, 20.6% (*N*=22) were classified as showing *predominantly negative reactivity*, showing a high increase in negative affect when exposed to violence but no high increase in positive affect when experiencing a positive event; 20.6% (*N*=22) were identified as showing *predominantly positive reactivity*, showing a high increase in positive affect across days when they did versus did not experience a positive event, but no high increase in negative affect when exposed to violence; 14.0% (*N*=15) adolescents showed *differential reactivity*, or high positive reactivity *and* high negative reactivity to positive and negative events, respectively; and the remaining 44.9% (*N*=48) showed *low reactivity* on both positive and negative dimensions. Adolescents in the negative (OR=5.77, 95% CI: 1.92, 17.33) and differential reactivity groups (OR=7.40, 95% CI: 2.00, 27.43) were significantly more likely to be female compared to adolescents in the low reactivity group. Reactivity groups did not differ in their odds of belonging to a white versus non-white ethnic group.

Table 3.4 compares adolescents across these four reactivity groups on their prevalence rates of differential susceptibility genes (*DRD4*-7R and 5-HTTLPR s/s) and on their levels of low self-control. Four main findings are apparent in Table 3.4. First, adolescents in the predominantly negative reactivity group were marginally more likely to possess the *DRD4*-7R allele compared to adolescents in the low reactivity group (OR=2.69, p=0.06), whereas no significant differences were found in the prevalence of *DRD4*-7R for predominantly positive

versus low (OR=0.90, p=0.86) or for differential versus low (OR=2.36, p=0.16) despite a sizeable odds ratio associated with the latter comparison. Second, adolescents in the differential versus low reactivity group were somewhat more likely to have lower self-control (b=2.94, SE=1.49, β =0.21, p=0.05). Adolescents in predominantly positive (b=1.32, SE=1.33, β =0.10, p=0.32) and predominantly negative reactivity groups (b=2.10, SE=1.26, β =0.18, p=0.10) did not differ from the low reactivity group in their levels of self-control, again despite a sizeable effect size difference in the latter comparison. Third, the reactivity groups did not significantly differ in their odds of carrying the 5-HTTLPR s/s. Fourth, none of the three differential susceptibility factors differentiated adolescents in predominantly negative versus differential reactivity groups (see column D in Table 3.4), suggesting these factors did not uniquely characterize youth who showed high reactivity to both positive and negative events.

Tests of Selection Effects: Do Adolescents with Differential Susceptibility Markers Experience More Positive or Negative Events in Daily Life?

We tested the possibility that adolescents with versus without differential susceptibility markers experienced positive and negative events more often in their daily lives. If adolescents with these differential susceptibility markers are more likely to experience positive and negative events in their daily lives than adolescents without these markers, this might suggest that youth with these characteristics are selecting into or otherwise eliciting these specific environments.

***DRD4*-7R.** We found no evidence that adolescents with versus without the *DRD4*-7R allele were exposed to violence (*b*=-0.02, SE=0.03, p=0.41, β=-0.07) or positive events (b=0.02, SE=0.03, p=0.57, β=0.05) on a higher proportion of days.

5-HTTLPR s/s. For adolescents with versus without the 5-HTTLPR s/s genotype, we found no differences in proportion of days exposed to violence (b=-0.02, SE=0.03, p=0.57, β=-0.05) or positive events (b=-0.01, SE=0.04, p=0.86, β=-0.02).

Low Self-Control. Adolescents with low self-control were exposed to violence on a higher proportion of days than adolescents with higher self-control (b=0.01, SE=0.00, p=0.01, β=0.22), suggesting that adolescents with low self-control may be more likely to select into contexts where violence is occurring. Adolescents with low self-control did not, however, experience a greater proportion of days with positive events (b=-0.01, SE=0.00, p=0.74, β=-0.03).

Discussion

The current study adopted a within-person approach and tested whether some adolescents are more sensitive to their environments than others, for better and for worse, as predicted by differential susceptibility theory. Using diary methods to repeatedly measure adolescents' environments, affect, and behavior in daily life, we found that adolescents with either the *DRD4*-7R allele or low levels of self-control showed (a) greater behavioral-affective lability, indicating that these youth showed a greater range of affect and behavior in daily life, and (b) higher levels of affective reactivity to events, with *DRD4*-7R carriers showing a pattern of increased reactivity to negative events *only*, and adolescents with low self-control showing a pattern of differential reactivity to both positive and negative events in their daily lives. Contrary to expectations, adolescents with the 5-HTTLPR s/s allele did not show increased lability or affective reactivity in their daily lives.

Our findings provide mixed support for differential susceptibility in daily life among adolescents with *DRD4*-7R. On the one hand, we found evidence that youth with *DRD4*-7R were more labile in risky behavior and affect balance in daily life, suggesting that these youth have a wider range of affective and behavioral outcomes and perhaps a greater potential for change. On the other hand, we did not find compelling evidence that youth who exhibited a pattern of differential reactivity in daily life (higher than average reactivity to *both* positive and negative experiences) were more likely to possess the *DRD4*-7R allele. Although, youth who showed predominantly negative reactivity were more somewhat more likely to be 7R carriers (p=0.06). This could mean that, among these adolescents, the *DRD4*-7R allele was functioning strictly as a vulnerability factor, as would be hypothesized by the diathesis-stress model (Monroe & Simons, 1991). However, our finding that youth with predominantly negative versus differential reactivity could not be discriminated by the presence of the *DRD4*-7R casts doubt on the specificity of *DRD4*-7R as a diathesis-stress marker. Further research with larger samples, offering greater statistical power, will be necessary to resolve this issue.

We found evidence for differential susceptibility in daily life among adolescents with low levels of self-control. Our findings suggest that youth with low self-control are more behaviorally and affectively labile, as they showed greater within-person variability in risky behavior (p=0.06) and in their affective balance. Additionally, there was a trend (p=0.05) among adolescents who showed differential reactivity in daily life to have lower levels of self-control, suggesting that low self-control may be associated with greater sensitivity to both positive and negative events. However, low self-control did not uniquely characterize adolescents who showed differential versus predominantly negative reactivity, again, suggesting that adolescents

with differential reactivity may not be uniquely characterized by low self-control. Future research replicating this method with larger samples will be necessary to support low self-control as a marker of differential reactivity in daily life.

We also found that adolescents with versus without low self-control were exposed to violence on a higher proportion of study days, suggesting the possibility of a selection effect. That is, adolescents with low self-control may be selecting into contexts where violence is more likely to occur. However, because self-control was assessed *after* the diary recording period, we cannot discern whether environments characterized by high levels of violence exposure *predict* low self-control, or whether self-control leads adolescents to select into contexts with high levels of violence exposure. The same can be said of our findings relating self-control to affective-behavioral lability and differential reactivity in daily life—we cannot be sure that low self-control is the *predictor* of these daily states rather than the *outcome*. Future research measuring low self-control both before and after diary studies with adolescents will be needed to address this problem.

We found no evidence for differential susceptibility in adolescents with the 5-HTTLPR s/s allele. The reasons why are unclear, but one possibility is that the effect size associated with this marker was too small to be detected in our sample. Another possibility is that 5-HTTLPR s/s simply did not mark differential susceptibility among the adolescents in our sample. Future research is needed to address the viability of 5-HTTLPR s/s as a marker of differential susceptibility among adolescents in daily life.

Our inability to discriminate adolescents in the differential reactivity group based on differential susceptibility factors may have been due to our relatively general measures of positive and negative environments in daily life. Our assessment of these included a single type of exposure tapping negative events (exposure to violence) and a single item tapping for positive events (did something really good happen to you today?). More comprehensive measurement of positive and negative events should be included in future research of adolescents' daily lives, as this may allow for more precise within-person reactivity effects and may potentially result in clearer discrimination of reactivity groups.

Of note in our findings is the lack of association between differential susceptibility markers and variability in single dimensions of positive and negative affect. We found some evidence that adolescents with *DRD4*-7R and low self-control showed greater lability in daily negative affect, however, these associations were rendered nonsignificant when the individual-level negative affect means were added to the models. Additionally, we found trend-level evidence that adolescents with *DRD4*-7R showed higher positive affective lability, but this association was also rendered nonsignificant when individual-level positive affect means were added to the model. These nonsignificant findings are interesting given our finding that adolescents with these characteristics (*DRD4*-7R and low self-control) showed greater lability in their daily affective balance even after adjusting for individual-level means. One likely reason for the difference in findings between negative affect and affective balance is the *very* high intercorrelation between individual-level means and iSDs for negative affect (r = 0.90) versus the complete lack of intercorrelation between individual-level means and iSDs for affective balance (r=-0.01). This would explain why adolescents with *DRD4*-7R and low self-control continued to

show greater lability in affective balance after adjusting for individual-level means, whereas they did not continue to show lability in negative affect when individual-level means were adjusted. The same may have been true of lability for positive affect versus affective balance, but to a lesser extent as the positive affect individual-level means and iSDs were only modestly correlated (r = 0.25). Ultimately, the reasons why *DRD4*-7R and low self-control are associated with lability in affective balance versus single affect dimensions are not clear, making this an important topic for future research.

Adolescents with predominantly positive reactivity in daily life were also not characterized by any of the three differential susceptibility markers we tested. This is interesting given that two of these (*DRD4*-7R and 5-HTTLPR s/s) have recently been suggested as potential markers of *vantage sensitivity*, a concept that describes enhanced sensitivity to exclusively positive experiences as a function of individual-level characteristics (Pluess & Belsky, 2013). Vantage sensitivity could reasonably manifest as predominantly positive reactivity in daily life, as these youth would be expected to show high reactivity to positive experiences, but not necessarily high reactivity to negative experiences. Again, future research should include more comprehensive assessments of positive and negative experiences in daily life to better test for vantage sensitivity. Additionally, future research using mobile technologies should consider the use of experimentally manipulated positive events, such as supportive messages or small monetary rewards, which could be delivered wirelessly during the course of a diary study with adolescents. Because these positive "events" could be delivered randomly throughout the diary recording period, their use could facilitate causal inferences regarding which adolescents are

more sensitive to positive experiences, and more powerfully inform theory and research into vantage sensitivity.

This study has limitations. First and foremost, the small number of adolescents exposed to both violence and positive events (n=107) and the small number of adolescents showing differential reactivity in daily life (n=15) means that we are likely underpowered in our tests of whether reactivity groups differ in their presentation of genetic and behavioral markers of differential susceptibility. This is also suggested by the sizeable, but non-significant, odds ratios associating *DRD4*-7R with differential reactivity (OR=2.36) and low self-control with predominantly negative reactivity (OR=2.10). Our relatively small sample size also prevented us from testing for differential effects by sex, which is important given that *DRD4*-7R and low self-control have shown evidence of sex differences in their effects (Dmitrieva et al., 2011; Leve et al., 2005). As mentioned above, future research replicating our within-person method with larger samples is needed to better characterize youth showing various patterns of reactivity. Second, our multilevel models testing affective reactivity to positive events and exposure to violence tested *same-day effects*, and therefore cannot entirely rule out the possibility that affective states precede and predict exposure to positive and negative events. Future research with more careful attention to the *within-day* timing and patterning of exposures and affect will be needed to sort out the temporality of these relationships. Third, and more generally, because exposures are naturally occurring in adolescents' daily lives, we cannot completely rule out selection effects in the way that an experimental design with randomly assigned exposures could. We therefore echo the suggestion of Ellis and colleagues (2011) for continued experimental

research testing differential susceptibility hypotheses, which might include experimental paradigms embedded in EMA data collection protocols.

There have been an increasing number of studies on the differential susceptibility model among youth, but the majority of this research has used cross-sectional and/or between-subjects designs. The current study took a novel approach to testing differential susceptibility in adolescents' daily lives, using within-person information collected via repeated mobile phone assessments of context, affect, and behavior. Our findings provide a preliminary suggestion that adolescents with *DRD4*-7R and low self-control may be more flexible in their range of affective and behavioral outcomes as well as more sensitive to their environmental circumstances. If our findings are borne out in future research, including those involving experimental paradigms, they will add to the growing body of research suggesting that adolescents with *DRD4*-7R or low self-control may be those who, although more vulnerable, may be more likely to benefit from targeted intervention efforts aimed at fostering healthy developmental pathways through adolescence and beyond.

Table 3.1. *Intrainividual standard deviations (iSDs) and intraindividual means (iMeans) for Daily Behavioral-Affective Measures*

	iSD	iMean	*r*	*p*
Risky Behavior	0.37	0.26	0.77	<0.001
Positive Affect	0.17	0.36	0.25	0.002
Negative Affect	0.07	0.06	0.90	<0.001
Affect Balance (Positive – Negative)	0.20	0.29	-0.01	0.948

r = Pearson correlation coefficient

Table 3.2. *Do Adolescents with Differential Susceptibility (DS) Markers Show More Affective-Behavioral Lability in Daily Life?*

	Risky Behavior iSD		Positive Affect iSD		Negative Affect iSD		Affect Balance iSD	
	Unadjusted	*Adjusted for iMeans*	*Unadjusted*	*Adjusted for iMeans*	*Unadjusted*	*Adjusted for iMeans*	*Unadjusted*	*Adjusted for iMeans*
	b (SE)	b (SE)	b (SE)	b (SE)	b (SE)	b (SE)	b (SE)	b (SE)
DS Markers								
DRD4-7R	0.11 (0.07)	**0.09** (0.04)*	0.02 (0.01)$^{+}$	0.02 (0.01)	**0.02** (0.01)*	0.00 (0.00)	**0.03** (0.01)*	**0.03** (0.01)*
	β = 0.14	β = 0.12	β = 0.16	β = 0.13	β = 0.17	β = 0.04	β = 0.19	β = 0.19
5-HTTLPR s/s	-0.15 (0.08)$^{+}$	-0.04 (0.05)	-0.01 (0.01)	-0.01 (0.01)	-0.01 (0.01)	-0.00 (0.00)	-0.02 (0.02)	-0.02 (0.02)
	β = -0.16	β = -0.05	β = -0.06	β = -0.06	β = -0.09	β = -0.03	β = -0.10	β = -0.10
Low Self-Control	**0.03** (0.01)***	0.01 (0.00)$^{+}$	0.00 (0.00)	0.00 (0.00)	**0.00** (0.00)***	0.00 (0.00)	**0.00** (0.00)*	**0.00** (0.00)*
	β = 0.37	β = 0.11	β = 0.01	β = 0.05	β = 0.28	β = 0.02	β = 0.17	β = 0.19

Table 3.2 Notes:

iSD=intraindividual standard deviation. iMean=intraindividual mean. b(SE)=unstandardized beta (and its standard error) from Ordinary Least Squares (OLS) regression model. β = standardized beta coefficient from OLS model. Significant estimates ($p<0.05$) are presented in **bold**.

***$p<0.001$, *$p<0.05$, $^{+}p<0.10$.

This pattern of results shown in the Adjusted for iMeans models held when sex and ethnicity were added as covariates, with the exception of the Low Self-Control effect on risky behavior lability. This effect became significant (p=0.046) when sex and ethnicity were added as covariates.

Table 3.3. *Multilevel Models Generating Negative and Positive Reactivity Slopes*

Negative Reactivity Model (N=113)			*Positive Reactivity Model (N=141)*		
Fixed Effects	Estimate	SE	Fixed Effects	Estimate	SE
Daily ETV	**0.02****	0.01	Daily Positive Event	**0.11*****	0.01
Person-Mean ETV	**0.20*****	0.04	Person-Mean Positive Events	**0.30****	0.09
Intercept	**0.06*****	0.01	Intercept	**0.34*****	0.02
Random Effects	Estimate	SE	Random Effects	Estimate	SE
Between person			*Between person*		
VAR(Intercept)	**0.004*****	0.0007	VAR(Intercept)	**0.038*****	0.0049
VAR(Daily ETV Slope)	0.001^{+}	0.0004	VAR(Daily Positive Event Slope)	**0.004****	0.0015
COV(Int, ETV Slope)	**0.001*****	0.0004	COV(Int, Positive Event Slope)	**-0.005***	0.0020
CORR (Int, ETV Slope)	0.91		CORR (Int, Positive Event Slope)	-0.37	

Table 3.3., Continued: *Multilevel Models Generating Negative and Positive Reactivity Slopes*

Random Effects	Estimate	SE	Random Effects	Estimate	SE
Within person			*Within person*		
Autocorrelation	**0.37*** **	0.0203	Autocorrelation	**0.40*** **	0.0185
Residual	**0.01*** **	0.0002	Residual	**0.03*** **	0.0009

Table 3.3 Notes:

VAR=Variance, COV=Covariance, CORR=Correlation. Significant estimates ($p<0.05$) are shown in **bold**. ***$p<0.001$, **$p<0.01$, *$p<0.05$, $^{+}p<0.10$. Person-mean ETV and person-mean positive event variables were centered around their sample means (M=0.10 and M=0.18, respectively).

Table 3.4. *Are Adolescents with Differential Susceptibility (DS) Markers More Reactive to Positive and Negative Daily Events?*

		Reactivity Groups				Comparison with Low Reactivity Group			
	N	Low Reactivity	Predominantly Positive Reactivity	Predominantly Negative Reactivity	Differential Reactivity	A Predominantly Positive vs Low	B Predominantly Negative vs Low	C Differential vs Low	D Differential vs Predominantly Negative
DS Markers									
DRD4-7R	105	27.1%	25.0%	50.0%	46.7%	0.90 (0.27, 2.97)	**2.69**$^{+}$ (0.94, 7.70)	2.36 (0.71, 7.80)	0.90 (0.24, 3.26)
5-HTTLPR s/s	105	18.8%	25.0%	22.7%	6.7%	1.44 (0.42, 5.02)	1.28 (0.37, 4.37)	0.31 (0.04, 2.67)	0.24 (0.03, 2.33)
Low Self-Control	102	9.94 (4.64)	11.26 (5.34)	12.04 (4.99)	12.88 (4.91)	1.32 (1.33) $\beta = 0.10$	2.10 (1.26) $\beta = 0.18$	**2.94** (1.49)$^{+}$ $\beta = 0.21$	0.84 (1.67) $\beta = 0.06$

Table 3.4 Notes:

Percentages and odds ratios (OR) with 95% Wald confidence intervals are presented for *DRD4*-7R and 5-HTTLPR s/s. Means (with standard deviations), unstandardized regression coefficients (b with standard errors), and standardized beta coefficients (β) are presented for low self-control. Significant estimates (at the $p<0.10$ level) are shown in **bold**.

This pattern of results held when sex and ethnicity (white versus non-white) were added to the models.

EPILOGUE

Children and adolescents living in socioeconomic disadvantage are exposed to many hassles, stressors, and risks in their daily lives. These seemingly minor yet pervasively experienced events can add up to large impacts on their well-being. This dissertation focused on gaining a better understanding of how these experiences impact low-income youth as they go through their daily lives. Using a within-person approach, the overarching aims of the dissertation were to (1) capture the effects of specific environmental "exposures" on low-income youths' affect and behavior in daily life, and (2) test whether some youth are more sensitive to their surrounding environments than others.

In Chapter 1, I reviewed theory and research on the everyday environments of low-income youth, and discussed applying diary methods via mobile technologies as a valuable future direction in this area. Chapter 1 articulated a within-person framework for understanding low-income children's environments and their effects, as well as for identifying youth who may be more sensitive to context than others, using mobile technologies to measure "life as lived".

Chapters 2 and 3 provided empirical examples informed by the within-person framework presented in Chapter 1, using mobile technologies to test environmental effects in daily life (and individual differences therein) among a sample of 151 youth from low-SES neighborhoods (the miLife study). Chapter 2 showed that adolescents were more likely to engage in problem behavior (antisocial behavior and substance use) on days they witnessed others using substances, compared to themselves on days when they did not witness others using substances. Chapter 2 also provided evidence of a gene-environment interaction, showing that adolescents with versus without the *DRD4*-7R allele displayed a greater increase in their likelihood of problem behavior

on days they were exposed to others' substance use versus days they were not exposed. That is, adolescents with versus without the *DRD4*-7R allele were more reactive to contexts facilitating engagement in antisocial behavior and substance use.

Chapter 3 tested whether some adolescents were more sensitive to both positive *and* negative events in their daily lives, as might be suggested by the theory of differential susceptibility to environment. Chapter 3 presented three findings. First, adolescents with either the *DRD4*-7R allele or low levels of self-control showed greater affective and behavioral *lability* over time, suggesting that these youth display a wider range of emotional and behavioral states in their everyday lives. Second, youth with versus without the *DRD4*-7R allele were more likely to show a pattern of *predominantly negative reactivity* (high reactivity to negative events but low reactivity to positive events) in daily life, whereas youth with low levels of self-control were more likely to show a pattern of *differential reactivity* (high reactivity to both positive and negative events) in daily life. Third, we found no evidence that adolescents with versus without the 5-HTTLPR s/s allele showed greater lability or reactivity to positive and negative events in daily life.

A few findings stand out across Chapters 2 and 3. The first is that everyday experiences have noticeable impacts on adolescents' affect in behavior, which can be clearly observed on a day-to-day basis. In both chapters, strong and significant associations between exposures (substance use exposure, violence exposure, and positive experiences), affect, and behavior were observed. These findings provide support for theories emphasizing the importance of everyday environments for child and adolescent well-being (Evans, 2004; Hertzman & Boyce, 2010; Repetti et al., 2002). The second is that adolescents with versus without the *DRD4*-7R allele

appear to be more reactive to negative events in their daily lives. Adolescent 7R carriers showed stronger behavioral reactivity to substance use exposure as well as stronger negative affective reactivity in response to violence exposure. This finding across two separate exposures suggests that the *DRD4*-7R allele may moderate adolescents' responses to numerous aspects of their environments.

What are the future directions suggested by this research? First and foremost, future research that assesses a wider array of positive and negative events in adolescents' daily lives is needed to ensure that the effects of adolescents' most salient experiences are captured. The assessment of multiple domains (i.e. at home versus in school or in the neighborhood) is especially important among adolescents because stressful and positive events might be expected to have very different meanings depending on whether they are experienced with family members versus with peers. Second, future research should assess *within-day changes* in affect and behavior following stressful and positive events. Because Chapters 2 and 3 analyzed same-day effects, the directionality and timing of reactivity effects could not be isolated. It may be that fluctuations in affect and behavior lead adolescents to select into or otherwise evoke positive and negative exposures from others in their surrounding environments. Studies that collect a higher density of observations for exposures, affect, and behavior over the course of a day could better assess which predicts which. Experimental paradigms may help with this issue, particularly those that can deliver exogenous "shocks" (that is, experimentally induced negative or positive experiences) via the study mobile devices as adolescents go through their daily lives. Although the ethics of delivering negative experiences to adolescents outside a protected laboratory context are debatable, positive "shocks", in the form of monetary bonuses or supportive

messages, could be feasibly delivered and would provide an experimental test of environmental sensitivity in daily life. Fourth, studies with larger sample sizes are needed to better estimate between-person differences in environmental within-person effects, especially differences associated with sex and ethnicity.

To continue advancing research in this area, we have fielded the Week in the Life Study (WITL), which is currently recruiting 100 male adolescents residing in low-income homes (ages 14-17). The WITL study builds upon the work presented here in three main ways. First, the WITL study includes a more comprehensive assessment of stressors in adolescents' daily lives. Stressors are assessed twice daily (as opposed to once daily in the miLife study), and include questions specific to events with parents, peers, and teachers in daily life. Thus, the study will be better positioned to examine temporal ordering of within-person event-behavior relationships, as well as better identify the precise domains in which adolescents encounter the greatest number and highest intensity of stressful events. Second, the WITL study includes an equally detailed and parallel battery of assessments for positive experiences in daily life, which will allow the study to better understand the factors that offer benefit or protection in adolescents' lives. Third, the study includes a wider battery of baseline factors that, according to differential susceptibility theory, might enhance susceptibility to environmental experience, including genetic markers, personality dimensions, and family background variables.

The research presented in this dissertation provides evidence that, for adolescents living in low-income environments, contextual triggers such as exposure to others' substance use, daily stressors, and positive experiences, are unique predictors of affect and behavior, with some youth being more reactive or susceptible to these experiences than others. Continued research on the

environments of low-income youth has the potential identify youth who, although most at risk, may be more likely to benefit from targeted intervention. In so doing, this line of research has the potential to make a positive impact on the health and well-being of low-income children and their families.

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