Variation in Experiences of Unpredictability and Mental Health: A Developmental Perspective

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To Myself

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ABSTRACT

Unpredictability, an aspect of early life adversity, creates significant disruptions for children and adolescents' psychosocial development throughout their lifetime. Despite growing evidence highlighting the importance of predictable caregiving in fostering long-term healthy development, there is still limited understanding of proximal unpredictability within caregiver-child relationships. Given that both early childhood and adolescence are dynamic periods characterized by increasing self-regulation capacities and susceptibility to mental health disorders, this dissertation aimed to address three critical gaps in understanding caregiver unpredictability and its implications for child and youth adjustment: whether it is domain general or specific, the cascade between distal and proximal experiences of unpredictability and the developmental systems most influenced by caregiver unpredictability during childhood and adolescence.

Study 1 examined the relations among family instability, maternal and paternal mood unpredictability, and youths' mental health problems in a sample of Mexican-origin families. Using random intercept cross-lagged models to disentangle between- and within-family differences, results showed that family instability was positively related to maternal and paternal mood unpredictability, and that maternal mood unpredictability was positively associated with youths' internalizing problems across adolescence. However, there was little evidence of reciprocal relations, suggesting a lack of transactional associations at the within-family level over time.

Study 2 was designed to extend prior research on caregivers' sensory signal unpredictability with infants, by (1) developing and validating an observational measure of caregiver affective and behavioral unpredictability in early childhood, and (2) exploring its

implications for preschoolers' development of biobehavioral self-regulation. Results demonstrated that caregiver unpredictability was related to only a subset of indices of biobehavioral regulation. At age four, caregiver affective and behavioral unpredictability was linked to greater respiratory sinus arrhythmia (RSA) suppression (i.e., decrease in RSA) during the Day/Night task, and to greater effortful control in a non-linear, inverted U-shape pattern. At age six, children whose caregivers exhibited greater sensory signal unpredictability had stronger RSA suppression during the Day/Night task. Conversely, children whose caregivers demonstrated lower and higher levels of affective and behavioral unpredictability had RSA augmentation relative to children whose caregivers were moderately unpredictable. However, neither sensory signals nor affective or behavioral unpredictability was associated with children's inhibitory control or behavioral adjustment.

Together, these studies emphasize the importance of developing and validating methods to capture the dynamic and nuanced nature of caregiver unpredictability, as well as considering its domain specificity. This dissertation also raises questions about the appropriate temporal lens for examining caregiver unpredictability, the significance of developmental timing, and the impact of unique experiences and vulnerabilities among Mexican-origin families living in unpredictable environments. In conclusion, this research program provides valuable insights into the effects of unpredictability on early childhood development and adolescent mental health. Systematic empirical and translational progress in understanding unpredictability will enhance efforts to ensure continuity and stability in children's lives, particularly for families experiencing other environmental adversities that threaten children's and adolescents' well-being.

CHAPTER ONE

GENERAL INTRODUCTION

Caregiver unpredictability has increasingly become a central focus in research seeking to understand developmental influences on self-regulation and stress physiology, given the substantial consequences of unpredictability for an individual's psychosocial development throughout their lifetime (Baram et al., 2012; Davis et al., 2017; Gee & Cohodes, 2021; Glynn & Baram, 2019; Tottenham, 2020). Predictable and positive caregiving in early childhood fosters long-term healthy development (Gee & Cohodes, 2021; Short et al., 2020). Further, contingent and consistent care contributes to attachment security by offering a safe environment and external support for infants' and children's emerging self-regulation abilities (Bornstein & Manian, 2013; Feldman, 2021; Lobo & Lunkenheimer, 2020; Provenzi et al., 2018). In animal studies, predictability has been shown to facilitate the growth of hippocampal/limbic and striatal/regulatory neural circuits (Bolton et al., 2018; Johnson et al., 2018; Molet et al., 2016), fostering the development of prefrontal-subcortical connections and in turn the normative maturation of stress response systems (Bolton et al., 2019; Tottenham, 2020). Conversely, unpredictability has been shown to disrupt the development of effortful control, memory, and stress physiology, with lasting adverse effects (Davis et al., 2017; Granger et al., 2021; Noroña-Zhou et al., 2020).

The organizational theory of development proposes that human adaptation (and maladaptation) is a multi-dimensional process, reflecting the use of internal and external resources to navigate developmentally-salient challenges (Sroufe, 2005). These challenges span cognitive, social, and emotional domains, and vary with respect to their significance and emergence across development. Early childhood is a pivotal period for the development of self-regulation, and enhanced regulatory skills are linked to school readiness and improved adjustment which together lead to more positive developmental trajectories (Blair & Raver, 2015; Diamond, 2016; Eisenberg et al., 2010; Montroy et al., 2016). Later on, adolescence embodies a transitional period involving both opportunities and vulnerabilities; for example, heightened brain plasticity and rapid cognitive and socioemotional maturation allow for adaptation, but also confer risk for mental health disorders (Dahl, 2004; Gee et al., 2022; Solmi et al., 2022). The profound economic and societal impacts of self-regulation issues and psychopathology among young individuals underscore the urgent need to address these concerns (Costello et al., 2007; Greenberg et al., 2021; Heckman, 2006; Heckman et al., 2006; Rivenbark et al., 2018). Epidemiological studies indicate that early life adversity is a leading transdiagnostic risk factor for disrupted self-regulation and the onset of psychopathology (Bandoli et al., 2017; Green et al., 2010; McLaughlin, 2016; McLaughlin et al., 2010). Acknowledging these structural determinants of adaptive development and the cultural and societal contexts in which families are situated (Hastings et al., 2022), this dissertation examines the influence of unpredictable caregiving -related early life adversity on preschoolers' self-regulation, and adolescents' mental health.

Although significant progress has been made in understanding distal aspects of unpredictability, such as caregiver transitions and income loss (Ellis et al., 2012), the contributions of proximal unpredictability within caregiver-child relationships on children's and adolescents' emotional and cognitive development remains understudied (Glynn & Baram, 2019). Most research on proximal unpredictability within caregiver-child relationships relies on retrospective questionnaires completed in adolescence or adulthood about earlier childhood experiences (Maranges et al., 2022; Mittal et al., 2015; Ross & McDuff, 2008). Less research, however, has focused on how concurrent experiences of proximal unpredictability affect children's socioemotional and cognitive development (Glynn & Baram, 2019). In my comprehensive review published in *Development and Psychopathology*, I identified several theoretical and methodological challenges hindering progress in this field (Ugarte & Hastings, 2023). Based on this review, my dissertation aims to address three specific theoretical and empirical gaps.

Gap 1. Is caregiver unpredictability domain-general or domain-specific regarding its features and influences on children's and youths' development?

As detailed in Ugarte & Hastings (2023), caregiver unpredictability has been examined using various methods and across varying time scales, such as applying entropy measures to data sources such as caregivers' responses to mood questionnaires (Glynn et al., 2018; Howland et al., 2021), and second-to-second sensory signal input during free play with their infants (Davis et al., 2017, 2019). However, it remains unclear whether these methods capture comparable phenomena, and if these different unpredictability measures relate to child or youth adjustment similarly. Researchers have yet to determine if caregiver unpredictability is domain-general, meaning consistently expressed across different inputs or features of caregiving, or domain-specific, meaning limited to particular inputs or valences (Ugarte & Hastings, 2023). If domain-general, one would expect caregivers exhibiting unpredictable sensory input to display unpredictability in their affect, behaviors, and self-reported mood states. If domain-specific, convergence across behaviors or methods would not be expected.

Moreover, caregiver unpredictability and its influence on children's adaptation may vary depending on the particular caregiver behaviors being considered (Ugarte & Hastings, 2023). This idea is in line with evolutionary-developmental theories which argue that natural selection shaped developmental systems capable of detecting and adapting to particular environmental conditions (Ellis et al., 2022). Adaptations in this context refer to variations in biological, psychological, and behavioral mechanisms that exhibit coordinated responses to contextual cues (Belsky et al., 1991; Draper & Harpending, 1988; Figueredo et al., 2006). No "single best" strategy exists for successful environmental adaptation, and strategies differ based on environmental cues (Ellis et al., 2017; Frankenhuis et al., 2013). Consequently, how children and youth adapt to their environment may depend on the distinct cues conveyed by various aspects of caregiver unpredictability.

Thus, whether there is domain generality or domain specificity warrants further investigation with new studies testing the relations among caregiver unpredictability across domains, as expressed and captured through different behaviors and methods, and the resulting convergent or distinct neurodevelopmental adaptations in children warrant further investigation.

Gap 2. Is there a cascade between distal and proximal experiences of unpredictability?

Current research has not yet explored the potential associations between distal experiences of unpredictability beyond the caregiver-child dyad and unpredictable patterns within caregiver-child relationships. Exposure to both social and non-social distal unpredictable events, such as caregiver employment status and household income loss (Nomaguchi & Johnson, 2016; Womack et al., 2022; Yeung et al., 2002) or changes in caregivers' romantic partners (Cavanagh & Huston, 2006; Hartman et al., 2018), might increase the likelihood of a child experiencing unpredictability within their most proximal environment—the caregiver-child dyad. On the other hand, this may not always be the case (Li & Belsky, 2022), as caregivers facing external challenges that interfere with care could draw upon various sources of resilience, such as social support, to provide consistent and predictable care (Masten et al., 2021). A third alternative is that distal unpredictability could disrupt caregiving in predictable ways, such as elevating average levels of caregivers' mood problems (Hadfield et al., 2018). Each of these hypotheses merit further investigation. Examining different levels of caregiver unpredictability within a developmental, longitudinal framework will offer a more comprehensive understanding of its cascading effects throughout development, which is another aim of the present dissertation.

Gap 3. Does the influence of unpredictability vary based on the sensitivity of the developing system and the timing of exposure?

The developmental effects of unpredictability may depend on the sensitivity of the developing system, the nature of the unpredictability, and the timing of exposure (Cohodes et al., 2021; Luby et al., 2020). For example, unpredictable caregiver sensory signals during infancy can lead to neurobiological vulnerability to impairments in memory, executive function, and effortful control (Davis et al., 2017; Granger et al., 2021). Infancy is a sensitive period for caregiver sensory signals, which shape visual, somatosensory, and stress-responsive hypothalamic brain structures (McLaughlin & Gabard-Durnam, 2022). It remains unclear whether early childhood continues to be sensitive period for sensory unpredictability, or if caregiver unpredictability in other behavioral domains becomes more detrimental at this age. During early childhood, caregiver-child interactions form a critical foundation for self-regulation development, influenced by factors such as caregivers’ emotional expressions and their provision of opportunities that foster children’s exploration and autonomy (Grolnick et al., 2002; Humphreys et al., 2021; Lobo & Lunkenheimer, 2020; Thompson, 2015, 2016). Unpredictable patterns of such caregiver attributes might compromise dyadic interactions, thus affecting children’s developing self-regulation capabilities (Feldman, 2007, 2021; Mohr et al., 2019).

In contrast, studies with older children and adolescents suggest that distal unpredictability may exert more direct effects on development, heightening youth's perceptions of volatility, uncertainty, and uncontrollability (Cabeza de Baca et al., 2016; Ellis et al., 2022; Hanson et al., 2017). Compared to infants and younger children, older children and adolescents engage more with external social environments, such as same-age peers. Maintaining caregiving predictability within potentially unpredictable external contexts could become more challenging for parents. As a result, unpredictability in different life spheres may uniquely impact developmental processes at specific life stages, warranting further exploration. I plan to assess these issues of sensitivity and timing in the current dissertation.

The Current Studies

Based on bioecological (Bronfenbrenner & Morris, 2006) and biopsychosocial (Cicchetti & Blender, 2004) frameworks, this dissertation was designed to explore how distal and proximal experiences of unpredictability contribute to the emergence and development of self-regulation during early childhood, and mental health problems during adolescence. Study 1 evaluates whether maternal and paternal mood unpredictability (as indexed by maternal and paternal mood entropy) serves as a link between environmental unpredictability (as indexed by family structural and socioeconomic instability) and adolescents' mental health in a sample of Mexican-origin families. Study 2 extends prior research on caregivers' sensory signal unpredictability with infants by developing and validating a novel observational measure of caregiver affective and behavioral unpredictability and exploring its concurrent and prospective implications for preschoolers' development of biobehavioral self-regulation and adjustment in a predominantly Caucasian sample.

This program of work presents longitudinal research about the role of unpredictability in guiding behavioral, affective, cognitive, and neurobiological adaptation across early childhood (Study 2) and adolescence (Study 1), involving participants who are ethnically and socioeconomically diverse. These investigations also aimed to identify how unpredictability in distinct groups (e.g., children at risk for developing externalizing problems) was associated with the development of mental health problems (Studies 1 and 2) and indices of behavioral and physiological regulation (Study 2). Moreover, this research program uses cutting-edge statistical methods such as random-intercept cross-lagged models (Study 1) and Bayesian statistics (Studies 1 and 2) to strengthen study inferences. The research also adhered to the following open science framework standards: hypotheses and methods were pre-registered, and reproducible analysis codes and outputs were made publicly available. Further, I developed an R package (*ecber*) to provide a novel set of tools for researchers interested in coding and calculating real-time caregiver unpredictability, using publicly-available and free video coding software.

Given that no studies to date have integrated proximal and distal experiences of unpredictability or assessed concurrent mood, affective, and behavioral unpredictability, this dissertation makes several novel contributions to the literature. Further, the body of work on caregiver unpredictability has not focused on Latino families, despite the unique challenges and adversities that these families face. By addressing the lack of diversity in prior study participants, examining caregiver unpredictability in Latino families may increase the generalizability – or lack thereof – of prior findings with predominantly Caucasian families. It is important for developmental science to include diverse populations such as these, to increase understanding of unpredictability's impact across different cultural and social contexts (Bornstein, 2019; Buhler-Wassmann & Hibel, 2021; Frankenhuis & Amir, 2022). Each study in this dissertation builds on past theoretical and empirical research (Davis et al., 2017; DiCorcia & Tronick, 2011; Ellis et al., 2022; Feldman, 2021; Glynn & Baram, 2019; Li et al., 2023) while offering innovative perspectives, paving the way for a deeper understanding of the complexities of unpredictability in caregiver-child relationships.

CHAPTER TWO

STUDY 1: FAMILY INSTABILITY, PARENTAL MOOD ENTROPY, AND YOUTH MENTAL HEALTH: TESTING INDIRECT AND DIRECT EFFECTS DURING ADOLESCENCE

The degree of predictability in youths' proximal environments (i.e., the caregiver-child relationship) has important implications for psychosocial functioning across the lifespan, with greater unpredictability conferring risk for less adaptive functioning (Baram et al., 2012; Doom et al., 2016; Kolak et al., 2018). Unpredictability of the proximal environment has been studied most often at one of two levels: either the family or the primary caregiver. Unpredictability at the family level has been assessed through indices such as changes in or loss of parents' employment, partner transitions, or other disruptive events (Ackerman, Izard, et al., 1999; Belsky et al., 2012a; Coe et al., 2020). Unpredictability at the caregiver level has been assessed by such indices as fluctuations in caregiver mood, referred to as entropy (Glynn et al., 2018; Howland et al., 2021). Despite the interplay of these two levels of analysis, no studies to date have combined them into one study; for example, by considering how disruptions in the family environment might influence caregiver unpredictability, and thereby affect adolescents. Using data from the California Families Project (CFP), a longitudinal study of Mexican-origin families in Northern California, this pre-registered study sought to evaluate whether caregivers' unpredictability (maternal and paternal mood entropy) served as a link between environmental unpredictability (family instability) and Mexican-origin adolescents' mental health from ages 10 to 16.

Family Instability and Caregiver Unpredictability

In studying environmental impacts on children and youths' development, the dimensional model of adversity distinguishes between experiences of harshness and experiences of unpredictability (Belsky et al., 2012b; Davies et al., 2019; Ellis et al., 2009, 2022). Harshness refers to insufficient resources or consistent threat, whereas unpredictability refers to stochastic variation and lack of consistency in environmental experiences (Doan & Evans, 2020; Young et al., 2020). Family instability, which can include housing instability, job instability, and caregiver changes, is often considered a cue of environmental unpredictability (Ackerman, Kogos, et al., 1999; Belsky et al., 2012b; Coe et al., 2020; Simpson et al., 2012). These events disrupt youths' and their families' daily structures and routines, while also reducing material and social resources and creating uncertainty about the future availability of such resources (Cabeza de Baca et al., 2016; Ugarte & Hastings, 2023). In addition, families are situated within broader contexts involving varying degrees of instability.

A plethora of social and economic disparities within the United States (U.S.) place Latino and particularly Mexican-origin families at a higher risk of experiencing instability (Cavanagh & Fomby, 2019; Hill, 2021). Compared to non-Hispanic White families, Latino families face higher rates of economic insecurity and material hardship (Rodems & Shaefer, 2020; Schweizer, 2019; U.S. Census Bureau, 2022). Additionally, Latinos have lower rates of educational attainment, especially among those of Mexican origin (Noe-Bustamante et al., 2017; Salgado & Ortiz, 2020); and latinos are also the most likely to work unstable schedules and experience greater volatility in working hours (Cai, 2021; McCrate, 2021). Undocumented immigrants, many of whom are of Mexican descent, are ineligible for numerous government assistance programs and may face workplace discrimination (Hispanic Research Center, 2019); and both of these problems contribute to higher economic instability. Such disparities result from structural barriers and oppressive systems, including language barriers, difficulties based on immigration status, racial and ethnic discrimination, and lack of access to resources and opportunities

(Hastings et al., 2022; Morello-Frosch & Lopez, 2006). Despite the growing body of work about family instability and the unique disruptive events that Latino youth and families experience, these populations remain under-represented in this line of research.

Empirical studies about family instability, a source of distal environmental unpredictability, have grown substantially during the past two decades (Young et al., 2020). However, there has been less research into the role of proximal experiences of unpredictability within caregiver-youth relationships (Ugarte & Hastings, 2023). Glynn and colleagues recently introduced a novel method to assess caregiver mood unpredictability using Shannon's entropy, a measure of randomness, applied to mood questionnaires that evaluate depression, anxiety, and perceived stress (Glynn et al., 2018; Glynn & Baram, 2019, Howland et al., 2021). Mood entropy is thought to reflect fluctuating and unpredictable mood patterns, indicative of trait-like mood instability (Glynn et al., 2018). Short-term changes in mood are a key component of mood dysregulation, contributing to maladaptive psychological functioning in adults (Broome et al., 2015; Ebner-Priemer et al., 2015; Houben et al., 2015; Koenigsberg, 2010).

Using Shannon's entropy as an index caregiver mood unpredictability is a relatively new approach, but preliminary evidence supports its validity. For example, research has identified an association between entropy and trait-like mood dysregulation dimensions, such as affective lability and alexithymia (Howland et al., 2021). Additionally, mood entropy has been shown to be relatively independent of other entropy indices unrelated to caregiver mood such as entropy of neighborhood quality (Ugarte & Hastings, 2023). Despite preliminary evidence of convergent and discriminant validity, further validity tests for using Shannon's entropy to index caregiver mood unpredictability are warranted.

To demonstrate the validity of Shannon's entropy as a measure of unpredictability in caregiver mood, the current study identified new constructs that were expected to be convergent, divergent, and predictive. First, associations between mood entropy and trait-like stress reactivity (e.g., mood lability and proneness to worry) were examined, along with the entropy of susceptibility to negative emotional states (Patrick et al., 2002). To address the alternative explanation that mood entropy might reflect a tendency to respond unpredictably or inconsistently to questionnaires, I extended previous tests by including other questionnaires involving self-reported measures of bilingual language practices and Mexican American cultural values. Stringent discriminant validity tests involve near-neighbor constructs that are known to be strongly related, either positively or negatively (Clark & Watson, 2019). Therefore, the current analyses also explored associations with entropy of positive emotionality and impulse control, two dimensions of trait-like variations in susceptibility to positive emotions and approach-withdrawal behaviors (Patrick et al., 2002).

In this study, I also investigated the predictive validity of mood entropy on aspects of the home environment, including higher levels of harsh parenting, as found in a recent study on prenatal mood entropy (Kelm, 2022). Furthermore, mood instability is a key characteristic of bipolar disorder (Broome et al., 2015; Hindley et al., 2021); and disruptions in caregiving are well-documented among families with a bipolar parent. For example, these families are more likely to have fewer routines and lower household structure (Iacono et al., 2018), use inconsistent disciplinary techniques (Calam et al., 2012; S. H.-Y. Liu et al., 2022; Reichart et al., 2007), and display parental hostility (Meyer et al., 2006). Consequently, I examined whether parents with high mood entropy would be perceived as inconsistent and hostile by their children, and whether caregivers would report fewer household routines.

Altogether, while the use of Shannon's entropy to assess caregiver mood unpredictability has shown promise in capturing trait-like mood instability, and revealing potential implications for caregiver-youth relationships, much remains to be explored in this field. Notably, no studies have examined mood entropy as an index of caregiver unpredictability within Latino families, despite their higher risk of family instability. In addition, given that cultural values and norms may influence how individuals experience and express emotions (Cordaro et al., 2018; Senft et al., 2022), investigating caregiver mood entropy within Latino families could offer a more comprehensive understanding of the construct. Furthermore, examining caregiver mood entropy in the context of family instability within Latino families may provide valuable insights into the complex environmental conditions that influence youths' developmental trajectories. To better comprehend the unique and additive contributions of distal and proximal unpredictability to adjustment, I first draw upon life history theory to explore the links between family instability and youths' mental health.

Family Instability and Youth Mental Health

Life history theory posits that distinct environmental conditions throughout evolutionary history have imposed specific selection pressures, therefore requiring different solutions to increase the likelihood of successful reproduction (Ellis et al., 2022). These solutions involve variations in biological, psychological, and behavioral mechanisms reflecting life history traits (Belsky et al., 1991; Draper & Harpending, 1988; Figueredo et al., 2006). Life history traits represent coordinated responses to contextual cues indicating either a shorter or longer lifespan, which lead to an adaptation of a faster or slower course of maturation, respectively. Reproductive strategies, such as the timing of puberty and earlier or later engagement in reproduction, manifest in faster to slower life history traits.

Although a life history perspective has not yet been applied to studies of family instability among Mexican-origin adolescents, research with other communities has shown that family instability fosters fast life history strategies characterized by heightened risk-taking and accelerated sexual development (Usacheva et al., 2022). Family instability beyond just household income is associated with increased externalizing behaviors (Doom et al., 2016; Hartman et al., 2018), diminished emotional control (Szepsenwol et al., 2021), and earlier and more frequent risk-taking (Brumbach et al., 2009; Li et al., 2018; Usacheva et al., 2022). Although internalizing problems are not typically included in these studies, as they do not reflect fast versus slow life history strategies (Li et al., 2018), research incorporating both types of problems suggest that family instability also heightens internalizing problems throughout adolescence (Forman & Davies, 2003; Schroeder et al., 2020; Womack et al., 2019), albeit with inconsistent findings (Farkas et al., 2022; Li et al., 2018, 2019). Overall, family instability has a negative impact on youths' mental health, with more consistent effects on externalizing problems (EP) than internalizing problems (IP). In order to more comprehensively understand the influence of unpredictability on youths' mental health, it is crucial to consider not only distal cues, such as family instability, but also proximal cues, such as parental mood entropy.

Caregiver Mood Entropy and Youth Mental Health

Mood instability and dysregulation are critical components of several psychiatric disorders (Broome et al., 2015). Despite theories that emphasize the significant role of caregiver unpredictability in childhood (Bronfenbrenner & Evans, 2000; S. Liu & Fisher, 2022; Luby et al., 2020), this topic has been relatively underexplored in the developmental literature. To my knowledge, only two studies have investigated the effects of parents' unpredictable and fluctuating mood patterns on youth development. For instance, maternal mood entropy during pregnancy across two independent cohorts was associated with negative affectivity and poorer cognitive development in children at 12 months, 24 months, and seven years of age (Glynn et al., 2018; Howland et al., 2021). Furthermore, entropy was linked to child-reported anxiety and depressive symptoms at 12 years, even after accounting for potential confounds such as socioeconomic status, cohabitation with the child's father, and concurrent average mood levels (Glynn et al., 2018). No studies have tested associations between entropy and EP in youths; therefore, it remains unclear whether caregiver mood entropy broadly predicts youths' mental health issues, or just IP in particular. Altogether, caregiver mood entropy - potentially indicative of mood unpredictability - serves as a unique risk factor posing various challenges to children's healthy development.

Although less studied, research has indicated that fathers' mental health also contributes to children's and adolescents' well-being and development (Cabrera et al., 2018; Volling & Cabrera, 2019). Numerous studies and meta-analyses have shown an increased risk of mental health problems among youths of fathers with heightened mood problems, although results have been somewhat inconsistent (Barnett et al., 2021; Cioffi et al., 2021; Kane & Garber, 2009). These associations may vary depending on factors such as youths' gender, behavioral outcomes, household economic strain, and whether mothers also experience mood problems. (Condon et al., 2022; Donado et al., 2020; Reeb et al., 2010, 2013). However, fathers have been underrepresented in unpredictability research, particularly regarding caregiving. Studies examining the impact of father unpredictability usually limit their role to whether they are present or absent in the home (Coe et al., 2020; Hartman et al., 2018; Usacheva et al., 2022). To my knowledge, no studies have investigated paternal mood or behavioral unpredictability as they relate to children's wellbeing. Consequently, this study examined the unique and prospective effects of both maternal and paternal mood entropy on offsprings' internalizing and externalizing problems during adolescence.

Mood Entropy as a Mediator between Instability and Youths' Mental Health

I sought to examine the impact of distal and proximal unpredictability on youths' mental health, while also extending previous work by considering mood entropy as a potential proximate process mediating the effects of distal unpredictability on mental health. Past research has not investigated whether family instability is related to the predictability of caregivers' mood, via "spilling over" to affect youths' mental health (Iacono et al., 2018). Theories of socialization from an evolutionary perspective (Belsky et al., 1991; Chisholm, 1996) propose that broader environmental unpredictability effects might be transmitted to children through caregiving behavior. Parental mood or behavioral fluctuations could signal environmental unpredictability, subsequently shaping child development (Lu et al., 2022).

Eller and colleagues (2022) proposed that fluctuations in caregiving might stem from instability within the nuclear family and wider social environment, including changes in caregivers' romantic relationships, housing, employment, and income loss. In addition, primate studies lend support to this hypothesis. Rosenblum and colleagues developed a primate model of unpredictable environmental stress, by manipulating food accessibility and quantity for bonnet macaque mother-infant dyads (variable foraging demand; Rosenblum & Andrews, 1994; Rosenblum & Paully, 1984). Unpredictable changes in food availability posed conflicting demands on caregivers, impairing their ability to interact consistently and effectively with their infants (Parker & Maestripieri, 2011). This manipulation resulted in mothers exhibiting increased anxiety and erratic physical contact with their offspring, as well as reduced normative affective reciprocity (J. D. Coplan et al., 2017; Rosenblum & Paully, 1984). These effects were not observed in conditions of either abundant or consistently scarce food availability.

Youths may perceive inconsistent quality of care or fluctuations in their caregiver mood as indicators of unpredictability in their broader environment (Eller et al., 2022). Chrisholm (1996) posited that children should have evolved over evolutionary time to recognize and respond to specific caregiver cues, understanding that unstable and unpredictable caregiving resulted from caregivers' inability (rather than unwillingness) to provide consistent care, due to instability in social and economic resources. Indeed, prior studies have shown that family instability disrupts caregivers' ability to provide consistent supportive and sensitive care, by hindering day-to-day interactions (Ackerman, Izard, et al., 1999a; Belsky et al., 2012b; Coe et al., 2017; Forman & Davies, 2003; Vargas et al., 2013). Maternal and paternal mood levels, as indexed by depression and/or anxiety, are also disrupted by various aspects of family instability (Hadfield et al., 2018), including partnership dissolution (Cavanagh & Huston, 2006), housing instability (Lee, 2022; Suglia et al., 2011), employment loss (Nomaguchi & Johnson, 2016), income loss (Yeung et al., 2002), and food insecurity (Guerrero et al., 2020). In turn, these mood levels increase children and youths' risk for externalizing and internalizing problems (Averdijk et al., 2012; Coley et al., 2015; Li et al., 2022; Osborne & McLanahan, 2007; Yeung et al., 2002; Womack et al., 2022; although see Li & Belsky, 2022 for null results). What remains unclear is whether family instability increases *unpredictability* in caregiver mood, and in turn greater youth problems, akin to the primate models reviewed above. The proposed study investigates whether the effects of family instability on youths’ mental health are mediated, at least partially, by parents' mood unpredictability over and above average mood levels.

Instability and Unpredictability across Adolescence

Current theories of early adversity propose that parental unpredictability plays a significant role on biopsychosocial development during childhood, but wanes in influence during adolescence (Cohodes et al., 2021; Smith & Pollak, 2021). While infants and young children may not fully recognize distal unpredictability, their growing exposure to social environments beyond the home during adolescence might challenge parents' ability to maintain predictability. For older children and adolescents, studies show that distal unpredictability is linked to perceptions of environmental volatility, uncertainty, and uncontrollability (Cabeza de Baca & Albert, 2019; Ellis et al., 2022; Hanson et al., 2017). Uncontrollable aspects of family instability, such as financial insecurity, frequent mobility, and parental transitions, could be particularly detrimental during adolescence (Cabeza de Baca & Albert, 2019; Cohodes et al., 2022). As a result, the impact of distal and proximal unpredictability may vary as children transition from late childhood to adolescence.

Findings are mixed regarding the mediating roles of family functioning and parents' mood during mid to late adolescence in the association between family instability and youths' mental health. Some studies have shown that family instability predicts heightened parent-adolescent conflict, parents' psychological control, and parents' psychological distress, which in turn confer increased risk for youths' externalizing and internalizing problems (Bachman et al., 2012; Forman & Davies, 2003; Langenkamp & Frisco, 2008; Vargas et al., 2013); however, other studies have found no such mediation effects of parent functioning (see Hadfield et al., 2018 for an extensive review). Given the importance of parental care and well-being as mediators in studies examining family instability in relation to young children's development (Coe et al., 2020; Hadfield et al., 2018; Womack et al., 2022), it may be the case that effects of caregiver unpredictability are more salient during childhood than in adolescence. Therefore, this study examined whether the saliency of parental mood unpredictability decreases between the ages of ten and 16 in youths, if the direct effects between family instability and youths' mental health increased in strength over adolescence, and if there are indirect effects of family instability on youths' mental health via caregiver mood entropy.

Present Study

The present pre-registered study (OSF) used longitudinal data from the California Families Project (CFP), an ongoing longitudinal study of 674 Mexican-origin families in Northern California. This population warrants greater empirical attention because they constitute the largest ethnic community in California (48%, State of California, Department of Finance, 2021) and are systematically marginalized and over-represented in poverty contexts (Bohn et al., 2020), but are underrepresented in developmental research about family instability.

I derived the following specific aims and hypotheses from the previous research reviewed above, as well as novel analytic approaches. Aim 1: Examine the construct validity of parental mood entropy as an indicator of unpredictability, using parent- and youth-reported indices of psychological functioning, cultural values, household environment, and parenting practices. As evidence of convergent validity, (H1a) I predicted that maternal and paternal mood entropy would be positively associated with self-reported mood lability, and entropy of negative emotionality. As evidence of discriminant validity, (H1b) I expected that maternal and paternal mood entropy would not be significantly associated with mothers' and fathers' entropy scores of neighborhood crime, neighborhood quality, acculturation, and Mexican cultural values. As evidence of predictive validity (H1c), I expected that parents with more unpredictable moods would be rated by their children as more inconsistent and hostile, and that parents would report less consistent family routines.

Aim 2: Explore associations among family instability, maternal and paternal mood entropy, and internalizing and externalizing dimensions of youths' mental health. I predicted that (H2a) family instability would be positively associated with adolescents' EP, and that (H2b) maternal mood entropy would be positively associated with IP. I did not have directional hypotheses regarding associations between family instability and IP, between maternal mood entropy and EP, or between paternal entropy with mental health problems in adolescents.

Aim 3: Examine the prospective indirect effects of family instability on youths' mental health via caregiver mood entropy. (H3) I predicted that maternal mood entropy would partially mediate the association between family instability and youths' problems. I did not have specific hypotheses for paternal entropy as a mediator, due to the lack of research involving fathers.

Aim 4: Examine the interaction between family instability and youths' age in predicting adolescents' mental health problems. I extended Aim 2 by examining age as a moderating factor in the relation between family instability and mental health. (H4) Lastly, I hypothesized that the direct effect between family instability and youths' problems would be more pronounced during mid and late adolescence, in comparison to early adolescence.

Method

Participants

Participants in the CFP include 674 families with a fifth-grade child (*M* age =10.8 years, *SD* = 0.60; 50.0% female) drawn randomly from school rosters from the Woodland and Sacramento school districts in California during the 2006-2007 and 2007-2008 school years. Both two-parent (*N* = 549, 82%) and single-parent (*N* = 125, 18%) families participated. Families were recruited by telephone or, for cases with no listed phone number, by a recruiter who went to their homes. Eligible families were of Mexican origin as determined by their ancestry and self-identification of Mexican heritage. Participating family members were compensated at every assessment. Full assessment interviews were conducted bi-annually (waves 1, 3, 5, and 7), when the children were approximately ages 10 (wave 1, *M* age = 10.86, SD = 0.50), 12 (wave 3, *M* age = 12.81, *SD* = 0.49), 14 (wave 5, *M* age = 14.75, *SD* = 0.49), and 16 (wave 7, *M* age = 16.80, *SD* = 0.51). Each wave of those assessments provided the data used in the current analyses. Retention rates compared to the original sample are as follows: 86% (age 12), 90% (age 14), and 89% (age 16).

In this sample, sixty-three percent of mothers and 65% of fathers had less than a high school education (median = 9th grade for both mothers and fathers). Median total household income was between $30,000 and $35,000 (overall range of income = < $5,000 to > $95,000). Concerning generational status, 83.6% of mothers and 89.4% of fathers were 1st generation (born in Mexico), and 16.4% of mothers and 10.6% of fathers were either 2nd (born in the US and at least 1 parent born in Mexico) or 3rd generation (both in the US and both parents born in the US). For youths, 28.4% were 1st generation, 62.7% were 2nd generation, and 9% were 3rd generation.

Procedure

Trained research staff interviewed participants in their homes in Spanish or English based on each participant's preference. Interviewers were all bilingual, and most were of Mexican heritage. Each participant (child, mother, and father) was interviewed separately by one of two interviewers, and efforts were made so that each member answered in private. Wave 1 interviews were conducted during the 5th grade, Wave 3 interviews during the 7th grade, Wave 5 interviews during the 9th grade, and Wave 7 interviews during the 11th grade for adolescents. Mothers provided demographic information about the family and household members.

Measures

Family Instability Assessment

Following previous studies (Ackerman et al., 1999; Belsky et al., 2012; Coe et al., 2020; Hartman et al., 2018; Womack et al., 2022), family instability was measured at each wave by the presence or absence (coded 1 or 0, respectively) of instability in six domains over the previous two years. First, instability included (a) residential transition, whether the participant relocated to another address. (b) Parental employment loss, whether parents lost their job. (c) Income loss, whether the household experienced a decrease in income-to-needs or parents reported a significant loss in income during the past year. (d) Household overcrowding, which is thought to contribute to instability through increased interfamilial conflict and elevating noise and confusion within a household (Doan & Evans, 2020). In line with Census Bureau guidelines, homes where person to room ratios were greater than 2 were considered overcrowded (United States Census Bureau, 2017). (e) Parental transition, whether there was a change in a parental figure's live-in status (e.g., a parental figure moved out, a parental figure moved in). Lastly, instability included (f) change in relational status, whether the caregiver experienced a romantic separation or found a new partner. Information sources and scoring for each indicator can be found in Table A1.1. Family instability was calculated as a composite ratio score (sum number of instability indicators reported at any given wave) to account for participants with missingness at the item level. Frequencies for each of the instability indicators and ratio instability scores can be found in Table 1.

Parent Mood Symptoms and Mood Entropy

At each wave, I used the Mini-Mood and Anxiety Symptoms Questionnaire (MASQ; Wardenaar et al., 2010) and the Center for Epidemiological Studies Depression Scale short-form

(CESD; Radloff, 1977) to asses parent mood symptoms and mood entropy. The MASQ has 26 questions and four subscales (general distress, anxiety, anxious arousal, and anhedonic depression), with responses recorded on a 4-point Likert scale from 1 (*Not at all*) to 4 (*Very much*). Across waves and caregivers, the MASQ exhibited acceptable internal consistency (all Cronbach's $\alpha > .77$). The CESD is a 10-item questionnaire assessing the presence of depressive symptoms in the last month. Responses are recorded on a 4-point Likert scale from 1 (*Almost never or never*) to 4 (*Almost always or always*). Across waves and caregivers, the questionnaire had acceptable internal consistency (all Cronbach's $\alpha >.74$).

Maternal and paternal unpredictability were calculated by applying Shannon's entropy to each caregiver's responses on all MASQ subscales and the CESD questionnaire at each assessment (See Glynn et al., 2018; Howland et al., 2021). The entropy score measures the unpredictability or inconsistency of responses across the items on a particular questionnaire or subscale. Responses are tabulated to determine the entropy score, and a probability distribution is created that shows the relative frequency of each response choice. The formula for Shannon's entropy is $\sum i \ P_i \log_2 P_i$, where P_i is the proportion of items that received the *i*-th response choice, $\log_2$ indicates the logarithm with a base of two and $\sum$ indicates that the sum is taken over all possible response choices. Entropy scores were normalized by expressing each score as a percentage of its maximum value. This resulted in entropy scores ranging from 0 (entirely predictable) to 100 (entirely unpredictable). See Table 1 for descriptive statistics and Table A1.2 for missingness. Lastly, I created a latent entropy variable for each caregiver at each wave using the entropy of each subscale of the MASQ and the CESD, saving factor scores for validity analyses.

Table 1

Descriptive Statistics for Instability Constructs and Covariates

Family Instability				
	W1 **Age 10.86** % Endorsed (% missing)	**W3** **Age 12.81** % Endorsed (% missing)	**W5** **Age 14.75** % Endorsed (% missing)	**W7** **Age 16.80** % Endorsed (% missing)
Residential transition	29.08 (0.30)	26.71 (14.09)	25.96 (9.94)	24.18 (10.39)
Employment loss	23.89 (0.45)	33.09 (14.09)	25.22 (9.94)	22.11 (10.39)
Income loss	51.48 (0.45)	67.66 (14.09)	60.24 (9.94)	58.62 (10.39)
Overcrowding	34.42 (1.34)	24.04 (15.13)	25.22 (11.28)	21.07 (13.06)
Caregiver transition	8.61 (4.90)	37.83 (8.90)	10.53 (12.02)	8.75 (12.17)
Caregiver romantic change	4.01 (0.59)	16.02 (7.72)	17.51 (8.46)	20.47 (8.90)
	***M* (*SD*)** **range**	***M* (*SD*)** **range**	***M* (*SD*)** **range**	***M* (*SD*)** **range**
Total instability score	0.26 (*0.19*) 0 – 0.83	0.38 (*0.20*) 0 – 1	0.30 (*0.21*) 0 – 1	0.29 (*0.21*) 0 – 0.1
Mood Entropy (Averages)				
Mother	58.51 *(19.86)* 0.00 - 98.75	58.21 *(18.72)* 0.00 - 98.55	54.54 *(19.92)* 0.00 – 94.77	53.49 *(19.88)* 0.00 – 98.55
Father	55.33 *(20.79)* 0.00 - 98.55	55.38 *(20.45)* 0.00 - 98.55	55.03*(19.96)* 0.00 - 98.55	54.87 *(19.63)* 0.00 – 98.55
Youth Problems (Averages)				
Internalizing	3.41 (*2.45)* 0 – 12.83	2.37 (*1.77)* 0 – 11.00	1.96 (*1.84)* 0 – 10.50	1.40 (*1.57)* 0 – 8.50
Externalizing	1.55 (1.52*)* 0 – 8.83	2.02 (*2.47)* 0 – 14.00	1.73 (*1.81)* 0 – 10.83	1.48 (*1.63)* 0 – 9.00
Time varying covariates				
Income-to-needs	1.34 (*0.94*) 0.06 – 5.71	1.32 (0.97) 0.06 – 6.38	1.28 (0.96) 0.05 – 6.44	1.35 (0.93) 0.07 – 6.22
Mother CESD (depressive symptoms)	1.75 (*0.46)* 1.00 – 3.80	1.76 (*0.44)* 1.00 – 3.40	1.69 (*0.43)* 1.00 – 3.50	1.66 (*0.39)* 1.00 – 3.50
Mother MASQ				
General distress	1.49 *(0.60*) 1.00 – 4.00	1.55 (*0.63*) 1.00 – 4.00	1.51 *(0.62)* 1.00 – 4.00	1.50 (*0.59)* 1.00 – 4.00
Anhedonic depression	1.88 (*0.66)* 1.00 – 4.00	1.97 (*0.64)* 1.00 – 4.00	2.00 (*0.67)* 1.00 – 4.00	1.96 (*0.69)* 1.00 – 4.00
Anxiety	1.83 (*0.70)* 1.00 – 4.00	1.91(*0.75)* 1.00 – 4.00	1.83 (*0.75)* 1.00 – 4.00	1.84 (*0.74)* 1.00 – 4.00
Anxious arousal	1.23 (*0.36)* 1.00 – 3.70	1.26(*0.41)* 1.00 – 3.90	1.24 (*0.40)* 1.00 – 3.40	1.27 (*0.43)* 1.00 – 4.00
Father CESD (depressive symptoms)	1.63 (*0.38)* 1.00 – 2.80	1.65 (*0.37)* 1.00 – 2.90	1.61 (*0.37)* 1.00 – 3.30	1.59 (*0.37)* 1.00 – 3.00
Father MASQ (Across all subscales)				

General distress	1.34 (*0.49)*	1.44 *(0.57)*	1.47 *(0.57)*	1.40 *(0.55)*
	1.00 – 3.86	1.00 – 4.00	1.00 – 4.00	1.00 – 4.00
Anhedonic depression	1.69 (*0.61)*	1.80 (*0.61)*	1.84 (*0.65)*	1.81 (*0.66)*
	1.00 – 4.00	1.00 – 4.00	1.00 – 4.00	1.00 – 4.00
Anxiety	1.67 (*0.66)*	1.66 (*0.66)*	1.79 (*0.72)*	1.72 (*0.72)*
	1.00 – 4.00	1.00 – 4.00	1.00 – 4.00	1.00 – 4.00
Anxious arousal	1.19 (*0.34)*	1.16 (*0.32)*	1.121(*0.39)*	1.20 (*0.39)*
	1.00 – 3.30	1.00 – 2.90	1.00 – 3.30	1.00 – 3.70
# of missing instability items	0.08 (0.42)	0.74 (1.81)	0.62 (1.72)	0.65 (1.77)
	0 – 6	0 – 6	0 – 6	0 - 6
Time-invariant covariates				
Youth sex	50.00 % female			
Household structure at W1	77.60 % two-parent			

Youths' Mental Health

Adolescents completed the National Institute of Mental Health (NIMH) Diagnostic Interview Schedule for Children (DISC; Shaffer et al., 2000) at each wave. Responses were recorded dichotomously (0= No, 1= Yes) if symptoms were present or not in the past year. I summed responses at each wave to create composite symptom counts for multiple disorders on the externalizing and internalizing spectrums. For my analyses, I included symptom counts for each of the following problems: Attention deficit hyperactivity, oppositional defiant, and conduct disorder as indices of EP, and generalized anxiety, major depression, and post-traumatic symptoms as indicators of IP. Missingness for each scale is detailed in Table A1.3.

Validity Measures

Multiple measures from mothers, fathers, and youths were used to assess the convergent, discriminant, and predictive validity of parental mood entropy. Detailed measure descriptions for each validity measure are available in Appendix 1 (section 4). Missingness and descriptive statistics for each scale are detailed in Table A1.4.

Convergent validity. At waves 3 and 7, I examined associations of parental mood entropy with mothers' and fathers' stress reactivity and entropy of negative emotionality using the Mini-Multidimensional Personality Questionnaire (Donnelan et al., 2005). Each item consists of a pair of opposing statements, and participants are asked to rate themselves on a scale from 1 to 5. The stress reactivity subscale included 5 items (e.g., "*I am not at all even-tempered, calm. I tend to be moody and emotionally unstable / I am extremely even-tempered. I am emotionally stable"*), with Cronbach's α ranging between .42 and .55 for mothers and fathers. The negative emotionality scale included 16 items (e.g., "*I believe that people often make things difficult for me / I do not believe that people make things difficult for me*"), with all αs > .74 for both parents.

Discriminant validity. At waves 1 through 5, I tested the discriminant validity of mood entropy with entropy scores of the Mexican American Cultural Values scale (MACVS; Knight et al., 2010) and the Acculturation Rating Scale for Mexican Americans-II (Cuéllar et al., 1995). For fathers, acculturation was available only at waves 3 and 5. I included four subscales of the MACVS: Traditional Gender Roles (5 items, αs > .69), Familismo (16 items, αs > .80), Respeto (8 items, αs > .59), and Independence (5 items, αs > .52). The acculturation measure is specifically focused on language use, with ten total items (5 per language) that measure English and Spanish use in everyday life (e.g., while speaking or watching television). Cronbach's α ranged between .43 and .88 for mothers and fathers.

At waves 5 and 7, I tested associations between mood entropy and entropy of the Criminal Events Scale (10 items assessing individual's perceptions of crimes such as stabbing, shootings, or drug use) and Neighborhood Quality (6 items, e.g., *"Your neighborhood is clean and attractive"*; Kim et al., 2008*)*. For fathers, these measures were only available for wave 7. Reliability was excellent, with Cronbach's α > .90 and .92 for each measure, respectively. Lastly, I tested associations between mood entropy and entropy of positive emotionality and impulse control (constraint) using the Mini-Multidimensional Personality Questionnaire at waves 3 and 7. The positive emotionality included 14 items (e.g., *"I am not at all enthusiastic. I am not interested in or excited by life / I am extremely enthusiastic. I am interested in and excited about life",* with all α' > .72 for mothers and fathers. The impulse control subscale consistent of 12 items (e.g., "*I am careful, I think before I act / I am extremely impulsive, I act without thinking*), with all α's > .61 for both parents.

Predictive validity. I tested for predictive validity at each wave using youths' ratings of parental hostility and inconsistent discipline, and parents' reports of family routines. At all waves, youth reported on mothers' and fathers' hostility using the Behavioral Affect Rating Scale (BARS; Lorenz et al., 2007). The BARS assesses hostility with 13 items (e.g., *"During the past 3 months, how often did your [mom/dad] call you bad names?"*). Cronbach's α ranged between .69 and .89. Parents' inconsistent discipline was assessed using 4 items of the Iowa Parenting Scale (L. G. Simons & Conger, 2007), such as *"When your mom/dad asks you to do something and you don't do it right away, how often does your mom/dad give up?"*. Cronbach's α ranged between .16 and .51. Lastly, caregivers reported on the routines they had for their child using 8-items (e.g., "*How often does your child go to bed at the same time each night?"*) derived from the Family and Community Health Study (FACHS; Simons et al., 2002). Cronbach's α ranged between .45 and .71 for mothers and fathers.

Covariates

Youths' sex and household structure (whether the participant lived in a two-parent or single-parent family) at Wave 1 were considered time-invariant covariates. Youths' age, household income-to-needs ratio, number of missing instability items (1-5) and mood levels at each wave were considered time-varying covariates and included in all models. For mood levels, I created a latent mood factor for each caregiver using the average scores of each subscale of the MASQ and the CESD, saving factor scores for all analyses. Household income-to-needs ratios were calculated at every wave by dividing the family's reported income by the income value corresponding with the poverty line for a family of that size that year, as indicated by the U. S. Census Bureau (https://www.census.gov/ data/tables/time-series/demo/income-poverty/historical-poverty-thresholds.html). Income-to-needs ratios ranged from 0 to 5 with ratios of 1 or less indicating poverty. Descriptive statistics can be found in Table 1.

Analytic Strategy

Validity Analyses (Hypotheses 1a and 1b).

I examined the associations among entropy factor scores and validity variables using Pearson Product-Moment correlations, adjusting for false discovery rate. I used Bayes factors to assess the strength of evidence for and against the alternative versus null hypotheses (Morey et al., 2016); and Bayes factors were calculated using default non-directional priors for medium effect sizes. Bayes factors with a value above 30 can be interpreted as strong evidence for the alternative hypothesis over the null hypothesis, values between 3 and 29 indicate moderate evidence in favor of the alternative hypothesis, and values below 0.33 indicate moderate evidence in favor of the null hypothesis. Effects were interpreted in terms of Bayes factors while also reporting Pearson *r* and *p*-values.

Main Analyses

To examine **hypotheses 2 to 4**, I used random intercept cross-lagged panel models (RI-CLPM) using data from waves 1, 3, 5, and 7. The RI-CLPM extends the cross-lagged panel model (CLPM), decomposing latent constructs into stable, trait-like components by including random intercepts and residual scores, which correspond to within-person deviations from trait levels (Hamaker et al., 2015; Mulder & Hamaker, 2020). The RI-CLPM examines whether increases in instability or parental mood entropy compared to the average of the family, mother, or father predict increases in youths' problems at the next time point.

Measurement invariance Before conducting the RI-CLPM, I tested for longitudinal metric measurement invariance across four waves of data to ensure that latent variables (mood entropy and youths' mental health problems) had the same meaning across the waves (Widaman et al., 2010). Models were compared using the log-likelihood ratio test (Vuong, 1989). I compared three measurement models: (a) freely estimating the factor loadings for the latent factors at each age of assessment (i.e., configural invariance); (b) constraining the respective factor loadings to be equal at each assessment (i.e., weak invariance); and (c) constraining the factor loadings and intercepts to be equal at each age of assessment (i.e., strong invariance).As I did not find evidence of strong measurement invariance for all constructs, I also examined partial measurement invariance (i.e., freeing one factor loading or one intercept of one of the constructs). I found evidence for partial strong longitudinal measurement invariance for all constructs except for EP, where I found weak partial invariance (Table A1.5). To assess parental mood levels at each wave, I created latent variables using mean scores for each of the MASQ and CESD subscales without testing for longitudinal measurement invariance, given that I was not interested in mean-level change. I used the retained model for each variable, saving factor scores of these latent variables to use in the subsequent analyses. Factor loadings and intercepts for all latent variables are shown in Table A1.6.

Random Intercept Cross-Lagged Panel Model. I built the RI-CLPM to test prospective and reciprocal effects among the family instability composite, parental entropy, and youths' problems factor scores (hypotheses 2 - 4), using youths' sex and household structure at wave 1 as time-invariant covariates; and missing instability items, income-to-needs, and parental mood levels as time-varying covariates. Youths' age was not included in the model as it was unrelated to my constructs of interest. I ran four models: two models for maternal entropy and IP and EP separately, and two models for paternal entropy and IP and EP, both using the maximum likelihood with the robust standard errors (MLR) estimator. Good model fit was defined as CFI and TLI greater than .92, and an RMSEA of less than .08 (Hu & Bentler, 1999). All autoregressive and cross-lagged paths between contiguous measurement occasions were freely estimated. I conducted sensitivity analyses using a reduced sample of fathers with at least one assessment (n = 523) to determine whether there were differences in findings. Additionally, I conducted standard CLPMs as auxiliary analyses (see section 7 on Appendix 1).

To test hypothesis 3, I examined the significance of indirect effects of random intercepts and within-person deviations in the model using bootstrapped bias-corrected 95% confidence intervals, to test for hypothesized mediation effects among family instability, mood entropy, and youths' psychopathology. To test hypothesis 4, I examined cross-wave differences of the direct effects of family instability on youths' problems by comparing models constraining cross-lagged coefficients to be equal with models where they were free to vary across waves.

All data cleaning and analyses were conducted in R (R Core Team, 2021) via RStudio and in Mplus (Muthen & Muthen, 2018), using full-information maximum likelihood estimation (FIML) to account for missing data (Enders & Bandalos, 2001). Code and output for all aims are available at https://osf.io/yubgv/.

Results

Validity of Mood Entropy Measure

Convergent Validity

As seen in Table 2, I found significant associations among mood entropy, stress reactivity, and entropy of negative emotionality for mothers and fathers. At waves 3 and 7, mothers and fathers with greater mood entropy reported higher levels of stress reactivity and higher entropy of negative emotionality, with BF values indicating substantial evidence in favor of the alternative hypothesis.

Discriminant Validity

There were no significant associations between entropy of acculturation or traditional Mexican American values and maternal or paternal mood entropy, with substantial evidence in favor of the null hypothesis. Contrary to expectations, maternal and paternal mood entropy were positively associated with entropy of parent-reported neighborhood criminal events and neighborhood quality at multiple waves, with decisive or strong evidence in favor of the alternative hypothesis. Correlations between entropy of positive emotionality and mood entropy were mixed, with some evidence in favor of the alternative hypothesis considered either anecdotal or strong at some waves. Although there were no significant associations between mood entropy and entropy of impulse control, some BF values indicated that the data could not sensitively distinguish between the alternative and null hypothesis.

Table 2
Construct Validity Associations

	Maternal Mood Entropy			Paternal Mood Entropy		
Convergent validity	*r*	*p*	BF	*R*	*p*	BF
Stress Reactivity						
Wave 3	**.34**	**<.001**	**>1000**	**.31**	**<.001**	**>1000**
Wave 7	**.33**	**<.001**	**>1000**	**.34**	**<.001**	**>1000**
Entropy of Negative Emotionality						
Wave 3	**.14**	**.001**	**20.09**	**.22**	**<.001**	**>1000**
Wave 7	**.19**	**<.001**	**>1000**	**.32**	**<.001**	**>1000**
Discriminant validity	*r*	*p*	BF	*R*	*p*	BF
Neighborhood Criminal Events Entropy						
Wave 5	**.24**	**<.001**	**>1000**	--	--	--
Wave 7	**.13**	**.002**	**11.47**	**.23**	**<.001**	**>1000**
Neighborhood Quality Entropy						
Wave 5	**.22**	**<.001**	**>1000**	--	--	--
Wave 7	**.14**	**.001**	**36.58**	**.24**	**<.001**	**>1000**
Acculturation Entropy						
Spanish						
Wave 1	.07	.539	0.54	--	--	--
Wave 3	.00	.978	0.10	.10	.157	0.69
Wave 5	.00	.978	0.10	.08	.157	0.46
English						
Wave 1	.04	.810	0.14	--	--	--
Wave 3	.05	.810	0.18	.00	.911	0.12
Wave 5	.03	.810	0.14	.04	.911	0.24
Cultural Values Entropy						
Traditional Gender roles						
Wave 1	.07	.612	0.36	.03	.674	0.14
Wave 3	-.02	.830	0.12	.04	.674	0.15
Wave 5	-.00	.912	0.10	-.10	.500	0.71
Familism						
Wave 1	-.01	.996	0.10	.02	.883	0.12
Wave 3	-.00	.996	0.10	.01	.883	0.12
Wave 5	-.00	.996	0.10	.08	.590	0.36
Independence						
Wave 1	-.02	.752	0.11	.06	.763	0.22
Wave 3	-.02	.752	0.11	-.06	.763	0.26
Wave 5	-.03	.752	0.13	.03	.776	0.15
Respeto						
Wave 1	-.06	.617	0.29	.02	.968	0.12
Wave 3	.02	.998	0.11	-.03	.968	0.14

Wave 5	.06	.617	0.25	.04	.968	0.17
Entropy of Positive Emotionality						
Wave 3	.10	.027	1.41	.11	.038	1.01
Wave 7	**.13**	**.008**	**10.87**	**.25**	**<.001**	**>1000**
Impulse Control Entropy						
Wave 3	.00	.966	0.10	.11	.075	1.14
Wave 7	.08	.215	0.61	.11	.075	1.02
Predictive validity	*r*	*p*	BF	*r*	*p*	BF
Youth-reported inconsistency						
Wave 1	.02	.632	0.11	.09	.103	0.55
Wave 3	.06	.226	0.27	**.14**	**.017**	**5.39**
Wave 5	.07	.178	0.34	**.15**	**.014**	**9.47**
Wave 7	.04	.414	0.16	.09	.103	0.61
Youth-reported hostility						
Wave 1	.07	.213	0.38	.03	.897	0.14
Wave 3	.01	.828	0.10	-.01	.910	0.13
Wave 5	.04	.564	0.14	-.02	.897	0.12
Wave 7	**.11**	**.053**	**3.78**	.09	.322	0.58
Family routines						
Wave 1	**-.15**	**<.001**	**127.39**	-.03	.535	0.15
Wave 3	**-.12**	**.008**	**6.54**	-.06	.310	0.22
Wave 5	**-.18**	**<.001**	**>1000**	**-.18**	**.003**	**106.35**
Wave 7	**-.19**	**<.001**	**>1000**	**-.15**	**.027**	**8.36**

Note. Mood entropy variables correspond to factor scores of four indicators. *r* = Pearson *r*, BF = Bayes Factors. Significant results with **BF > 3** are bolded. Shaded rows highlight results ***against*** hypotheses. Analyses were adjusted for multiple comparisons.

Predictive Validity

Finally, although there were no significant associations between maternal mood entropy and inconsistent parenting or maternal hostility, there was moderate to decisive evidence in favor of the alternative hypothesis for the association between mood entropy and family routines at every wave for mothers. For fathers, there were significant and moderate-to-strong associations between entropy and both inconsistency and family routines at two of the four waves.

Out of 80 tests, 59 (73.75%) supported construct validity. Overall, I considered it tenable to use mood entropy as a source of parental unpredictability for this study, although more research is needed to establish robust construct validity.

Random Intercept Cross-lagged Panel Models among Family Instability, Mood Entropy, and Youths' Problems

Table 3 provides bivariate correlations among my main variables of interest. Figures 1 and 2 show model fit indices, and autoregressive and cross-lagged coefficients for mothers' and fathers' RI-CLPM models, respectively. Table 4 shows standardized concurrent within-person associations, as well as correlations between random intercepts. The effects of the control variables in all four models are presented in Tables A1.8a and A1.8b in Appendix 1.

Family Instability, Maternal Mood Entropy, and Youths' Problems

In line with my expectations, the random intercepts for family instability and maternal mood entropy were positively correlated ($r = .32$; $p < 0.001$; see Table 4). On average, at the between-person level, mothers who experienced heightened instability also reported higher mood entropy from waves 1 to 7. Similarly, the random intercept of maternal mood entropy was related to that of IP across adolescence, suggesting that, at the between-persons level, adolescents living with mothers with greater mood entropy reported more IP from age 10 to 16. Youths' problems were not associated with family instability, contrary to predictions.

The within-person associations among variables can be visualized in Figure 1. There was only evidence of autoregressive effects of family instability in one out of three lags, suggesting that individuals experiencing elevated instability (relative to their own expected or average instability) were not likely to experience markedly higher or lower instability on the next occasion. For mood entropy, mothers reporting higher entropy relative to their average at waves 3 or 5 were likely to report lower entropy at waves 5 and 7. This was not the case for IP or EP, as increases in youths' problems at any wave predicted further increases in problems at the next wave. Within-person covariances showed that higher family instability was associated with higher mood entropy and lower IP only at wave 3. Within-person cross-lagged effects among instability, entropy, and youths' problems were not statistically significant. Marginally, however, elevations in EP at W5 somewhat predicted increased maternal entropy at W7 ($p < .10$).

Table 3

Spearman Rank Correlations of Main Variables of Interest

	W1 FI	W3 FI	W5 FI	W7 FI	W1 ME	W3 ME	W5 ME	W7 ME	W1 FE	W3 FE	W5 FE	W7 FE	W1 IP	W1 IP	W5 IP	W7 IP	W1 EP	W3 EP	W5 EP	W7 EP
W1 FI	--																			
W3 FI	**.29*****	--																		
W5 FI	**.25*****	**.34*****	--																	
W7 FI	**.25*****	**.29*****	**.40*****	--																
W1 ME	**.18*****	.08	**.15*****	**.11***	--															
W3 ME	**.18*****	**.14*****	**.17*****	**.12****	**.67*****	--														
W5 ME	**.14****	**.10***	**.17*****	**.11***	**.61*****	**.65*****	--													
W7 ME	**.16*****	**.15*****	**.15****	**.19*****	**.56*****	**.69*****	**.61*****	--												
W1 FE	**.24*****	**.18*****	**.16*****	**.17*****	**.19*****	**.16*****	.08	**.10***	--											
W3 FE	**.18*****	**.17*****	**.16*****	**.22*****	**.15****	**.19*****	.09	**.15****	**.79*****	--										
W5 FE	**.20*****	**.17*****	**.15****	**.18*****	**.16*****	**.15****	.07	**.12***	**.87*****	**.83*****	--									
W7 FE	**.17*****	**.12***	**.13***	**.20*****	**.16*****	**.17*****	**.10***	**.14****	**.76*****	**.83*****	**.84*****	--								
W1 IP	.08	.05	.05	.03	**.10***	**.11***	**.12****	**.14*****	.04	.02	.01	.01	--							
W3 IP	.06	-.03	.05	.03	.07	.05	.07	**.10***	.00	.03	-.00	.06	**.59*****	--						
W5 IP	.02	-.02	.03	.01	.08	.05	.05	.08	.03	.04	.03	.07	**.50*****	**.67*****	--					
W7 IP	.01	.02	.05	.02	.05	.03	.06	**.09***	.01	.04	.00	.05	**.45*****	**.50*****	**.71*****	--				
W1 EP	.05	.05	.04	.03	.06	.07	.05	**.10***	.00	.00	-.00	.02	**.59*****	**.38*****	**.32*****	**.26*****	--			
W3 EP	.00	-.01	.05	.04	.00	.03	.05	.06	.03	.00	-.02	.01	**.32*****	**.60*****	**.47*****	**.37*****	**.47*****	--		
W5 EP	-.04	.00	.03	.02	.07	.07	.06	**.10***	.01	-.04	-.03	.00	**.29*****	**.46*****	**.63*****	**.50*****	**.45*****	**.71*****	--	
W7 EP	-.02	.05	.07	.05	.06	.06	**.09***	**.14*****	.00	-.00	-.01	.03	**.25*****	**.39*****	**.49*****	**.55*****	**.35*****	**.62*****	**.76*****	--

Note. FI = Family instability, ME = Mother mood entropy, FE = Father mood entropy, IP = Internalizing problems, EP = Externalizing problems. Correlations were ran with factor scores. Significant results are bolded. *p 0.05, **p 0.01, ***$p < 0.001$.

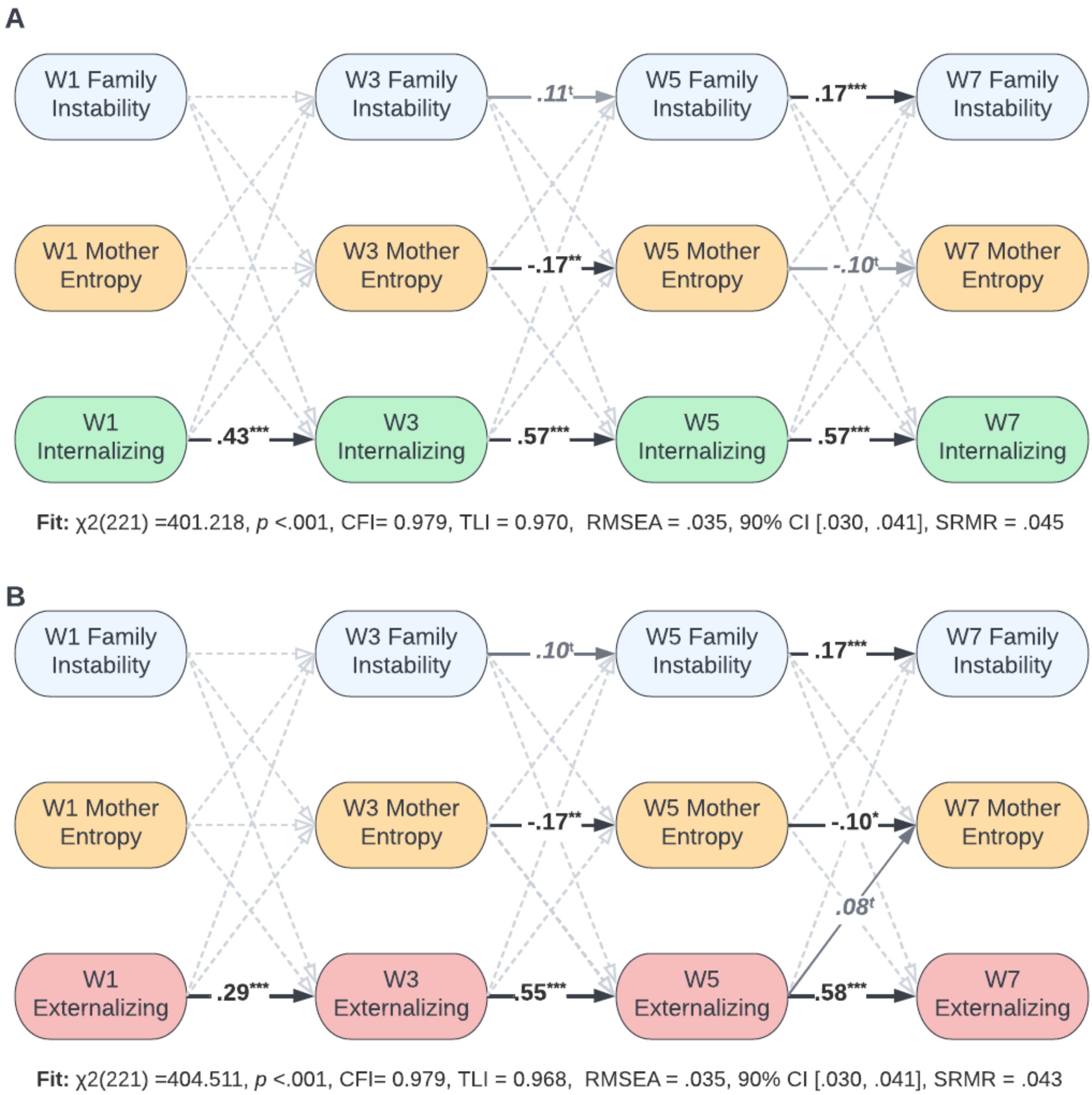


Figure 1

Standardized path coefficients of the final RI-CLPM for family instability, maternal entropy, and youths' internalizing (A) and externalizing (B) problems. Dashed lines represent nonsignificant paths; solid lines represent significant or marginal paths. For simplicity, control variables and covariances are not presented in the figure. $t < 0.10$, $*p < 0.05$; $**p < 0.01$; $***p < 0.001$.

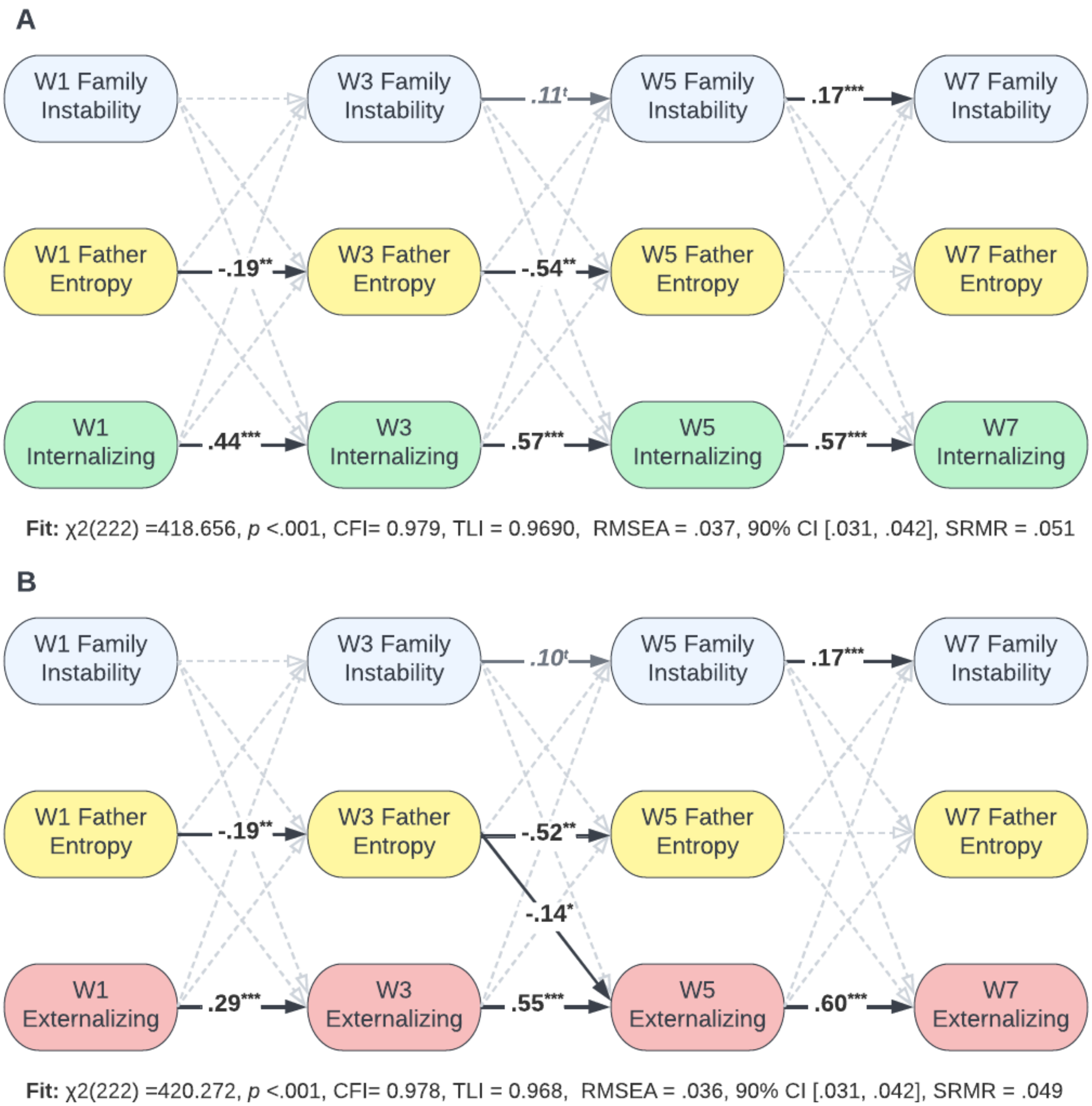


Figure 2

Standardized path coefficients of the final RI-CLPM for family instability, paternal entropy, and youths' internalizing (A) and externalizing (B) problems. Dashed lines represent nonsignificant paths; solid lines represent significant or marginal paths. For simplicity, control variables and covariances are not presented in the figure. $t < 0.10$, $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Table 4

Standardized Between and Within-Person Covariances of RI-CLPM Models

	Between-Person			Within-Person												
	RI			**W1**			**W3**			**W5**			**W7**			
	β	***SE***	***p***	***β***	***SE***	***p***	***β***	***SE***	***p***	***β***	***SE***	***p***	***β***	***SE***	***p***	
Instability ↔ Mother Entropy	**.32**	**.05**	**<.001**	.07	.05	.241	**.11**	**.05**	**.033**	.01	.07	.888	.01	.07	.891	
Instability ↔ Father Entropy	**.38**	**.06**	**<.001**	.04	.05	.501	.00	.09	.965	-.02	.14	.883	-.02	.06	.727	
Instability ↔ IP	.12	.10	.121	.03	.06	.533	**-.11**	**.06**	**.028**	.03	.05	.489	-.02	.04	.644	
Instability ↔ EP	.10	.09	.298	.04	.06	.509	-.06	.05	.285	.03	.05	.558	.02	.05	.703	
Mother Entropy ↔ IP	**.24**	**.07**	**<.001**	-.06	.05	.245	-.11	.07	.075	-.09	.07	.184	-.00	.05	.981	
Mother Entropy ↔ EP	.10	.06	.113	-.01	.05	.794	.03	.07	.723	-.01	.07	.880	.06	.06	.305	
Father Entropy ↔ IP	.08	.08	.279	-.03	.06	.658	-.05	.10	.648	.04	.15	.883	.07	.05	.212	
Father Entropy ↔ EP	.08	.08	.327	-01	.05	.706	-.12	.09	.190	-.30	.18	.093	.02	.05	.733	

Note. Repeated estimates were averaged across the four models for display purposes. Full models are reported in Tables A1.8. RI = Random intercepts. IP = Internalizing problems. EP = Externalizing problems. Significant coefficients ($p < .05$) are bolded.

Family Instability, Paternal Mood Entropy, and Youths' Problems

As expected, the random intercepts for family instability and paternal mood entropy were positively related (see Table 4). On average, at the between-persons level, fathers who experienced heightened instability also reported higher mood entropy from waves 1 to 7. Across adolescence, however, family instability and paternal mood entropy were not significantly related to youths' problems. Considering within-persons effects, as seen in Figure 2, evidence for autoregressive effects of paternal entropy was present in two out of three lags, suggesting that fathers reporting higher entropy relative to their average were likely to report *lower* entropy on the next occasion (except from waves 5 to 7). The within-person cross-lagged effects among instability, paternal entropy, and youths' problems were not statistically significant, with one exception; that elevations in fathers' entropy with respect to their own mean at W3 predicted *decreases* in youths' EP at W5. Consistent with using FIML in the entire sample (n = 674), sensitivity analyses testing these models with a smaller sample size of fathers who had data from at least one wave (n = 523) yielded the same results.

Indirect effects and cross-wave differences by age

Although within-person associations were not significant, at the between-person level I observed associations between family instability and maternal mood entropy, and between maternal mood entropy and youths' IP. Therefore, I tested the indirect effects of the random effects of instability, maternal mood entropy, and youths' IP. Instead of establishing covariances between these variables, I set regression paths. Bias-corrected percentile bootstrapping analysis showed that the indirect pathway between instability and IP via mood entropy was significant (b = 0.26, p = .008, 95% CI [0.08, 0.49]). Importantly, these results were not replicated when using average mood levels (b = 0.18, p =.139, 95% CI [-0.08, 0.45]), indicating that the overall level of maternal symptoms did not function in a similar way as maternal mood entropy. Due to the lack of significant associations between instability and youths' problems at the between or within-person level, I did not test cross-wave differences.

Discussion

I evaluated whether family instability, a cue of environmental unpredictability, predicted Mexican-origin youths' mental health problems via parental mood unpredictability across adolescence. My work builds on developmental theory and prior research, by highlighting (a) the two adversity dimensions that regulate development (harshness and unpredictability; Ellis et al., 2022), (b) the adverse effects of family instability (Ackerman, Kogos, et al., 1999; Doan & Evans, 2020), and (c) Glynn et al.'s (2018) use of Shannon's entropy on mood questionnaires to indicate caregiver unpredictability. Notably, I controlled for indicators of harshness such as income-to-needs ratio and parental mood levels; thus, any effects of unpredictability on youths' adjustment operated above and beyond those associated with harshness. Findings revealed that, across adolescence, family instability was related to maternal and paternal mood unpredictability; but not to youths' problems. In turn, only maternal mood unpredictability was associated with youths' IP. With only one exception, none of these variables were reciprocally related, suggesting that they were not related transactionally across time at the within-person level.

My first aim was to establish construct validity of mood entropy as an indicator of unpredictability. Although more research is needed to establish robust validity, three critical elements of this conceptualization of unpredictability support the use of this indicator. First, mood entropy was positively correlated with trait-like stress reactivity and entropy of negative emotionality; and yet, because the correlation coefficients were only small to moderate, it does suggest that they are not redundant constructs. Second, over 80% of the tests supported discriminant validity, meaning that results cannot be attributed to a general style of responding to questionnaires. Third, mood entropy was either non-significantly or weakly associated with near-neighbor constructs, such as entropy of non-negative mood-related dimensions, including impulse control and positive emotionality. This suggests that parental mood entropy measures likely captured negative mood unpredictability specifically, rather than a tendency to be inconsistent or unpredictable in the susceptibility to experience positive emotional states or to report approach-withdrawal behaviors. It is important to highlight that my study is the first to examine the validity of mood entropy in a large, Mexican-origin sample of mothers and fathers. The inclusion of this sample is a significant contribution, as previous research in this area had predominantly focused on Caucasian, White samples composed only of mothers. Establishing the validity of mood entropy in a Mexican-origin sample broadens the generalizability of the construct, providing a foundation for further investigations of mood unpredictability across diverse populations.

Although predictive validity was moderate, I demonstrated that greater mood entropy scores were associated with fewer family routines in mothers and, to a lesser extent, in fathers. Maternal mood entropy was not associated with youth-reported inconsistent discipline or hostility (although entropy was weakly positively related to hostility at wave 7), and paternal mood entropy was only related to inconsistent discipline at waves 3 and 5. It is important to note that my hypotheses were based on studies with parents who met the criteria for bipolar disorder (Calam et al., 2012; Iacono et al., 2018; S. H.-Y. Liu et al., 2022; Meyer et al., 2006; Reichart et al., 2007), as studies rarely examine the specific effects of mood dysregulation or mood lability on parenting practices. Although mood dysregulation may influence how parents respond to children's cues, global or trait-like emotional characteristics and mood problems are distinct constructs from parenting-related mood and regulation (Leerkes & Augustine, 2019). Further, mood dysregulation is not necessarily indicative of a psychiatric disorder, as it can be experienced by individuals in response to a range of stressors and life events. In contrast, a diagnosis of bipolar disorder requires the presence of clinically significant and persistent symptoms that impair social, occupational, or other areas of functioning (Broome et al., 2015). Relations between mood entropy and parental inconsistency and hostility may be more complex, as parents with more unpredictable moods will not necessarily be permissive or hostile (e.g., criticize, yell, or swear). Perhaps non-parametric tests exploring non-linear associations of mood entropy with youths' tendencies to report "sometimes" for parental practices could provide additional information about the contributions of mood unpredictability to parental practices.

The present paper is the first attempt to explore the role of two different sources of unpredictability in relation to youths' problems, by examining cross-domain spillover effects between family instability, a salient and widely studied source of distal unpredictability (Ellis et al., 2022; Li et al., 2023), and parent mood entropy, a novel indicator of more proximal unpredictability (Glynn et al., 2018; Howland et al., 2021). My findings show that, although youths who experienced higher family instability also had caregivers with greater mood unpredictability, variations in instability within a particular family were not associated with mood unpredictability two years later. These results are consistent with studies finding no evidence of associations between family instability and mothers' unpredictable hostility during a conflict discussion (Li et al., 2023), as well as income unpredictability and harsh-inconsistent parenting (Li & Belsky, 2022). This pattern suggests that, although they might covary, distal and proximal unpredictability might not be causally linked.

In agreement with prior findings (Glynn et al., 2018; Howland et al., 2021), my study found that maternal mood unpredictability was associated with youths' internalizing problems (IP) throughout adolescence, beyond the influence of mood levels. Notably, significant indirect effects of random intercepts suggested that exposure to family instability across adolescence was linked to increased maternal unpredictability which, in turn, was associated with a higher likelihood of youths' IP. These indirect effects were not observed with mood levels. These results not only emphasize the importance of considering chronic "trait-like" patterns in family instability and maternal mood unpredictability when understanding the development of youths' IP, but also the potential cumulative effects of these factors over time. It is possible that the accumulation or chronicity of unpredictability (Doom et al., 2016; McLaughlin et al., 2021; Plamondon et al., 2022), rather than specific stochastic changes in environmental and caregiving conditions at particular time points, contribute to internalizing symptoms in youths. As a result, this form of adversity may be more strongly linked to caregivers' and youths' distress due to its chronic nature, rather than stemming from an acute event (Reiss et al., 2019). Further investigation is needed to determine why these between-person effects did not emerge for average mood levels.

Given that these findings were not replicated at the within-person level and directionality could not be established, it is possible that other unmeasured proximal processes (e.g., parent-child conflict or parental sensitivity; Li & Belsky, 2022; Palermo et al., 2018; Vargas et al., 2013) might override effects. Additionally, other maternal dispositional factors, such as physiological regulation, could influence the extent to which family instability impacts adolescents (see Li et al., 2022). Alternatively, underlying genetic characteristics might contribute to the shared variance between mothers' mood unpredictability and youths' internalizing problems (Hannigan et al., 2018).

Contrary to prior findings (Cavanagh & Fomby, 2019; Coe et al., 2020; Hartman et al., 2018), I did not find a significant relation between family instability and youths' EP. The racial and ethnic composition of my sample could potentially explain these results. Although Latino and Black youths are more likely to experience instability (Brown et al., 2016), family instability is less strongly related to Black and Latino youths' reports of mental health problems compared to White youths (Cavanagh & Fomby, 2019; Fomby & Cherlin, 2007; but see Vargas et al., 2013). Latino families also experience intersecting protective and risk factors that could alter how instability shapes developmental contexts; and culturally adaptive practices or beliefs might support or buffer youths against the impacts of instability (Barnett et al., 2021; García Coll et al., 1996). Familism, respect for one's elders, and maintaining heritage cultural practices have been found to diminish the risk for the development of EP (Atherton et al., 2018; Cahill et al., 2021). Alternatively, the stressors encountered by low-income ethnic minority families, including marginalization, acculturative stress, neighborhood segregation, and discrimination, might obscure the specific effect of instability on youths' mental health (Bao & Greder, 2022; McCord et al., 2019; Mendoza et al., 2017). Further, dispositional factors such as emotion regulation, temperament, and age may exacerbate or attenuate associations between instability and youths' problems (Aune et al., 2023; Li et al., 2023). For example, Li and colleagues (2023) found that instability was associated with physiological dysregulation and mental health problems only for adolescents with irritable temperaments. Future research should examine whether culturally-relevant risk and protective factors, and internal dispositional factors moderate associations between instability and youths' problems, particularly during adolescence. Due to the lack of associations between instability and youths' problems at any time point, I did not test moderation by age.

Notably, associations between mood unpredictability and internalizing problems across adolescence emerged only for mothers and not for fathers. This is consistent with a recent study reporting that mothers, but not fathers, were susceptible to family instability via showing more dysregulated engagement towards their children and their partners (Li et al., 2022). Independent of environmental risks, findings from empirical studies examining average levels of mood including both parents show inconsistent results (Cioffi et al., 2021; Pietikäinen et al., 2020; Tyrell et al., 2019). Long-term population studies and meta-analyses suggest that paternal depressive symptoms are non-significantly or only weakly associated with youths' internalizing problems when mothers report no symptoms; and that paternal depression appears to exert its influence on youths' depression mostly through maternal depression (Donado et al., 2020; Gutierrez-Galve et al., 2019). However, I found that children at age 13 with fathers exhibiting *more* mood entropy than usual later reported *fewer* EP than usual at age 15. Given that a recent meta-analysis found a small but significant positive relation between levels of paternal depression and children's EP (Cheung & Theule, 2019), it is possible that unpredictable mood problems - even if typically high - afford hope that a father's mental health condition might improve. Such a belief could facilitate coping in both mothers and youths, resulting in a more supportive environment and thereby a reduced chance of youths developing elevated problems two years later. Evidently, more research exploring mood unpredictability simultaneously in both parents is needed.

Limitations and Future Directions

My results need to be considered in light of several limitations. To begin with, findings must be interpreted within the context of my specific sample of Mexican-origin youths from predominantly low-income households in Northern California. A year and a half after data collection for the CFP began, the US was hit with an unpredictable macroeconomic shock: The great recession of 2008 (Brooks-Gunn et al., 2013; Kalil, 2013; Schneider et al., 2015). Hispanic children, particularly those of immigrant parents, were the hardest hit by the recession, with the number of Hispanic children and youths in poverty increasing by 36.3% between 2007 and 2010. The impact of the recession is evident in my sample, with over 67% of my participants reporting income and employment loss at wave 3 (see Table 1). While informative and valuable for strengthening the field's understanding of the community's socioeconomic and psychosocial challenges, these findings are less generalizable to the general population because family instability levels might differ substantially. Minoritized families experiencing disadvantage are most likely to lack stable and well-structured environmental conditions, making them more vulnerable to acute unpredictable events such as economic shocks, pandemic, or natural disasters (Lai & La Greca, 2020; Pollak & Wolfe, 2020; Yoshikawa et al., 2012). The COVID-19 pandemic is an example of an unpredictable event that strongly impacted the family environment and youths' mental health, but to varying degrees across minoritized racial-ethnic communities (S. Liu & Fisher, 2022; Stinson et al., 2021).

Second, the time interval of two years between measures could be viewed as a rather long period to capture within-person, transactional processes (e.g., cross-lags). Given the significant developmental changes that occur during early and mid-adolescence, it will be important for future research to examine shorter windows of time to fully explore these reciprocal relations. Third, following that mood entropy is derived from mood scores and typically strongly correlated with each other (see Tables S8a and b), including them simultaneously in the model increases the chance of making type 2 errors (i.e., false negatives). Future work using mood entropy and average mood scores in regression models could use regularization techniques to improve the stability and accuracy of estimated coefficients, if these two are collinear (Turgeon & Lanovaz, 2020).

Fourth, information on family instability and caregivers' mental health prior to age ten was not collected, thus limiting the consideration of how exposure during childhood may have contributed to adolescents' mental health. Studies have also shown that family instability is associated with higher EP more strongly in middle to late childhood compared to adolescence; and that the effects of family instability on late adolescence are largely explained by the onset of mental health problems before adolescence, rather than continued instability (Bakker et al., 2012; Womack et al., 2022). Thus, it is crucial to interpret my findings regarding youths' mental health related to experiences of instability and parental mental health throughout early to mid-adolescence within the context of these limitations. Still, my results suggest that chronic instability may continue to affect youths' mental health beyond childhood via maternal mood unpredictability. Lastly, although family instability and parental mood might be important sources of unpredictability, there may also be meaningful changes in other conditions outside the family environment (e.g., peer relationships, neighborhood safety) that convey developmentally significant information of the current environment during adolescence. As such, future research could integrate other sources of unpredictability.

Conclusions

Despite these limitations, the present study significantly contributes to our understanding two sources of unpredictability and their contributions to adolescent mental health. By examining the impact of chronic instability and parental mood unpredictability in a sample of Mexican-origin adolescents, the current study also contributes to a growing body of research re-centering diverse communities, following the overreliance on WEIRD (White, Educated, Industrialized, Rich, and Democratic) samples in research (Henrich et al., 2010). Compared to previous studies (Glynn et al., 2018; Howland et al., 2021; Li et al., 2023), its longitudinal and multi-wave design strengthened the ability to discern predictive relations, as did its consideration of time sequence and stability effects. By using RI-CLPM and thus disaggregating between- and within-person effects, I found that chronic exposure to instability was associated with elevated mood unpredictability in Mexican-origin fathers and mothers; and that adolescents living in families where mothers report more mood unpredictability across adolescence also reported more IP. How this plays out over time, as youths navigate their way through adolescence, remains unclear. More research is needed to identify biopsychosocial mechanisms that should become the focus of intervention efforts to prevent or decrease mental health problems at the level of the individual adolescent in contexts of unpredictability.

CHAPTER THREE

STUDY 2: OBSERVED CAREGIVER AFFECTIVE AND BEHAVIORAL UNPREDICTABILITY AND THE DEVELOPMENT OF CHILDREN'S BIOBEHAVIORAL REGULATION DURING EARLY CHILDHOOD

Early adversity has been associated with significant and lasting risks for physical, cognitive, behavioral, and emotional health problems (Cohodes et al., 2021; Gehred et al., 2021; Shonkoff, 2012). Current theoretical models suggest that unpredictability is a key feature of early adversity and has the potential to disrupt self-regulatory processes, resulting in increased risk for mental health problems across the lifespan (Ellis et al., 2022; Gee & Cohodes, 2021; McLaughlin et al., 2021; Smith & Pollak, 2021). However, the majority of research on proximal experiences of unpredictability that occur within caregiver–child relationships has been derived from retrospective questionnaire measures completed in adolescence or adulthood about prior childhood experiences (Maranges et al., 2022; Mittal et al., 2015; Ross & McDuff, 2008). Less research has centered on concurrent experiences of caregiver unpredictability and how they shape children's socioemotional and cognitive development (Glynn & Baram, 2019). To know whether unpredictability plays a critical and detrimental role, as suggested by multiple theories about caregiving and childhood adversity (Ellis et al., 2022; Evans et al., 2005; Gee & Cohodes, 2021; Smith & Pollak, 2021; Tottenham, 2020; Bowlby, 1969), effective procedures for measuring and quantifying unpredictability must be developed.

Pioneering studies have investigated how unpredictable patterns of caregiver sensory signals during infancy influence crucial emotional and cognitive circuitry, with significant implications for child and adolescent's effortful control, neuroendocrine stress response, and cognitive development (Davis et al., 2017, 2019; Granger et al., 2021; Molet et al., 2016;

Noroña-Zhou et al., 2020). Caregiver sensory signals include auditory, tactile, and visual input to the child. One problem, however, is that observational approaches to sensory signal unpredictability have only been developed and validated for parents of infants. Expanding methods of observing caregiver unpredictability to include more complex experiences beyond just sensory inputs is critical to properly understand the impacts of caregiver unpredictability after infancy (Ugarte & Hastings, 2023). The current study attempts to address this gap by developing an observational method to characterize caregiver unpredictability during early childhood, when patterns of more complex behavioral and affective signals may support or disrupt children's biobehavioral regulation.

Early childhood is a critical period for the development of multiple components of self-regulation, such as executive functioning (Blair & Ku, 2022; Eisenberg et al., 2010) and physiological regulation (Calkins & Keane, 2004; Hastings et al., 2013). Preschoolers experience rapid growth across multiple domains of functioning that contribute to self-regulation, including linguistic, cognitive, emotional and social competence, while also internalizing caregivers' affective and behavioral signals that further shape regulatory behaviors (Choe et al., 2013; Olson & Lunkenheimer, 2009). Therefore, heightened caregiver unpredictability during this period can undermine normative developmental processes, which in turn puts children at risk for psychopathology (Essex et al., 2006). Assessing unpredictability as children progress into and beyond the preschool period can elucidate how this specific aspect of early adversity influences the developing child, and how we can foster proximal environments that provide more predictability and stability in young children's lives.

The goals of this study are twofold. First, I developed and validated an observational measure for caregiver affective and behavioral unpredictability in early childhood, based on

Davis' pioneering work with unpredictable sensory signals during infancy (Davis et al., 2017). Second, I examined the concurrent and prospective associations between my newly developed observational measure of caregiver affective and behavioral unpredictability, and multiple aspects of preschoolers' self-regulation: inhibitory and effortful control, physiological regulation, and behavior adjustment. Importantly, I investigated these associations while also accounting for the effects of average levels of caregiver quality and unpredictable sensory signals, in order to isolate the unique influence of caregiver affective and behavioral unpredictability.

Conceptualizing and Assessing Caregiver Unpredictability

A starting point for this investigation was to identify the unique characteristics of theory about and measurement of unpredictable sensory signals (Glynn & Baram, 2019). Unpredictability has been quantified using entropy rate, a measure of the randomness of stochastic processes (Namdari & Li, 2019), wherein the number of transitions between all possible behaviors is transformed into a probability distribution, with higher values indicating less predictable maternal behaviors (Davis et al., 2017, 2022; Vegetabile et al., 2019). In their initial study, Davis et al. (2017) coded maternal sensory signals (auditory, tactile, and visual input) during a semi-structured 10-minute play episode, and estimated the entropy rate of maternal behavior. However, Davis' trailblazing work on caregiver unpredictability has focused exclusively on sensory inputs to the infant (e.g., touch or vocalizations), which are not equivalent to or interchangeable with other inputs, such as caregivers' emotional expressions or behavioral responses to children's bids or needs. To date, studies of caregiver unpredictability beyond infancy and sensory inputs have been primarily based on either retrospective self-reports of having experienced caregiver unpredictability during one's upbringing (Glynn et al., 2019; Ugarte & Hastings, 2023) or computations of Shannon's entropy index in questionnaires of maternal mood (Glynn et al., 2018; Howland et al., 2021). Observational assessments of caregiver-child interactions that capture entropy of salient emotion and behavior inputs have yet to be developed.

Early caregiver-child relationships are fundamental to healthy socioemotional development, and are jointly shaped by each parent's attributes as well as by the mutual influences of both partners (Thompson, 2015). To identify which features of caregiver emotions and behaviors might be particularly disruptive if they are unpredictable during early childhood, I draw upon constructs and observational methodologies derived from parental socialization of emotion (Denham et al., 2015; Eisenberg et al., 2010) and self-determination theory (SDT; Deci & Ryan, 2012; Ryan et al., 2006). Parents' emotional expression and warmth are important influences on early socialization (Thompson, 2015). Dyadic interactions characterized by caregivers' positive affect and relational warmth provide appropriate models of emotion regulation and make children more receptive to caregivers' socialization efforts, thereby increasing emotional competence in children (Denham et al., 2015; Eisenberg et al., 2010). SDT proposes that autonomy-supportive parental behaviors are marked by the provision of choice, structure aimed to support children's goals, and non-intrusive control (Grusec, 2011; Whipple et al., 2011). Caregivers who support autonomy foster children's innate propensities to explore and develop a sense of volition over their "internal and external worlds" (Ryan et al., 1992, p. 170).

Taken together, caregivers' warmth and autonomy support offer opportunities to practice self-regulation in a relational context, modeling patterns that are eventually internalized as regulatory skills (Lobo & Lunkenheimer, 2020). If unpredictable, such patterns may disrupt moment-to-moment coordination of dyadic emotions and behavior, undermining young children's emotional, behavioral, and physiological regulation (Lunkenheimer, Hamby, et al., 2020). Thus, the observational protocol developed and tested in this study assesses and quantifies caregivers' unpredictability of emotional expression, and autonomy-supportive/intrusive behaviors during early childhood.

An important aspect of developing a reliable index of caregiver unpredictability is evaluating its validity as a measure of unpredictability. To establish convergent validity, I examined the associations between observed caregiver affective and behavioral unpredictability and mood unpredictability as indexed by Shannon's entropy of caregiver responses to mood questionnaires (Glynn et al., 2018; Howland et al., 2021), and with caregivers' average levels of depression and anxiety. Previous research using microanalytic coding of real-time caregiver-child interactions has found that mothers with more of these symptoms tend to exhibit more unpredictable behaviors (Bornstein & Putnick, 2021; Feldman, 2021; Holmberg et al., 2020; Priel et al., 2020). Additionally, I assessed discriminant validity by exploring associations between caregiver unpredictability and self-reported authoritarian parenting, which is characterized by low flexibility and warmth, high control and power assertion, and rigidity in their expectations for their children's behavior (R. J. Coplan et al., 2002; Grusec, 2011; Maccoby, 1984). Due to these characteristics, authoritarian parents may be less likely to engage in unpredictable or erratic behaviors toward their children. Overall, examining the validity of this new measure is a critical step. Without evidence of validity, I cannot be confident that the measure is identifying meaningful aspects of caregiver unpredictability, which is essential for understanding how it may impact children's ability to regulate their behavior and emotions.

Multiple Systems of Self-regulation

The preschool period is characterized by rapid increases in behavioral, cognitive, and emotional regulatory functioning that all support self-regulation and children's successful transition to school settings (Diamond, 2016; Montroy et al., 2016; Raver et al., 2011). As early childhood is a sensitive period for the development of self-regulation, examining the consequences of caregiver unpredictability during this time is necessary to understand how this specific aspect of socialization influences children's regulatory development.

Self-regulation is a multi-faceted construct consisting of cognitive, behavioral, emotional, and physiological processes, which are interrelated in producing both volitional and non-volitional regulation (Barrett et al., 2012; Blair & Ku, 2022; Holochwost et al., 2021). Self-regulation helps children manage emotional arousal and organize their behavior in response to external and internal demands, thereby enhancing behavioral adjustment and preventing problems such as aggression and social withdrawal (Thompson, 2015).

Executive function, a cognitive component of self-regulation, includes inhibitory control or the ability to inhibit a dominant response to a stimulus in favor of a less prominent one (Blair & Ku, 2022). Effortful control refers to the temperamental ability to focus attention, inhibit impulses, and detect errors (Rothbart, 2007). While inhibitory control and effortful control are partially overlapping constructs, they contribute to the core of internally based, volitional self-regulation (Eisenberg et al., 2013). These abilities undergo significant development during early childhood, particularly between 3 and 6 years of age, due to neurological maturation and environmental opportunities for practice such behaviors (Durbin, 2018; Lengua et al., 2015; Rothbart, 2007; Thompson, 2015). Preschool children with better inhibitory control and effortful control are less likely to exhibit externalizing (EP) and internalizing problems (IP; Eisenberg et al., 2010; Kochanska et al., 2001; Olson et al., 2017).

While inhibitory control and effortful control are considered "top-down" volitional processes, "bottom-up" components of self-regulation are relatively non-volitional and emerge early in life, involving multiple neural and physiological systems. The parasympathetic nervous system (PNS), one of the most extensively-studied systems, plays a critical role in regulating state, motor activity, and emotion. The PNS assists in restoring balance by down-regulating autonomic arousal and supporting an orienting response (Porges, 2007; Porges & Furman, 2011).

Polyvagal theory (Porges, 2003, 2007) asserts that the myelinated vagus promotes affiliative behaviors and social engagement by down-regulating the sympathetic nervous system (SNS), supporting adequate physiological arousal to stimuli and facilitating an orienting response. The vagus connects and rapidly carries information between the central nervous system and PNS-innervated peripheral tissue, affecting numerous somatic targets, including the cardiopulmonary system, from which respiratory sinus arrhythmia (RSA) can be assessed to index PNS activity (Beauchaine et al., 2019; Hastings et al., 2013).

Extensive research has focused on baseline RSA, or PNS activity, in a wakeful relaxed state (Hastings et al., 2013; Zisner & Beauchaine, 2016), and RSA reactivity to stimuli, which are thought to jointly reflect the capacity for flexible physiological self-regulation (Porges, 2003, 2007; Porges & Furman, 2011). Baseline RSA is a measure of tonic level of PNS control over cardiac activity, and is associated with individual differences in trait-like levels of arousal and emotional reactivity (Hastings et al., 2013). Children with higher baseline RSA are thought to have greater capacities to regulate attention and arousal through parasympathetic modulation (Zisner & Beauchaine, 2016). Although results across studies are not always consistent, and there is also evidence of non-linear associations (Kogan et al., 2013; Ugarte et al., 2021), higher baseline RSA has often been generally associated with greater effortful control and fewer IP and EP (Bellato et al., 2023; Calkins, 1997; Eisenberg et al., 2010; Graziano & Derefinko, 2013).

Polyvagal theory suggests that mild to moderate RSA withdrawal accelerates heart rate and supports attention to important cues (Hastings et al., 2008; Porges, 2007). During a challenge, the vagal system decreases its influence on the heart, increasing heart rate and promoting active coping. However, as challenges become more severe, the vagal system withdraws its inhibitory influence on the sympathetic system, promoting active mobilization of the stress response systems. RSA reactivity, according to Porges (2004) reflects a process called "neuroception," where the autonomic nervous system evaluates risk and safety in the environment and regulates the expression of adaptive behaviors accordingly, outside of conscious awareness (Porges, 2004). Patterns of autonomic reactivity can be used to gauge individuals' sub-conscious appraisal of environmental safety and threat, influencing the expression and regulation of emotions and social behavior (Morton et al., 2022; Porges, 2004).

Children who struggle with self-regulation, particularly those with higher levels of EP and IP, have been shown to exhibit atypical patterns of PNS activity compared to children with fewer difficulties. Though some studies and meta-analyses have reported inconsistent findings, different tasks have been used to elicit PNS changes, from negative emotion inductions to executive function tests, and task specificity needs to be considered when interpreting autonomic changes (Obradović, 2012; Obradović et al., 2011; Zeytinoglu et al., 2020).

For instance, Graziano and Derefinko (2013) found that reduced RSA withdrawal to a variety of emotional and cognitive stimuli was linked to both more EP and more IP, while Beauchaine and colleagues (2019) found that greater RSA withdrawal was associated with more EP but not more IP. Mild RSA suppression has been associated with better performance in executive function tasks, indicating that moderate arousal and orientation without engaging the sympathetic branch could be beneficial (Marcovitch et al., 2010; Porges, 2007; Sulik et al., 2015). In prior examinations of the current sample, higher RSA suppression to inhibitory control tasks was linked to lower inhibitory control at age four, as well as higher levels of EP at ages four and six (Kahle et al., 2018; Utendale et al., 2014). In this study, I focused on RSA reactivity to a cognitive task designed to assess inhibitory control in children. Therefore, I expected that children with self-regulation difficulties would exhibit substantial decreases in RSA from baseline to the task.

Overall, self-regulation is a complex system that involves interactions between physiological and cognitive processes, and it has significant implications for behavioral competence and successful development throughout one's lifespan (Heckman, 2006; Montroy et al., 2016; Raver et al., 2011; Thompson, 2015). Understanding how preschoolers' biobehavioral regulatory skills are socialized in the context of unpredictable caregiver-child interactions is key to inform etiology and intervention.

Caregiver Unpredictability and Child Adjustment

Decades of research have focused on how caregivers support or undermine children's biobehavioral regulation, influencing trajectories of behavioral adjustment (Finegood et al., 2016; *From Neurons to Neighborhoods*, 2000; Humphreys et al., 2021; Thompson, 2016). As a first step to understanding how unpredictability within caregiver-child interactions influences young children's self-regulation, it is important to examine the overall quality of caregiving behaviors. Specifically, more positive caregiving behaviors, such as warmth and autonomy granting, and fewer intrusive and controlling caregiving behaviors have been shown to foster children's self-regulation and minimize children's EP and IP (Pinquart, 2017a, 2017b). Caregiving behaviors have also been linked to early childhood executive functioning performance. In a meta-analysis of 42 studies, Valcan and colleagues (2018) investigated the associations between different indices of caregiving and executive functioning in early childhood. Positive caregiving behaviors such as warmth and responsiveness were related to higher global executive functioning and to inhibitory control more specifically. These results were comparable to behaviors that directly scaffolded children's cognitions such as autonomy support. In contrast, intrusive and controlling caregiving behaviors were related to lower global executive functioning and inhibitory control. Findings linking caregiving behaviors to PNS functioning are less consistent. A recent meta-analysis of 103 studies found that positive caregiving was related to higher baseline PNS activity in experimental and intervention studies, and the effect was stronger among children who were at elevated developmental risk (Alen et al., 2022). No effects were observed for more negative caregiving strategies or PNS reactivity.

While the studies described above have identified the role of *valence* or *levels* of caregiver behaviors in children's development of biobehavioral regulation, recent work has suggested the importance of *patterns* of caregiver cues on children's development. Across two independent cohorts, infants experiencing higher sensory signal unpredictability at five and six months had worse effortful control at age one, five, and 9.5 years of age, even after accounting for socioeconomic status and maternal sensitivity (Davis et al., 2017, 2019; Holmberg et al., 2022). Sensory signal unpredictability has also been strongly linked to neuroendocrine response to acute stressors and memory function across different species (Davis et al., 2022; Noroña-Zhou et al., 2020). In rodents, unpredictable maternal care has been shown to cause enhanced anxiety-like behaviors and anhedonia, and altered functional connectivity between reward and fear circuits, indicating an association between fragmented maternal care and the development of biological systems that underlie internalizing-like behaviors (see Baram & Glynn, 2019 for a review). Additionally, maternal mood unpredictability, measured by calculating the entropy of mothers' responses to mood questionnaires, has been associated with more IP (Glynn et al., 2018), and with poorer cognitive development and less expressive language (Howland et al., 2021). No other studies have explored the role of caregiver affective and behavioral unpredictability on children's development.

Currently, there is a dearth of research examining caregiver unpredictability and children's parasympathetic regulation. One recent study found that unpredictability in maternal minute-to-minute hostility (indexed as the standard deviation of time-specific residuals of a six-minute interaction paradigm) was not associated with vagal reactivity to a social stressor in early adolescence (Li et al., 2023). However, maternal hostility unpredictability was associated with youth's social withdrawal, indicative of greater IP. Further, unpredictability was also related to difficulties in attention shifting for youth with temperamental traits reflecting greater behavioral inhibition in novel situations. More research on which biobehavioral systems are affected by which aspects of caregiver unpredictability is warranted. Therefore, the second goal of this study was to examine the predictive associations of caregiver affective and behavioral unpredictability in early childhood on children's biobehavioral regulation and behavioral adjustment.

Exploratory Proposal: Curvilinear Associations between Caregiver Unpredictability and Child Adjustment

In addition to testing linear associations, I explored quadratic associations between affective and behavioral unpredictability and children's biobehavioral regulation. Steeling effects models propose that mild to moderate levels of stress exposure may be beneficial for children's development, contrary to the belief that all stress exposure is harmful (e.g., inoculation hypothesis; (Davies et al., 2022; Oshri, 2022; Rutter, 2012). Studies have shown that both very high and very low levels of predictability in dyadic interactions can lead to maladaptive outcomes, with midrange models being the most optimal (Beebe et al., 2016; Granic & Lougheed, 2015; Lobo & Lunkenheimer, 2020; Lunkenheimer, Hamby, et al., 2020). Excessive predictability in the context of caregiver-infant interactions (e.g., caregiver responding to cues that were not eliciting of a response) may indicate caregiver intrusion or vigilance (Beebe et al., 2020), disrupting children's exploration and opportunities to exercise their developing regulatory skills (Bornstein & Manian, 2013).

Indeed, studies have found that mid-range levels of contingency and responsiveness characterize greater maternal sensitivity (Bornstein & Manian, 2013), promote infants' attachment security (Beebe et al., 2010; Jaffe et al., 2001), and provide opportunities for dyads to practice reparation during mismatched emotional states (Provenzi et al., 2018; Tronick et al., 1980) and for children to practice self-regulation (Leerkes & Augustine, 2019; Repetti & Robles, 2016). Conversely, a complete lack of coordination may overwhelm children's capacities for self-regulation, ultimately undermining their development over time (DiCorcia & Tronick, 2011; Wass et al., 2023). For instance, Finch and Obradovic (2017) found that children whose mothers reported fewer *and* more emotional challenges (e.g., emotion regulation difficulties, parental distress) had lower inhibitory control, working memory, and assessor-rated self-regulation. Based on these findings, I examined quadratic relations between caregivers' affective and behavioral unpredictability and children's biobehavioral regulation and behavioral adjustment.

Present study

The goal of this pre-registered study (OSF) was to investigate whether four-year-old children's exposure to caregiver affective and behavioral unpredictability was associated with difficulties in cognitive and physiological self-regulation, as well as behavioral adjustment beyond just the variance explained by average levels of affect and behaviors and sensory signal unpredictability. My primary aims were twofold: (1) to develop and validate a coding scheme for caregiver unpredictability, based on caregivers' expressed affect and support of young children's autonomous behaviors, and (2) to examine whether this novel measure of unpredictability uncovers associations between caregiving patterns and the development of cognitive and physiological self-regulation and behavior problems from four to six years of age.

For Aim 1, I hypothesized that the entropy rate of caregivers' affect and behaviors would be (H1.1) positively correlated with the entropy rate of sensory signals, (H1.2) positively correlated with average levels of - and Shannon's entropy index for - maternal anxiety and depression (convergent validity), and (H1.3) weakly or non-significantly correlated with mother-reported authoritarian parenting style (discriminant validity).

For Aim 2, I first hypothesized that (H2.1) greater caregiver unpredictability would be associated with lower inhibitory control and effortful control in children, both concurrently at age four and prospectively at age six. (H2.2) I had no directional hypotheses regarding the concurrent and prospective associations between greater caregiver unpredictability and children's parasympathetic activity during baseline and during the inhibitory control task, given the lack of previous literature. I also hypothesized that (H2.3) caregiver unpredictability would be positively associated with children's EP and IP, both concurrently at age four and prospectively at age six.

Lastly, in an exploratory follow-up to these hypotheses, I examined curvilinear (specifically quadratic) associations between unpredictability and the multiple indices of self-regulation described above.

Method

Participants

The proposed study used data from a study about biopsychosocial processes contributing to positive development in 98 4-year-old children at risk for EP. Data were collected between the years 2004 and 2010. At time one (T1), 49 girls and 49 boys (*n* = 98) aged 4.0– 4.9 years at screening (age at lab visit *M* = 4.61 years, *SD* = 0.28) were recruited from a large city in Canada. At time two (T2), 42 girls and 45 boys (*n* = 87) returned to the lab when they were aged 6.0–6.9 years (*M* = 6.57 years, *SD* = 0.30). All participating caregivers were mothers (age at lab visit *M* = 36.43, *SD* = 4.81). Families were predominantly White (69.7%), with fewer identifying as Asian, mixed ethnicity, Black, Latinx/Hispanic, or other. Families were mostly English-speaking (81.6%) and from working to upper-middle SES (38% = $10–60,000 CND; 30% = $60–100,000; 24% = $100–200,000; 8% did not answer). Children with aggression and EP were over-recruited using targeted advertising; 37 children had aggression and/or EP T-scores ≥ 60 at screening. All children lived with their mothers and had no identified physical or cognitive challenges.

Procedure

At T1, families were contacted through direct mailing, letters distributed to daycares and preschools, and advertisements in local free magazines. Interested parents contacted the lab and were screened with items on the Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2000) Preschool form (ages 1 1⁄2- 5). Caregivers completed consent forms and questionnaires prior to the laboratory assessment. Children and their mothers attended an approximately 3-hour visit to a university laboratory. After providing consent, mothers and children were video-recorded in two dyadic tasks: a free play task and a puzzle task. During the 5-minute free play, dyads played with a variety of age-appropriate toys. Next, they were given 5 minutes to complete a puzzle, and caregivers were instructed to help their child as much as they thought their child needed. Videotapes were available for 95 participants (97% of the sample). Out of the 95 participating dyads, 69% of them interacted in English, 19% in French, 8% interacted in English and in French, and 1% interacted in Spanish. After the dyadic interactions, and approximately 1 hour into the testing session, cardiac monitors were attached, and baseline cardiac data were recorded. Approximately 1 hour later, children completed one task assessing inhibitory control. At T2, families were invited back to the laboratory two years after their first visit (*n* = 84). At the T2 visit, mothers completed questionnaires, and the cardiac monitor was attached to children 1 hour after arrival followed by a baseline and the same inhibitory control task. Mothers were financially compensated with $75 for their participation at both Time 1 and 2, and children received a t-shirt at the end of each visit.

Measures

Caregiver Unpredictability

Unpredictability of sensory signals. Sensory signals were coded using the Conte Center's sensory signals coding manual and coding template available at https://contecenter.uci.edu/shared-resources/ on BORIS video coding software (Friard & Gamba, 2016). This scheme counts each initiation of maternal auditory (all vocal utterances), visual (i.e., caregiver manipulates an object and child is looking at the caregiver), and tactile (physical contact from caregiver to child) signals on a moment-to-moment basis (Davis et al., 2017, 2019). Each of these behaviors is coded in separate passes, combining mutually exclusive duration codes and event sampling (e.g., counting the frequency of these behaviors). One English- and Spanish-speaking graduate and four English-speaking undergraduate research assistants were trained by the coding system developer. The four research assistants, who were blind to all information on study participants, coded all videos. In line with previous studies assessing sensory signal unpredictability (Davis et al., 2017, 2019) interrater reliability was calculated for 20% of the videos using duration agreement, which is calculated as the seconds of agreement divided by the sum of seconds of agreement and disagreement. Interrater agreement averaged 95.06% between independent coders.

To quantify the unpredictability of maternal sensory signals, changes among all possible combinations (n = 7) of caregiver visual, auditory, and tactile sensory signals are identified as transitions. Transition counts were then transformed into a matrix of transition probabilities and into a discrete-state first-order Markov sequence, which is used to calculate the entropy rate of caregivers' sensory signals (Davis et al., 2017; Vegetabile et al., 2019). Entropy rate can vary between a minimum value of zero, when a process is perfectly predictable, to a maximum value of 2.807 (the logarithm [base two] of the number of possible transitions [7] of sensory signals at each step), when all possible transitions are equally likely and maternal signals are most unpredictable (for more details on the conceptualization and calculation of entropy rate see Vegetabile et al., 2019). Entropy rates of sensory signal unpredictability during play and puzzle were quantified separately.

Unpredictability of affect and behaviors. A separate team of three undergraduate students and the lead researcher coded maternal affect and autonomy-supporting behaviors. Affect and behaviors were coded in real-time on a second-by-second basis using mutually exclusive codes. For affect, these codes included positive, neutral, and negative affect; and for behaviors, these codes included autonomy support, no behavior, and intrusiveness. The three affect codes were mutually exclusive, as were the three behavior codes; and for each second mothers were coded as displaying one of the affect codes and one of the behavior codes. The full coding scheme is provided in Appendix 2, section 1.

Affect was identified by observing vocal tone, facial expressions, and body movements. *Positive affect* included positive fluctuations in vocal tone, smiling, laughter, a sing-song tone, joint excitement, consoling and validating children's emotions, warm eye contact, and body movements indicating warmth, affection, or happiness, such as hugs and kisses. *Neutral affect* indicated the lack of any verbal or nonverbal affective expression (e.g. neither smiling nor frowning), and a relatively steady vocal tone with little variation or inflection. *Negative affect* referred to narrowed or rolled eyes, frowns, sounds of exasperation or irritation, use of stern voice, criticism, mocking, or nervous vocalizations.

Autonomy support included behaviors like instructions, praise, suggestions, discussion of emotions, physical or verbal scaffolding of the child's behavior, redirecting the child to on-task behavior, offering the child options to choose from, and playing with her child while following his or her lead. Importantly, these behaviors were independent of affect. *Intrusiveness* indicated caregivers that were interfering with children's actions, excessively intervening given their child's needs, inserting themselves without being needed or invited, or using control strategies such as threats to get their child to comply, etc. *No behavior* referred to occasions when caregivers were looking at their children but not actively participating in their activity or when caregivers were engaged in another activity, not involving the child.

The English- and Spanish-speaking lead researcher and team of one English-speaking and two English- and French-speaking undergraduate research assistants coded the data, which were tested for reliability on 20% of the videotapes in relation to the standard set by the lead author of this project. Rather than solely using duration agreement as an interrater reliability statistic, I also used Cohen's kappa and observer accuracy (Bruckner & Yoder, 2006). Duration agreement might be too liberal since it does not correct for chance agreement (Bakeman, 2022), but a standard a priori cut-off criterion for Cohen's kappa is likely too conservative when the behaviors of interest have base rates or prevalence much higher or lower than .5 (Bruckner & Yoder, 2006). Observer accuracy considers the kappa statistic and the observed base rates of behaviors in the sample (Bakeman, 2022). These three reliability statistics were calculated using KappaAcc (Bakeman, 2022), available from https://bakeman.gsucreate.org/kappaacc/. Table 1 shows average interrater reliability for affect and behavior codes.

To quantify unpredictability, changes between all possible combinations of affect and behaviors codes (n = 9 states) were identified as transitions, and transformed to discrete-state Markov sequences used to calculate entropy rate. Entropy rates for caregiver affective and behavioral unpredictability during play and puzzle were quantified separately. An R package to calculate entropy rate of maternal sensory signals and of affect and behaviors can be downloaded from https://github.com/chitram1/ecber.

Table 1.
Reliability and Estimated Accuracy for Affect and Behavior Codes

	Percent Agreement	**Cohen's Kappa**	**Accuracy**
Play			
Affect	88.44	0.76	92.56
Behaviors	86.17	0.74	91.28
Puzzle			
Affect	87.72	0.73	92.06
Behaviors	86.28	0.76	92.18

Convergent and discriminant validity

Caregiver mental health. At T1, mothers completed the Symptom Checklist-90-Revised (SCL-90-R; Derogatis & Unger, 2010). The SCL-90-R assesses psychological distress in terms of nine primary symptoms, and I used the depression and anxiety subscales to calculate mood levels and mood unpredictability (Glynn et al., 2018). Caregivers indicated how distressed they felt about specific symptoms in the past seven days, from 0 (not at all) to 4 (extremely). The depression subscale has 12 items and includes statements such as "*Feeling low in energy or slowed down*" or "*Feeling of being trapped or caught*". The anxiety subscale has nine items and includes statements such as "*Trembling*" or "*Feeling fearful*". Both scales showed good internal consistency (average Cronbach's $\alpha = 0.88$).

To calculate mood unpredictability, I applied Shannon's entropy formula to participants' responses. Responses were tabulated to create a probability distribution that shows the relative frequency of each response choice. The formula for Shannon's entropy is $\sum i$ Pi log2 Pi, where Pi is the proportion of items that received the *i*-th response choice, log2 indicates the logarithm with a base of two, and $\sum$ indicates that the sum is taken over all possible response choices. Entropy scores were normalized by expressing each score as a percentage of its maximum value. This resulted in entropy scores ranging from 0 (entirely predictable) to 100 (entirely unpredictable).

Authoritarian parenting. At T1, mothers completed the Parenting Styles and Dimensions Questionnaire (Robinson et al., 2001) to assess their authoritarian parenting style. This questionnaire contains 24 items measuring levels of verbal hostility (i.e., "*I yell or shout when my child misbehaves*"), corporal punishment (i.e., "*I slap my child when he or she misbehaves*"), punitive or non-reasoning strategies (i.e., "*I take away privileges without much explanation*"), and directedness (i.e., "*I scold and criticize to make my child improve*"), generating an overall authoritarian score. Mothers endorsed items on a scale from 1 (never) to 5 (always). The overall scale of authoritarian parenting showed good internal consistency, with α = 0.85.

Biobehavioral Regulation

Effortful control. At T1 and T2, mothers completed the Colorado Child Temperament Inventory (CCTI; Rowe & Plomin, 1977). Questions assess the extent to which the child displays certain characteristics, which are scored on a 7-point Likert scale ranging from 1 (extremely untrue) to 7 (extremely true). Effortful control is derived from two subscales: attention-span and persistence/inhibition (13 items), and soothability (5 items), and includes items such as "*Has difficulty waiting in line*" or "*If talked to, stops crying*." At T1 and T2, the overall effortful control scale showed good internal consistency, T1 α = 0.86, T2 α = .89.

Inhibitory control. At T1 and T2, children completed the Day/Night Task (Gerstadt et al., 1994), which assesses the inhibition of prepotent responding. This task, also known as the Child Stroop test, assesses the ability to inhibit prepotent responses. Children were presented with laminated cards (measuring 13.5 x 10 cm) that displayed either an image of the sun or an image of the moon and stars. The children were instructed to say "night" in response to the sun and "day" in response to the moon and stars, requiring them to inhibit the dominant response of matching the picture to its label and instead say a semantically opposite word. The cards were presented in a fixed, pseudo-random order by trained graduate students, and the children were asked to repeat the rules after the experimenter explained them. To ensure that the children understood the rules, they were given training trials until they passed both a "night" and "day" trial. During the training trials, positive feedback was given for correct responses, and incorrect responses were corrected. The children were then given 16 test trials, during which no feedback was provided.

The accuracy of the responses was scored from video recordings by trained coders who were blind to the children's levels of EP. The sum of correct responses for each task was recorded as the response accuracy score. Nine children were missing inhibitory control data at T1 due to child refusal, administration error, or video recording error. However, all children provided data at T2 (n = 84). The reliability between two coders was r = 1.00 at both time points.

Cardiac data. At T1 and T2, cardiac interbeat intervals (IBIs) were recorded using MiniLogger Series 2000, an ambulatory monitor with a sampling rate of 250 Hz, which was attached to children's upper chest with two adhesive electrodes. IBI data was edited and analyzed using Mxedit software (Delta Biometrics, Inc., Bethesda, MD). Raw IBIs were inspected and edited by reliable, trained editors following recommended best practices (Berntson et al., 1997). RSA was computed using the Porges-Byrne algorithm in Mxedit (Porges & Byrne, 1992), which applies a 21-point moving polynomial filter to capture variability in children's IBI at the natural frequency range of young children's respiration (0.24 to 1.04 Hz).

Baseline cardiac data were acquired during three baseline procedures lasting a total of five minutes: listening to soothing music (1 min), watching a calming video (3 min), and sitting quietly (1min). Baseline was calculated as the average of the RSA score for each of the three activities, which were highly inter-correlated (all rs > 0.82 at 4 and 6 years). To assess RSA reactivity, children's cardiac activity was recorded during the Day/Night task. Mean duration of the Day/Night task was 62.25 s (SD = 23.71) at 4 years and 46.69 s (SD = 7.78) at 6 years. RSA reactivity was indexed by a change score calculated by subtracting baseline RSA from task RSA. More negative scores of RSA reactivity reflect greater reductions in RSA from baseline to the task (i.e., decreases in parasympathetic influence). At ages 4 and 6, children on average showed reductions in RSA from baseline to the Day/Night task, with considerable variability (at 4 years, $M = -0.42$, $SD = 0.78$; at 6 years, $M = -0.62$, $SD = 0.67$).

Behavior problems

Child behavior checklist. At T1 and T2, mothers completed the full version of the Child Behavior Checklist (CBCL), with the form matched to the child's age. The preschool form (ages 1.5–5) was used at T1, and the school age form (ages 6–18) used at T2 (Achenbach & Rescorla, 2000). The CBCL is the most extensively used instrument for assessing children's adjustment at different developmental stages and has good reliability and validity. The broad-band IP and EP scores were used for these analyses. Raw scores are not comparable between the two, however, because the preschool and school-age forms of the CBCL include different numbers of items in their IP and EP scores. Therefore, the CBCL broadband T-scores for EP and IP, which are age- and gender-standardized based on population norms, were used in all analyses. Both scales showed good internal consistency, T1 IP $\alpha = 0.71$, T1 EP $\alpha = .94$, T2 IP $\alpha = 0.77$, T2 EP $\alpha = .91$.

Analytic Strategy

Missing data and outliers

Out of the final sample of 98 participants, data to calculate affective and behavioral and sensory signal entropy during play were missing for nine and seven caregivers, respectively. During the puzzle, 12 and 16 dyads did not have data for affective and behavioral and sensory signal entropy, respectively. The missing data were due to either missing videotapes ($n = 3$) or more than 15% (45 seconds) of missing video data. The reasons for the missing data included the experimenter interrupting the task too early, the child leaving the room, or the mothers' affect or behavior being too ambiguous or not visible enough to assign a code correctly.

At T1, cardiac data was missing for 13 children at baseline and 23 for Day/Night due to refusal to wear ambulatory monitors, excessive movement, or experimenter error resulting in unusable data. Due to attrition, failure to complete questionnaires, refusal to wear electrodes, or excessive movement at T2, 11 children had missing CBCL data, 14 did not have effortful control data, 19 did not have RSA baseline data, and 30 did not have RSA reactivity. Little's MCAR test showed that the data were missing completely at random ($\chi^2(494) = 510.591$, $p = .293$).

Six outliers (values greater than three standard deviations from the mean) were identified for affective and behavioral unpredictability during play ($n = 1$), T1 RSA reactivity ($n = 1$), T2 baseline RSA ($n = 1$), and T2 inhibitory control ($n = 3$). These outliers were winsorized prior to analysis (Wilcox, 2012).

Aim 1

Associations among caregiver affective and behavioral unpredictability and validity variables were tested using Pearson Product-Moment correlations with the R package Correlations (Makowski et al., 2020), adjusting for false discovery rate. I used Bayes factors (BF) to assess the strength of evidence for and against the alternative and null hypotheses (Morey et al., 2016). BF were calculated using default non-directional priors for medium effect sizes with the package BayesFactors (Rouder et al., 2012). BF with a value above 30 can be interpreted as strong evidence for the alternative hypothesis over the null hypothesis, values between 3 and 29 indicate moderate evidence in favor of the alternative hypothesis, and values below 0.33 indicate moderate evidence in favor of the null hypothesis. Effects were interpreted in terms of BF while also reporting Pearson *r* and *p*-values.

Aim 2

Covariates. Child sex, child age, and family socioeconomic status were considered control variables in all models. Socioeconomic status was derived from mothers' reports of their family income, their household roster, and their achieved level of education, as well as the father's achieved level of education in two-parent households. Income-to-needs ratio was calculated by dividing their income with the income value corresponding with the Canadian federal poverty line for a family of that size for the year of data collection (2005). Income-to-needs ratios ranged from 0.13 to 8.70 ($M = 2.61$, $SD = 1.79$) and 47.8% of families lived at or below 200% of the federal poverty line. Maximum achieved education in the family was calculated by selecting the highest achieved education between mother and father on a 6-point scale score that ranged from (1) completed high school (grade 11, in Quebec) to (6) Ph.D., M.D., J.D. or similar post-graduate degree. Scores for income and education were significantly correlated, $r = .45$, $p < .001$; therefore, the two scores were standardized, reversed, and then averaged to provide a single score for socioeconomic resources in which higher scores reflected lower SES. In models examining behavioral and physiological indices of self-regulation, EP at T1 was used as a covariate to account for any bias attributed to oversampling for EP.

Average levels of caregiver behavior and affect. To understand the unique influence of caregiver unpredictability on child adjustment, I controlled for average levels of affect and behaviors in the same tasks. Based on the number of codes ($n = 6$) across both play and puzzle tasks, I had twelve variables that indexed affect and behaviors. Each variable represents the proportion of the duration (in seconds) of each code relative to the total number of seconds of available video data for each task. To create indices that captured average levels of caregiver behavior and affect during play and the puzzle and to reduce the number of variables that went into each model, I conducted Principal Components Analysis (PCA) using the Psych package

(Revelle, 2023) in R version 4.2.1. Four criteria were used to determine the number of components to extract: a priori theory, the scree test, the eigenvalue-greater-than-one criteria, and the interpretability of the solution. PCA-derived factors scores were saved for main analyses.

Main analyses. To conduct my primary analyses, I used Bayesian estimation, which is an alternative to maximum likelihood (ML) estimation. Bayesian methods are particularly useful when dealing with small sample sizes, a large number of models, and non-normally distributed data and parameters (Asparouhov & Muthén, 2021; van de Schoot et al., 2021). Bayesian models often provide more conservative estimates of the uncertainty around model parameters, which can help to reduce the risk of false positives. Further, Bayesian estimates provide posterior probability intervals that are easier to interpret than traditional confidence intervals (van de Schoot et al., 2014). For example, a 95% credible interval means that there is a 95% probability that the estimated value lies within the limits of the given interval. If the 95% credible intervals do not contain zero, the effects are considered non-null (i.e., significant). For a detailed comparison between ML and Bayesian approaches in developmental research, see Grogan-Kaylor et al. (2018) and van de Schoot et al. (2014).

I conducted separate analyses for play and puzzle tasks, each including predictive paths from affective and behavioral unpredictability to unpredictability of sensory signals at T1. To preserve power and increase parsimony, covariates and PCA-derived factor scores were only retained in the final models if they were correlated with any dependent variable at $p <.10$. Path analyses were used to predict the following indices of biobehavioral regulation and behavioral adjustment at both T1 and T2: (1) effortful control, (2) inhibitory control, (3) baseline RSA and RSA reactivity, and (4) EP and IP. I ran eight models, including stability paths for outcomes from T1 and T2, as well as significant covariances between predictors and between outcomes in models 3 and 4.

For exploratory analyses, I centered caregiver affective and behavioral unpredictability prior to creating a quadratic term, to decrease multicollinearity and allow for the interpretation of both linear and quadratic coefficients (Aiken et al., 1991). I then re-ran the eight models, adding a quadratic term in addition to the linear term.

I used Mplus version 8 (Muthén & Muthén, 1998-2018) to conduct Bayesian path analysis using starting values based on ML estimates. Bayesian estimation was accomplished through the implementation of the Markov Chain Monte Carlo (MCMC) estimation using Random Gibbs algorithm (Asparouhov & Muthen, 2010) with 40,000 iterations (20,000 burn-in phase, 20,000 postburn-in). Three Markov chains were implemented for each parameter, and the Gelman and Rubin convergence diagnostic was implemented with a convergence criterion of .05. Due to a lack of sufficient prior information about the distribution of our parameters for the sample, I used the default uninformative priors provided by Mplus, which correspond to normal distributions with a prior mean of zero and an infinitive large prior variance (Asparouhov & Muthen, 2010). Considering that small samples can be sensitive to uninformative priors, I inspected parameters' trace plots, chain autocorrelation plots, and posterior distribution histograms and kernel density plots, as recommended by Smid and Winter (2020) and Depaoli and van de Schoot (2017; see Table A2.1). To account for missing data, I used the Bayes estimator default method in Mplus which uses full information from all observations to impute missing data, akin to Full Information Maximum Likelihood in ML. Additionally, I conducted standard path analyses in Lavaan (Rosseel, 2012) using Maximum Likelihood, with Robust estimators as auxiliary analyses to check whether results across both methods were consistent (see sections 3 and 4 in Appendix 2). Code and output for all aims are available at https://osf.io/9rs68/.

Results

Descriptive Statistics and Preliminary Analyses

Table 2 displays descriptive statistics for all study variables. Table 3 displays PCA results regarding caregivers' average levels of affect and behaviors. Kaiser's eigenvalue-greater-than-one criteria suggested four components, and explained 88% of the variance. The inflection in the scree plot justified retaining four components. Based on the convergence of these criteria, four components were extracted. I investigated each with orthogonal (varimax) and oblique (oblimin) procedures. Given the non-significant correlations among the four components resulting from the oblique procedure (ranging from -0.12 to 0.04), and the clear component loadings in the orthogonal rotation, I determined that an orthogonal solution was most appropriate. The rotated solution yielded four interpretable components (see Table 2), each listed with the proportion of variance accounted for: high positive affect in combination with low neutral affect across play and the puzzle ("positive affect"; 26%), high intrusiveness coupled with negative affect ("negative control"; 20%), low involvement during play with some neutral affect and low autonomy support during play ("non-involvement play"; 19%), and high autonomy support in combination with low non-involvement during the puzzle ("autonomy support puzzle"; 15%). I saved factor scores for the next set of analyses.

Assumptions of normality were met for all variables except for maternal depressive and anxiety symptoms, negative control, and T2 inhibitory control. Paired samples *t*-tests revealed significant decreases in sensory signal unpredictability from play to the puzzle, $t(78) = -5.56$, $p < .001$. No differences were found for affective and behavioral unpredictability. Table 4 shows bivariate correlations among covariates, predictors, and indices of biobehavioral regulation. Exploration of sociodemographic factors revealed that caregiver unpredictability was not related to child sex (all *t's* < 1.3) and child age was negatively associated with affective and behavioral unpredictability during play, although the evidence was considered weak or anecdotal (BF = 2.83). Similarly, caregivers who reported lower family SES displayed more unpredictable sensory signals, but BF values indicated the evidence was anecdotal ($BF_{play} = 1.60$, $BF_{puzzle} = 2.06$). Unlike sensory signal unpredictability, affective and behavioral unpredictability during play was related to higher positive affect among caregivers, and affective and behavioral unpredictability during the puzzle was related to lower positive affect. Sensory signal unpredictability during play was negatively correlated with level of caregiver involvement during play. In addition, higher levels of unpredictability in caregivers' affect and behaviors during the puzzle were positively correlated with the amount of autonomy support they provided during the task. Finally, higher levels of unpredictability in all aspects of caregiving were positively correlated with more negative control across both tasks.

In bivariate correlations (Table 4), caregiver unpredictability was mostly unrelated to children's biobehavioral regulation and behavioral adjustment; however, three significant associations emerged with BF values > 3. Unpredictability of sensory signals during play was negatively associated with RSA reactivity at T2, such that children whose caregivers provided more unpredictable sensory input during play had more RSA suppression at age six. Contrary to my expectations, affective and behavioral unpredictability during play was negatively associated with IP at T2, and affective and behavioral unpredictability during the puzzle was positively associated with baseline RSA at T1.

Table 2
Descriptive Statistics for Study Variables

Variable	***M* (or N)**	***SD* (or %)**	**Min**	**Max**	**Skew**	**% NA**
Demographics						
Child sex (female)	49	50%				
Child age	4.61	0.28	4.08	5.1	-0.20	0.00
T1 Income-to-Needs	2.61	1.79	0.13	8.7	1.24	8.16
Education level	4.57	1.49	1	7	-0.88	0.00
Validity indicators						
Depressive symptoms	0.55	0.6	0	3.15	1.94	1.02
Anxiety symptoms	0.33	0.45	0	2.7	2.65	1.02
Depression entropy	41.79	25.16	0	97.24	0.02	1.02
Anxiety Entropy	28.43	25.04	0	91.39	0.48	1.02
Authoritarian parenting	2.05	0.41	1.25	3.19	0.60	4.08
Caregiver Unpredictability						
AB Entropy Play	1.17	0.21	0.66	1.69	-0.14	9.18
AB Entropy Puzzle	1.17	0.20	0.70	1.77	0.37	12.24
SS Entropy Play	0.63	0.20	0.06	1.03	-0.79	7.14
SS Entropy Puzzle	0.48	0.20	0.00	0.84	-0.35	16.33
Indices of self-regulation and behavioral adjustment						
T1 Effortful control	4.62	0.91	1.94	6.43	-0.62	2.04
T2 Effortful control	4.69	0.93	2.24	6.52	-0.5	14.29
T1 Inhibitory control	10.76	5.14	0	16	-0.88	9.18
T2 Inhibitory control	14.55	1.84	7	16	-1.91	14.29
T1 Baseline RSA	6.71	1.20	3.26	9.36	-0.45	13.27
T2 Baseline RSA	7.08	1.10	3.69	9.92	0.11	19.39
T1 RSA reactivity	-0.42	0.78	-2.21	2.09	0.81	23.47
T2 RSA reactivity	-0.62	0.67	-2.24	0.93	0.05	30.61
T1 Externalizing	51.92	11.35	32	80	0.35	3.06
T2 Externalizing	54.16	10.31	33	76	0.12	11.22
T1 Internalizing	51.06	9.70	29	74	-0.13	3.06
T2 Internalizing	51.31	9.51	33	68	-0.05	11.22

***Note*.** AB Entropy = Affective and behavioral unpredictability. SS entropy = Sensory signal unpredictability.

Table 3.
Factor Loadings and Descriptive Statistics for Average Levels of Caregivers' Behavior and Affect

	Factor Loadings			
	1	**2**	**3**	**4**
Play				
Positive affect	**0.81**	-0.06	**-0.46**	-0.11
Neutral affect	**-0.82**	-0.07	**0.43**	0.14
Negative affect	0.00	**0.80**	0.17	-0.07
Autonomy support	0.07	-0.24	**-0.92**	0.10
Neither	-0.05	-0.08	**0.95**	-0.09
Intrusiveness	0.00	**0.81**	-0.02	0.00
Puzzle				
Positive affect	**0.90**	-0.13	0.14	0.20
Neutral affect	**-0.92**	-0.04	-0.15	-0.18
Negative affect	0.13	**0.64**	0.09	-0.01
Autonomy support	0.20	-0.27	-0.03	**0.89**
Neither	0.03	-0.25	0.13	**-0.94**
Intrusiveness	-0.29	**0.72**	-0.12	0.08
% of variance	26%	20%	19%	15%
Factor label	Positive affect	Negative control	Non-involvement play	Autonomy support puzzle
Descriptive statistics	***M* (*SD*)** **Range**	***M* (*SD*)** **Range**	***M* (*SD*)** **Range**	***M* (*SD*)** **Range**
	-0.02 (1.00) -1.52 – 2.62	0.00 (1.03) -1.03 – 4.64	0.01 (1.02) -2.31 – 2.11	-0.02 (1.00) -2.24 – 2.81

Table 4

Spearman Correlations Between Study Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1. Child Age	--																						
2. Child Sex	-.01	--																					
3. SES	.16	-.16	--																				
4. AB Play	-.24*	-.03	.16	--																			
5. AB Puzzle	-.10	-.09	.13	**.26***	--																		
6. SS Play	-.18†	.09	.21*	.20†	.21†	--																	
7. SS Puzzle	-.21†	-.14	.27*	.24*	**.40*****	.26*	--																
8.Pos Affect	**-.26***	.16	-.04	**.38*****	**-.25***	.07	.10	--															
9. Neg Control	-.21†	-.06	**.26***	**.74*****	**.54*****	**.39*****	**.37*****	.13	--														
10. NI Play	.07	-.09	-.04	.12	-.15	**-.28***	-.04	.04	-.09	--													
11.AS Puzzle	-.11	**.32****	-.18†	-.03	**.27***	-.05	.14	.00	.00	-.07	--												
12. T1 EC	-.02	**.24***	**-.27***	.02	-.16	-.02	-.14	**.40*****	-.08	.06	.19	--											
13. T2 EC	-.05	.20†	-.23*	.07	-.16	.00	-.15	**.38****	.04	.17	.07	**.69*****	--										
14. T1 IC	.15	.00	-.14	-.15	-.02	-.07	-.20†	.03	-.04	.02	.01	.21†	**.25***	--									
15. T2 IC	.00	.16	.14	.11	-.06	.11	-.01	.18	.23†	-.08	.04	.15	.15	**.26***	--								
16. T1 BRSA	.04	.02	.04	.08	**.27***	-.09	.10	-.12	.20	.02	.07	.02	.00	.06	.06	--							
17. T2 BRSA	.03	-.08	.12	-.06	.14	.18	.05	.00	.02	-.08	.04	.08	-.07	.08	.00	**.51*****	--						
18. T1 RRSA	.13	.05	-.16	-.03	-.21†	-.01	-.14	.09	-.01	**.30***	.22†	**.28***	.31*	**.30****	.05	**-.22**†	-.20	--					
19. T2 RRSA	.09	-.02	-.06	.13	-.04	**-.37****	-.09	.20	-.03	.11	.18	.11	.09	-.10	.02	-.11	-.24†	.22	--				
20. T1 EP	.02	-.13	**.32****	-.06	.12	.08	.08	-.20†	.00	-.07	-.12	**-.68*****	**-.67*****	**-.22***	-.09	-.04	.00	**-.37****	-.16	--			
21. T2 EP	.07	-.06	.16†	-.19†	-.06	.07	-.03	-.20†	-.16	-.24*	-.01	**-.50*****	**-.59*****	-.25*	-.09	.02	.10	**-.38****	-.20	**.68*****	--		
22. T1 IP	-.03	**-.26***	**.30****	-.02	.20†	-.03	.25*	-.18	.06	-.05	-.11	**-.48*****	**-.42*****	-.14	-.15	-.11	.00	**-.38*****	-.18	**.73*****	**.47*****	--	

23. T2 IP	.24*	-.23*	.21*	**-.27***	.00	-.10	.10	-.24*	-.14	**-.25***	-.11	**-.27***	**-.38*****	-.12	-.18	.03	.07	**-.32****	-.22†	**.40*****	**.54*****	**.57*****	--

Note. Child sex (1 = male, 2 = female). SES = Family socioeconomic status, AB = Affective and behavioral unpredictability, SS = Sensory signal unpredictability, NI = Non-involvement, AS = Autonomy support, EC = Effortful control, IC = Inhibitory control, BRSA = Baseline RSA, RRSA = RSA reactivity, EP = Externalizing problems, IP = Internalizing problems. Coefficients with Bayes Factors > 3 are bolded. Coefficients are not adjusted for multiple comparisons † *p* <0.10, **p* 0.05, ***p* 0.01, ****p* < 0.001.

Lastly, there were several interrelations between children's indices of biobehavioral regulation and indices of behavioral adjustment, with BF values > 3. Caregiver-reported effortful control was negatively associated with EP and IP, concurrently and prospectively; and positively associated with inhibitory control at T2. At T1, children with higher inhibitory control had lower EP. Children whose RSA increased during the Day/Night task respective to their baseline at T1 had lower baseline RSA, higher effortful and inhibitory control concurrently, and lower EP and IP concurrently and prospectively.

Aim 1. Validity Analyses

There were significant associations between affective and behavioral unpredictability and sensory signal unpredictability during play (Pearson $r = .22$, $p = .04$), although the BF value evidenced this association as anecdotal (BF = 1.69). The association was stronger for the puzzle, such that mothers who were more unpredictable in their affect and behaviors also displayed unpredictable sensory input to the child ($r = .39$, $p < .001$), with a BF value of = 122.26, indicating substantial evidence in favor of the alternative hypothesis.

Contrary to my expectations, there were no significant associations between affective and behavioral unpredictability and symptoms of depression or anxiety in mothers (all p's > .08, BF < 0.996). Similarly, mothers who displayed more unpredictable patterns of behavior and affect were no more likely to report mood unpredictability (all p's > .181, BF < 0.834). Finally, in line with my expectations, there were no significant associations between mothers' report of authoritarian parenting and unpredictability during play or the puzzle, with evidence in favor of the null hypothesis ($r_{play} = -.09$, $p = 0.43$, BF = 0.332; $r_{puzzle} = -.08$, $p = .47$, BF = .320).

Aim 2.1: Effortful and Inhibitory Control

The standardized posterior distribution medians and Bayesian 95% credible intervals for indices of biobehavioral regulation, covariates, and unpredictability during play and the puzzle are displayed in Tables 5 and 6. Bayesian models for effortful control (Play: 95% Bayesian Posterior $\chi 2$ $p = .496$; Puzzle: 95% Bayesian Posterior $\chi 2$ $p = .568$), and inhibitory control (Play: 95% Bayesian Posterior $\chi 2$ $p = .567$; Puzzle: 95% Bayesian Posterior $\chi 2$ $p = .544$) had good fit for the data.

There were no associations between affective and behavioral or sensory signal unpredictability, and mother-reported effortful control or inhibitory control during the Day/Night task. These findings were consistent with MLR models (see Tables A2.2 and A2.4 for results). At T1, mothers who displayed more positive affect across tasks rated their children as having more effortful control, and children with more EP at T1 were rated as having lower effortful control, concurrently and prospectively.

Aim 2.2: Parasympathetic Activity

The Bayesian model for RSA was also a good fit for the data (Play: 95% Bayesian Posterior $\chi 2$ $p = .621$; Puzzle: 95% Bayesian Posterior $\chi 2$ $p = .592$). Preschoolers whose mothers displayed more sensory signal unpredictability during play had lower RSA reactivity, indicating more RSA suppression, during the Day/Night task at T2. Conversely, preschoolers whose mothers displayed more affective and behavioral unpredictability during the puzzle had more RSA suppression to the Day/Night task concurrently at T1. I found no associations between caregiver unpredictability and baseline RSA. Importantly, these associations were over and above mothers' average displays of parenting behaviors through both tasks. These findings were also consistent with MLR models (see Tables A2.3 and A2.5 for results).

Table 5.
Associations between Caregiver Unpredictability during Play and Indices of Self-regulation

	T1 EC		T2 EC		T1 IC		T2 IC		T1 Baseline RSA		T2 Baseline RSA		T1 RSA Reactivity		T2 RSA Reactivity	
	PM	**95% CI**	**PM**	**95% CI**	**PM**	**95% CI**	**PM**	**95% CI**	**PM**	**95% CI**	**PM**	**95% CI**	**PM**	**95% CI**	**PM**	**95% CI**
T1 EC	--	--	**0.43**	**[.22, .63]**	--	--	--	--	--	--	--	--	--	--	--	--
T1 IC	--	--	--	--	--	--	**0.25**	**[.01, .46]**	--	--	--	--	--	--	--	--
T1 Base RSA	--	--	--	--	--	--	--	--	--	--	**0.53**	**[.33, .70]**	--	--	--	--
T1 RSA R	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.05	[-.20, .30]
T1 EP	**-0.65**	**[-.76, -.52]**	**-0.35**	**[-.54, -.14]**	-0.16	[-.36, .05]	-0.04	[-.25, .17]	0.00	[-.20, .20]	-0.02	[-.20, .16]	**-0.30**	**[-.46, -.10]**	-0.07	[-.29, .16]
Child Sex	0.10	[-.05, .26]	0.04	[-.11, .19]	--	--	--	--	--	--	--	--			--	--
Low SES	-0.04	[-.19, .12]	0.07	[-.09, .22]												
Positive Affect	**0.21**	**[.04, .37]**	0.17	[-.01, .35]	--	--	--	--	--	--	--	--			--	--
Neg Control	--		--	--	--	--	--	--	**0.32**	**[.05, .56]**	-0.01	[-.33, .29]	0.06	[-.26, .36]	0.24	[-.10, .54]
Non-Involvmnt	--		--	--	--	--	--	--	-0.06	[-.29, .17]	0.06	[-.13, .36]	**0.33**	**[.09, .54]**	-0.10	[-.37, .17]
AB Entropy	-0.04	[-.20, .13]	-.05	[-.24, .14]	-0.12	[-.33, .11]	0.04	[-.20, .27]	-0.14	[-.40, .12]	-0.16	[-.46, .14]	-0.07	[-.35, .22]	0.17	[-.15, .46]
SS Entropy	0.02	[-.14, .17]	-.00	[-.16, .16]	-0.02	[-.28, .15]	0.08	[-.14, .29]	-0.14	[-.37, .10]	0.23	[-.02, .46]	0.15	[-.09, .38]	**-0.47**	**[-.69, -.22]**

Note. Coefficients are standardized. Non-null results are bolded. PM = Posterior median, CI = Credible interval, EC = Effortful control, IC = Inhibitory control, Base RSA = Baseline RSA, RSA R = RSA reactivity. EP = Externalizing problems, AB Entropy = Affective and behavioral unpredictability, SS Entropy = Sensory signal unpredictability.

Table 6.
Associations between Caregiver Unpredictability during Puzzle and Indices of Self-regulation

	T1 EC		**T2 EC**		**T1 IC**		**T2 IC**		**T1 Baseline RSA**		**T2 Baseline RSA**		**T1 RSA Reactivity**		**T2 RSA Reactivity**	
	PM	**95% CI**	**PM**	**95% CI**	**PM**	**95% CI**	**PM**	**95% CI**	**PM**	**95% CI**	**PM**	**95% CI**	**PM**	**95% CI**	**PM**	**95% CI**
T1 EC	--	--	**0.44**	**[.23, .63]**	--	--	--	--	--	--	--	--	--	--	--	--
T1 IC	--	--	--	--	--	--	0.22	[-.02, .43]	--	--	--	--	--	--	--	--
T1 Base RSA	--	--	--	--	--	--	--	--	--	--	**0.54**	**[.33, .70]**	--	--	--	--
T1 RSA R	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-0.02	[-.29, .25]
T1 EP	**-0.66**	**[-.75, -.53]**	**-0.34**	**[-.53, -.13]**	-0.16	[-.35, .05]	-0.04	[-.45, .17]	0.01	[-.19, .21]	-0.01	[-.19, .19]	**-0.24**	**[-.43, -.04]**	-0.06	[-.29, .18]
Child Sex	0.11	[-.04, .26]	0.04	[-.11, .19]	--	--	--	--	--	--	--	--			--	--
Low SES	-0.03	[-.19, .13]	0.06	[-.11, .23]												
Positive Affect	**0.20**	**[.03, .36]**	0.16	[-.01, .33]	--	--	--	--	--	--	--	--			--	--
Neg Control	--		--	--	--	--	--	--	0.13	[-.12, .36]	0.05	[-.24, .32]	0.20	[-.08, .46]	0.20	[-.13, .50]
Autonomy sup	--		--	--	--	--	--	--	0.01	[-.21, .23]	0.02	[-.21, .24]	**0.26**	**[.01, .49]**	-0.17	[-.09, .42]
AB Entropy	0.03	[-.14, .20]	-0.07	[-.23, .10]	0.05	[-.18, .28]	-0.10	[-.33, .13]	0.15	[-.12, .40]	-0.09	[-.36, .19]	**-0.31**	**[-.57, -.03]**	-0.15	[-.46, .18]
SS Entropy	-0.06	[-.23, .11]	0.03	[-.15, .21]	-0.20	[-.43, .05]	0.00	[-.24, .24]	-0.05	[-.28, .18]	0.08	[-.16, .31]	0.04	[-.28, .20]	-0.09	[-.36, -.20]

Note. Note. Coefficients are standardized. Non-null results are bolded. PM = Posterior median, CI = Credible interval, EC = Effortful control, IC = Inhibitory control, Base RSA = Baseline RSA, RSA R = RSA reactivity. EP = Externalizing problems, AB Entropy = Affective and behavioral unpredictability, SS Entropy = Sensory signal unpredictability.

Concurrently at T1, mothers who were less involved in children's activities during play and who provided more autonomy support during the puzzle task had children with RSA augmentation to the Day/Night task. Further, caregivers who displayed more negative and intrusive behaviors across both tasks had children with higher baseline RSA concurrently, although this result emerged only in the model examining associations between unpredictability and PNS functioning during play. Lastly, children with more EP exhibited more RSA suppression to the Day/Night task concurrently at T1.

Aim 2.3. Behavioral Adjustment

The Bayesian model for behavioral adjustment showed good fit to the data (Play: 95% Bayesian Posterior $\chi 2$ $p = .547$; Puzzle: 95% Bayesian Posterior $\chi 2$ $p = .530$). Results revealed that, across play and puzzle contexts, caregiver unpredictability did not significantly predict children's IP or EP, either concurrently or prospectively (see Tables A2.6 – A2.8 for model results). Unlike previous findings, there was a significant and negative association between affective and behavioral unpredictability during play and IP at T2 in the MLR model. Caregivers who were more unpredictable reported fewer IP at age six (ß = -0.18, $SE = .09$, $p = .043$). Caregivers who were less involved with their children's activities during play reported fewer IP at age six (Standardized posterior median = -0.19, 95% CI = [-.374, -.004]). No other associations emerged with observed quality of caregiving.

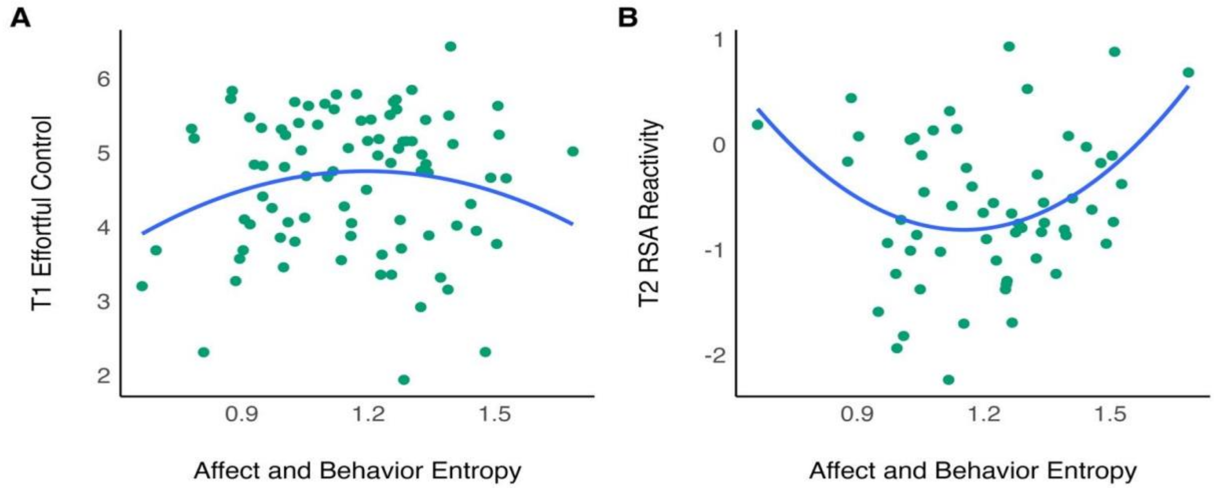
Exploratory Analyses: Curvilinear Effects of Affective and Behavioral Unpredictability

I re-ran the eight Bayesian models with the same covariates and predictors, adding a squared term for affect and behavior unpredictability. Here, I report the only two significant findings. First, a quadratic association was observed between affective and behavioral unpredictability during play and children's effortful control (Standardized posterior median = -

0.15, 95% CI = [-.289, -.002], R2 change in outcome from linear model = .05). Specifically, children whose caregivers were either highly predictable or highly unpredictable exhibited lower levels of effortful control relative to children whose caregivers were moderately unpredictable (see Figure 1a). Second, a quadratic association was found between affective and behavioral unpredictability during play and RSA reactivity at age six (Standardized posterior median = 0.28, 95% CI = [.043, .495], R2 change in outcome from linear model = .03), indicating that children whose caregivers were either highly predictable or highly unpredictable exhibited greater RSA augmentation to the Day/Night task relative to children whose caregivers were moderately unpredictable (see Figure 1b). These findings were also replicated in MLR models.

Figure 1.

Scatterplots depicting quadratic associations between affective and behavioral unpredictability during play (i.e., entropy), caregiver-reported effortful control at age four, and RSA reactivity at age six (lower scores denote RSA suppression)



Discussion

The overarching goal of this study was to explore whether exposure to caregiver affective and behavioral unpredictability was associated with difficulties in biobehavioral regulation and behavior problems among four-year-old children. My study builds on developmental theory and prior research by highlighting (a) that unpredictability is a key feature of early adversity that potentially disrupts biobehavioral regulation (Ellis et al., 2022; Gee & Cohodes, 2021; Smith & Pollak, 2021), (b) the importance of caregivers' warmth and autonomy support during early childhood (Eisenberg et al., 2010; Thompson, 2015; Whipple et al., 2011), and (c) the approach by Davis et al. (2017) to use of entropy rate to operationalize unpredictability.

Findings revealed that caregivers' affective and behavioral unpredictability were associated with sensory signal unpredictability strongly during a puzzle task and weakly during free play; and it was unrelated to caregivers' mental health or authoritarian parenting style. Central to the goal of this study, I found that caregiver affective and behavioral unpredictability was related to only a subset of the indices of biobehavioral regulation. Caregiver affective and behavioral unpredictability during the puzzle was related to RSA reactivity concurrently, such that children whose mothers displayed more unpredictable patterns of affect or behavior during the puzzle task exhibited more RSA suppression during the Day/Night task. Similarly, caregiver sensory signal unpredictability during play was related to RSA reactivity prospectively at T2, such that earlier experiences of unpredictability predicted children exhibiting greater RSA suppression while completing the Day/Night task two years later. Further, caregiver affective and behavioral unpredictability during play was linked to effortful control at T1, and to RSA reactivity at T2, in a non-linear U-shaped fashion. Children whose mothers were either highly predictable or highly unpredictable during play had lower effortful control at T1, and demonstrated increases in RSA in response to the Day/Night task at T2, compared to children experiencing moderate levels of unpredictability. Notably, I controlled for average levels of affect and behavior in the same tasks; thus, any effects of unpredictability on indices of biobehavioral regulation operated above and beyond these factors. Caregiver affective and behavioral unpredictability was not associated with children's inhibitory control or behavioral adjustment. Overall, this study provides partial support for the notion that caregivers' affective and behavioral entropy, a potential indicator of caregiver unpredictability, is a detrimental feature of the socialization context, as suggested by theories of early adversity.

Validity of the Assessment

The first aim of this study was to develop and validate a novel measure to assess caregiver unpredictability based on the entropy rate of expressed affect and support (or lack of support) of young children's autonomous behaviors. I hypothesized that the entropy rate of caregivers' affect and behaviors would be positively related to the entropy rate of sensory signals, which was partially supported. Caregivers who were more unpredictable in their affect and behaviors also provided unpredictable sensory input, but they did so more strongly during the puzzle than during free play, with evidence suggesting that this last association was anecdotal (BF < 3). The free play task is typically more child-directed and unstructured, which may have allowed for greater variability in caregivers' patterns of affect and behaviors as they tried (or failed to try) to match their children's arousal levels and respect their children's need for exploration (Grusec & Davidov, 2010; King et al., 2021). In contrast, the puzzle task involves a more explicit structure that limits the range of activities, and may elicit more parental scaffolding under time pressure (Lunkenheimer et al., 2017, 2018). Grolnick (2002) proposed that when caregivers perceive pressure regarding their children's performance, they may adopt more outcome-oriented goals at the cost of their children's autonomy. Changes in task demands may have decreased children's influence on their caregivers' behaviors, allowing for more stable individual differences in caregivers' unpredictability to emerge. These findings suggest that unpredictability might be sensitive to task demands, considering that both types of caregiver unpredictability were modestly related across tasks (see Table 4).

I found support for my hypothesis that caregiver affective and behavioral unpredictability would not be related to authoritarian parenting. Authoritarian parenting is characterized by high levels of control and rigidity paired with low flexibility and low warmth (R. J. Coplan et al., 2002; Maccoby, 1984), which are characteristics I did not expect to see in unpredictable parents, because unpredictable caregivers are less rigid in their responses by displaying both high and low warmth and high and low control during the same interaction. However, I did not find support for my hypothesis that affective and behavioral unpredictability would be associated with caregivers' symptoms of depression and anxiety, or the entropy of those symptoms. This was surprising, considering that previous studies relying on microanalytic coding (e.g., real-time interactions) have revealed that caregiver depression and anxiety are related to lower contingency, higher overactivity, and more behavioral variability (Beebe et al., 2011; Bornstein & Putnick, 2021; Feldman, 2021; Wass et al., 2023). There are several possible reasons why these patterns did not emerge. First, mothers in this study endorsed very few symptoms of both disorders, limiting their variability and reducing statistical power; for example, there was a marginally positive association between unpredictability during play and depressive symptoms. Second, my questionnaire measure of entropy might not have captured caregiver unpredictability regarding contingencies between caregivers and children (Bornstein et al., 2021). Third, although global or trait-like emotional characteristics and mood problems can influence how parents respond to child cues, they are distinct constructs from parenting-related affect and regulation (Leerkes & Augustine, 2019). Fourth, it is also possible that maternal self-regulation and/or children's characteristics moderate this association (Bailes & Leerkes, 2023; Leerkes & Augustine, 2019; Peltola et al., 2017). For example, Holmberg and colleagues (2020) found that more anxious mothers exhibited more unpredictable sensory signals; however, this association was not significant for mothers with high self-regulation (specifically activation control; see Holmberg et al., 2020). Future research with mothers who vary in their degree of clinical and non-clinical symptoms could help disentangle these possibilities.

Caregiver affective and behavioral unpredictability during free play and during the puzzle were significantly associated with the PCA-derived parental factors, which provide an interesting picture of what the entropy measure is capturing. For instance, affective and behavioral unpredictability during play was positively associated with intrusiveness and negative affect; and was also associated with positive affect across play *and* puzzle activities. This behavioral signature has been previously described as "oversolicitousness," or caregivers who are highly affectionate, involved, and controlling when unnecessary (Rubin et al., 1997). Similarly, Feldman (Feldman, 2021; Feldman et al., 2013) has found that anxious mothers tend to display high positive arousal and involvement during play, coupled with high intrusiveness and attempts to lead interactions. Conversely, affective and behavioral unpredictability during the puzzle activity was negatively related to positive affect, and positively related to negative control and autonomy support. Overall, these caregivers were more likely to have a more extensive repertoire of behaviors (i.e., behavioral variability) and lower positive affective content. This pattern has been described by Lunkenheimer and colleagues (Lobo & Lunkenheimer, 2020; Lunkenheimer, Hamby, et al., 2020), finding that dyadic behavioral variability in combination with low positive content is a particularly significant risk factor for children's regulatory development. It is important to note that the number of behavioral transitions was strongly related to caregiver entropy (*r* = .40 - .53). However, none of my results were replicated when I used the number of transitions as explanatory variables (see Table A2.9), suggesting that the degree of predictability of behaviors - rather than quantity - accounts for the observed associations.

Caregiver Unpredictability and Children's Biobehavioral Regulation

Effortful and Inhibitory Control

The second aim of this study was to examine whether parent unpredictability contributed to the development of children's cognitive and physiological self-regulation and behavior problems. Specifically, I hypothesized that greater caregiver unpredictability would be associated with lower inhibitory control and effortful control in children, both concurrently at age four and prospectively at age six. The results did not appear to support this hypothesis, as there was no significant linear association between caregivers' unpredictability (of affect, behaviors, or sensory signals) and these behavioral indices of biobehavioral regulation. Still, in exploratory curvilinear analyses, I found that moderate levels of affective and behavioral unpredictability during free play were associated with greater effortful control, compared to both higher and lower levels of unpredictability. These results are consistent with previous research reporting that moderate levels of caregiver emotional challenges were associated with better assessor-rated executive functions (Finch & Obradović, 2017).

Caregivers whose predictability is excessive might undermine children's regulatory capacities, by providing few opportunities to practice self-reliance and self-initiated coping techniques (Repetti & Robles, 2016; Rubin et al., 1997; van den Boom, 1994). Further, high levels of predictability may indicate a lack of range in caregivers' affective and behavioral experiences, and fewer attempts to engage and coordinate states of arousal with their children (Lunkenheimer et al., 2011, 2013). Moderate exposure to caregiver unpredictability during play may provide children with opportunities to engage in and practice self-regulation strategies (Leerkes, 2011; Repetti & Robles, 2016). For example, when parents exhibit positive affect and behaviors, it may elicit children's attention and promote mutuality and reciprocity, while the down-regulation of these behaviors may help the dyad practice regulation and recovery (DiCorcia & Tronick, 2011; Leerkes, 2011). Conversely, high levels of *un*predictability may overwhelm children's capacities for self-regulation, undermining the development of these skills.

I found no evidence suggesting that sensory signal unpredictability was related to effortful control or inhibitory control. Prior research has shown that sensory signal unpredictability assessed during infancy is associated with children's later effortful control (Davis, 2017). This effect, however, diminishes during early childhood when the caregiver reports effortful control, but is still significant when effortful control is assessed with a direct behavioral evaluation (Davis, 2019; Holmberg, 2022). Infancy is a sensitive period for sensory signals, as they shape specific visual, somatosensory, and stress-responsive hypothalamic brain synapses, circuits, and regions (Gabard-Durnam & McLaughlin, 2020). Therefore, early childhood may no longer be a period as sensitive to sensory unpredictability (Luby et al., 2020, 2021). It is important to note that inhibitory control at T2 had a ceiling effect, limiting its variability and reducing statistical power to detect any longitudinal effects.

Parasympathetic Functioning

I had no directional hypotheses regarding associations between caregiver unpredictability and children's baseline RSA and reactive RSA during the Day/Night task. Results indicated that children of caregivers exhibiting more affective and behavioral unpredictability during the puzzle task displayed more RSA suppression in response to the Day/Night task at age four. Moreover, children who experienced more unpredictable sensory inputs during play also displayed more RSA suppression during the task at age six. In line with Polyvagal theory and the principle of neuroception (Porges, 2003, 2004), novel but non-threatening situations such as the Day/Night task should evoke a mild decrease in PNS influence, supporting children's attention and orientation towards the task (Hastings et al., 2013; Zeytinoglu et al., 2020). In contrast, greater PNS withdrawal indexed by stronger RSA suppression might indicate that the task is being perceived as threatening, releasing the vagal "brake" on SNS activation of arousal.

It is important to note that the meaning of physiological changes should be evaluated in the context of children's other regulatory abilities and typical task-specific patterns of physiological responding (Beauchaine, 2015; Hastings & Kahle, 2019; Obradović, 2016). The current analyses and previous papers involving this sample (Kahle et al., 2018; Utendale et al., 2014) have demonstrated that children with greater RSA suppression at age four had lower inhibitory and effortful control concurrently, and higher EP and IP concurrently and prospectively at age six, suggesting that this parasympathetic response was "maladaptive." However, my study did not reveal any association between RSA suppression at age six and cognitive regulation or behavioral adjustment. Considering the normative increases in inhibitory control from ages four to six, Day/Night should be a relatively easy task. Therefore, I would expect that children would have to mobilize fewer physiological resources to perform well in the task, such that strong RSA suppression would be particularly inappropriate (Kahle et al., 2018; Quiñones-Camacho & Davis, 2018; Zeytinoglu et al., 2020). Given that behavioral indices of self-regulation and adjustment are associated with a range of autonomic reactions, it may be unlikely that caregiver unpredictability is related to a single pattern of RSA reactivity. Instead, children whose caregivers are unpredictable might generally deviate from physiological patterns that are effective for responding to the task at hand.

During the puzzle task, effective parent behavior involves providing suitable structure, strategies, and feedback for children to learn and practice their cognitive regulatory skills (Grusec & Davidov, 2010). Caregivers whose affective and behavioral patterns are more unpredictable may fail to effectively scaffold children's skills and model effortful behaviors that are well-matched to the task goal (Leerkes & Augustine, 2019; Lunkenheimer et al., 2017). Failing to provide appropriate autonomy support, such as scaffolding children's attempts to place pieces correctly, may decrease children's confidence in their abilities (Mattanah et al., 2005) and increase the likelihood of perceiving a novel cognitive challenge such as the Day/Night task as threatening with a need to exhibit RSA suppression. Notably, caregivers who provided more autonomy support during the puzzle had children who exhibited RSA augmentation to the Day/Night task.

During free play, appropriate parent behavior would involve accommodating children's need for exploration while establishing mutual reciprocity as well as affective and behavioral attunement (Feldman, 2021; Grusec & Davidov, 2010; King et al., 2021). Caregivers who provide unpredictable sensory or affective/behavioral input to the child may be overstimulating and over arousing, disrupting moment-to-moment dyadic affective and behavioral synchrony (Feldman, 2021). Further, they might have trouble modulating their own and their children's arousal, undermining dyadic co-regulation (Leerkes & Augustine, 2019; Wass et al., 2023). With time, these interactions might undermine children's developing self-regulatory capacities (Feldman, 2007; Lunkenheimer, Hamby, et al., 2020), including patterns of behavioral organization (Feldman, 2012; Wass et al., 2023) and parasympathetic regulation (Alkon et al., 2003; Giuliano et al., 2015; Hastings et al., 2019). One possible interpretation is that caregivers who provide more unpredictable sensory input during play contribute to children's likelihood of perceiving independent tasks (where they need to coordinate their behavior) as more threatening at age six. However, this hypothesis should be interpreted with caution, due to the absence of links between RSA reactivity and behavioral correlates.

Interestingly, I found that affective and behavioral unpredictability during play also influenced RSA reactivity at age six following a U-shaped pattern, over and above sensory signals. While moderate levels of affective and behavioral unpredictability were associated with RSA suppression, children exposed to either very low or very high unpredictability exhibited either blunted RSA change or mild RSA augmentation in response to the task, respectively. Although this could be considered adaptive based on the associations between RSA reactivity and adjustment at age four, it could also reflect disengagement from the task and thus be maladaptive. Moderate RSA withdrawal produces temporary arousal that can promote increased engagement and sustained attention in response to mildly stressful or challenging stimuli (Hastings et al., 2013; Obradović & Finch, 2017). Indeed, studies have found that moderate levels of arousal are optimal for executive function performance, particularly for emotionally neutral cognitive tasks, while extremely low or high RSA levels may hinder it (Marcovitch et al., 2010; Obradović & Finch, 2017). In line with the principles of allostasis, effective physiological support of self-regulation is reflected in patterns of change that support adaptive behaviors to specific contextual demands (Berntson et al., 1994; Hastings et al., 2013; Hastings & Kahle, 2019). Children exhibiting blunted RSA or RSA augmentation might have not experienced sufficient arousal to support engagement and the deployment of attention resources to the task (Hastings et al., 2013).

Although caregiver unpredictability predicted children's parasympathetic reactivity, it did not predict differences in baseline RSA in the path models. This pattern mirrors prior findings that parental behaviors predict preschoolers' RSA reactivity more strongly than resting RSA (Hastings et al., 2008, 2019; Perry et al., 2013, 2018; Zhang et al., 2020). Preschoolers experience significant changes in RSA reactivity between ages three and five, whereas baseline RSA has higher rank-order stability and normatively increases from ages two to seven (Dollar et al., 2020; Zeytinoglu et al., 2020). As a period of significant change, it might also reflect a period of greater sensitivity to parental influence on children's regulatory efforts (Hastings et al., 2023). Indeed, intervention studies have found that changes in parental behaviors are related to baseline RSA, but more so if they occur during infancy (Porges et al., 2019; Tabachnick et al., 2019) or early adolescence (Katz et al., 2020; although see Bell et al., 2018). It is also possible that caregiver quality, rather than patterns, more strongly influence trait-like differences in resting RSA.

Behavioral Adjustment

The final hypothesis stated that caregiver unpredictability would be associated with higher EP and IP in children, both concurrently and prospectively. However, these results did not support my expectations, as I did not find any significant positive associations between unpredictability and IP. In fact, in both bivariate correlations and maximum likelihood models, I observed that affective and behavioral unpredictability during play was associated with lower levels of IP at age six; however, this association was considered null in the Bayesian model. Additionally, I found no significant associations between unpredictability and EP. It is important to note that this model had the largest number of parameters, and that there was strong comorbidity between IP and EP (T1 $r = .73$, T2 $r = .54$). These considerations limited the variability of both disorders and reduced statistical power.

In addition to issues with statistical power, there are other potential reasons for this pattern of findings. For example, it is unclear whether the impact of unpredictability differs based on the valence of the experience, such as whether it is aversive or rewarding (Ugarte & Hastings, 2023). Previous research has shown that dyadic behavioral variability has different effects on preschool children's self-regulation, depending on the affective valence of the interaction content (Lobo & Lunkenheimer, 2020; Lunkenheimer, Skoranski, et al., 2020). Specifically, greater affective and behavioral variability predicted greater inhibitory control, social persistence, and lower emotional negativity, when the affective content of the interaction was positive; but these patterns were reversed when the affective content was neutral or negative (Lobo & Lunkenheimer, 2020; Lunkenheimer, et al., 2020). This finding could explain my observation of lower levels of IP at age six, as affective and behavioral unpredictability was positively related to positive affect during play. Although this study was underpowered to examine moderation effects in the context of complex models, future research should explore interactions between linear and curvilinear unpredictability and affective content in larger samples.

The Importance of Caregiver Unpredictability for Physiological Aspects of Self-Regulation

The present findings raise intriguing questions regarding the differential impact of caregiver unpredictability on various aspects of children's development. Specifically, the results suggest that unpredictability may be more salient for PNS functioning than for other dimensions of self-regulation and behavioral problems. Based on the principle of neuroception and theories of self-regulation, predictable rhythms of caregiver sensory signals, affect, and behavior seem to be shaping non-volitional bottom-up processes of appraising and regulating arousal to novel situations during early childhood (Blair & Ku, 2022; Blair & Raver, 2012; Porges & Furman, 2011). The topological theory of early adversity underscores the importance of perceptions (rather than experiences) of unpredictability as a driver of individual differences in biobehavioral development (Smith & Pollak, 2021). Individuals' capacity to perceive uncertainty depends on whether unpredictable events actually change the environment (e.g., by changing rewards) and internally stored information (e.g., lived experiences), leading to significant changes in behavior as a result of learning (Soltani & Izquierdo, 2019).

Munakata and colleagues (in press) suggest that the timescale of unpredictability may be critical in determining whether and how children perceive and respond to it. Unpredictable behaviors that occur on a scale of seconds, such as those captured by my measure, might not involve traceable changes in the environment and thus may be harder for children to perceive or recognize consciously. In turn, perception may be a prerequisite for children's abilities to mount coordinated and adaptive behavioral responses to their caregiving contexts. Still, this does not necessarily mean that no damage has been done after exposure to unpredictability. Theories of biological embedding suggest that experiencing chronic stressors leads to lasting alterations in neurobiological and neural functioning (Hastings et al., 2023; Taylor et al., 1997). For instance, studies have elucidated that 12-month old infants exposed to unpredictable sensory input show blunted cortisol reactivity, and imbalance of medial temporal lobe–prefrontal cortex connectivity at age ten (Davis et al., 2022; Granger et al., 2021; Noroña-Zhou et al., 2020).

To my knowledge, this is the first study to examine the relations between second-to-second unpredictability and PNS functioning. As one of the peripheral stress response systems that most readily responds to external demands, particularly those of a social nature, the PNS is sensitive to socialization experiences (Alkon et al., 2003; Bourne et al., 2022; Hastings & Kahle, 2019; Porges & Furman, 2011). Atypical patterns of RSA reactivity during early childhood may set the stage for subsequent developmental trajectories as children transition to elementary school settings, even if the link between RSA reactivity and behavior is not observable concurrently (Hastings et al., 2008, 2011). Although replication is warranted, this study provides initial evidence that caregiver unpredictability, both sensory and affective/behavioral, can get "under the skin" by shaping the maturation of neurophysiological responses such as RSA reactivity to novel tasks.

Limitations and Future Directions

These findings should be considered within the context of several limitations. The sample was not designed to be representative of the broader population, as it had low ethnic diversity and was intentionally designed to oversample for EP during early childhood and. Consequently, caution should be exercised when generalizing these results to other populations, as the findings warrant future replication with different community samples. Additionally, this study had a relatively small sample with considerable missing data, as indicated in Table 3; and a low parameter-to-sample size ratio, which increases the likelihood of Type II errors due to inadequate power. Conversely, the large number of models tested (n = 16) may have resulted in Type I errors. Therefore, larger sample sizes are needed to ensure that these findings are robust despite these limitations.

I attempted to address the issue of parameter to sample size ratio and the number of models tested by using Bayesian estimation, as recommended by van de Schoot et al. (2021) and Asparouhov and Muthén (2021). However, as mentioned in the analytic approach, sample size can be sensitive to uninformed priors. Although the examination of trace plots, posterior distributions, and chain autocorrelations suggests that priors did not bias model parameters, future studies could integrate informative (or weakly informative) priors to enhance the robustness of Bayesian regression findings (Depaoli & van de Schoot, 2017; Smid & Winter, 2020).

Regarding the estimation of entropy, I assumed that the probability distribution of behaviors across both tasks was stationary, meaning that the probabilities of occurrence of different behaviors were the same from the beginning to the end of each task (Vegetabile et al., 2019). Alternatively, during the puzzle task, some caregivers may have changed the range of their behaviors due to time constraint of completing the puzzle before the 5-minute mark. Moreover, previous studies examining sensory signals have used longer 10-minute tasks, whereas the current study used 5-minute tasks. Therefore, this calculation of entropy was based on shorter sequences of behaviors (i.e., fewer transitions), which could impact the reliability of the entropy estimate. Future iterations of this study could consider using the number of transitions or global indices of task activity (e.g., a dummy indicator if the dyad finished the puzzle early or not) as covariates.

Additionally, it is worth noting that my calculations of caregiver unpredictability were solely based on caregivers' behaviors, without taking into account the extent to which children's activity levels during the tasks influenced caregivers' behaviors. During early childhood, children become increasingly active participants in day-to-day co-regulation processes, contributing to dyadic patterns of behavior and affect (Feldman, 2015; Lobo & Lunkenheimer, 2020; Lunkenheimer, Hamby, et al., 2020). While controlling for children's EP *could* account for children's activity levels to some extent, future studies may consider instead incorporating measures of child activity levels to provide a more comprehensive understanding of dyadic regulation processes.

The present study employed mother reports to assess children's effortful control and behavioral adjustment, which could increase the risk of reporter bias. While maternal reports are informative about children's maladjustment, it is advisable for future research to incorporate multiple informants to capture children's effortful control and behavior problems more comprehensively (Müller et al., 2014; Rowe & Kandel, 1997). In terms of RSA measurement, respiration was not directly assessed for each participant, and the impact of participant movement or vocalizations was not accounted for which could potentially affect the precision of RSA assessment (Beauchaine et al., 2019; Shader et al., 2018). Future studies should quantify speech rate and movement and include them as covariates, to ensure that significant findings pertaining to RSA are not due to these confounding factors. Additionally, future research should recognize the dynamic changes in sympathetic influences and parasympathetic responses to emotions, as autonomic regulation of emotion is a multisystem process.

It should be noted that the present study used a static change score of RSA from baseline to task, which raises two methodological concerns (Burt & Obradović, 2013). First, these statistical approaches are unable to model measurement error and account for unreliability in physiological measures. Second, they lack temporal sensitivity to fluctuations in PNS activity that unfold over time in response to stimuli. Future studies should incorporate complex, non-linear measures that reflect flexible PNS responses, particularly across longer tasks with multiple data points, such as latent basis growth curve models (Miller et al., 2013; Ugarte, Miller, et al., 2021) and cardiac fractality which captures the optimal temporal variability and organization of the heart rate variability series (Berry et al., 2019). Moreover, it remains unclear whether the findings for RSA reactivity to an inhibitory control task would extend to parasympathetic responses to other types of tasks, such as emotional inductions, which may demand different patterns of physiological responses that may or may not relate to maladjustment (Obradović et al., 2011). Therefore, further research is needed to understand the complex nature of the physiology of self-regulation, and to increase the ecological validity of stimuli to more accurately portray children's day-to-day regulation demands.

Lastly, while this study explored the main effects of caregiver unpredictability and children's PNS functioning on behavioral regulation and adjustment, I did not examine the potential interaction between these variables due to constraints of the sample size. Biopsychosocial models of development underscore the importance of examining ANS functioning as a source of individual differences in the associations between environmental inputs and children's development (Cicchetti & Blender, 2004; Del Giudice et al., 2011; Hastings & Kahle, 2019). Past research has shown that children's PNS physiology at baseline or in response to stimuli can moderate the links between caregiving and aspects of children's socioemotional and cognitive development (El-Sheikh & Whitson, 2006; Hastings & De, 2008; Hastings & Kahle, 2019; Perry et al., 2012, 2013; Ugarte, Miller, et al., 2021). Therefore, it is possible that caregiver unpredictability might affect children differently depending on their PNS functioning.

Conclusion

Despite its limitations, the present study significantly contributes to our understanding of the different dimensions of caregiver-related adversity (Tottenham, 2020). Specifically, these preliminary findings suggest that caregiver sensory signal unpredictability contributes to parasympathetic regulation during early childhood, which had not previously been investigated.

Moreover, I demonstrated that the assessment of real-time unpredictability of caregivers' affect and behaviors is feasible, and that it influences children's effortful control and parasympathetic regulation in both linear and curvilinear ways.

The preschool period is characterized by rapid increases in behavioral, cognitive, and emotional regulatory functioning (Calkins & Keane, 2004; Diamond, 2016; Eisenberg et al., 2010; Montroy et al., 2016). Better regulatory skills are associated with later school readiness and better adjustment, setting the stage for a more positive developmental trajectory compared to children with poorer self-regulatory skills in early childhood (Blair & Raver, 2015; Eisenberg et al., 2010; Heckman, 2006; Raver et al., 2011; Robson et al., 2020). This pathway underscores the need to identify factors that may compromise the development of biobehavioral regulation during this period, including the unpredictability of caregivers' behaviors. While my study provides preliminary evidence, further research with larger and more diverse samples is necessary to validate these findings and assess their generalizability.

To deepen our understanding of the effects of caregiver unpredictability on children's development, it is crucial to develop and validate methods to adequately capture its dynamic nature. Properly assessing the degree of predictability of caregivers will enable researchers to distinguish unpredictability from other types of early life adversities that can threaten the developmental health and well-being of young children. By doing so, we can explore the mechanisms underlying the associations between early experiences and children's development with more precision, and thereby identify potential targets for prevention and intervention aimed at supporting stability and continuity in the lives of children.

CHAPTER FOUR

GENERAL DISCUSSION

Unpredictability as an aspect of early life adversity significantly disrupts children's and adolescents' psychosocial development throughout their lifetime (Davis et al., 2022; Ellis et al., 2022; Gee, 2021; Glynn & Baram, 2019; S. Liu & Fisher, 2022). Despite growing evidence highlighting the importance of predictable caregiving in fostering attachment security, self-regulation abilities, and long-term healthy development (Gee & Cohodes, 2021; Short et al., 2020; Tottenham, 2020), our understanding of proximal unpredictability within caregiver-child relationships remains limited (Glynn & Baram, 2019). Furthermore, the interaction between distal and proximal experiences of unpredictability within the caregiver-child dyad has yet to be explored. Given that both early childhood and adolescence are dynamic periods characterized by increases in self-regulation capacities and susceptibility to mental health disorders (Blair & Raver, 2015; Gee et al., 2022; Montroy et al., 2016; Solmi et al., 2022), this dissertation aimed to address three critical gaps in the current understanding of caregiver unpredictability (Ugarte & Hastings, 2023): its domain generality or specificity, the cascade between distal and proximal experiences of unpredictability, and the specific developing systems that may be most influenced by caregiver unpredictability in childhood and adolescence. By examining these gaps, my research program aimed to advance knowledge in the field, paving the way for more effective interventions and social programming efforts to foster predictability in the lives of children and families.

Main Findings and Theoretical Implications

Study 1 examined relations among family instability (a cue to environmental unpredictability), parental mood unpredictability, and Mexican-origin youths' mental health problems across adolescence. My findings suggested that family instability was related to maternal and paternal mood unpredictability, with maternal mood unpredictability being associated with youths' internalizing problems across adolescence. These variables, however, exhibited little evidence of reciprocal relations, implying a lack of transactional connections at the within-person level across time.

In Study 2, I developed a novel measure to assess caregiver affective and behavioral unpredictability and explored its associations with preschoolers' biobehavioral regulation and behavioral problems concurrently at age four and prospectively at age six. Our results demonstrated that caregiver affective and behavioral unpredictability were moderately associated with sensory signal unpredictability during a puzzle task, and weakly during free play. Caregiver unpredictability, however, was related to only a subset of indices of biobehavioral regulation. Concurrently at age four, caregiver affective and behavioral unpredictability was linked to greater RSA suppression during the Day/Night task and to caregiver-reported effortful control in a non-linear, inverted U-shaped pattern. Regarding prospective associations at age six, children whose caregivers exhibited greater sensory signal unpredictability had stronger RSA suppression to the Day/Night task, and children whose caregivers demonstrated lower and higher levels of affective and behavioral unpredictability had RSA augmentation. Surprisingly, neither sensory signal nor affective and behavioral unpredictability were associated with children's inhibitory control or behavioral adjustment.

These studies together suggest that unpredictability within the caregiver-child relationship influences youths' mental health and preschoolers' biobehavioral regulation, but with some associations being more robust than others. Based on these results, I will discuss theoretical implications for research about unpredictability. Examining the complex interplay between different aspects of unpredictability contributes to our understanding of how early life adversity might impact children's development, and also offers potential directions for future research in this area.

My findings demonstrate the complexity of unpredictability and its various dimensions. Across Studies 1 and 2, I applied the measure of entropy to different caregiver inputs: responses to mood questionnaires, patterns of observed sensory signal input, and affect and behaviors during interactions with their children. Study 2 revealed that affective and behavioral unpredictability was not related to mood entropy, and that sensory signals and affective and behavioral unpredictability were only modestly related to each other within and across tasks. Further, entropy of caregivers' mood, sensory signals, and affect and behaviors differed in terms of their linear and curvilinear predictive associations with youth's internalizing problems (Study 1); and entropy was associated with children's bottom-up regulatory processes, as indexed by RSA, as well as top-down regulatory processes, as indexed by effortful control (Study 2).

The incongruency across methods, as well as the influence of different conceptualizations of unpredictability on children's and youths' development, jointly support the possibility that caregiver unpredictability may be domain-specific (evident in particular inputs) rather than domain-general (consistently expressed across different inputs or features of caregiving). This insight represents a significant step forward in the field of unpredictability research. Theoretical consensus has emerged about its unique influence on children's experiences, unpredictability is distinct from other adversity sources (Cohodes et al., 2021; Ellis et al., 2022; Smith & Pollak, 2021); and reviews have highlighted translational implications for policymaking and preventative intervention strategies (Humphreys et al., 2021; S. Liu & Fisher, 2022). Yet, researchers continue to wrestle with its construct validity, both theoretically and empirically.

This validity includes the overlap with other child-caregiver relationship adversity dimensions, and the use of unpredictability as an umbrella term for adverse experiences (Ugarte & Hastings, 2023).

Our findings imply that the measures used to assess caregiver unpredictability in Studies 1 and 2 are neither equivalent nor interchangeable, because they potentially capture distinct experiences that influence our understanding of early adversity's impact on developing children and youth. Based on the pattern of results, future research should not conflate these unique aspects of caregiver unpredictability; instead, investigators should be more precise in defining and measuring them. Consistent terminology and measures will facilitate comparison and integration across working groups, thus reducing ambiguity and fostering knowledge accumulation among research groups focused on unpredictability (Frankenhuis & Walasek, 2020; Haslbeck et al., 2021; Young et al., 2020). Enhanced knowledge accumulation will aid in comprehending causal mechanisms and developing targeted interventions that promote predictability (Eronen & Bringmann, 2021; Hodson, 2021).

Similarly, the findings in this dissertation raise the question of what temporal lens should be applied to understanding the effects of caregiver unpredictability. Study 1 examined whether family instability, a distal cue of unpredictability, influenced unpredictable patterns of one feature of the caregiver-adolescent relationship: maternal and paternal mood unpredictability. Contrary to expectations based on evolutionary theories of adversity (Ellis et al., 2022), my findings demonstrated that chronic unpredictability, rather than specific stochastic environmental and caregiving changes, contributed to caregivers' mood unpredictability and youths' internalizing symptoms. Although the two-year timescale of Study 2 might not optimally capture immediate transactional processes, my analyses indicated little evidence for within-wave covariation, suggesting that cumulative effects of prolonged unpredictability exposure had a more substantial impact than isolated incidents or short-term family instability or mood unpredictability fluctuations (Doom et al., 2016; McLaughlin et al., 2021; Plamondon et al., 2022; Reiss et al., 2019).

Unmeasured proximal processes - rather than mood entropy - could have influenced how family instability affects adolescent mental health, such as youths' caregiving relationship experiences within each time point (Li & Belsky, 2022; Palermo et al., 2018; Vargas et al., 2013). Parental mood entropy had only a weak relation with youths' perceived caregiver hostility and inconsistency. Specifically, maternal mood entropy was not linked to youth-reported inconsistent discipline and hostility (though entropy had a weak positive association with hostility at wave 7), and paternal mood entropy was related to more inconsistent discipline only for adolescent ages 13 and 15. Global emotional characteristics and mood problems are distinct from parenting-related mood and regulation; therefore, mood unpredictability may not influence specific caregiving behaviors that could potentially disrupt youths' well-being (Leerkes & Augustine, 2019).

Stochastic associations might emerge when assessing unpredictability in parental behavior; for example, by calculating through questionnaires the entropy of warmth and hostility, or entropy of parent-youth relationship quality. Future research should explore the feasibility and validity of this approach, incorporating more intensive repeated measures at shorter timescales (e.g., month-to-month) to better examine the stochasticity of environmental and caregiver mood unpredictability's associations with youth mental health.

The thorough examination of the validity of entropy-based mood measures in a Mexican-origin sample introduces new possibilities for assessing and understanding unpredictability effects in families and youths from various sociocultural backgrounds. As done in Study 1, future research could leverage existing longitudinal and panel studies with caregiver mood data, and employ causal inference methodologies (e.g., marginal structural models). This approach would reveal the connections between distal unpredictable experiences (e.g., income volatility, family instability) and caregiver mood entropy, as well as test whether proximal and distal unpredictability cues result in distinct neurodevelopmental changes from infancy to adolescence (Cohodes et al., 2021; Smith & Pollak, 2021; Ugarte & Hastings, 2023).

The results of study 2 emphasize the significance of developmental timing in the effects of observed caregiver unpredictability on children's biobehavioral regulation and mental health (Gee & Cohodes, 2021; Luby et al., 2020, 2021). Dynamic systems theory suggests that development progresses through oscillations between predictable dyadic interactions and periods of disequilibrium, reorganization, and unpredictability (Lewis, 2011; Thelen & Smith, 1994). Thus, increased dyadic unpredictability could be a temporary product of developmental change, fostering caregivers' adaptation and adjustment to changes in their children (Granic & Hollenstein, 2015). Curvilinear findings in Study 2 suggest that moderate exposure to caregiver affective and behavioral unpredictability during play may enable children to practice self-regulation strategies (DiCorcia & Tronick, 2011; Leerkes & Augustine, 2019; Repetti & Robles, 2016). Moderate caregiver unpredictability levels might also promote positive adaptation by helping children better prepare for future challenges (Oshri, 2022; Rutter, 2012). Determining whether or not these nonlinear relations are common to other sources of unpredictability, and whether they occur across different developmental periods, remains to be explored.

Lastly, inclusion of the sample used in Study 1 highlights the unique experiences and vulnerabilities of Mexican-origin families in unpredictable environments. Study 1 demonstrated that mood entropy was a valid indicator of unpredictability in this population, who typically experiences higher environmental unpredictability than the predominantly-White samples assessed in previous work; however, it also indicated that family instability did not lead to increased EP among these youths, contrary to previous literature (Belsky et al., 2012a; Doom et al., 2016; Hartman et al., 2018; Li et al., 2018; Schroeder et al., 2020; Usacheva et al., 2022; Womack et al., 2019). Socially marginalized communities - such as the Mexican American community - possess cultural wealth, including beliefs and behaviors, that foster positive outcomes (Yosso, 2005). Culturally-grounded research focusing on unpredictability experiences across diverse sociocultural groups is essential to better understand family adaptation strategies in such contexts.

Dyads do not exist in a vacuum, but rather within complex ecological niches with unique environmental demands to which the dyad must adapt (Bronfenbrenner, 1999; Nketia et al., 2021). Minoritized families facing disadvantage are more likely to experience unstable and poorly structured environments, making them more susceptible to acute unpredictable events like economic shocks, pandemics, or natural disasters (Lai & La Greca, 2020; Pollak & Wolfe, 2020; Yoshikawa et al., 2012). The COVID-19 pandemic exemplifies an unpredictable event that significantly impacted family environments and youths' mental health, but with varying effects across minoritized racial-ethnic communities (S. Liu & Fisher, 2022; Stinson et al., 2021). Additionally, massive forced migration and large-scale natural disasters due to climate change may exacerbate unpredictability and helplessness for caregivers and children, especially among vulnerable populations (Masten et al., 2021; Wuermli et al., 2021). Applying rigorous methodological and quantitative approaches to investigate unpredictability within caregiver-offspring relationships across diverse populations (and crisis contexts) can provide valuable insights into the effects of distal and proximal unpredictability on caregivers and children.

Limitations and Strengths

Our findings from Study 1 and Study 2 should be interpreted in light of several limitations. In Study 1, the generalizability of my results was restricted by the specific sample of Mexican-origin youths from predominantly low-income households in Northern California, the impact of the 2008 recession, and the two-year time interval between measures. Future research should examine shorter time windows to fully explore reciprocal relations, and incorporate additional sources of unpredictability, such as caregiver and peer relationships, discrimination, and neighborhood safety. In addition, information on family instability and caregivers' mental health before age ten should be collected to determine how exposure during childhood may have contributed to adolescents' mental health.

Study 2 had a smaller sample with considerable missing data, and replied upon mother reports for effortful control and behavioral adjustment, both of which limit the robustness and generalizability of these findings. Future research should replicate these findings by including larger and more diverse samples, incorporating multiple informants, and addressing methodological concerns related to RSA measurement. Future studies should also consider dynamic changes in autonomic regulation, by employing nonlinear approaches that reflect flexible PNS responses. To increase the ecological validity of stimuli, it is essential to explore parasympathetic responses to various types of tasks, such as emotional inductions. Addressing Study 1 and Study 2 limitations in future research will allow for a more comprehensive understanding of the role that unpredictability plays in caregiver-offspring relationships, and its impact on children's self-regulation and youths' mental health across diverse populations and contexts.

Despite these limitations, the strengths of Study 1 and Study 2 provide valuable insight into the effects of unpredictability on adolescent mental health and early childhood development, respectively. In Study 1, the focus on Mexican-origin adolescents contributes to a growing body of research that is inclusive of diverse communities, countering the historical overreliance on WEIRD samples (Henrich et al., 2010). Additionally, the longitudinal and multi-wave design of Study 1 allows for a more thorough understanding of predictive relations, by considering time sequence and stability effects. Study 2 offers significant contributions to the work about different aspects of caregiver-related unpredictability, and their influences on children's parasympathetic regulation during early childhood. The project also demonstrates that assessing real-time unpredictability of caregivers' affect and behaviors is feasible, and that unpredictability influences children's effortful control and parasympathetic regulation in both linear and curvilinear ways. This process is particularly important during the preschool period, when rapid increases in behavioral, cognitive, and emotional regulatory functioning occur and set the stage for a more positive developmental trajectory (Blair & Raver, 2015; Eisenberg et al., 2010; Heckman, 2006; Raver et al., 2011; Robson et al., 2020).

These strengths underscore the significance of developing and validating methods to capture the dynamic and nuanced nature of caregiver unpredictability. The field would benefit from additional specific methodologies, which can track how unpredictability is expressed over varying behaviors and ecological levels. This discovery will enable researchers to more precisely examine the mechanisms linking early unpredictability and later children's development. Moreover, refining unpredictability measures allows for the identification of environmental and individual factors closely associated with distinct aspects of caregiver and caregiver-child unpredictability, which can then inform screening, intervention, or policy relief efforts. To accomplish these objectives, it is essential to replicate the results from my research program with larger, more diverse samples, to both validate results and increase generalizability.

Conclusion

The purpose of this research program was to address three critical gaps in the understanding of caregiver unpredictability: the domain specificity regarding features of caregiving and their implications for child and youth adjustment, the cascade between distal and proximal experiences of unpredictability and the influence of unpredictability on the sensitivity of the developing system, and the timing of exposure to unpredictability and its association with child well-being. In Study 1, family instability was related to maternal and paternal mood unpredictability in Mexican-origin youths, with maternal mood unpredictability being associated with youths' internalizing problems. Among younger children, Study 2 revealed that caregiver affective and behavioral unpredictability was moderately associated with sensory signal unpredictability. Both types of unpredictability were linked to indices of biobehavioral regulation in preschoolers, with affective and behavioral unpredictability showing a non-linear U-shaped relation with effortful control and RSA reactivity.

Caregivers' adequate support for and organization of children's emotions and behaviors are critical for children's healthy development (Humphreys et al., 2021; King et al., 2021). Properly assessing the degree of predictability of caregiver mood, emotions, and behaviors will provide further insight into unpredictability as a distinguishable component of the broader spectrum of early life adversities that can threaten the developmental health and well-being of children and adolescents (Gee & Cohodes, 2021; Humphreys et al., 2021; Tottenham, 2020). My research will provide the tools and evidence needed to advance work about the specific biobehavioral effects resulting from different dimensions of caregiver unpredictability. Pending further investigation, results from this research program could inform how to best design and implement developmentally-sensitive interventions, as well as social programs that support and strengthen the capacity of caregivers to offer predictable, sensitive care to their children (Humphreys et al., 2021; Luby et al., 2020; McLaughlin et al., 2021). Such interventions are especially important for families who experience other environment adversities (i.e., poverty, family instability) that threaten child and youth well-being (Shonkoff, 2012). Systematic empirical and translational progress in understanding unpredictability will further enhance efforts to ensure continuity and stability in children's lives (Doan & Evans, 2020, Ugarte & Hastings, 2023).

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APPENDIX 1

Supplementary Materials for Study 1

1. Family Instability Measure

Table A1.1

Information Sources and Scoring for Family Instability

Construct	Questionnaire	Question & Scoring
Residential Transitions	Major Events Inventory (Conger et al., 1992)	In the past three months, you moved to a worse residence or neighborhood ("Yes" = 1)
	Neighborhood Cultural/Social Cohesion scale (Sampson et al., 1997)	How many different homes have you lived in during the past 3 years? (≥ 2 homes = 1)
	Demographics Questionnaire	How long have you lived in this home? (<2 homes = 1)
Employment loss	Major Events Inventory (Conger et al., 1992)	In the past three months: • You got laid off ("Yes" = 1). • You were fired ("Yes" = 1). • You could not find a job ("Yes" = 1). • You changed jobs for a worse one ("Yes" = 1).
	Employment Questionnaire	What is your present work situation? • Temporarily laid off ("Yes" = 1). • Unemployed but looking for work ("Yes" = 1).
Income loss	Demographics Questionnaire	From waves 3 through 7, decreases in income to needs in comparison to prior wave (Decrease = 1).
	Major Events Inventory (Conger et al., 1992)	In the past three months: • You suffered a financial loss or loss of property, not related to work ("Yes" = 1). • You took a cut in wage or salary ("Yes" = 1).
	Finances Questionnaire	During the past 12 months, did you have what you would consider to be a major reduction in income? ("Yes" = 1).
Overcrowding	Demographics Questionnaire	How many bedrooms do you have in your home? Including yourself, how many people live in your household? Please include anyone who is living here 50% of the time or more. *Person to room ratios greater than 2 were coded as 1, in line with Census Bureau guidelines for overcrowding (United States Census Bureau, 2017).*
Parental transitions	Demographics Questionnaire	Differences in response to the question "Please select which parents are living in the home" between waves (Not equal across contiguous waves = 1). Wave that the mother/father changed from the original mother/father to another mother/father figure for the first time (Wave number = "Yes").
Relational status	Major Events Inventory (Conger et al., 1992)	In the last three months, you got separated or divorced ("Yes" = 1).

	Demographics Questionnaire	Differences in response to the question "What is your current marital status?" between visits (Not equal across contiguous waves = 1). Differences in response to the question (if not married) "What best describes your current relationship status?" between visits (Not equal across contiguous waves = 1).

Note. If a participant scored a "1" in any question within a construct, they scored a "1" for that construct.

2. Missingness of Parental Mood

Table A1.2.

Missingness per Wave for MASQ and CESD

Mothers				
	W1	**W3**	**W5**	**W7**
	% missing	% missing	% missing	% missing
CESD	5.34	14.99	11.57	13.06
MASQ	5.34	14.99	11.57	13.06
Fathers (Total sample)	% missing	% missing	% missing	% missing
CESD	40.21	43.47	40.65	44.96
MASQ	40.21	43.47	40.65	44.96
Fathers (Participating fathers)	% missing	% missing	% missing	% missing
CESD	22.94	26.96	23.52	29.07
MASQ	22.94	26.96	23.52	29.07

Note. Total sample = 674. Participating fathers sample = 523.

3. Missingness for Internalizing and Externalizing problems

Table A1.3.

Missingness for Internalizing and Externalizing Problems

	W1	**W3**	**W5**	**W7**
	% missing	% missing	% missing	% missing
IP	1.63	14.84	12.61	11.57
EP	1.63	14.84	10.53	10.98

Note. Total sample = 674. IP = Internalizing; EP = Externalizing.

4. Validity Measures

4.1. Convergent validity

Stress reaction. At waves 3 and 7, I examined associations between mother's and father's stress reaction, and entropy of negative emotionality, positive emotionality, and impulse control using the Mini-Multidimensional Personality Questionnaire (Donnelan et al., 2005). The stress reaction subscale consists of 5 items and is designed to assess an individual's emotional lability and tendency to worry and be oversensitive to their environment. Each questions consists of a pair of opposing statements and participants are asked to rate themselves on a scale from 1 to 5 based on which statement best describes them. For example, one item reads: *"I am not at all even-tempered, calm. I tend to be moody* *and emotionally unstable / I am extremely even-tempered. I am emotionally stable."* Cronbach's α ranged between .42 and .55.

Negative emotionality. This scale includes three subscales (stress reaction, alienation, and aggression), and a total of 16 items consisting of a pair of opposing statements. High scores indicate a pronesses to experience anxiety, anger, and emotional and behavioral negative engagement. Example items include: *"I believe that people often make things difficult for me / I do not believe that people make things difficult for me"* and *"I sometimes enjoy teasing or frightening others / I could never enjoy teasing or frightening others"*. I applied Shannon's entropy formula to each caregiver's responses on all 16 items at each assessment (waves 3 and 7).

4.2. Discriminant validity

Mexican-American cultural values. At assessments 1, 3 and 5, caregivers completed the Mexican American Cultural Values Scale (MACVS; Knight et al., 2010). Response options ranged from 1 (*Not at all*) to 4 (*Very much*) for all scales. The 5-item Traditional Gender Roles scale includes statements such as, *"It is important for the man to have more power in the family than the woman."* The Familism and Respeto subscales include 16 items related to familism values and 8 items related to respect for parents and elders, respectively. Sample items include, "*Family provides a sense of security because they will always be there for you*" and "*Children should always be polite when speaking to any adult*". Lastly, the Independence subscale includes 5 items. For example, one item reads "*The most important thing parents can teach their children is to be independent from others*". I applied Shannon's entropy formula to each caregiver's responses on each subscale at each assessment (waves 1 through 5).

Acculturation. At assessments 1, 3, and 5, I used the Acculturation Rating Scale for Mexican Americans–II Scale (Cuellar et al., 1995), which is specifically focused in Language use.

Ten total items (five per language) reliably measure English use and Spanish use. Caregivers were asked to report how often they spoke, wrote, thought, listened to music, and watched television in each language on a 4-point frequency scale ranging from 1 (*almost never or never*) to 4 (*almost always or always).* I applied Shannon's entropy formula to each caregiver's responses on each subscale at each assessment (waves 1 through 5).

Neighborhood criminal events and neighborhood quality. At waves 5 an 7, I tested the discriminant validity of maternal mood entropy with entropy scores of the Criminal Events Scale and Neighborhood Quality (Kim et al., 2008). Criminal events is 10-item scale evaluating individual's perceptions of neighborhood crime (e.g., stabbings, shootings, violent assault, and drug use) on a 4-point frequency scale ranging from 1 (*almost never or never*) to 4 (*almost always or always).* The Neighborhood Quality Evaluation Scale is a six-item evaluation of the attractiveness of the neighborhood, rated on a 4-point frequency scale ranging from 1 (*Not true at all*) to 4 (*Very true*). Sample items include "*Your neighborhood is clean and attractive"* and "*It is safe in your neighborhood*". I applied Shannon's entropy formula to each caregiver's responses on each subscale at each assessment (waves 5 and 7 for mothers, wave 7 for fathers).

Positive emotionality. This scale of the MPQ includes four subscales (wellbeing, social potency, achievement and social closeness), and a total of 14 items consisting of a pair of opposing statements. High scores indicate a pronesses to behavior and temperamental characteristics conducive to joy, and to active and rewarding engagement with social and work environments. Items include: *"I am not at all enthusiastic. I am not interested in or excited by life / I am extremely enthusiastic. I am interested in and excited about life"* and *"I prefer to work out problems alone / I always seek support from others when faced with problems"*. I applied Shannon's entropy formula to each caregiver's responses on all 14 items at each assessment (waves 3 and 7).

Impulse control. This scale of the MPQ includes three subscales (control, harm avoidance, and traditionalism), and a total of 12 items consisting of a pair of opposing statements. High scores indicate tendencies to inhibit and restrain impulse expression, unconventional behavior, and risk-taking. Items include: *"I am careful, I think before I act / I am extremely impulsive, I act without thinking"* and *"I am not at all strict. I am flexible about rules / I am extremely strict. I believe in rules and discipline"*. I applied Shannon's entropy formula to each caregiver's responses on all 12 items at each assessment (waves 3 and 7).

4.3. Predictive validity

Parental hostility. At all waves, youths reported on mothers' and fathers' hostility using the Behavioral Affect Rating Scale (BARS; e.g., Lorenz et al., 1991). The BARS assesses hostility with 13 items. Youths were instructed to assess the behavior within the past 3 months. Item examples are "*During the past 3 months when you and your [mom/dad] have spent time talking or doing things together, how often did your [mom/dad] get angry at you?"* and "*During the past 3 months, how often did your [mom/dad] call you bad names*?". Cronbach's α ranged between .69 and .89.

Parental inconsistency. At all waves, youths reported on each parent's inconsistent discipline practices using a measure adapted from the Iowa Youth and Families Project (Conger & Elder, 1994). Youths used a 4-point scale (coded so that higher values represented worse parenting) to report on 4 items such as, "*When your mom asks you to do something and you don't do it right away, how often does your mom/dad give up?"* (inconsistent discipline). Cronbach's α ranged between .16 and .51.

Family routines. At all waves, caregivers' reported on the routines they had for their child using 8-items derived from the Family and Community Health Study (FACHS; Simons et al., 2002). Response options ranged from 1 (*Almost never or never)* to 4 (*Almost always or always)*, and sample items include "*How often does[Child's name] go to bed at the same time each night?"* and "How often does your family eat a meal together?". Cronbach's α ranged between .45 and .71.

Table A1.4

Descriptive Statistics for Validity Variables

	% Missing	*Mean* (SD)	Min - Max
Wave 1 - Mother			
	% Missing	***Mean* (SD)**	**Min - Max**
Mexican American Cultural Values Entropy			
Traditional gender roles	5.04	58.51 (22.69)	0.00 – 96.10
Familism	5.04	48.81 (21.98)	0.00 – 98.86
Independence	5.04	54.65 (24.05)	0.00 – 96.10
Respeto	5.04	48.32 (23.06)	0.00 – 95.28
Acculturation Entropy			
Spanish	5.04	28.42 (28.24)	0.00 – 96.10
English	5.04	43.58 (25.32)	0.00 – 96.10
Youth-reported inconsistency	1.93	2.03 (0.44)	1.00 – 3.25
Youth-reported hostility	1.19	1.51 (0.33)	1.00 – 3.69
Family routines	2.08	3.08 (0.40)	1.62 – 4.00
Wave 1 – Father (Participating fathers)			
	% Missing	***Mean* (SD)**	**Min - Max**
Mexican American Cultural Values Entropy			
Traditional gender roles	22.75	57.71 (23.51)	0.00 – 96.10
Familism	22.56	49.19 (22.21)	0.00 – 98.86
Independence	22.56	55.87 (22.71)	0.00 – 96.10
Respeto	22.56	50.53 (22.45)	0.00 – 95.28
Youth-reported inconsistency	12.91*	2.02 (0.47)	1.00 – 4.00
Youth-reported hostility	14.54*	1.39 (0.29)	1.00 – 3.31
Family routines	17.78	2.98 (0.42)	1.50 – 4.00
Wave 3 - Mother			
	% Missing	***Mean* (SD)**	**Min - Max**
Mexican American Cultural Values Entropy			
Traditional gender roles	14.99	59.79 (22.84)	0.00 - 100
Familism	14.99	48.62 (21.81)	0.00 – 96.81
Independence	14.99	55.01 (23.48)	0.00 – 96.10
Respeto	14.99	49.01 (22.40)	0.00 – 95.28
Acculturation Entropy			
Spanish	14.99	29.89 (29.41)	0.00 – 96.10
English	14.99	39.70 (25.55)	0.00 – 96.10
Youth-reported inconsistency	14.69	1.96 (0.41)	1.00 – 3.00
Youth-reported hostility	14.54	1.41 (0.31)	1.00 – 2.92
Family routines	14.84	2.95 (0.42)	1.38 – 4.00
Stress reaction	15.28	2.81 (0.66)	1.00 – 4.80
Negative emotionality entropy	15.43	65.70 (18.66)	0.00 – 99.54
Positive emotionality entropy	14.43	62.28 (16.69)	0.00 – 97.80
Impulse control entropy	15.28	59.73 (19.73)	0.00 – 96.02
Wave 3 – Father (Participating Fathers)			
	% Missing	***Mean* (SD)**	**Min - Max**
Mexican American Cultural Values Entropy			
Traditional gender roles	27.15	58.83 (23.71)	0.00 - 100

Familism	27.15	46.64 (21.89)	0.00 – 95.28
Independence	27.15	53.96 (23.26)	0.00 – 96.10
Respeto	27.15	48.00 (22.11)	0.00 – 95.28
Acculturation Entropy			
Spanish	23.51	34.05 (27.60)	0.00 – 96.10
English	23.51	44.42 (24.71)	0.00 – 96.10
Youth-reported inconsistency	23.89*	1.96 (0.45)	1.00 – 3.75
Youth-reported hostility	24.78*	1.35 (0.32)	1.00 – 3.77
Family routines	26.58	2.93 (0.41)	1.62 – 4.00
Stress reaction	26.96	2.60 (0.60)	1.00 – 4.60
Negative emotionality entropy	26.96	63.85 (18.61)	0.00 – 99.54
Positive emotionality entropy	26.96	62.95 (17.42)	0.00 – 97.80
Impulse control entropy	26.96	61.51 (20.30)	0.00 – 96.02
Wave 5 - Mother			
	% Missing	***Mean* (SD)**	**Min - Max**
Mexican American Cultural Values Entropy			
Traditional gender roles	11.57	58.85 (22.84)	0.00 – 96.10
Familism	11.57	50.79 (21.60)	0.00 – 98.86
Independence	11.57	54.57 (23.87)	0.00 – 96.10
Respeto	11.57	48.34 (23.77)	0.00 – 95.28
Acculturation Entropy			
Spanish	11.57	27.93 (28.91)	0.00 – 96.10
English	11.57	38.09 (25.09)	0.00 – 96.10
Youth-reported inconsistency	10.39	1.93 (0.42)	1.00 – 3.25
Youth-reported hostility	10.39	1.51 (0.41)	1.00 – 3.38
Family routines	11.57	2.81 (0.44)	1.38 – 4.00
Neighborhood criminal events entropy	12.02	25.31 (23.65)	0.00 – 92.32
Neighborhood quality entropy	11.57	29.38 (24.59)	0.00 – 95.91
Wave 5 – Father (Participating Fathers)			
	% Missing	***Mean* (SD)**	**Min - Max**
Mexican American Cultural Values Entropy			
Traditional gender roles	23.71	57.03 (22.69)	0.00 - 100
Familism	23.51	48.47 (21.88)	0.00 – 94.14
Independence	23.51	52.90 (21.60)	0.00 – 96.10
Respeto	23.51	50.19 (22.65)	0.00 – 95.28
Acculturation Entropy			
Spanish	23.51	34.95 (28.93)	0.00 – 96.10
English	23.51	41.45 (25.45)	0.00 – 96.10
Youth-reported inconsistency	17.95*	1.89 (0.46)	1.00 – 3.25
Youth-reported hostility	17.95*	1.43 (0.38)	1.00 – 3.38
Family routines	23.51	2.75 (0.45)	1.50- 4.00
Wave 7 - Mother			
	% Missing	***Mean* (SD)**	**Min - Max**
Youth-reported inconsistency	11.28	1.92 (0.39)	1.00 – 3.25
Youth-reported hostility	11.28	1.53 (0.39)	1.00 – 3.31
Family routines	13.06	2.70 (0.44)	1.00 – 4.00
Stress reaction	13.06	2.83 (0.73)	1.00 – 5.00

	% Missing	*Mean* (SD)	Min - Max
Negative emotionality entropy	13.06	62.70 (21.35)	0.00 – 98.22
Positive emotionality entropy	13.06	60.16 (19.06)	0.00 – 99.31
Impulse control entropy	13.06	56.23 (22.35)	0.00 – 96.97
Neighborhood criminal events entropy	13.35	24.32 (24.93)	0.00 – 94.77
Neighborhood quality entropy	13.06	29.63 (25.51)	0.00 – 95.91
Wave 7 – Father (Participating Fathers)			
	% Missing	***Mean* (SD)**	**Min - Max**
Youth-reported inconsistency	21.22*	1.88 (0.49)	1.00 – 3.50
Youth-reported hostility	21.51*	1.47 (0.43)	1.00 – 21.51
Family routines	29.07	2.71 (0.48)	1.38 – 4.00
Stress reaction	29.07	2.57 (0.75)	1.00 – 5.00
Negative emotionality entropy	29.07	57.55 (22.16)	0.00 – 95.92
Positive emotionality entropy	29.07	58.88 (20.03)	0.00 – 96.30
Impulse control entropy	29.07	56.99 (22.96)	0.00 – 98.73
Neighborhood criminal events entropy	29.07	27.02 (24.64)	0.00 – 96.10
Neighborhood quality entropy	29.07	31.61 (24.33)	0.00 – 79.25

Note. Total sample = 674. Participating fathers sample = 523. * % of complete sample.

5. Measurement Invariance Fit Indices

Table A1.5

Measurement Invariance Fit Indices

Maternal mood entropy

	χ^2	*df*	p-value	CFI	TLI	RMSEA [90% CI]	Model comp	−2ΔLL(df), p value
Configural	149.955	134	.1638	0.990	0.980	.013 [.000, .024]		
Weak	165.300	146	.1310	0.989	0.986	.014 [.000, .024]	C	−2ΔLL(12) = 15.49, .216
Partial Strong	**176.072**	**154**	**.1075**	**0.988**	**0.985**	**.015 [.000, .024]**	**W**	**−2ΔLL(8) = 10.79, .214**
Strong	214.406	158	.0019	0.968	0.962	.023 [.014, .031]	W	−2ΔLL(12) = 50.23, <.001

Paternal mood entropy

	χ^2	*df*	p-value	CFI	TLI	RMSEA [90% CI]	Model comp	−2ΔLL(df), p value
Configural	126.535	134	.664	1.00	1.008	.000 [.000, .018]		
Weak	142.215	146	.573	1.00	1.004	.000 [.000, .019]	C	−2ΔLL(12) = 15.79, .201
Partial Strong	**151.205**	**157**	**.6154**	**1.00**	**1.005**	**.000 [.000, .018]**	**W**	**−2ΔLL(14) = 8.95, .62**
Strong	163.227	158	.3714	0.996	0.995	.008 [.000, .022]	W	−2ΔLL(12) = 20.90, .049

Internalizing Problems

	χ^2	*df*	p-value	CFI	TLI	RMSEA [90% CI]	Model comp	−2ΔLL(df), p value
Configural	48.749	30	.0167	0.984	0.964	.030 [.013, .046]		
Weak	69.829	36	<.001	0.970	0.946	.037 [.024, .050]	C	−2ΔLL(6) = 16.58, .011
Partial weak	58.031	37	.0085	0.980	0.962	.031 [.016, .045]	C	−2ΔLL(5) = 8.82, .116
Partial Strong	**64.977**	**38**	**.0041**	**0.976**	**0.959**	**.032 [.018, .046]**	**PW**	**−2ΔLL(3) = 6.85, .077**
Strong	131.867	40	<.001	0.919	0.867	.058 [.047, .070]	PW	−2ΔLL(5) = 137, <.001

Externalizing problems

	χ^2	*df*	p-value	CFI	TLI	RMSEA [90% CI]	Model comp	−2ΔLL(*df*), p-value
Configural	41.962	30	.072	0.99	0.979	.024 [.000, .040]		
Weak	97.885	36	<.001	0.95	0.908	.051 [.039, .063]	C	−2ΔLL(6) = 39.37, <.001
Partial weak	**42.337**	**34**	**.154**	**0.993**	**0.987**	**.019 [.000, .036]**	**C**	**−2ΔLL(4) = 2.30, .681**
Strong	51.187	38	.0748	0.989	0.982	.023 [.000, .037]	PW	−2ΔLL(4) = 9.45, .051

Note. χ^2 = Chi-square test statistics; df = degrees of freedom; CFI = comparative fit index; RMSEA = root-mean-square error of approximation; 90%CI = 90% confidence interval; Model comp = Comparison model used for log likelihood ratio test; -2 ΔLL = Log likelihood ratio test.

6. Measurement invariance results

Table A1.6a.

Unstandardized Parameter Estimates for Maternal Mood Entropy

	W1		**W3**		**W5**		**W7**	
	Estimate	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
Factor loadings								
CESD	9.25	0.73	9.25	0.73	9.25	0.73	9.25	0.73
M - GD	20.18	1.03	20.18	1.03	20.18	1.03	20.18	1.03
M - AD	9.60	0.83	9.60	0.83	9.60	0.83	9.60	0.83
M - ANX	7.41	0.84	7.41	0.84	7.41	0.84	7.41	0.84
M - AR	13.50	0.86	13.50	0.86	13.50	0.86	13.50	0.86
Intercepts								
CESD	57.89	0.67	57.89	0.67	**55.11**	**0.90**	**54.39**	**0.95**
M - GD	33.86	1.04	33.86	1.04	33.86	1.04	33.86	1.04
M - AD	38.52	0.69	38.52	0.69	38.52	0.69	38.52	0.69
M - ANX	**31.84**	**1.06**	28.43	0.73	28.43	0.73	28.43	0.73
M - AR	23.19	0.93	23.19	0.93	23.19	0.93	**25.85**	**1.29**
Means								
Entropy	0.00	0.00	0.10$^{\tau}$	0.06	-0.05	0.06	-0.09	0.06

Note. M – GD = MASQ General Distress; M – AD = MASQ Anhedonic Depression; M – ANX = MASQ Anxiety; M – AR = MASQ Anxious Arousal. Unconstrained parameters are bolded. $^{\tau}$ <.01.

Table A1.6b.
Unstandardized Parameter Estimates for Paternal Mood Entropy

	W1		W3		W5		W7	
	Estimate	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
Factor loadings								
CESD	9.94	0.78	9.94	0.78	9.94	0.78	9.94	0.78
M - GD	20.04	1.16	20.04	1.16	20.04	1.16	20.04	1.16
M - AD	8.95	0.86	8.95	0.86	8.95	0.86	8.95	0.86
M - ANX	6.62	0.84	6.62	0.84	6.62	0.84	6.62	0.84
M - AR	13.14	1.15	13.14	1.15	13.14	1.15	13.14	1.15
Intercepts								
CESD	54.45	0.79	54.45	0.79	54.45	0.79	54.45	0.79
M - GD	27.24	1.25	27.24	1.25	27.24	1.25	27.24	1.25
M - AD	33.65	0.85	33.65	0.85	33.65	0.85	33.65	0.85
M - ANX	24.88	0.79	24.88	0.79	24.88	0.79	24.88	0.79
M - AR	17.68	1.03	**13.64**	**1.43**	17.68	1.03	17.68	1.03
Means								
Entropy	0.00	0.00	0.20*	0.08	0.12^{τ}	0.07	0.03	0.07

Note. M – GD = MASQ General Distress; M – AD = MASQ Anhedonic Depression; M – ANX = MASQ Anxiety; M – AR = MASQ Anxious Arousal. Unconstrained parameters are bolded. $^{\tau}$ *<.01, *p < .05.*

Table A1.6c.
Unstandardized Parameter Estimates for Internalizing Problems

	W1		W3		W5		W7	
	Estimate	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
Factor loadings								
ANX	1.39	0.10	1.39	0.10	1.39	0.10	1.39	0.10
DEP	3.12	0.20	3.12	0.20	3.12	0.20	3.12	0.20
PT	**1.22**	**0.21**	0.53	0.08	0.53	0.08	0.53	0.08
Intercepts								
ANX	3.82	0.09	3.82	0.09	3.82	0.09	3.82	0.09
DEP	**5.50**	**0.17**	**7.26**	**0.42**	8.60	0.57	8.60	0.57
PT	1.06	0.13	1.06	0.13	1.06	0.13	**1.20**	**0.17**
Means								
Internalizing Problems	0.00	0.00	-1.04***	0.10	-1.41***	0.14	-1.70***	0.13

Note. ANX = Anxiety symptoms; DEP = Depressive Symptoms; PT = Post-Traumatic Stress Symptoms. Unconstrained parameters are bolded. ****p <.001.*

Table A1.6d.
Unstandardized Parameter Estimates for Externalizing Problems

	W1		W3		W5		W7	
	Estimate	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
Factor loadings								
ADHD	1.55	0.11	1.55	0.11	1.55	0.11	1.55	0.11
ODD	1.87	0.12	1.87	0.12	1.87	0.12	1.87	0.12
CPD	0.43	0.06	0.43	0.06	**0.77**	**0.10**	**1.16**	**0.15**
Intercepts								
ADHD	2.14	0.08	2.14	0.08	2.14	0.08	2.14	0.08
ODD	2.18	0.09	2.18	0.09	2.18	0.09	2.18	0.09
CPD	0.43	0.04	0.43	0.04	**0.98**	**0.07**	**1.64**	**0.11**
Means								
Externalizing Problems	0.00	0.00	-0.02	0.06	0.04	0.06	-0.34***	0.05

Note. ADHD = Attention Deficit & Hyperactivity Disorder symptoms; ODD = Oppositional Defiant Disorder symptoms; CPD = Conduct Problems Disorder symptoms. Unconstrained parameters are bolded. ****p <.001.*

Section 7: Analysis and Results of Cross-Lagged Panel Model (CLPM)

In addition to the main RI-CLPMs, standard CLPMs were constructed in which between- and within-person variance were blended. The same covariates were regressed on all variables at W1-W7. Model fit and model results can be found in https://osf.io/4db7t. For mothers, youth IP at waves 1 (β = 0.05, p = .075) and 3 (β = 0.05, p = .062) marginally predicted elevated entropy at waves 3 and 5, respectively. Except for the autoregressive effect of entropy from W1 to W3, these effects were significant and positive, indicating that elevated instability, entropy, or IP at a prior wave predicted higher instability, entropy, or IP at the next wave. Similarly, youth's EP at wave 5 significantly predicted elevated entropy at W5 (β = 0.06, p = .007). For fathers, instability at wave 3 marginally predicted higher paternal entropy at wave 5 (β = 0.04, p = .067) and youth's IP at wave 5 significantly predicted higher entropy at wave 7 (β = 0.04, p = .038). Autoregressive effects of paternal entropy were significant and positive at all waves, suggesting that higher entropy at a prior wave predicted higher entropy at the next wave. No associations emerged with externalizing problems. In short, the CLPM findings indicated some evidence for evocative effects of youths' problems on parental mood entropy. Interestingly, in comparison to RI-CLPM findings, the autoregressive effects of entropy were in the opposite direction.

Section 8. Effects of control variables in final RI-CLPM models

Table A1.8a.

Standardized Coefficients and P-Values of Covariates in Mothers' Models

	Youth's Sex		Family Structure		Income-to-needs		Mood average		Missing items	
	β	*p*	β	*p*	β	*p*	β	*p*	β	*p*
W1 Instability	--	--	-.00	.992	**-.11**	**.030**	.04	.417	.19	.150
W3 Instability	--	--	.02	.610	**-.12**	**.032**	-.09	.068	**-.31**	**.002**
W5 Instability	--	--	**-.20**	**<.001**	**-.14**	**.025**	.09	.055	-.20	.316
W7 Instability	--	--	**-.16**	**<.001**	**-.26**	**<.001**	**.10**	**.010**	**-.42**	**<.001**
W1 Mood Entropy	-.03	.491	-.02	.733	.02	.547	**.61**	**<.001**	--	--
W3 Mood Entropy	.04	.474	.05	.389	-.11	.113	**.56**	**<.001**	--	--
W5 Mood Entropy	.02	.549	-.01	.925	.03	.549	**.67**	**<.001**	--	--
W7 Mood Entropy	-.06	.227	-.02	.666	-.06	.115	**.72**	**<.001**	--	--
W1 Internalizing	**-.13**	**.004**	--	--	.07	.164	.04	.384	--	--
W3 Internalizing	**-.09**	**.014**	--	--	.07	.251	.05	.340	--	--
W5 Internalizing	**-.22**	**<.001**	--	--	-.04	.231	-.01	.878	--	--
W7 Internalizing	**-.12**	**.001**	--	--	-.06	.170	.04	.343	--	--
W1 Externalizing	-.01	.753	--	--	-.01	.836	.02	.666	--	--
W3 Externalizing	-.06	.158	--	--	.02	.706	.04	.437	--	--
W5 Externalizing	**-.15**	**<.001**	--	--	.02	.625	.01	.813	--	--
W7 Externalizing	-.05	.205	--	--	-.01	.706	.05	.221	--	--
Covariances of time-varying covariates with random intercepts										
					r	*p*	*r*	*p*	*r*	*p*
RI – Instability					**-.56**	**<.001**	**.39**	**<.001**	**-.21**	**.039**
RI – Mood Entropy					**-.19**	**<.001**	**.74**	**<.001**	--	--
RI – Internalizing					**-.13**	**.039**	**.15**	**.020**	--	--
RI – Externalizing					**-.12**	**.036**	.10	.121		

Note. Significant coefficients are bolded. Youth's sex and family structure are time-invariant. Time-varying covariates and main predictors are concurrent in time (e.g., W1 Instability on W1 Income-to-needs).

Table A1.8b.

Standardized Coefficients and P-Values of Covariates in Fathers' Models

	Youth's Sex		Family Structure		Income-to-needs		Mood average		Missing items	
	β	*p*	β	*p*	β	*p*	β	*p*	β	*p*
W1 Instability	--	--	-.04	.420	**-.10**	**.039**	**.14**	**.012**	.19	.143
W3 Instability	--	--	.00	.955	-.11	.062	.06	.346	**-.30**	**.003**
W5 Instability	--	--	**-.22**	**<.001**	**-.14**	**.021**	.01	.833	-.20	.309
W7 Instability	--	--	**-.18**	**<.001**	**-.27**	**<.001**	.04	.407	**-.42**	**<.001**
W1 Mood Entropy	.01	.926	-.04	.654	-.00	.938	**.71**	**<.001**	--	--
W3 Mood Entropy	.02	.804	-.13	.484	-.00	.967	**.58**	**<.001**	--	--
W5 Mood Entropy	.01	.906	-.12	605	-.04	.538	**.64**	**<.001**	--	--
W7 Mood Entropy	.02	.712	-.13	.181	-.02	.625	**.66**	**<.001**	--	--
W1 Internalizing	**-.13**	**.005**	--	--	.07	.157	.07	.233	--	--
W3 Internalizing	**-.09**	**.017**	--	--	.08	.210	-.01	.904	--	--
W5 Internalizing	**-.22**	**<.001**	--	--	-.05	.173	.00	.949	--	--
W7 Internalizing	**-.12**	**.001**	--	--	-.07	.113	-.01	.826	--	--
W1 Externalizing	-.02	.740	--	--	-.01	.907	-.03	.669	--	--
W3 Externalizing	-.06	.156	--	--	.03	.616	.01	.836	--	--
W5 Externalizing	**-.14**	**<.001**	--	--	.02	.605	**-.12**	**.014**	--	--
W7 Externalizing	-.05	.236	--	--	-.02	.631	.09	.067	--	--
Covariances of time-varying covariates with random intercepts										

	r	*p*	*r*	*p*	*r*	*p*
RI – Instability	**-.57**	**<.001**	**.38**	**<.001**	**-.19**	**.042**
RI – Mood Entropy	**-.16**	**.001**	**.84**	**<.001**	--	--
RI – Internalizing	**-.13**	**.040**	.07	.436	--	--
RI – Externalizing	**-.12**	**.037**	.08	.320	--	--

Note. Significant coefficients are bolded. Youth's sex and family structure are time-invariant. Time-varying covariates and main predictors are concurrent in time (e.g., W1 Instability on W1 Income-to-needs).

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APPENDIX 2
Supplementary Materials for Study 2

Section 1. Affective and Behavioral Unpredictability Coding System

Pass 1 - Affect (Duration)

**** ALL codes to be turned on at the moment when the caregiver shows Affect, even if emotion is brief.
When experimenter enters room: use CAN'T TELL codes

Affect	Definition	Examples	Key to Note
Positive	Praises child WITH ENERGY/WARMTH/NON-ROBOTIC (ex: "Good job!") **Expressing physical affect:** Smiles, joy, warm eye contact, body movement indicating warmth. **Vocal tone:** Warm and happy, sing-song tone.	**Happy Vocal Cues:** Pitch becomes higher/louder - Laughing, giggling, sing-song humming **Happy Facial Cues**: Smiling; corners of mouth are turned up, cheek area rounds. - May be accompanied by wrinkling around eyes. Brows may raise in happy surprise ***Consoling/supporting, kissing child, caressing hair, hugs are positive.**	**Questions naturally elevate pitch. This is not positive.** "mhm" vocalizations. Even if pitch is elevated, it does not mean positive. Pay attention to how AND what they are saying **CONTEXT OF INTERACTION IS IMPORTANT**
Neutral	Lack clear indication of positive or negative affect	Caregiver sits, touches, or holds the child without displaying any particular affect. Common while waiting, while observing the child.	
Negative	Expresses physical or verbal negative affect (distressed, sad, angry, worried).	Criticisms: - EX: "Why don't you ever clean your room?" Punishing, mocking, laughing at the child. VERY disengaged/boredom. **Sad Vocal Cues:** Voice lowers, drops off at end of utterance. **Sad Facial Cues:** Lip corners pulled down, pouting bottom lip, droopy eyes.	Tone of voice can help determine whether a statement can be considered positive or negative. - EX: Voice exasperated, irritated, etc **(negative)** - EX: Monotone, no elevated pitch, etc **(neutral)** **WATCH FOR CONTEXT.** If the child is doing something "dangerous" (ex: might bump head) and caregiver says "be

		Angry Vocal Cues: Loud harsh pitch, contemptuous tone. **Angry Facial Cues:** Furrowed brows, “hard stare,”tightened lips. **Worry Vocal Cues:** Strained and shaky voice (sound fearful). **Worry Facial Cues:** Furrowed brows, wide eyes, retracted lips.	careful” **THIS IS NOT CONSIDERED WORRY.**

Pass 2 - Autonomy & Intrusive Behaviors (Duration)

** ALL codes to be turned on at the moment when the caregiver shows Affect, even if emotion is brief.
When experimenter enters room: use CAN’T TELL codes

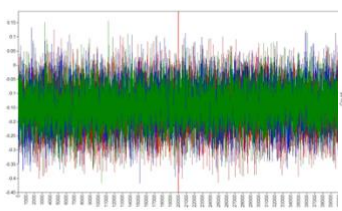
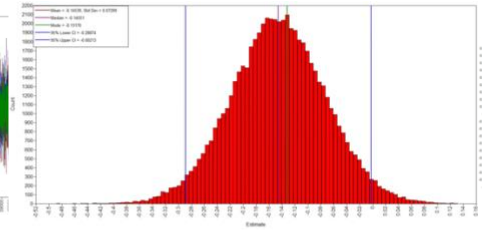
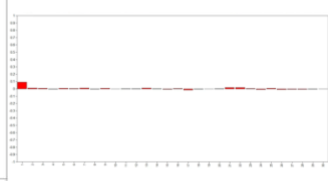
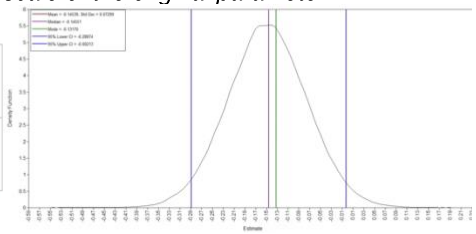
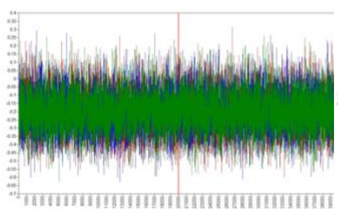
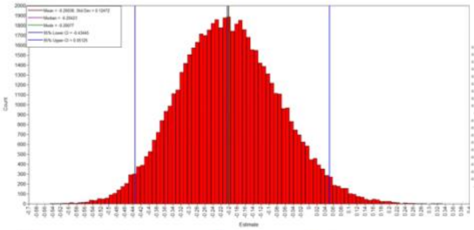
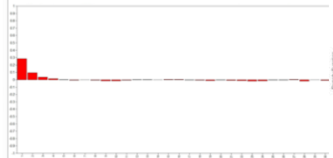
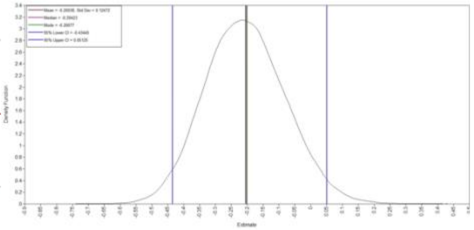
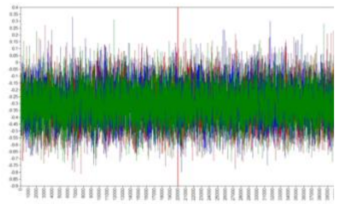
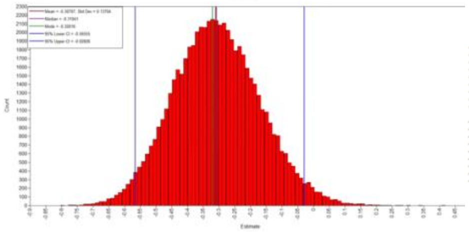
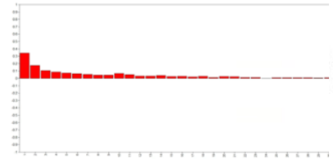
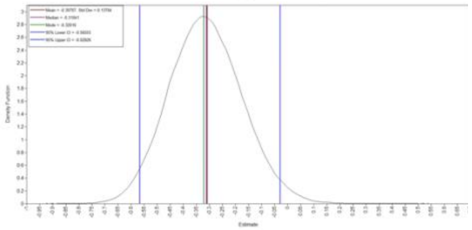
Behavior	Definition	Examples	Key to Note
Autonomy Support	Caregiver provides help and support when needed, gives useful hints - Encouragement & teaching - Positive, constructive strategies to regulate child behavior or affect.	Instructions, teaching about skills and emotions, redirecting attention to appropriate behavior, distracting from upsetting stimuli: - EX: pointing to puzzle board and asking “What do you think goes here?” **Active listening** and **eye-contact** Participating when child asks: - EX: holding baby for child so they can interact with it - Encouraging “mhm” not just watching Facilitating toy use: - EX: actively adjusting puzzle position for better engagement. - EX: child asks for help pushing puzzle piece.	**2 second rule:** If caregiver continues to display Autonomy Support within 2 seconds, leave code EXCEPT if they switch to Intrusiveness. - **Applies when finishing sentence, then start counting.** Attentively waiting for an answer (interacting/looking at child) is **AS**. Looking elsewhere is **Neither**. Passively holding puzzle is **NOT AS.** Answering basic questions about experimenter: “When is he coming back?” is **NOT AS.** Complex questions about experimenter: “Did Alex felt bad when he fell down?” is **AS**.
Neither	Behaviors not specifically aimed at controlling or modifying child behavior or affect. - Not providing specific	Monitoring child, waiting to be asked for help or to be done with activity. - EX: watching child the complete puzzle.	Observe context to determine if “mhm” is AS or if “automatic” response to observation it is NEITHER.

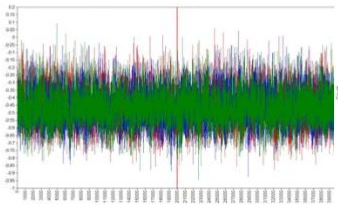
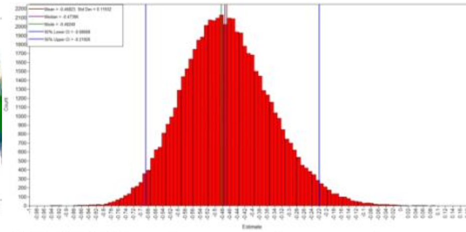
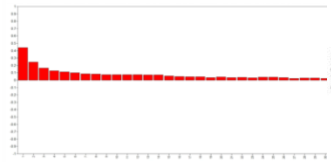
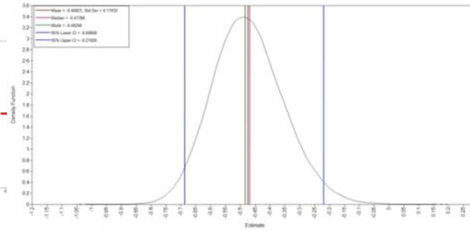
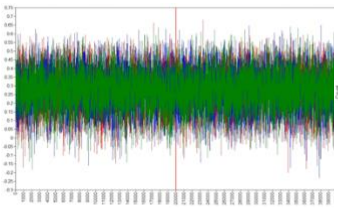
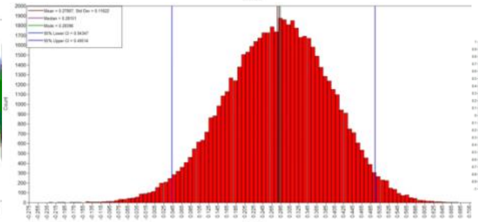
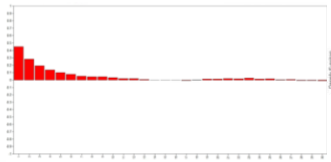
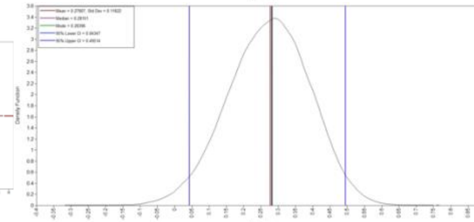
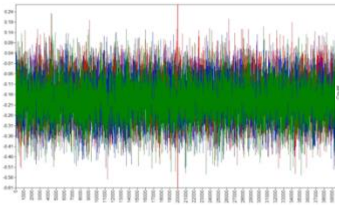
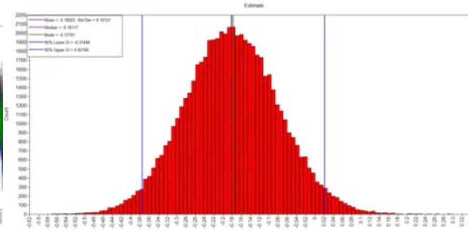
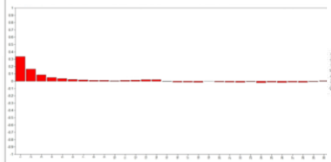
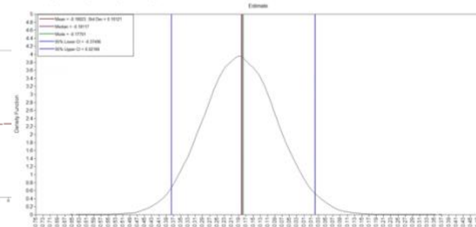
	structure, or acknowledging on-task behavior.	- EX: pushing puzzle piece while child is doing something else. **Brief verbalizations: “yeah” “uh huh” “mkay”** Repeating what the child is saying is NEITHER.	Extra comments **(not needed hints)**: code **NEITHER**. Commenting on child action is not AS unless the child responds back then code AS. **When the code could go either way, code NEITHER.**
Intrusive	**Anything that disrupts or modifies the child’s autonomous behavior.** Physical aggression, interrupting/leading and aggressive play. **Verbal:** Caregiver interrupts child, not respecting natural break of conversation. Caregiver frequently sets the pace of the interaction, asking questions, and making the activity about them.	Pushing toy in child’s face/hand, throwing or taking the toy, moving hand away from the toy. - EX: interrupting attempt of child to squish puzzle piece down. Reprimands come out of nowhere (not in response to child behavior). Adamantly wanting a response (watch tone of voice), repetitively asking questions (or in different forms) about activity**.** - **Asking once is not Intrusive.** ***Intrusive** ends when the child engages again. - EX: answers questions, or engage in conversation	2 second rule: if caregiver continues displaying Intrusiveness within 2 seconds leave code on EXCEPT if they switch to Autonomy Support. - **Applies when finishing sentence, then start counting.** **Use NEITHER if on the fence and have considered context.** Pointing without wanting to change child action is not Intrusive. Questions about activity when child is not paying attention **IS NOT Intrusive** unless **repetitive AND disturbs child (watch their reaction).** **Negative does not mean Intrusiveness.**
Question Types	● Regarding the action of the child is **AS**, if it is a comment in the form of an observation then it is **NEITHER**. Code **AS** for question, after question code **NEITHER.** ● Trying to correct the child when making a mistake is **AS** then **NEITHER** (depends if engages with answer or not). Code **NEITHER** after question. ● Related to activity and seek to be responded (leaning in, child attempts to respond) is **AS** without breaking into **NEITHER** until end of interaction. ● Unrelated to child (changing subject) and insistent is **INTRUSIVE** then **NEITHER** (depends on caregiver reaction, if continues to ask it is **INTRUSIVE**).		

Section 2. Visual Inspection of Bayesian Model Parameters

Table A2.1

Trace Plots, Histograms, Autocorrelation, and Kernel Density Plots of Parameters of Interest

Parameters	Trace plot	Histogram	Autocorrelation	Kernel density plot
	Chains should be overlapping with each other and resemble a fuzzy hungry caterpillar and the y-axis range should be plausible.	*Histograms should have a smoothed density and no gaps.*	*Each Markov chain should have low autocorrelation between iterations.*	*Plot should be smooth, posterior standard deviation should not be greater than the scale of the original parameters, and the range of the posterior credible interval should not be greater than the underlying scale of the original parameter.*
T1 Effortful control on Q AB Entropy Play				
T1 Inhibitory control on SS Entropy Puzzle				
T1 RSA reactivity on AB Entropy Puzzle				

T2 RSA reactivity on SS Entropy Play				
T2 RSA reactivity on Q AB Entropy Play				
T2 IP on AB Entropy Play				

Note. AB = Affective and behavioral, SS = Sensory signals, Q = Quadratic, IP = Internalizing problems. Checking guidelines descriptions were made based on Depaoli and van de Schoot (2017), and Smid and Winter (2020).

Section 3. Caregiver unpredictability and indices of self-regulation results using MLR in Lavaan

Table A2.2.

Associations Between Caregiver Unpredictability During Play and Behavioral Indices of Self-Regulation Using Maximum Likelihood with Robust Estimation

	T1 Effortful Control		T2 Effortful Control		T1 Inhibitory Control		T2 Inhibitory Control	
	B (SE)	95% CI	B (SE)	95% CI	B (SE)	95% CI	B (SE)	95% CI
T1 Effortful control	--	--	**0.44*** (.10)**	**[.24, .63]**	--	--	--	--
T1 Inhibitory control	--	--	--	--	--	--	**0.25* (.12)**	**[.03, .48]**
T1 Externalizing	**-0.68***(.06)**	**[-.80, -.57]**	**-0.37*** (.10)**	**[-.57, -.18]**	-0.18 (.11)	[-.38, .04]	-0.04 (.10)	[-.24, .16]
Child Sex	0.11 (.08)	[-.04, .26]	0.05 (.07)	[-.10, .19]	--	--	--	--
Low SES	-0.04 (.07)	[-.17, .10]	0.07 (.08)	[-.09, .22]	--	--	--	--
Positive Affect	**0.21** (.07)**	**[.07, .37]**	**0.18* (.08)**	**[.03, .34]**	--	--	--	--
AB Entropy	-0.04 (.08)	[-.20, .12]	-0.06 (.09)	[-.24, .13]	-0.12 (.11)	[-.32, .09]	0.04 (.11)	[-.17, .26]
SS Entropy	0.02 (.07)	[-.12, .17]	-0.00 (.07)	[-.13, .13]	-0.02 (.12)	[-.28, .22]	0.08 (.09)	[-.11, .26]
Model Fit indices	χ2 (16) = 15.617, p = .480; CFI = 0.999, TLI = 0.999; RMSEA = .009 [.000,.097], SRMR = .074				χ2 (10) = 13.947, p = .175; CFI = 1.000, TLI = 2.993; RMSEA = .000 [.000,.055], SRMR = .015			

Note. AB Entropy = Affective and behavioral unpredictability, SS Entropy = Sensory signal unpredictability. Coefficients are standardized. Significant results are bolded. *p 0.05, **p 0.01, ***$p < 0.001$.

Table A2.3.

Associations Between Caregiver Unpredictability During Play and Parasympathetic Regulation Using Maximum Likelihood with Robust Estimation

	T1 Baseline RSA		T2 Baseline RSA		T1 RSA Reactivity		T2 RSA Reactivity	
	B (SE)	95% CI	B (SE)	95% CI	B (SE)	95% CI	B (SE)	95% CI
T1 Baseline RSA	--	--	**0.55*** (.09)**	**[.39, .72]**	--	--	--	--
T1 RSA Reactivity	--	--	--	--	--	--	0.05 (.14)	[-.22, .32]
T1 Externalizing	0.00 (.10)	[-.20, .20]	-0.02 (.10)	[-.21, .17]	**-0.32*** (.08)**	**[-.47, -.16]**	-0.07 (.12)	[-.32, .17]
Negative Control	**0.34** (.13)**	**[.09, .58]**	-0.02 (.16)	[-.32, .28]	0.06 (.15)	[-.23, .36]	**0.27* (.12)**	**[.03, .51]**
Non-Involvement	-0.07 (.13)	[-.32, .18]	0.13 (.14)	[-.14, .40]	**0.35** (.10)**	**[.15, .55]**	-0.11 (.15)	[-.41, .19]
AB Entropy	-0.15 (.13)	[-.40, .10]	-0.18 (.15)	[-.47, .12]	-0.07 (.13)	[-.32, .18]	0.18 (.14)	[-.10, .46]
SS Entropy	-0.14 (.13)	[-.38, .09]	**0.25* (.10)**	**[.05, .45]**	0.16 (.11)	[-.05, .37]	**-0.52*** (.09)**	**[-.69, -.34]**
Model Fit indices	χ2 (11) = 7.018, p = .798; CFI = 1.000, TLI = 1.113; RMSEA = .000 [.000,.067], SRMR = .036							

Note. AB Entropy = Affective and behavioral unpredictability, SS Entropy = Sensory signal unpredictability. Coefficients are standardized. Significant results are bolded. *p 0.05, **p 0.01, ***$p < 0.001$.

Table A2.4.
Associations Between Caregiver Unpredictability During Puzzle and Behavioral Indices of Self-Regulation Using Maximum Likelihood with Robust Estimation

	T1 Effortful Control		T2 Effortful Control		T1 Inhibitory Control		T2 Inhibitory Control	
	B (SE)	**95% CI**	**B (SE)**	**95% CI**	**B (SE)**	**95% CI**	**B (SE)**	**95% CI**
T1 Effortful control	--	--	**0.45^{***} (.10)**	**[.25, .65]**	--	--	--	--
T1 Inhibitory control	--	--	--	--	--	--	0.22 (.12)	[-.01, .46]
T1 Externalizing	**-0.68^{***}(.06)**	**[-.80, -.57]**	**-0.37^{***} (.10)**	**[-.56, -.16]**	-0.17 (.11)	[-.37, .04]	-0.04 (.10)	[-.24, .16]
Child Sex	0.11 (.08)	[-.04, .26]	0.04 (.07)	[-.10, .19]	--	--	--	--
Low SES	-0.03 (.07)	[-.17, .12]	0.06 (.08)	[-.09, .21]	--	--	--	--
Positive Affect	**0.21^{*} (.06)**	**[.04, .37]**	**0.16^{*} (.08)**	**[.01, .31]**	--	--	--	--
AB Entropy	0.04 (.09)	[-.15, .22]	-0.07 (.09)	[-.24, .10]	0.05 (.11)	[-.17, .26]	-0.11 (.12)	[-.42, .13]
SS Entropy	-0.07 (.09)	[-.24, .12]	0.03 (.10)	[-.16, .22]	-0.21 (.11)	[-.42, .04]	0.00 (.12)	[-.23, .26]
Model Fit indices	χ2 (14) = 9.83, p = .480; CFI = 1.000, TLI = 1.049; RMSEA = .000 [.000,.068], SRMR = .074				χ2 (10) = 1.060, p = .787; CFI = 1.000, TLI = 1.384; RMSEA = .000 [.000,.119], SRMR = .028			

Note. AB Entropy = Affective and behavioral unpredictability, SS Entropy = Sensory signal unpredictability. Coefficients are standardized. Significant results are bolded. **p* 0.05, ***p* 0.01, ****p* < 0.001.

Table A2.5.
Associations Between Caregiver Unpredictability During Puzzle and Parasympathetic Regulation Using Maximum Likelihood with Robust Estimation

	T1 Baseline RSA		T2 Baseline RSA		T1 RSA Reactivity		T2 RSA Reactivity	
	B (SE)	**95% CI**	**B (SE)**	**95% CI**	**B (SE)**	**95% CI**	**B (SE)**	**95% CI**
T1 Baseline RSA	--	--	**0.55^{***} (.09)**	**[.38, .72]**	--	--	--	--
T1 RSA Reactivity	--	--	--	--	--	--	-0.02 (.17)	[-.35, .30]
T1 Externalizing	0.02 (.10)	[-.18, .22]	-0.01 (.10)	[-.19, .17]	**-0.26^{**} (.09)**	**[-.43, -.08]**	-0.06 (.13)	[-.32, .20]
Negative Control	0.14 (.13)	[-.11, .39]	0.05 (.16)	[-.26, .28]	0.21 (.12)	[-.01, .44]	0.22 (.16)	[-.10, .55]
Autonomy support	0.02 (.13)	[-.23, .27]	-0.00 (.12)	[-.24, .40]	**0.28^{*} (.12)**	**[.04, .51]**	0.21 (.13)	[-.05, .46]
AB Entropy	0.15 (.11)	[-.07, .37]	-0.09 (.14)	[-.35, .12]	**-0.31^{*} (.13)**	**[-.57, -.05]**	-0.16 (.18)	[-.52, .19]
SS Entropy	-0.05 (.11)	[-.27, .17]	0.08 (.11)	[-.13, .45]	-0.05 (.11)	[-.26, .16]	-0.10 (.13)	[-.36, .16]
Model Fit indices	χ2 (22) = 20.877, p = .528; CFI = 0.996, TLI = 0.991; RMSEA = .016 [.000,.102], SRMR = .068							

Note. AB Entropy = Affective and behavioral unpredictability, SS Entropy = Sensory signal unpredictability. Coefficients are standardized. Significant results are bolded. **p* 0.05, ***p* 0.01, ****p* < 0.001.

Section 4. Caregiver unpredictability and children's behavioral adjustment results using Bayesian estimation in Mplus and MLR in Lavaan

Table A2.6.

Associations Between Caregiver Unpredictability and Children's Behavioral Adjustment

Play	**T1 Externalizing**		**T2 Externalizing**		**T1 Internalizing**		**T2 Internalizing**	
	PM	**95% CI**	**PM**	**95% CI**	**PM**	**95% CI**	**PM**	**95% CI**
T1 Externalizing	--	--	**0.65**	**[.52, .76]**	--	--	--	--
T1 Internalizing	--	--	--	--	--	--	**0.56**	**[.41, .68]**
Child sex	-0.07	[-.26, .12]	-0.00	[-.16, .16]	**-0.20**	**[-.38,-.01]**	-0.08	[-.24, .08]
Child age	-0.10	[-.30, .11]	0.12	[-.05, .29]	-0.09	[-.29, .11]	**0.24**	**[.07, .41]**
Low SES	**0.27**	**[.07, .44]**	0.01	[-.16, .17]	**0.24**	**[.05, .42]**	0.02	[-.15, .19]
Positive Affect	-0.11	[-.33, .12]	-0.00	[-.20, .20]	-0.12	[-.34, .10]	-0.01	[-.20, .17]
Non-involvement	-0.03	[-.24, .19]	-0.11	[-.31, .08]	-0.00	[-.22, .21]	**-0.19**	**[-.37,-.00]**
AB Entropy	-0.06	[-.28, .17]	-0.10	[-.31, .12]	0.00	[-.22, .23]	-0.18	[-.38, .02]
SS Entropy	0.07	[-.22, .24]	0.06	[-.14, .25]	0.07	[-.16, .29]	0.00	[-.18, .18]
Puzzle								
T1 EP	--	--	**0.68**	**[.56, .78]**	--	--	--	--
T1 IP	--	--	--	--	--	--	**0.55**	**[.40, .68]**
Child sex	-0.07	[-.26, .13]	-0.00	[-.16, .15]	**-0.19**	**[-.37, -.01]**	-0.07	[-.24, .11]
Child age	-0.11	[-.31, .11]	0.09	[-.09, .26]	-0.07	[-.27, .15]	**0.26**	**[.07, .43]**
Low SES	**0.28**	**[.07, .46]**	0.03	[-.14, .20]	**0.21**	**[.01, .40]**	-0.00	[-.18, .18]
Positive Affect	-0.14	[-.35, .09]	-0.07	[-.26, .13]	-0.08	[-.30, .14]	-0.07	[-.27, .13]
AB Entropy	0.04	[-.19, .26]	-0.09	[-.28, .10]	0.09	[-.13, .30]	-0.09	[-.28, .10]
SS Entropy	-0.07	[-.30, .16]	-0.06	[-.26, .13]	0.10	[-.13, .32]	0.02	[-.18, .22]

Note. Coefficients are standardized. Non-null results are bolded. PM = Posterior median, CI = Credible interval, AB Entropy = Affective and behavioral unpredictability, SS Entropy = Sensory signal unpredictability.

Table A2.7.

Associations Between Caregiver Unpredictability During Play and Children's Behavioral Adjustment Using Maximum Likelihood with Robust Estimation

	T1 Externalizing		**T2 Externalizing**		**T1 Internalizing**		**T2 Internalizing**	
	B (SE)	**95% CI**	**B (SE)**	**95% CI**	**B (SE)**	**95% CI**	**B (SE)**	**95% CI**
T1 Externalizing	--	--	**0.66*** (.08)**	**[.51, .80]**	--	--	--	--
T1 Internalizing	--	--	--	--	--	--	**0.54*** (.07)**	**[.41, .68]**
Child sex	-0.07 (.10)	[-.26, .12]	-0.00 (.08)	[-.16, -.15]	**-0.20* (.10)**	**[-.39, -.01]**	-0.08 (.08)	[-.24, .08]
Child age	-0.10 (.12)	[-.34, .13]	0.13 (.08)	[-.03, .28]	-0.10 (.11)	[-.31, .11]	**0.24** (.08)**	**[.08, .40]**
Low SES	**0.28** (.11)**	**[.07, .48]**	-0.00 (.09)	[-.18, .18]	**0.26* (.11)**	**[.05, .46]**	0.02 (.10)	[-.17, .20]
Positive Affect	-0.11 (.11)	[-.33, .10]	-0.07 (.09)	[-.24, .20]	-0.13 (.10)	[-.33, .07]	-0.02 (.08)	[-.18, .14]
Non-involvement	-0.03 (.12)	[-.27, .21]	-0.11 (.14)	[-.38, .16]	-0.05 (.12)	[-.25, .24]	-0.19 (.11)	[-.34, .00]
AB Entropy	-0.06 (.11)	[-.27, .15]	-0.09 (.11)	[-.30, .12]	0.00 (.10)	[-.20, .21]	**-0.18* (.09)**	**[-.35, -.00]**
SS Entropy	-0.00 (.12)	[-.24, .24]	0.08 (.10)	[-.12, .27]	0.06 (.12)	[-.17, .30]	0.01 (.08)	[-.16, .17]
Model Fit indices	χ2 (22) = 21.806, p = .472; CFI = 1.000, TLI = 1.002; RMSEA = .023 [.000,.092], SRMR = .058							

Note. AB Entropy = Affective and behavioral unpredictability, SS Entropy = Sensory signal unpredictability. Coefficients are standardized. Significant results are bolded. $^{*}p$ 0.05, $^{**}p$ 0.01, $^{***}p < 0.001$.

Table A2.8.
Associations Between Caregiver Unpredictability During Puzzle and Children's Behavioral Adjustment Using Maximum Likelihood with Robust Estimation

	T1 Externalizing		T2 Externalizing		T1 Internalizing		T2 Internalizing	
	B (SE)	95% CI	B (SE)	95% CI	B (SE)	95% CI	B (SE)	95% CI
T1 Externalizing	--	--	**0.66*** (.07)**	**[.52, .80]**	--	--	--	--
T1 Internalizing	--	--	--	--	--	--	**0.56*** (.06)**	**[.44, .69]**
Child sex	-0.07 (.10)	[-.26, .13]	-0.00 (.08)	[-.16, .15]	**-0.19* (.10)**	**[-.39, -.00]**	-0.07 (.08)	[-.24, .09]
Child age	-0.12 (.11)	[-.33, .10]	0.09 (.08)	[-.08, .26]	-0.07 (.11)	[-.28, .14]	**0.27** (.09)**	**[.10, .45]**
Low SES	**0.28** (.10)**	**[.08, .48]**	0.02 (.09)	[-.15, .19]	**0.22* (.11)**	**[.02, .43]**	-0.01 (.10)	[-.19, .18]
Positive Affect	-0.14 (.11)	[-.35, .07]	-0.07 (.11)	[-.29, .15]	-0.08 (.11)	[-.29, .12]	-0.08 (.09)	[-.26 .11]
AB Entropy	0.04 (.11)	[-.17, .24]	-0.09 (.12)	[-.32, .15]	0.08 (.11)	[-.14, .31]	-0.10 (.08)	[-.26, .06]
SS Entropy	-0.07 (.12)	[-.30, .16]	-0.05 (.10)	[-.24, .15]	0.11 (.11)	[-.11, .33]	0.04 (.11)	[-.17, .25]
Model Fit indices	χ2 (16) = 17.927, p = .328; CFI = 0.989, TLI = 0.970; RMSEA = .041 [.000, .110], SRMR = .067							

Note. AB Entropy = Affective and behavioral unpredictability, SS Entropy = Sensory signal unpredictability. Coefficients are standardized. Significant results are bolded. *p 0.05, **p 0.01, ***p < 0.001.

Section 5. Caregiver Transitions Results

Table A2.9
Parameter Estimates of Associations Between Transitions and Outcomes of Interest

Parameters	Estimates	
	PM	95% CI
RSA reactivity T2 on SS Transitions	-0.11	[-.42. .21]
RSA reactivity T1 on AB Transitions	0.24	[-.49, .04]
Effortful control T1 on Q AB Transitions	0.11	[-.77, .99]
RSA reactivity T2 on Q AB Transitions	-0.77	[-2.02, .712]*

Note. *The parameter's range seems to be implausible, indicating there were calculation problems in the model. AB = Affective and behavioral, SS = Sensory signals, Q = Quadratic.