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PERCEIVED SOCIAL THREAT ACROSS DEVELOPMENT

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*This work is dedicated to my parents, Jim and Julie Silver, for loving and supporting me every
step of the way.*

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Abstract

This dissertation examines interactions between social motivations and affective-cognitive functioning following social threat using an integrative approach that explores emotional, behavioral, and physiological mechanisms across development. The ability to perceive and respond adaptively to threats in the environment is essential to human survival. We have evolved a set of complex, interconnected systems to respond with a high degree of specificity to threats in our environment. Critically, as a socially interdependent species, humans must attend to the social environment to detect potential social threats. The maintenance of social connections is essential to our sense of satisfaction and well-being, and the perception of deficits in quality connections in a social network represents a threat to survival. Coordinating adaptive responses to anticipated or real future social threats also requires affective-cognitive processes directed at the formation and maintenance of memory for past experiences. Integration of prior experiences of threat throughout life contributes to future perceptions of the social environment, and adverse experiences in early life have particularly far-reaching implications for affective and cognitive development. Therefore, an increased understanding of the context-dependent, multi-level response patterns generated in the face of social threat will provide advances in knowledge of how individuals are differentially impacted by similar adverse or potentially traumatic social experiences. In this dissertation I ask 1) How does the predictability of social stressors influence self-regulatory behaviors in children exposed to early life stress?, 2) How does prior exposure to social stress shape perceived social isolation and emotion regulation in violence-exposed adolescents?, and 3) How does acute social stress impact autobiographical memory and episodic future thinking? To investigate these questions, I use observational and experimental

measurements of physiological, emotional, and behavioral factors presented within a developmental framework.

Chapter 1: General Background and Introduction

1.1 Stress Responses

In order to respond to perturbations in the internal or external environment, organisms have integrated multi-level networks of systems that adjust the internal environment of the organism according to real or perceived environmental demands (McEwen & Gianaros, 2010). This toolbox of responses includes autonomic, endocrine, neural, immune, and behavioral adjustments which promote the energetic and motivational shifts necessary to respond to current need states and prepare an organism for future perturbations. Stress, a term Hans Selye aptly borrowed from engineering (Sapolsky, 2015; Selye, 1976), describes these processes and refers to the balance of forces in a system. Under this framework, a stressor is a demand for change, and stress responses are generated to resolve the imbalance. Activation of response systems are dependent upon perception of a stressor and central integration and coordination by the brain (McEwen, 2009). This dissertation focuses primarily on one type of stressor – social threat. To fully understand the processes involved in perception of social threat and subsequent responses, it is necessary to consider the multilevel nature of stress responses which span the biological and psychological domains. As such, this dissertation seeks to utilize a multilevel integrative analysis (Berntson et al., 2012; Cacioppo et al., 2000) to offer a more holistic understanding of the mechanisms by which social factors interact with biological and psychological processes to generate complex behaviors.

Interactions between central neural processes and peripheral somatovisceral systems allow for dynamic and flexible responses to a wide spectrum of stressors. Stress responses were once thought occur in stereotyped “non-specific” response patterns (Selye, 1976), but we now

know that organisms perceive and integrate specific qualities of stressors to generate stressor- and context-specific response patterns according to current or anticipated need states (B. S. McEwen, 2013). This specificity and flexibility are critical for navigating complex social situations, which require dynamic and nuanced psychological and behavioral responses as demands fluidly change. Further adding to the flexibility of responses, our stress response systems are not designed to keep a static internal state, nor do they function in an exclusively reflexive manner. The initial concept of homeostasis, first put forth by Walter Cannon, asserts that the internal milieu is constantly trying to return to a fixed set point (Cannon, 1929), but this rigid framework does not account for the vast array of dynamic responses across systems. While we do observe a number of reflexive responses that appear to maintain set points, such as the baroreceptor reflex under orthostatic stress (Gianaros et al., 2012), we also observe apparently anti-homeostatic mechanisms. For example, fever induction requires internal bodily temperature to be raised above the typical temperature range (Berntson & Cacioppo, 2009). This flexibility in systems allows for complex interactions that allow an organism to respond adaptively, with specificity, to a large spectrum of stressors.

The orchestration of balance across systems is essential to successful navigation of environmental stressors and can also provide insight into patterns of disruption when stressors are extreme or prolonged. To describe the active processes involved in maintaining balance, we use the term allostasis. Allostasis is the adaptive process of achieving stability through change, allowing the body to maintain balance and cope effectively with environmental demands (McEwen, 1998). In contrast to homeostasis, the allostatic framework accounts for the fact that stress responses can occur before a stressor is present (anticipatory responses), or they can occur in the presence of an imagined threat which is never realized (Schulkin & Sterling, 2019). When

the perceived stressor is not resolved over time the constant activation, or inactivation, of the stress response systems places burdens on the body (Lupien et al., 2009; B. S. McEwen, 2007), and the stress response itself can cause damage to the response systems and their target organs. These maladaptive effects of stress activation are called the allostatic load of an individual, which refers to the “wear-and-tear” on the brain and body (B. S. McEwen & Gianaros, 2010). In sum, the body is not constrained to one homeostatic state, and the various systems are not constrained to functioning in entirely reciprocal ways; this complexity creates a range of stress responses which are nuanced and can be finely tuned to the individual and situation.

The integration of contextual and perceptual factors at multiple levels of processing results in widely varied responses to stressors. Re-representation of information at multiple levels of the neuroaxis, first conceptualized by John Hughlings Jackson in the late 1800s, allows for lower-level responses to be simultaneously coordinated with top-down control from higher order areas (Gillett & Franz, 2013). The same information is processed at each level of the neuroaxis, with increasing complexity and processing time as it ascends (Berntson et al., 2012; Norman et al., 2014). Additionally, bi-directional heterarchical projections generate more complex response patterns because higher level structures, such as the prefrontal cortex (PFC), have direct descending projections that can modulate lower levels without having to go through intermediate levels (Norman et al., 2014). Psychological stressors (e.g. social threat) are more likely to involve complex patterns, as is the case with the orienting response, which involves co-activation of the parasympathetic and sympathetic branches of the autonomic nervous system (ANS; Gianaros & Quigley, 2001; Hagenaars et al., 2014; Quigley & Berntson, 1990). This pattern contrasts with the reciprocal activation observed during the more stereotyped startle response (Quigley & Berntson, 1990). The perception of other factors, such as a lack of

controllability or predictability, can also shape responses to the same stressors (Hadad-Ophir et al., 2017; Maier & Seligman, 1976). Rodent models of stress have demonstrated both active and passive coping strategies in response to identical stress induction paradigms, such as a forced swim test (de Boer et al., 2017). Studies in rats demonstrate that predictability, induced by exposure to cued or un-cued electric shocks, differentially impacts stress responses, such as stress-induced analgesia (Drugan et al., 1985). In humans, a stress-induction task can be perceived as either a threat or a challenge, depending upon an individual's appraisal of their coping resources as either insufficient or sufficient to respond; while both appraisals are associated with significant increases in blood pressure, they differ in the underlying cardiac and vascular mechanisms driving the pressure changes (Mendes et al., 2001; Seery, 2011). Thus, conceptualizing stress as based entirely on the type of event itself is typically insufficient to explain variations in stress responses. This variability in responses extends to the social environment as well, where perceptual cues are essential to determining the nature of each social interaction.

Affective-cognitive processes are also heavily involved in directing social behavior, acting as a primary stress response system in the face of ever-changing environmental and social demands. Affective states (emotions) are comprised of feeling states that result in goal-oriented overt behaviors and physiological activation in response to a salient stimulus (Lang & Bradley, 2010). Functioning as motivational programs, shifts in affective states direct approach/avoid behaviors such that organisms can respond effectively to stimuli in the environment. The rapid central integration of affect with autonomic activity, thought to occur via the Central Autonomic Network (CAN; Thayer and Lane, 2000), promotes flexible and dynamic responses to perceived social threat in social contexts. The autonomic nervous system (ANS) is another primary stress

response systems which coordinates central and peripheral responses on rapid timescales. The ANS is also connected to higher order structures like the PFC or hippocampus, areas involved in directing shifts in affect, attention, memory, and other processes that are important for self-regulation and moderating other systems such as the cortisol stress response (Critchley et al., 2000; Porges, 2007). Critically, among its many functions, ANS activity is associated with activity in brain regions related to the perception and integration of threat-relevant information (Thayer & Lane 2000). In particular, resting PNS activity is thought to be an index of threat sensitivity, wherein lower baseline PNS activity indicates a hypervigilance to threat (Thayer & Lane, 2000). The ANS is also likely an underlying mechanism by which perception of social threat and related responses are coordinated. These same neural areas are also involved in the CAN; this overlapping neural circuitry allows us to index higher order cognitive processes with observations of autonomic activity.

Importantly, to recognize and respond to future situations of social threat, it is necessary to call upon prior experiences and update memory into an integrated understanding of the current situation. Consistent evidence has revealed that stress alters memory, often biasing cognitive processes towards the detection of threat (de Quervain et al., 2017; Schwabe, 2017). Stress-induced changes in learning and memory are in part modulated by adrenergic activity (de Quervain et al., 2017; Sandi & Pinelo-Nava, 2007). Releases of epinephrine and norepinephrine stimulate the vagus to indirectly activate neural networks involved in memory formation, and glucocorticoid effects on memory are in many cases dependent on concurrent ANS activation (Gagnon & Wagner, 2016; Schwabe, 2017; Shields et al., 2016). Concurrent with stress shaping memory, the memory of prior experiences of threat can likewise shape stress responses. For example, women with a history of childhood maltreatment demonstrate increased stress

reactivity across pituitary and autonomic systems as compared to women without prior exposure to maltreatment (Heim et al., 2000a). This exaggerated response suggests that past memory of trauma can sensitize stress response systems to shape future responses. Together, the cross-talk between systems adjusts physiological and psychological states to promote efficient and dynamic responses to a wide array of social stressors that an individual may encounter.

1.2 Social Threat

As a socially interdependent species, humans depend on the formation and maintenance of meaningful relationships, making the need to belong to social groups a fundamental part of human life (Baumeister & Leary, 2007). For social species, group living offers benefits, such as reproductive opportunities, defense from predators, and localization of resources, which increase likelihood of survival (Alexander, 1974; House et al., 1988). Indeed, humans depend on the establishment and maintenance of healthy social relationships to promote well-being (Baumeister & Leary, 2017; Umberson et al., 2010). The importance of these relationships is reflected in many psychophysiological processes, which motivate and facilitate interpersonal connections. Social connection is inherently rewarding (Eisenberger & Cole, 2012; Tamir & Hughes, 2018). For example, humans exhibit activation in reward-related circuits in response to social play, positive emotional expressions, and expressions of romantic love (Bartels & Zeki, 2004; Krach et al., 2010; Vanderschuren et al., 2016). However, disconnection from the group represents a significant social threat. Indeed, exclusion from the group or other forms of relationship loss causes distress among individuals and greatly impacts both mental and physical health (Bernstein Dr. & Claypool, 2012; J. T. Cacioppo & Hawkley, 2003; Hess & Pickett, 2010). There are also significant disadvantages to living in community with other conspecifics (Alexander, 1974). One

of the most salient of these is the risk of violence perpetuated by others in the group. Indeed, childhood abuse and interpersonal violence are highly prevalent and are associated with increased risk of feelings of isolation (Tung et al., 2019a), incidence of psychopathology (C. M. Jones et al., 2020; B. S. McEwen, 2013; Nusslock et al., 2016), and risk for adverse health outcomes such as cardiovascular disease (M. A. Bellis et al., 2019). To simultaneously cope with both risk of becoming disconnected and risk of harm inflicted by others, we must be able to flexibly process social information, draw upon past experiences, and effectively calibrate expectations of social threat to meet the fluctuating demands of complex social dynamics.

The perception of social threat induces neuroendocrine, autonomic, psychological, and behavioral responses (J. T. Cacioppo & Hawkley, 2003; Hawkley & Cacioppo, 2010a; G. A. Matthews & Tye, 2019; Porges, 2003). One of the most salient forms of social threat is perceived social isolation, also called loneliness, which is the discrepancy between the desired and actual quantity or quality of social relationships (J. T. Cacioppo & Hawkley, 2009). Much like hunger or thirst, acute loneliness induces aversive feeling states and serves as a motivation to alter behavior and avoid potential damage from perceived threat (Masi et al., 2010; Spithoven et al., 2017). When experienced over prolonged periods of time, perceived social isolation increases the risk for a broad range of negative physical and mental health outcomes and is negatively related to well-being (E. E. Lee et al., 2019). For example, prolonged loneliness is associated with increased levels of depression (J. T. Cacioppo & Cacioppo, 2018; S. Cacioppo et al., 2015; Jaremka et al., 2013, 2014), increased suicidal ideation (Rudatsikira et al., 2007), diminished immunity (Dixon et al., 2001; Glaser et al., 1985), and decreased quality of sleep (J. T. Cacioppo et al., 2002; T. Matthews et al., 2017).

Another salient form of social threat is exposure to harm from other people, which often occurs in the form of abuse or violence (e.g., physical abuse, gun violence). These experiences range from physical injury to sexual assault to emotional abuse and increase both immediate and long-term health risk (Danese et al., 2007; Finkelhor et al., 2015; McLaughlin et al., 2012; Mercy et al., 2017). Importantly, the majority of experiences typically considered to be the greatest life stressors, from childhood through adulthood, are social in nature (Bernstein et al., 2003; Cohen et al., 2019; Felitti et al., 1998). Individuals exposed to the most extreme forms of these social threats - abuse and violence - show higher rates of psychiatric disorders such as depression, anxiety and post-traumatic stress disorder (PTSD; Famularo et al., 1992; Heim & Binder, 2012; Heim & Nemeroff, 2001; Katerndahl et al., 2005; Wise et al., 2001), as well as increased rates of metabolic syndrome (C. Lee et al., 2014), coronary heart disease (Rich-Edwards et al., 2012), cancer (D. W. Brown et al., 2010), and autoimmune conditions (Nusslock et al., 2016). Abuse in childhood, such as physical or sexual abuse, has been shown to predict adverse physical health outcomes and neurobiological health in adulthood (Bertone-Johnson et al., 2012; Odebrecht et al., 2010; Slopen et al., 2013), and individuals raised in high risk environments have increased rates of incarceration, substance abuse, chronic illness, and shorter life expectancies (Felitti et al., 1998; Flaherty et al., 2009). Experiences of social threat early in life have also been shown to disrupt early attachment learning (Moriceau et al., 2009), which has implications for later attachment and social relationships.

The ability to form and maintain social connections depends upon complex affective and cognitive processes. Repeated or prolonged perception of social threat in the environment can have deleterious effects on affective-cognitive processes and behavior. Under the Evolutionary Theory of Loneliness (ETL), acute perception of social isolation induces feelings of loneliness to

motivate reconnection with others (Hawkley & Cacioppo, 2010b). This theory posits that loneliness shifts physiological and behavioral responses through the prioritization of social information processing to promote evolutionary fitness. In the short-term, this increased threat vigilance allows individuals to rapidly identify and respond flexibly to social threats (J. T. Cacioppo et al., 2011), facilitating repair or maintenance of bonds. Evidence suggests loneliness induces shifts towards enhanced processing of social information, particularly cues that may indicate social threat (Gardner et al., 2005; Spithoven et al., 2017). Indeed, loneliness has been associated with increased sensitivity to the detection of negative emotions like sadness and fear (Vanhalst et al., 2015), better recall of negative social information (Gardner et al., 2005; Hess & Pickett, 2010), visual attention towards social threat (Bangee et al., 2014), and increased expectations of social rejection (W. H. Jones et al., 1981). Similar patterns of threat vigilance are observed in individuals exposed to interpersonal violence and abuse (Dalgleish et al., 2001; Yoon & Weierich, 2016). For example trauma exposed women demonstrate attentional biases towards cues of potential threat (DePierro et al., 2013a). This vigilance for social threat mirrors the cognitive and behavioral shifts towards threat perception observed in other psychological states such as anxiety (Richards et al., 2014). The expectation for negative social interactions may in fact generate a self-fulfilling prophecy, by which negative expectations elicit negative reactions from others, reinforce negative perceptions, and ultimately lead to a sort of prolonged loneliness-loop (Hawkley & Cacioppo, 2010b). Cognitive biases related to the formation and recall of memory for past social interactions likely play a central role in the perception of threat in the social environment. Sustained altered cognition as described here can actually make prolonged loneliness more likely and compound the adverse psychological and physiological effects of perceived social isolation (Masi et al., 2010).

1.3 Social Threat Across Development

The way social threat is perceived and experienced changes throughout development, depending upon a multitude of factors which include the developmental timing of exposure and the type of social threats encountered. Beginning early in life, we begin to create frameworks for the social world and develop expectations about what social threats are most likely. Early life is a sensitive time for the developing brain (Luby et al., 2020; Tierney & Charles A. Nelson, 2009). Experience-dependent learning occurs throughout early life, facilitated by high rates of synaptic regrowth and neural remodeling (Lupien et al., 2009). Due to the increased plasticity in early life, as compared to other times in the lifespan, chronic or extreme stress can be profoundly harmful, leading to lasting neurobiological and psychopathological outcomes (Agorastos et al., 2019; Danese & J Lewis, 2017; Lupien et al., 2009). Chronic or extreme stress at any time in development, including early life, has been associated with alterations in cognitive processes related to perception of, and responses to, stressors (Liston et al., 2006; Lupien et al., 2009). The social environment is also extremely important during this time, as children develop attachments to caregivers and create mental models of the social world (Bowlby, 1969, 1979). Specifically, evidence suggests early adversity is thought to modulate antisocial behaviors later in life via neurobiological shifts in the “social brain” (Sandi & Haller, 2015).

The brain learns about and adapts to the early social environment as a way of predicting and preparing for similar future environments, and affective-cognitive processes are adjusted and biased accordingly. Children who have experienced early life stress (ELS) are more likely to judge ambiguous and neutral facial expressions as angry or threatening (S. D. Pollak et al., 2000). Physically abused children require less perceptual input to identify facial expressions of anger than their non-abused peers (Seth D. Pollak & Sinha, 2002), indicating an increased

sensitivity to signs of anger. Reductions in executive function abilities, including cognitive ability, working memory and inhibitory control has been found in children who faced ELS (Hostinar et al., 2012; Monahan et al., 2015). Deficits in self-regulation can have negative implications for a child's ability to navigate social situations. Inability to regulate negative emotions is associated with poorer peer relations and higher cortisol levels in children (Gunnar et al., 2003). Together integration of past experiences, alterations in physiological responses, and the increased bias towards threat detection in children may contribute to a wide range of behavioral outcomes that extend beyond childhood, including difficulties with the regulation of cognitive-affective processes and behavior.

As children transition into adolescence, the nature and impact of social threats continue to evolve. Adolescence is marked by significant neurobiological and psychosocial changes that influence how social threats are perceived and managed. During this developmental period, the brain undergoes extensive remodeling, particularly in regions involved in social cognition and emotional regulation, such as the prefrontal cortex and the amygdala (Blakemore, 2008; Casey et al., 2008). The heightened plasticity of the adolescent brain makes it a time when the brain may be particularly sensitive to the social environment, and thus more vulnerable to the effects of social threat. Adolescents are increasingly influenced by peer interactions and social hierarchies, which can amplify the perceived salience of social threats (Steinberg & Morris, 2001). Peer acceptance and rejection become critical factors that shape self-esteem and social identity, often leading to increased sensitivity to social evaluation and stress (Blakemore & Mills, 2014; Somerville, 2013). Adolescents are also at higher risk of intimate partner or interpersonal violence due to their entry into dating relationship, evolving emotional regulation, and the intense social dynamics characteristic of this developmental stage (Finkelhor et al., 2015; Foshee

et al., 2001; Margolin et al., 2010). Moreover, the interplay between hormonal changes and social experiences can exacerbate stress responses and emotional volatility during adolescence (Romeo, 2013). Further research is needed to fully understand the long-term consequences of these interactions and the mechanisms by which they influence emotional regulation and stress responses. As a result, exposure to chronic social stressors during this time can have profound implications, potentially disrupting typical developmental trajectories and contributing to long-term psychosocial difficulties (Oldehinkel & Bouma, 2011). Understanding the unique challenges of adolescence is crucial for developing interventions that support healthy development and resilience in the face of social threats.

As individuals progress into adulthood, their past experiences with social threats continue to shape how they perceive and respond to novel acute stressors. Adults can draw upon their accumulated knowledge and coping strategies developed over a lifetime to navigate social threats. Adults who have experienced chronic or severe social threats in childhood and adolescence may exhibit increased sensitivity to stress and a tendency to perceive neutral or ambiguous situations as threatening (Hammen et al., 2000; Sandre et al., 2018). This heightened vigilance can lead to a perpetuation of stress and anxiety in social interactions, and indeed early experience of social threat is linked to greater perceived social isolation in adulthood (Landry et al., 2022). This continued path of development underscores the importance of examining social threat across the lifespan, including into early adulthood. The ways in which individuals cope with and adapt to social threats in adulthood are deeply rooted in earlier experiences. Developing an understanding this developmental trajectory can allow for more effective interventions that can address maladaptive patterns established in childhood and adolescence. Effective coping mechanisms and a strong social support network can mitigate the impact of social threats and

foster resilience (Azpiazu Izaguirre et al., 2021; Ozbay et al., 2007). The ability to regulate emotions and maintain perspective, essential skills often developed through early experiences, helps prevent the escalation of stress responses and promotes psychological well-being in adulthood (Gross, 2002). Additionally, the integration of past experiences into a coherent self-narrative provides adults with a sense of continuity and control, which is crucial for resilience when facing new challenges (McAdams, 2001). By continuing to study social threat across development into early adulthood, we can better understand the long-term effects of early stressors and develop targeted strategies to support individuals and promote well-being throughout the lifespan.

Altered ANS activity may provide mechanistic insights into how the perception of social threat impacts affect, cognition, and behavior. Evidence from non-human animal models reveals that extended social isolation caused increased heart rate, drops in parasympathetic cardiac control and increased stress reactivity to a novel social stressor (Grippe et al., 2007; Hawkley et al., 2012; Norman et al., 2010). A systematic review of studies on loneliness and acute physiological stress reactivity in humans finds that high levels of loneliness are generally predictive of exaggerated reactivity to acute stress across physiological measures (E. G. Brown et al., 2018). Lonely individuals demonstrate diminished cardiovascular reactivity, via parasympathetic control, to acute stressors (Norman et al., 2011; Piejka et al., 2021). Further, a study by Cacioppo and colleagues (2002) revealed differences in patterns of cardiovascular activation between lonely and non-lonely individuals. In response to a social speech task, lonely individuals demonstrated higher total peripheral resistance (TPR) and sympathetic activation and decreased cardiac output and parasympathetic activation (Cacioppo et al., 2002), consistent with a threat appraisal profile (Seery, 2011). Studies have found that parasympathetic activity, as

measured by HF-HRV, decreases during negative social interactions (Shahrestani et al., 2015). Over time, if this altered cardiovascular activation is sustained, it is likely to cause to “wear and tear” on the system and contribute to risk for cardiovascular disease and other chronic health outcomes. ANS activity therefore provides a causal mechanism by which loneliness impacts physiological function. Together, this evidence suggests that loneliness influences the way individuals perceive and respond to their social environment, and the resulting individual variability across behavioral and psychophysiological responses to social threat may underly the long-term adverse consequences that have been observed.

Shifts in autonomic reactivity have been observed in children and adults with a history of violence and abuse exposure. Chronic perceptions of threat may lead to disruptions, via over or under activation, of neurophysiological stress response systems; primary among these systems, as discussed throughout, is the ANS. Studies have revealed a variety of autonomic responses following stress early in life, including increased reactivity the SNS (M. D. De Bellis et al., 1994; Heim et al., 2000b), blunted autonomic reactivity (Gunnar et al., 2009), or asymmetry in the responses of the ANS and cortisol response systems (McLaughlin et al., 2015). For example, Dale and colleagues (2018) found that women with a history of abuse displayed lower vagal control, had increased heart rate, and reported more psychological distress during an emotional stress task than non-abused peers (Dale et al., 2018). However evidence for the relationship between exposures to interpersonal threats and ANS functioning continues to be largely heterogeneous and may depend on factors such as psychopathology and age (Sigrist et al., 2021). Developmental trajectories of the ANS are also likely to have substantial implications for social behaviors throughout life. In infants and children, the development of vagal regulation of the heart is related to self-regulatory and social engagement skills (Porges & Furman, 2011). ELS is

also associated with neural development in structures related to affective-cognitive processes necessary for processing and coordinating social behaviors, such as the PFC, amygdala, and hippocampus (Lupien et al., 2011; McLaughlin et al., 2016). Compelling evidence has linked violence exposure to adverse outcomes, but the specific effects of perceived social threat across development and throughout adulthood has yet to be fully teased apart.

1.4 The Current Work

There remains a need to characterize responses to perceived social threat across development, and in particular the contributions of perceived social isolation and prior exposure to social threat, including ELS and interpersonal violence. This dissertation describes three experiments examining the varied ways in which ELS, perceived social isolation, and acute social threat interact, including investigations of physiological, behavioral, and emotional mechanisms. Study 1 utilizes a prospective longitudinal framework to examine changes in perception of social threat in a population of preschool children exposed to high-stress environments. Study 2 also uses a prospective longitudinal framework to investigate how the interaction between incidents of interpersonal violence and perceived social isolation impacts emotion regulation in a sample of adolescent girls. Finally, Study 3 explores autobiographical memory detail following acute psychosocial stress in young adults.

Chapter 2: Unpredictability of Social Stressors Predicts Child Self-Regulatory Behaviors

2.1 Introduction

Chronic or extreme stress in childhood increases health risk across the lifespan (Famularo et al., 1992; Heim & Binder, 2012; Heim & Nemeroff, 2001; Katerndahl et al., 2005; Wise et al., 2001, Merrick et al., 2019; Nusslock et al., 2016). Ranging from physical and emotional abuse within the family to community or neighborhood violence, the often-interpersonal nature of ELS lends itself to the formation of increased sensitivity to potential social threats. For example, physically abused children require less visual input and are faster to identify facial expressions of anger than their non-abused peers (Seth D. Pollak & Sinha, 2002). Children exposed to early threatening environments also exhibit heightened attention and stress reactivity to potential threats (McLaughlin et al., 2015; Seth D. Pollak & Tolley-Schell, 2003). This increased orientation towards the identification and resolution of social threats is also associated with development of brain structure and functioning in areas related to threat perception, social and emotional learning, and self-regulatory processes (e.g. prefrontal cortex, amygdala; Gary W. Evans & Kim, 2013; Lupien et al., 2009). Yet, children vary widely in how they respond to the same types of ELS exposures (K. E. Smith & Pollak, 2020), resulting in a spectrum of psychological and behavioral outcomes. This variability has implications for how early experiences shape long-term physical and mental health outcomes, making it critical to identify potential mechanisms underlying variability in responses to ELS in order to develop a full understanding of how early experiences impact individuals throughout life. In this study, I

examine environmental unpredictability as one potential mechanism contributing to outcomes in children exposed to high levels of ELS.

In particular, self-regulatory abilities have been shown to vary following ELS exposure. Self-regulation includes the ability to control attention and emotions, plan, and initiate or inhibit behaviors for reaching goals (Heatherton, 2011; Palacios-Barrios & Hanson, 2019), all of which are necessary to navigate complex social situations, from relationships with peers to family dynamics. Self-regulatory behaviors may be thought of as indicating capacity to adapt to changes in the environment, where increased flexibility is beneficial in environments characterized by adversity or change. ELS exposure has been associated with altered self-regulatory abilities in children (Gary W. Evans & Kim, 2013; Kim & Cicchetti, 2010; B. S. McEwen, 2012; Palacios-Barrios & Hanson, 2019), including increased impulsivity, reduced delay of gratification behaviors, and increased presentation of externalizing behaviors (Grasso et al., 2013; S. H. Shin et al., 2018; Skibo et al., 2020). Early adverse experiences, like maltreatment, have also been linked to difficulties with regulating emotions (Kim-Spoon et al., 2013). However, the way ELS impacts self-regulation has been shown to vary along with factors such as the type and timing of stress exposure (Hambrick et al., 2019), the presence of supportive caregiving (Kok et al., 2022), and individual differences in physiological stress response systems (Berry et al., 2019). As a result, not all children will experience impaired self-regulation following adversity, and some may even demonstrate enhanced abilities. For example, Warren and Barnett (2020) found an association between unpredictability as indexed by the number of times a father-figure transitions in or out of the home and better effortful control in a preschool-aged children. Importantly, past models have generally used cumulative measures of ELS to link stress exposure to self-regulatory abilities. However, these measures have not been able to fully explain

the variability observed in responses, leaving critical gaps in our understanding of how ELS shapes self-regulatory outcomes.

Specifically, one significant gap lies in the role of environmental unpredictability. While cumulative measures of ELS capture the total amount of stress exposure, they often do not address the consistency and predictability of these stressors. This is crucial because unpredictability in cues signaling either threat or safety in the environment is thought to be one mechanism underlying differences in child outcomes following ELS (Ellis et al., 2022; Young et al., 2020). Indeed, consistent evidence from the human and non-human animal literature demonstrates that the predictability of a stressor is one of the most powerful determinants of stress responses. When the developing brain is exposed to consistent positive environmental cues, such as nurturing caregiver behaviors, a predictable and stable framework is established, which is thought to signal a safe environment (Gee & Cohodes, 2021). However, environments characterized by high levels of ELS also tend to also be characterized by unpredictability (Ellis et al., 2022). In these cases, environmental cues may not reliably predict outcomes (e.g. availability of food or safety). For example, a child experiencing food insecurity may not consistently receive meals at home. Current theories posit that as cognitive and affective processes develop, they are able to detect and respond to the underlying statistical structure of environmental cues in order to make inferences and guide adaptive responding (Ellis et al., 2022; Frankenhuis et al., 2019). Additionally, early-life unpredictability has been found to be an independent predictor of adult psychopathology, above and beyond experiences which typically constitute childhood trauma (Spadoni et al., 2022), suggesting that unpredictability may provide additional explanatory power for outcomes following ELS.

Children integrate information about the presence and structure of threat in their environment with the unpredictability of the environment to direct learning, expectations, and behavior (Ellis et al., 2022). As children monitor the environment, they learn what to expect and adjust behaviors to maximize their ability to survive in these contexts. For example, if food availability is unpredictable, a child may prioritize eating in the present moment over delaying-gratification, because the future availability of food is not guaranteed. Indeed, children are less likely to delay gratification on the classic marshmallow task when the environment contains uncertainty generated by cues of experimenter unreliability (Kidd et al., 2013). This evidence suggests that children's decision-making is shaped by their beliefs about the structure of the environment. From a life history perspective, outcomes such as prioritization of immediate over delayed gratification are thought to reflect strategies enacted in the face of an ambiguous future which is likely to be characterized by further unpredictability (Cabeza de Baca et al., 2016; Ellis et al., 2022). Environmental unpredictability in childhood has also been linked to outcomes in adolescence and beyond, including externalizing behaviors (Doom et al., 2016), risk of depression (Gilman et al., 2003; Manczak et al., 2016), substance use (Buu et al., 2015; Doom et al., 2016), and risk taking behaviors (e.g. having more sexual partners; Simpson et al., 2012). Similarly, these behavioral outcomes reflect decisions to prioritize current need states over future ones.

Like ELS, environmental unpredictability has also been associated with self-regulatory abilities. Unpredictability in the early environment has been shown predict decreased effortful control, deficits in attention, and increased impulsivity in childhood (Davis et al., 2019; McCoy & Raver, 2014), indicative of shifts in self-regulatory behaviors associated with the structure of the environment. Unpredictability in signals coming from caregivers (e.g. maternal mood)

predicts poor effortful control in childhood (Glynn & Baram, 2019; Holmberg et al., 2022). Adults with childhoods characterized by more unpredictability also display less delayed discounting and more externalizing behaviors, even when controlling for the harshness of the childhood environment (Martinez et al., 2022). While these behavioral patterns may appear as deficits in self-regulatory abilities, this evidence may also reflect shifts towards strategies which optimize benefits in environments which are changing or uncertain. Other evidence indicates that unpredictability in childhood may provide adaptive benefits when individuals are faced with uncertain contexts. For example, unpredictable childhood environments have been shown to increase working memory updating under conditions of uncertainty in adulthood (Young et al., 2018), suggesting that the early environments plays a role in shaping later cognitive abilities in a way that provides benefits for future similar environments. Similarly, Warren and Barnett (2020) find that unpredictability (defined by parental transitions indexing environmental change) is associated with better effortful control in children. Together this evidence suggests that in some contexts unpredictability may enhance aspects of self-regulation, and there is specificity to the way early unpredictability impacts cognitive development to shape self-regulatory abilities in an adaptive manner for future similar environments. The seemingly contradictory findings may result from the way different aspects of unpredictability are perceived by the individual and differentially impact neural, psychological, and behavioral processes. Therefore, it is essential to understand how and when the predictability of exposure to social threat, particularly in early childhood, impacts the processes that underly self-regulatory processes.

While the field agrees that environmental unpredictability shapes outcomes, various methods have been used to measure environmental unpredictability, and it is not yet clear how to best index unpredictability as it relates to variability in child outcomes (e.g., self-regulation).

Previously, unpredictability has often been assessed by the degree of variation in environmental stressors, such as events or exposures that are linked to environmental harshness (Ellis et al., 2009). For example, a researcher may identify the number of times a child moves across a given time period as an index of unpredictability in the environment. Other approaches have included assessing variance (change from the mean) in harshness across a measurement period (Li et al., 2018), disorder in the environment (entropy; Aran et al., 2024; Glynn & Baram, 2019), or the degree to which current signals predict future levels of harshness (autocorrelation; Burgess & Marshall, 2011). Another approach has been to use retrospective reports of unpredictability in the childhood environment (e.g. Questionnaire of Unpredictability in Childhood; Glynn et al., 2018). Each of these approaches captures related, but distinct, components of unpredictability. Yet it is not clear the extent to which the properties of environmental unpredictability captured by each of these measures impacts developmental processes like self-regulation, or, further, whether these separate indices shape outcomes in the same ways. Recent discourse has called for investigations assessing multiple measures of unpredictability concurrently in order to address this open question (Doom et al., 2024; Frankenhuis et al., 2019). Therefore, there remains a need to characterize and compare the components of unpredictability and examine the mechanisms by which different aspects of environmental predictability contribute to long-term adverse effects within the context of ELS.

Recent work proposes that critical insights may be derived from the investigation of how different dimensions of environmental unpredictability differentially impact outcomes following ELS (Young et al., 2020). According to the arguments put forth by Young and colleagues (2020) the structure of environments, whether they are stationary (mean and variance not changing with time) or non-stationary (mean and variance changing across time), has implications for the

course of development. Within the context of ELS, this change predominantly refers to adverse experiences or exposures. For example, an environment with a consistent moderate level of physical abuse would likely result in different outcomes from a child than an environment with rapid shifts between extreme physical abuse and no abuse. Indeed, even in the face of adversity, environments with a consistent structure have been found to foster resilience (Crespo et al., 2013; Shi et al., 2021). Walasek and colleagues (2024) recently put forth a novel statistical framework, to address these distinct dimensions of unpredictability. In this statistical framework, there are distinctions between distributional statistics (e.g., mean, median, range, standard deviation), which do not depend on the order of the data, and dynamic statistics (e.g. autocorrelation), which depend upon the time order of the data (Walasek et al., 2024). Dynamic statistics may offer additional predictive power related to how data unfolds over time – a critical component of developmental processes. For example, changepoints identify shifts in the mean or variance of a signal across time, and entropy provides a measure of disorder within a time series. By using a range of dynamic statistics (for further definitions see Table 1), we can detect patterns in time series data to identify and characterize environmental unpredictability. Indeed, evidence from Walasek and colleagues (2024) does demonstrate interrelations between unpredictability statistics when applied to data on crime in a large metropolitan city, indicating that similar patterns of environmental unpredictability could potentially predict shifts in child self-regulatory outcomes. By leveraging these dynamic statistics, we can gain a deeper understanding of how varying levels of unpredictability impact developmental processes and ultimately influence children's ability to regulate their behavior over time.

In the current work, I consider several measures of unpredictability in environmental stressors for children exposed to ELS with the aim of capturing different aspects of unpredictable

environments and multiple levels of complexity to determine how they may differentially contribute to child outcomes. First, I consider the overall variance of potential stressors in a child's environment, defined by the standard deviation, as a means of capturing a broad measure the structure of the environment. For example, a child who transitions between two caregivers may experience greater overall variability – standard deviation – in time spent with each caregiver as compared to a child who resides permanently in a two-caregiver home. However, the standard deviation is a distributional statistic and does not provide insight into the time course of potential stressors. Therefore, it is important to consider the way the variance in potential stressors may change or fluctuate over time, which can occur with different degrees of predictability. For example, the child transitioning between caregivers may do so on a regular weekly schedule, reflecting more predictable change. However, there may be a time period of increased variability of transitions between caregivers (e.g., spending 1-2 weeks with each caregiver during summer vacation without a schedule), which would reflect changes in the frequency and number of these changes. To examine how often the variance changes, we consider change points in variance, where the variance either increases or decreases significantly, and represents an inflection point. We also consider change points in the mean to assess how often the overall number of potential stressors demonstrates abrupt shifts, where the mean either increases or decreases. In our example, this might look like a month with daily transitions between caregivers followed by a return to weekly transitions the next month, where the mean number of transitions per week changes between these two months, representing a changepoint. However, consider that the degree to which these changes fluctuate may vary in predictable or unpredictable ways. To capture this aspect of predictability of in changes, we consider the autocorrelation of potential stressors in the environment. Autocorrelation in a series of data

indicates the extent to which past sequences of signals predict future sequences in the series. In other words, how informative is the past and current environment in telling you about the future environment. In our example, the child may know that summer vacation will change their schedule, causing increased frequency and/or variability of transitions between caregivers, while fall will bring more consistency. Finally, it is useful to investigate the disorder of potential stressors in the environment, which we can index using entropy and color of noise. Entropy characterizes the disorder of a signal in a data series, and color of noise captures the spectral distribution of the noise, or the extent to which noise in early life stressors are autocorrelated across time lags (Walasek et al., 2024, Frankenhuis et al., 2019). For research on ELS, adverse exposures are considered the signal, as they represent specific stressors or stimuli of interest that are the focus of the study. The noise, on the other hand, encompasses any variability that is left after extracting systematic patterns or trends in time series data. This distinction allows us to differentiate between the signals of interest and the background variability that may influence our observations. In the case of the child transitioning between homes, high entropy and low color of noise would indicate greater disorder and randomness in transitions between homes.

Once the different aspects of unpredictability have been identified, there is a need to consider the relationships between different measures of environmental unpredictability to understand how the different statistical properties interact to shape outcomes. Indeed, research by Nweze et al. (2023) demonstrates that different types of early life stress (ELS) tend to cluster in meaningful ways, which in turn differentially predict adult cognitive outcomes. For instance, their study found that ELS characterized by high variability in caregiver availability and family dysfunction was associated with better executive functioning in adulthood than ELS characterized by greater global adversity. Another recent investigation of childhood

unpredictability found that two distinct dimensions of unpredictability (stochasticity and volatility) interact to predict externalizing behaviors later in childhood (Farkas et al., 2024). These findings suggest that it is not merely the presence of stress, but the specific patterns of unpredictability that play a crucial role in determining long-term cognitive outcomes. By examining how different dimensions of unpredictability (such as randomness in stress exposure, variability in stressor intensity, and shifts in stressor characteristics) cluster together, we can gain deeper insights into the mechanisms through which ELS impacts development. However, it remains to be fully elucidated how characteristics of unpredictability cluster and whether these patterns also differentially impact cognitive outcomes. However, further research is needed to explore how the relationships between unpredictability statistics manifest in early childhood environments, and how these relationships may vary across contexts and timescales. In order to fully elucidate how and when each aspect of environmental unpredictability influences development in the face of ELS, it is critical to apply these statistical frameworks to a variety of timescales, ages, and types of datasets.

The current study applied a novel statistical framework (Walasek et al., 2024) to a longitudinal investigation of child self-regulatory behaviors across a preschool intervention program for children at high risk of stress exposure. Using a prospective longitudinal study design, I collected information about potential stressors occurring in each child's life. Taking advantage of the high frequency sampling rate in our sample, I was then able to utilize the time series data to extract multiple measures of unpredictability, in line with methods described by Walasek et al. (2024), and examine how these measures related to child self-regulatory behaviors across the course of the program. I hypothesized that 1) higher levels of unpredictability would predict lower initial (baseline) behavior ratings and 2) higher levels of unpredictability would

predict less positive improvement in behavior changes across time. I expected the relationship between unpredictability and self-regulatory behaviors to vary by measure of unpredictability used, however I did not make specific predictions about the direction of these relationships. I also explore whether unpredictability statistics are correlated, according to guidance from Walasek et al. (2024). I predicted that they would correlate with each other, but I did not make specific predictions about which components will correlate. Ultimately, the findings from this study will contribute to our continually evolving understanding of how ELS exerts lasting impacts on child outcomes, and which factors contribute to long-term health-risk and behavioral outcomes.

2.2 Methods

2.2.1 Sample Description

Participants in the current study were 173 children ages 3 to 7 years ($M = 5.0$, $SD = 0.75$; 25.8% female; 39.9% children were White, 26.0% African American – Black, and 34.1% were Multi-Racial or Other) who participated in the Child & Parent Services (CAPS) Building Blocks Laboratory Preschool Program. These children attended the preschool between the years of 2008 and 2019, during which time behavioral data was collected daily in the classroom along with other forms of data collected by the preschool. This work was approved by both the CAPS' Building Blocks' Preschool Program and the University of Chicago's Institutional Review Board. All parents provided consent for use of their child's data.

2.2.2 Program Description

The CAPS' Building Blocks' Preschool Program was a 10-month-long for preschoolers and kindergarteners who have been identified as at-risk of exposure ELS, such as abuse or maltreatment, parental financial instability, etc. Potential students were referred to Building Blocks by the Elkhart public school systems, child protective services, and other child service

agencies (mental health, social work, etc.) throughout the Elkhart County area. The program involved teachers spending time working closely with children to support children's use of self-regulatory techniques, including emotion recognition, appropriate emotion expression techniques, and appropriate peer interaction and play, as well as typical academic skills including reading, writing, and math. Building Blocks staff documented daily classroom behavior and events for each child. In addition, a team of social workers and teachers collaborated to support child caregivers with regular home visits and to collect information about children's home environments. Together this resulted in a wealth of data that can be used to examine individual variation in these children's behavioral patterns.

All measures were collected by the preschool in four formats: 1) Documentation of the home, family environment, and family's/child's past history during intake interviews of children and families admitted to the program; 2) Daily documentation of each child's behavior in the classroom by the teachers throughout the child's time in the program; 3) Collection of physiological data (for a subset of children) daily in the classroom through the use of ambulatory physiological monitors; and 4) Documentation of the home environment including any significant stressful events that occurred within the family during the child's time in the preschool program.

2.2.3 Study Measures

All data was extracted and analyzed from information documented by the staff at Building Blocks. The current study focuses on two main aspects of these data: 1) Measures of children's classroom behavior and self-regulatory behaviors coded from school documentation of daily

time outs and safe holds; and 2) Measures of children's teacher-rated self-regulatory behaviors taken from teacher documentation of child's behavior in the classroom.

Teacher-Rated Self-Regulatory Scores

Teachers provided monthly ratings of 3 dimensions of self-regulatory behavior. Teachers rated children's ability to 1) cope with disappointment or change, 2) express anger appropriately, 3) and control impulses on a Likert scale from 0 – 5, with higher numbers indicating better functioning. These ratings are based on children's ability to express themselves using appropriate strategies encouraged by the preschool rather than expressing themselves through hitting, biting, screaming, withdrawal from group activities, etc. Teacher ratings on these three dimensions are highly correlated, so a composite teacher rating score was calculated by adding the three ratings at each time point to create a composite score of child self-regulatory behavior.

Stressful Life Events

Throughout each child's enrollment in the program, information about the children's lives, including significant, adverse, or potentially stressful life events, was collected regularly by teachers and social workers. Caregivers were required to participate in weekly home visits provided by the school, during which a social worker collected information about the home environment.

In order to analyze child responses to stressful life events, all documentation collected by the preschool (intake interviews, classroom documentation, and information collected at home visits) was examined to identify significant or adverse events occurring during a child's time in the program. Potentially stressful events were identified based on commonly used life events checklists which aim to identify environmental changes and potentially traumatic events (Famularo et al., 1992; Hooper et al., 2011). All documentation was searched using pre-determined key words (e.g.,

“spanked”, “moved”, “private parts”) to identify potential stressors, and text was extracted to summarize these events.

Two researchers (EMS and KES) then independently coded potentially stressful events according to pre-determined criteria set by the research team (Table 3). All disagreements were resolved via discussion between the two researchers.

Unpredictability Statistics

The following statistics were used to assess environmental unpredictability in the child environment: Standard Deviation, Coefficient of Variation, Changepoints in Variance, Changepoints in Mean, Autocorrelation, Color of Noise, and Entropy. These statistics were derived from the stressful life events for each child and calculated following procedures described by Walasek and colleagues (2024). Standard deviation refers to the total amount of variance in the time series data for each participant. The Coefficient of Variation was calculated as Standard Deviation divided by the mean number of potential stressors identified. Changepoints in Variance and Changepoints in Mean were identified by the number of abrupt shifts in the mean and variance across 2-week intervals throughout each subject’s time in the program. Autocorrelation was calculated with a 1-month lag (the same timescale as the behavior ratings). Color of Noise was quantified as the extent to which noise in potential stressors was autocorrelated across 1-month time lags. Finally, Entropy was calculated by deriving the sample entropy from the time series data. Higher Standard Deviation, Coefficient of Variation, Changepoints in Variance, Changepoints in Mean and Entropy indicate higher levels of unpredictability. The same is true for lower values of absolute Color of Noise and Autocorrelation.

2.2.4 Analysis Plan

The relationship between unpredictability statistics and baseline behavior ratings was assessed using Ordinary Least Squares (OLS) multiple regression. Hierarchical linear model modeling (HLM) techniques was used to assess the relationship between unpredictability statistics and changes in children's self-regulatory behaviors over the course of their time in the CAPS preschool program. HLM is a complex form of ordinary least squares (OLS) regression which is used to analyze variance in outcome variables when the predictor values are clustered at different levels (Woltman et al., 2012). Because HLM accounts for variance in hierarchically structured data, these models are well-suited for longitudinal data, where observations are nested within each subject. This approach accounts for variation in observed outcomes across individuals over time and handles missing data without need for imputation. All models were run using the lme4 package in R version 4.3.1. All variables were z-scored ($M = 0$, $SD = 1$) prior to analysis so that coefficients could be used to estimate effect sizes (Lorah, 2018). Finally, I consider correlations between unpredictability statistics. Winsorizing was applied to mitigate the influence of extreme values or outliers. In this analysis, data was winsorized using the Winsorize function from the DescTools package in R, which means values beyond the 95th percentile were set to the 95th percentile value and values below the 5th percentile were set to the 5th percentile value. All models were run with and without outliers, and the results with winsorized data are reported for consistency. Additionally, I controlled for potential confounding variables, including age, sex, race, cohort year, and the teacher who provided the ratings.

2.3 Results

Correlations

First, I examined associations between my unpredictability measures by looking at the correlations between measures. I expected to find some associations, such that higher unpredictability in one measure would be associated with greater unpredictability in other measures.

However, I did not have specific expectations about which measures would be correlated. As expected, measures of environmental unpredictability in stressful life events for the children demonstrated correlation patterns (Table 2). Consistent with findings from Walasek et al. (2024) Color of Noise and Entropy demonstrate a significant negative correlation ($r = -.30, p < .001$), indicating that greater disorder (or randomness) in exposure to stressors is associated with greater stochasticity in the structure of noise. Standard Deviation was significantly correlated with all measures except Changepoints in Variance ($r = -.03, p > .05$). Color of Noise showed positive correlations with Autocorrelation and Changepoints in Mean and Changepoints in Variance, indicating lower unpredictability as indexed by Color of Noise is associated with higher unpredictability as indexed by these measures. Each measure thus captures a different dimension of unpredictability, providing a more nuanced understanding of how environmental stressors are structured and experienced.

Unpredictability and Self-Regulatory Behavior Ratings

I expected that subjects with environments characterized by greater unpredictability would receive lower initial ratings of self-regulatory abilities and demonstrate slower rates of improvement. Overall, self-regulatory behaviors improved across time in the program ($\beta = 0.35, SE = 0.03, p < .001$). In line with my predictions, several unpredictability statistics were associated with teacher ratings of self-regulatory behavior both when children entered the CAPS program and across time in the program.

Standard Deviation

First, I examined the relationship of Standard Deviation of potential stressors with teacher ratings of child self-regulatory behaviors. Standard Deviation is a distributional statistic that offers

insight into the total overall variation in stressors for each child. Standard deviation was not associated with behavior ratings when children first entered the program ($\beta = -0.25$, $SE = 0.17$, $p = .15$). Similarly, Standard Deviation did not moderate the effect of time on these improvements ($\beta = 0.01$, $SE = 0.03$, $p = .87$), indicating that changes in behavior ratings did not differ by level of Standard Deviation in environmental stressors (Figure 1).

Changepoints in Variance

Next, I assessed the relationship between Changepoints in Variance and behavior ratings. Greater unpredictability indexed by Changepoints in Variance, which indicates how often the overall variation changed in either the positive or negative direction, was associated with higher behavior ratings when children first entered the program ($\beta = 0.48$, $SE = 0.17$, $p = .01$). When I examined how Changepoints in Variance relates to changes in behavior across time in the program, I found that Changepoints in Variance interacted with time ($\beta = -0.10$, $SE = 0.03$, $p < .001$), indicating that Changepoints in Variance is a measure that does moderate behavior changes across time (Figure 2). A simple slopes analysis at one standard deviation above and below the mean for Changepoints in Variance was conducted to probe the interaction effect. At lower levels of Changepoints in Variance (one SD below the mean), self-regulatory behaviors increased across time ($\beta = 0.44$, $SE = 0.04$, $p < .001$, 95% CI [0.36, 0.52]). At higher levels of Changepoints in Variance (one SD above the mean), the effect remained significant, but the strength was attenuated ($\beta = 0.24$, $SE = 0.04$, $p < .001$, 95% CI [0.15, 0.32]). Pairwise comparisons indicated a significant difference in these slopes (contrast estimate = 0.20, $SE = 0.06$, $p = .001$). This suggests that improvements in self-regulatory behavior across time are more pronounced for individuals with lower levels of Changepoints in Variance.

Changepoints in Mean

Changepoints in Mean was not associated with child self-regulatory behaviors at the start of the program ($\beta = -0.03$, $SE = 0.17$, $p = .89$). Similarly, Changepoints in Mean ($\beta = -0.04$, $SE = 0.03$, $p = .21$) did not moderate behavioral improvements across time.

Coefficient of Variation

The Coefficient of Variation, which is a standardized way of assessing variability to compare across subjects, was positively associated with behavior scores at the beginning of the program ($\beta = 0.49$, $SE = 0.16$, $p = .003$). The Coefficient of Variation also moderated the effect of time on behavioral improvements ($\beta = -0.09$, $SE = 0.03$, $p = .004$) (Figure 3). A simple slopes analysis at one standard deviation above and below the mean for the Coefficient of Variation was conducted to probe the interaction effect. At lower levels of the Coefficient of Variation (one SD below the mean), self-regulatory behaviors increased across time ($\beta = 0.43$, $SE = 0.04$, $p < .001$, 95% CI [0.35, 0.51]). At higher levels of the Coefficient of Variation (one SD above the mean), the effect remained significant, but the strength was attenuated ($\beta = 0.26$, $SE = 0.04$, $p < .001$, 95% CI [0.17, 0.33]). Pairwise comparisons indicated a significant difference in these slopes (contrast estimate = 0.18, $SE = 0.06$, $p = .003$). This suggests that improvements in self-regulatory behavior across time are more pronounced for individuals with lower levels of the Coefficient of Variation.

Autocorrelation

Autocorrelation was not associated with self-regulatory behavior ratings at the start of the program ($\beta = -0.23$, $SE = 0.17$, $p = .18$). Autocorrelation did not moderate behavioral improvements across time ($\beta = 0.04$, $SE = 0.03$, $p = .16$).

Entropy

Entropy was negatively associated with behavior ratings at the start of the program ($\beta = -0.56$, $SE = 0.15$, $p < 0.001$) indicating that higher levels of unpredictability were related to worse behavior scores. Entropy did not moderate behavior trajectories across time in the program, however the interaction trended towards significance ($\beta = 0.06$, $SE = 0.03$, $p = .054$), such that higher unpredictability (i.e., higher entropy) may be associated with greater improvements in behavior across time.

Color of Noise

Color of Noise was positively associated with behavior ratings at the start of the program ($\beta = 0.57$, $SE = 0.16$, $p < .001$), indicating that higher unpredictability was related to worse self-regulatory behaviors when children enrolled in the program. However, this relationship became non-significant when covariates were included in the model. Higher unpredictability as indexed by the Color of Noise did moderate behavioral improvements ($\beta = -0.07$, $SE = 0.03$, $p = .03$), such that individuals with higher levels of unpredictability as indexed by this measure demonstrated greater behavioral improvements as compared to their peers with lower levels of unpredictability (Figure 4). A simple slopes analysis at one standard deviation above and below the mean for the Color of Noise was conducted to probe the interaction effect. At lower levels of the Color of Noise (one SD below the mean), self-regulatory behaviors increased across time ($\beta = 0.41$, $SE = 0.04$, $p < .001$, 95% CI [0.32, 0.48]). At higher levels of the Color of Noise (one SD above the mean), the effect remained significant, but the strength was attenuated ($\beta = 0.27$, $SE = 0.04$, $p < .001$, 95% CI [0.19, 0.36]). Pairwise comparisons indicated a significant difference in these slopes (contrast estimate = 0.13, $SE = 0.06$, $p = .03$). This suggests that improvements in self-regulatory behavior

across time are more pronounced for individuals with higher levels of unpredictability as indexed by lower levels of the Color of Noise.

2.4 Discussion

This study examined the relationship between environmental unpredictability and child self-regulatory behaviors, utilizing multiple indices of unpredictability to compare across measures. I addressed this question in a population of children at high risk of experiencing chronic or extreme social stressors, which are likely to be marked by varying degrees of predictability. Specifically, I examined the relationships between unpredictability of potential stressors in the child environment and teacher ratings of child self-regulatory behaviors across enrollment in a one-year intervention program for at-risk children. I found that the overall variance of potential stressors in the child environment, as indexed by Standard Deviation, was not associated with self-regulatory behaviors, while measures that capture information about the amount of uncertainty in the variability of potential stressors were associated with child behavioral improvement. Higher levels of two distributional measures of unpredictability (Changepoints in Variance and the Coefficient of Variation) predicted attenuated improvements in child self-regulatory behaviors. However, for some dynamic measures of unpredictability (Entropy and Color of Noise), greater unpredictability was associated with larger positive change in child self-regulatory behaviors across time in the program. Importantly, the measures of unpredictability indexed in this study were not uniformly associated with self-regulatory behaviors, indicating a need for further investigation. The current study builds on past research linking unpredictability in the early environment and self-regulation, revealing evidence of specificity in the way individual indices of environmental unpredictability are differentially related to the development of self-regulatory behaviors. These findings contribute to ongoing

efforts to identify patterns of environmental unpredictability contributing to developmental trajectories across childhood.

The current findings are aligned with evidence that unpredictability in the childhood environment is related to self-regulatory behaviors, including reduced likelihood of delaying gratification and increased externalizing behaviors (Davis & Glynn, 2024; Doom et al., 2016). More specifically, the current results align with previous investigations linking environmental unpredictability measured by Entropy (Davis et al., 2017; Glynn & Baram, 2019) and the Coefficient of Variation (Liu et al., 2022) to child outcomes. Importantly, the events that were identified as potentially stressful in the current study capture components of unpredictability that have been previously associated with developmental outcomes, including residential instability (Gilman et al., 2003), household chaos (G. W. Evans et al., 2005), and neighborhood instability (Buu et al., 2015). I found that upon entry to the intervention program children with higher levels of environmental unpredictability – as indexed by Entropy, the Coefficient of Variation, and the Color of Noise – received lower ratings for their self-regulatory behaviors. This evidence is in line with the fact that adverse environments are often characterized by greater variability, and, indeed, exposure to adverse events tends to be associated with deficits in self-regulatory behaviors (Palacios-Barrios & Hanson, 2019). However, I did not find a relationship between the overall amount of variability in potential stressors – Standard Deviation – and initial child behavior ratings. These results suggest that 1) when accounting for the number of stressors (e.g. the mean), it is the relative variability in those stressors that is most impactful for shaping behavior, and 2) the dynamics of the stressors as they occur across time are a critical aspect of unpredictability as it relates to self-regulatory behavior. That is to say, whether a child is exposed to a large quantity of stressors or very few, the relative amount of variability and disorder of

those stressors may be what is driving shifts in self-regulatory behaviors. Not all measures of unpredictability were associated with initial behavior ratings, suggesting that these measures are capturing different aspects of the environment which differentially impact self-regulatory processes and behaviors. This finding is aligned with evidence that these measures capture different components of environmental unpredictability (Walasek et al., 2024).

While my work does align with previously demonstrated links between environmental unpredictability and reductions in self-regulatory behaviors, the current findings suggest that there may be specificity to the way this relationship unfolds over time. Indeed, recent work has begun to demonstrate specificity to the way unpredictability shapes development (Li et al., 2023). It is not surprising that, in light of the interventional nature of the program in this study, self-regulatory behavior improved across the program overall. However, higher levels of Changepoints in Variance and the Coefficient of Variation were both related to an attenuated increase in teacher ratings of self-regulatory behavior across time in the program. That is, children with higher unpredictability as indexed by these two measures demonstrated slower rate of improvement. Notably, while Changepoints in Variance and the Coefficient of Variation are dynamic statistics, meaning they depend on the order of the time series data, these statistics do not capture information about the direction or degree of change at each change point. This distinction that may matter when considering the impact of change points on child behavior. Again, these results suggest that variability has specific effects on self-regulatory behavior when we are able to account for the mean or examine shifts in variability. It is possible that I did not see effects of the Standard Deviation or Changepoints in Mean on changes in behavior ratings, because these measures are aggregate measures that capture more than just the variability. In contrast, Color of Noise and Entropy (although a trending effect) were associated with faster

rates of improvement in self-regulatory behaviors across the program. Importantly, these two measures are classified as dynamic statistics, meaning they account for additional complexities of time series data and may be better thought of as indicators of the degree of uncertainty of the variability (i.e., uncertain unpredictability vs. certain unpredictability). One explanation for this finding is that children with greater degrees of uncertainty in the variability of their home environments are the most responsive to, and most likely to benefit from, the structured environment instituted by an intervention program like CAPS. Indeed, children from more disadvantaged backgrounds, which are often marked by unpredictability, tend to show more short-term improvement when enrolled in childhood interventions than their more advantaged peers (Burger, 2010). This may reflect increased flexibility which facilitates an increased capacity to adjust to new or changing environments, consistent with evidence that in some cases unpredictability enhances certain aspects of self-regulation and associated processes (Warren & Barnett, 2020; Young et al., 2018)

Utilizing several measures of statistical unpredictability may be especially critical when assessing how social threat, in its many forms, shapes child developmental trajectories. It may be the case that the patterns of unpredictability are integrated into perception of the environment as children learn and direct their behavioral responses. Indeed, recent discourse has highlighted the importance of including multiple measures of unpredictability for comparison within the developmental research (Doom et al., 2024; Young et al., 2020). Recent work comparing dimensions of unpredictability has found interactive effects on outcomes (Farkas et al., 2024). Here, I find that indices of unpredictability are generally related such that higher unpredictability in one measure is associated with greater unpredictability in others. However, there is considerable variability in the observed relationships. For example, I find that Color of Noise is

correlated with all measures of unpredictability used in this study, but the direction of these relationships differs across measures of unpredictability. This finding is in line with findings from Walasek and colleagues (2024) who found color of noise to be negatively correlated with Entropy and Standard Deviation while positively correlated with Changepoints in the Mean and Autocorrelation. These patterns suggest an underlying structure to the data, where unpredictability statistics may cluster in specific ways to indicate meaningful differences in the environment, which has implications for the development of self-regulatory processes and ultimately social behavior.

Together the current research indicates a need for further research examining the characteristics of unpredictability that differentially impact child behavior, cognition, and affect. While previous work has tended to focus on cumulative measures, retrospective measures, or one measure of environmental unpredictability at a time, the current study offers the advantage of examining multiple aspects of unpredictability in my sample simultaneously and prospectively. Future work should focus on identifying patterns in unpredictability statistics within longitudinal datasets examining early environments. One way this can be accomplished is by utilizing cluster analyses, such as k-means cluster analysis, to examine the underlying structure of the data and profiles of unpredictability across individuals. Additionally, I was unable to collect data for more than the one year each child was enrolled in the CAPS program. Therefore, future studies should expand the timeframe across multiple years to obtain additional insights into the ways environmental unpredictability impact the development of self-regulatory behaviors as they unfold across childhood.

Overall, I found that some, but not all, measures of environmental unpredictability are predictive of child self-regulatory behavior, both at the beginning of a preschool intervention

program and across time in the program. These results suggest that different measures of unpredictability in the early environment may influence different processes related to the development of self-regulatory behaviors. The remaining issue is further elucidating the mechanisms through which the different components of environmental unpredictability impact cognitive and affective development, particularly as they relate to the social environment. Future work should focus on expanding the current study to examine the interplay between environment, physiological stress responses, and developmental patterns of affective-cognitive development. Ultimately this work contributes to our understanding of early life stress, with the goal of identifying characteristics of environments that promote healthy development and social connection.

2.5 Appendix A: Chapter 2 Tables and Figures

Statistic	Type	Interpretation
Standard Deviation	Distributional	Average fluctuations around mean level
Coefficient of Variation	Distributional	The relative variability indicating the size of the standard deviation in relation to its mean
Changepoints in Variance	Dynamic	How often variance in levels change across the measurement period
Changepoints in Mean	Dynamic	How often the average level changes across the measurement period
Autocorrelation	Dynamic	The extent to which past values correlate with current values; high absolute autocorrelation indicates high predictability
Entropy	Dynamic	Sample entropy for time series indicates the extent to which similar sequences in values are followed by additional similar values; low entropy indicates long sequences of similar levels
Color of Noise (spectral coefficient)	Dynamic	The extent to which noise in dimensions of the environment is autocorrelated across time lags; often called color of noise

Table 1. Glossary of environmental unpredictability statistics. Follows the framework from Walasek et al. (2024),

	Standard Deviation	Color of Noise	Entropy	Autocorrelation	Change Points in Mean	Change Points in Variance	Coefficient of Variation
Standard Deviation							
Color of Noise	-0.1**						
Entropy	0.44****	-0.3****					
Autocorrelation	0.17****	-0.079*	0.049				
Change Points in Mean	0.65****	0.13****	0.18****	0.24****			
Change Points in Variance	-0.031	0.18****	-0.1**	-0.11***	0.14****		
Coefficient of Variation	-0.47****	0.072*	-0.56****	-0.21****	-0.28****	0.12****	

Table 2. Correlations between measures of unpredictability. The significance levels are indicated as follows: ($p < .05$, $*p < .01$, $**p < .001$, $***p < .0001$).

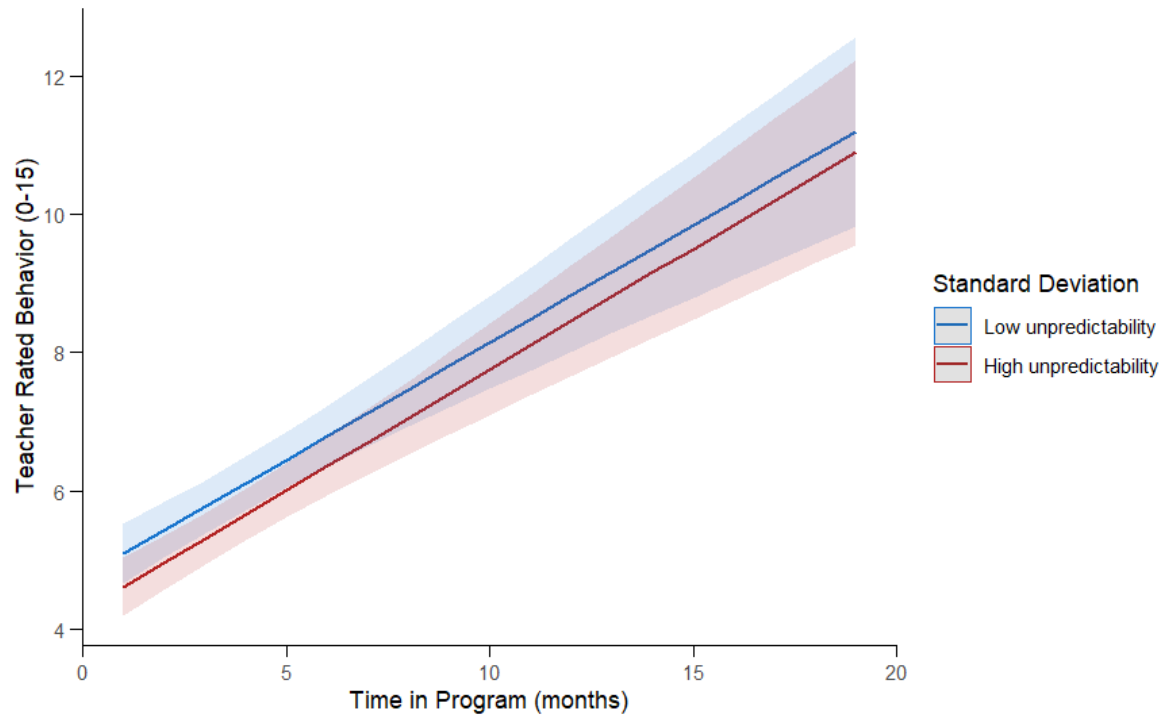


Figure 1. *Changes in teacher ratings of self-regulatory behaviors by Standard Deviation.* Initial behavior ratings were not associated with Standard Deviation of stressors ($\beta = 0.01$, $p = .78$), and no differences were observed between low unpredictability (-1 SD) and high unpredictability (+1 SD) groups in behavior change across time ($\beta = 0.01$, $SE = 0.03$, $p = .87$).

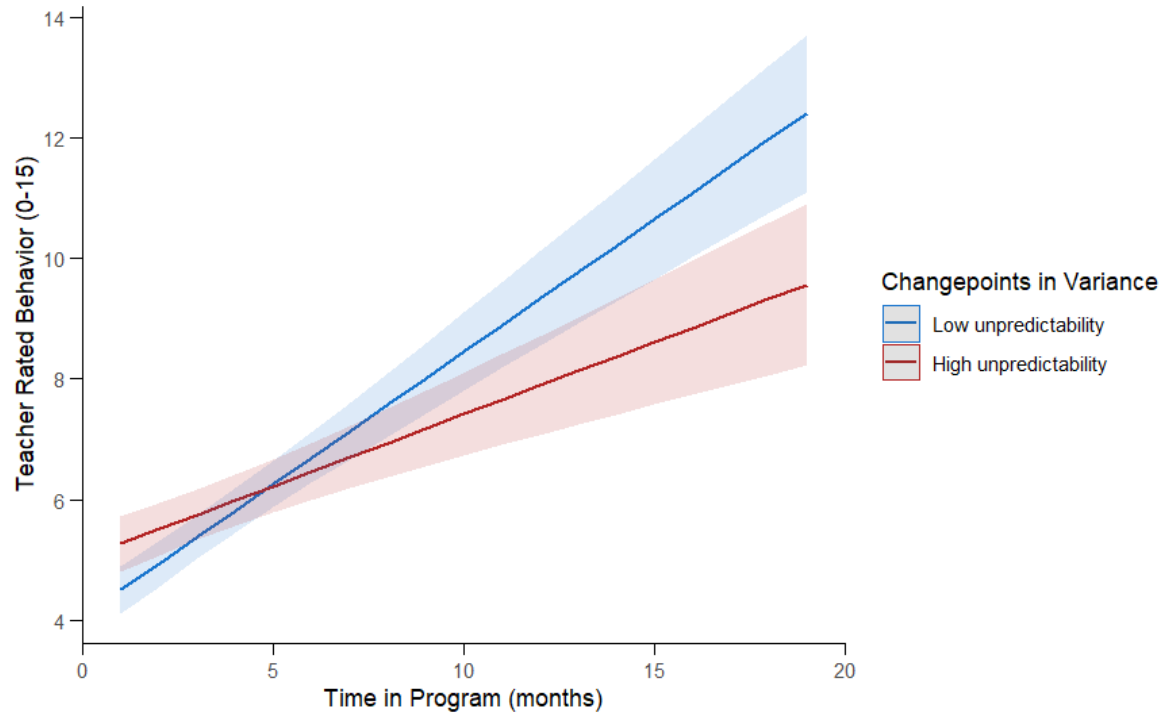


Figure 2. *Changes in teacher ratings of self-regulatory behaviors by Changepoints in Variance.* Greater Changepoints in Variance was associated with higher behavior scores at the beginning of the program ($\beta = 0.48$, $SE = 0.17$, $p = .01$), indicating that more unpredictability as indexed by this measure was related to better behavior ratings. Changepoints in Variance also moderated changes in teacher ratings of self-regulatory behavior across time in the CAPS program ($\beta = -0.10$, $p < .001$). Low unpredictability ($-1SD$) was associated with faster rate of improvement ($\beta = 0.44$, $SE = 0.04$, $p < .001$, 95% CI [0.36, 0.52]) in teacher ratings than high unpredictability ($+1SD$) ($\beta = 0.24$, $SE = 0.04$, $p < .001$, 95% CI [0.15, 0.32]) .

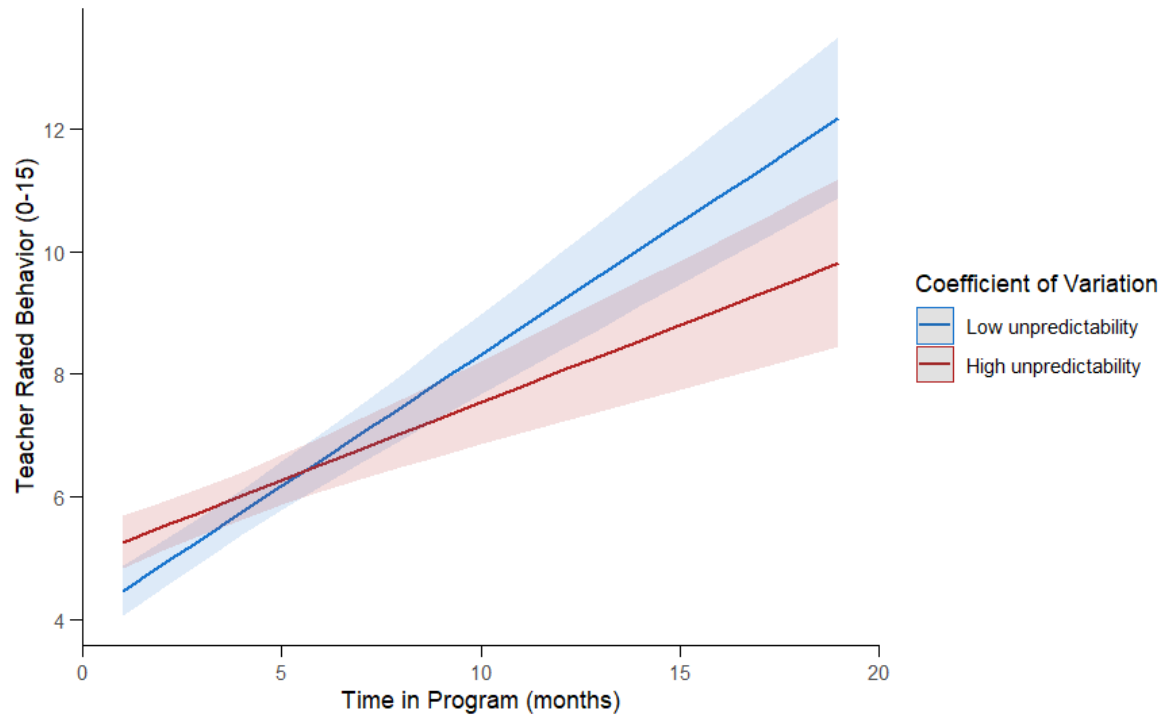


Figure 3. *Changes in teacher ratings of self-regulatory behaviors by Coefficient of Variation.* The Coefficient of Variation was positively associated with behavior scores at the beginning of the program ($\beta = 0.49$, $SE = 0.16$, $p = .003$). The Coefficient of Variation also moderated changes in teacher ratings of self-regulatory behavior across time in the CAPS program ($\beta = -0.09$, $SE = 0.03$, $p = .004$). Low unpredictability ($-1SD$) was associated with faster rate of improvement ($\beta = 0.43$, $SE = 0.04$, $p < .001$, 95% CI [0.35, 0.51]) in teacher ratings than high unpredictability ($+1SD$) ($\beta = 0.26$, $SE = 0.04$, $p < .001$, 95% CI [0.17, 0.33]).

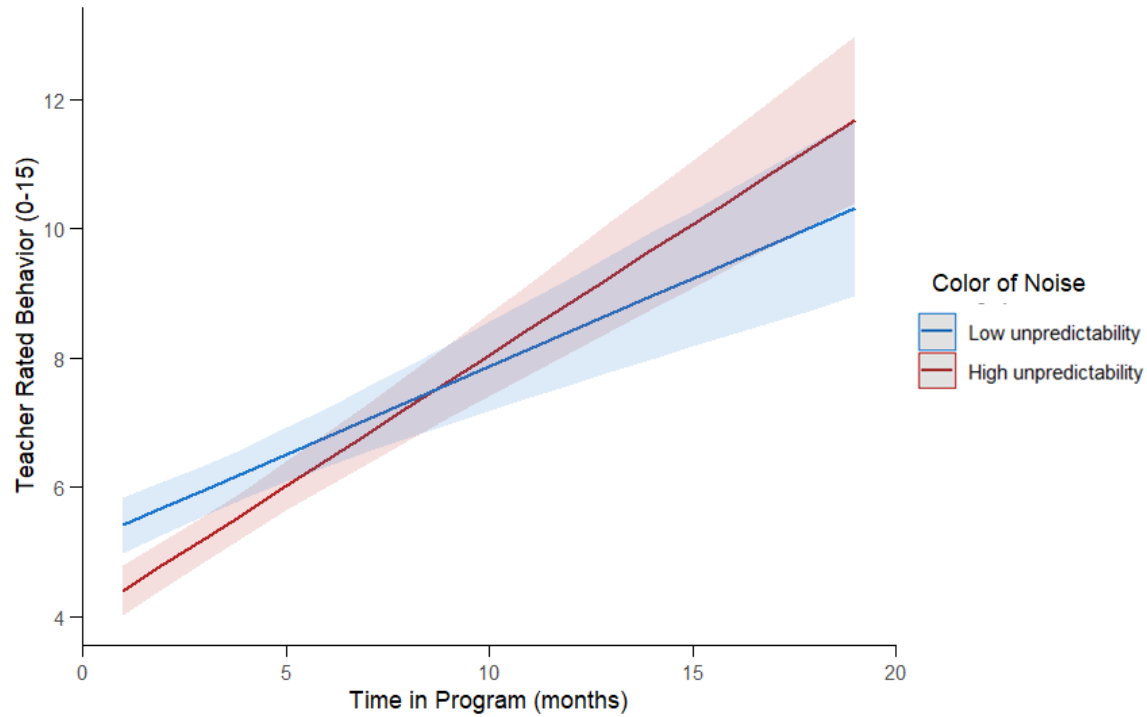


Figure 4. *Changes in teacher ratings of self-regulatory behaviors by the Color of Noise.* Color of Noise was positively associated with behavior ratings at the start of the program ($\beta = 0.57$, $SE = 0.16$, $p < .001$). The Color of Noise also moderated behavioral improvements ($\beta = -0.07$, $SE = 0.03$, $p = .03$), such that individuals with higher levels of unpredictability ($-1SD$) demonstrated greater behavioral improvements ($\beta = 0.41$, $SE = 0.04$, $p < .001$, 95% CI [0.32, 0.48]) as compared to their peers with lower levels of unpredictability ($+1SD$) ($\beta = 0.27$, $SE = 0.04$, $p < .001$, 95% CI [0.19, 0.36]).

Chapter 3: Interpersonal Violence Exposure, Loneliness, and Parasympathetic Activity in Adolescents

3.1 Introduction

Exposure to interpersonal violence is associated with long-term consequences for physical health, psychological well-being, social functioning, and overall quality of life (Finegood et al., 2024; McLaughlin et al., 2013). Interpersonal violence exposure (IVE) refers to violence inflicted upon an individual by another individual or group, which can be directly experienced or witnessed (Talevi et al., 2018), and refers to situations that “either result in or have a high likelihood of resulting in injury, death, psychological harm, maldevelopment or deprivation” (World Health Organization, 2014, p. 82) for the individual who is experiencing or observing the violence. Experiences that qualify as IVE range from physical and sexual abuse, to bullying and even broader community violence (Grych & Swan, 2012; Mercy et al., 2017) and can span various contexts, from the family unit to the larger community.

In adolescence, exposure to interpersonal violence is both prevalent and varied. A national survey revealed that 67.5% of children and adolescents report at least one type of exposure to interpersonal violence, 50% had more than one exposure, and 4.4% reported more than 10 exposures in their lifetime (Finkelhor et al., 2015). Among adolescents ages 14 to 17, rates of physical assault (70%), sexual assault (27%), maltreatment (41%) and witnessing violence (72%) are high (Finkelhor et al., 2015). Higher levels of exposure to interpersonal violence is associated with maladaptive adjustment for mental health, interpersonal functioning, and health risk behaviors (Beauchaine, 2015; Propper & Holochwost, 2013). For example, experiences of direct

victimization and community violence have been associated with higher rates of depression (Cisler et al., 2012), externalizing and internalizing behaviors (Heleniak et al., 2018), anxiety (Margolin et al., 2010), and post-traumatic stress disorder (PTSD; McLaughlin et al., 2013). IVE has also been associated with increased aggression in adolescence (Herts et al., 2012), impulsive behaviors (Monahan et al., 2015) and the perpetuation of interpersonal violence (Foshee et al., 2016). Importantly, there is variability in the way individuals respond to the same types of stressors (K. E. Smith & Pollak, 2020). For example, the majority of adults (60-80%) have been exposed to a potentially traumatic stressor (Overstreet et al., 2017), yet the vast majority of these individuals will not develop pathological symptoms. Similarly, adolescent mental health outcomes following violence exposure have been shown to vary (Miliauskas et al., 2022). Therefore, it is critical to consider contextual factors, including individual physiology, perception, and developmental stage which may contribute to variability in responses following violence exposure in adolescents.

Adolescence is a time of rapid emotional, behavioral, and neural change (Blakemore, 2008; Orben et al., 2020), making it a time where individuals may be particularly vulnerable to the effects of IVE. It is during this time that adolescents begin to seek separation from the family unit through a process of individuation (Blos, 2017) and begin to spend more time with peers and in romantic relationships (Orben et al., 2020), resulting in considerable changes to both the types of social relationships and time spent within those relationships. Social changes occur alongside puberty, a time of rapid neural and physiological changes, including increased neuroplasticity (Marshall, 2016). Pubertal alterations in physical appearance are coupled with maturation of brain regions associated with emotional regulation. Additionally, the maturation of regions that are oriented towards the detection of threat, such as the amygdala and ventral striatum occurs

before maturation of regions that inhibit reactivity, such as the prefrontal cortex (Goossens, 2018; Somerville et al., 2010), which impacts processes related to the regulation of emotions and behaviors. Together, high risk of IVE and developmental changes in brain and behavior during adolescence create contexts in which individuals may be particularly at risk of adverse outcomes.

Violence exposure is associated with shifts in vigilance for social threat and subsequent repeated or sustained activation of stress response systems (e.g., autonomic or neuroendocrine). Indeed, IVE is associated with shifts in affective processes which increase threat vigilance and shape regulation of emotion. Children and adolescents with a history of maltreatment have been shown to identify fearful expressions more rapidly (Masten et al., 2008), suggesting a perceptual sensitivity to cues of interpersonal threat. Adults with a history of IVE have been shown to demonstrate an attentional bias towards cues of interpersonal violence (DePierro et al., 2013b) and enhanced memory for threat-relevant information (Minshew & D'Andrea, 2015). In line with this evidence, neuroimaging studies have demonstrated structural and functional alterations in brain regions involved in threat processing, such as the amygdala and anterior cingulate cortex, among individuals exposed to violence (Tottenham & Sheridan, 2009). Sustained vigilance to threat can result in repeated or chronic activation of stress response systems, such as the autonomic nervous system, and ultimately contribute to both mental and physical health outcomes observed in those with IVE.

Emotion Regulation

Variability in outcomes following IVE may result from differences in emotion regulation strategies used by individuals following violence exposure. According to James Gross's process model of emotion, emotion regulation encompasses the active processes through which individuals manage and modify their emotional experiences, expressions, and physiological

responses (Gross, 2015). According to this model, the process of regulating emotions involves the activation of a goal directed at reducing negative feeling states or increasing positive feeling states. The emotion regulation strategies (e.g., cognitive reappraisal or emotion suppression) an individual will use depends on both the stage in the process (i.e., broad categories of situation selection, situation modification, attentional deployment, cognitive change, and response modulation) and effectiveness of the strategy. Importantly, this emotion regulation framework has been linked to individual outcomes and health-risk (Aldao et al., 2010; Gross & John, 2003). For example, emotion regulation strategies predict symptom severity for PTSD, anxiety, and depression (Boden et al., 2013; Schäfer et al., 2016). Emotion regulation is also impacted by experiences of violence. IVE, occurring both early in life and throughout adolescence and adulthood, has been consistently associated with difficulties in emotion regulation (Burns et al., 2010; Cloitre et al., 2005; Ehring & Quack, 2010). Additionally, existing evidence indicates that difficulties in emotion regulation contribute to trauma symptoms (Simpson et al., 2021; Stevens et al., 2013). Variability in emotion regulation abilities following IVE likely reflect a corresponding orientation towards the detection of and responsivity to perceived threats.

One mechanism that may underly differences in emotion regulation following IVE is autonomic activity. In particular, higher resting parasympathetic nervous system (PNS) activity may be a marker of adaptive flexibility that facilitates regulation of emotions and social engagement (Geisler et al., 2013; Isgett et al., 2017; K. E. Smith & Pollak, 2022; T. W. Smith et al., 2020), serving to cope with violence exposure. The PNS is regulated by higher order neural structures, like the ventromedial prefrontal cortex (vmPFC), which are involved in modulating self-regulatory processes like emotion regulation and social engagement (Critchley et al., 2000; Porges, 2007). Resting PNS activity is associated with social behaviors (e.g., social interaction,

cooperation), social engagement (Geisler et al., 2013), and perceptions of social support in the environment (Beffara et al., 2016; Kemp et al., 2017; Porges, 2003). Resting PNS activity is also considered a marker of threat vigilance (R. Smith et al., 2017), and lower resting PNS activity has been linked to avoidance behaviors and poor regulation of negative emotions in social contexts (Balzarotti et al., 2017; Katahira et al., 2014). Violence exposure is also associated with lower resting PNS activity, which may index decreased emotion regulation capacity (Beauchaine et al., 2007; El-Sheikh & Hinnant, 2011; Rigterink et al., 2010a). This mechanism might therefore also provide insights into shifts in the perception of social threats following IVE and the associated emotion regulation outcomes.

Loneliness

Another variable that has been demonstrated to result in changes in the way individuals perceive the social environment is loneliness. Loneliness is defined by a negative emotional state that arises from the perception of deficits in the desired quantity or quality of social relationships (Cacioppo & Hawkley, 2009, Perlman & Peplau, 1981). Loneliness is thought to serve as cue of unsafety within the social environment, facilitating detection and management of social threat, while simultaneously motivating repair of social connections as a means of preemptively avoiding the dangers of exclusion and subsequent isolation (J. T. Cacioppo & Hawkley, 2009). Importantly, loneliness is associated with shifts towards cognitive and affective processing of social information, particularly any potential cues of social threat (Spithoven et al., 2017). Indeed, loneliness has been associated with increased sensitivity to the detection of negative emotions like sadness and fear (Vanhalst, Gibb, et al., 2015), better recall of negative social information (Gardner et al., 2005; Hess & Pickett, 2010), visual attention towards social threat (Bangee et al., 2014), and increased expectations of social rejection (W. H. Jones et al., 1981).

As is the case with IVE, prolonged perception of social threat induced by loneliness is associated with increased health risk in the long-term (Hawkey & Cacioppo, 2010b; Holt-Lunstad, 2018). Yet studies looking at loneliness have almost exclusively utilized adult samples (Mund et al., 2019), leaving My knowledge of adolescent loneliness more limited, particularly as loneliness relates to other contextual factors, such as exposure to interpersonal violence.

As adolescents transition into the adult social world and experience novel social challenges for the first time, feelings of social isolation may be particularly salient. Temporary bouts of loneliness are a normative part of development (Fardghassemi & Joffe, 2021), and most adolescents are able to cope with feelings of loneliness, providing a beneficial capacity to integrate into social networks. However, some evidence suggests that adolescence is a time of relatively high loneliness, as compared to other points across the lifespan (Hawthorne, 2008). For adolescents who are not able to resolve feelings of loneliness, continued perception of social isolation can have a negative impact. Prolonged experience of loneliness predicts health outcomes in late adolescence (Qualter et al., 2013), and loneliness trajectories predict self-reported social skills, depression, and suicidal ideation (Schinka et al., 2013). Additionally, chronically lonely adolescents are less likely to accept invitations for social inclusion and are less likely to use adaptive emotion regulation strategies (Vanhalst et al., 2018), indicating that lonely individuals may be less likely to access social support. Due to the changing social landscape and developmental shifts during adolescence, this developmental stage is a critical time point to consider when assessing how experience of social threat and loneliness affect long-term outcomes.

Emerging evidence suggests that violence exposure is related to loneliness. For example, recent work shows that adults in an urban environment who report higher levels of violence

exposure also report elevated levels of loneliness (Tung et al., 2019b). Early experiences of abuse and neglect in childhood are also associated with loneliness in adolescence (Barnes et al., 2022) and adulthood (S. F. Allen et al., 2023; de Heer et al., 2022). Peer victimization in adolescence has also been linked to loneliness (Cava et al., 2021; Vanhalst et al., 2014). Together this evidence suggests that violence exposure, whether experienced early or later in life, contributes to shaping the perception of social relationships. When combined with exposure to interpersonal violence, loneliness may color adolescents' view of the social world such that typical social challenges are interpreted as threat, thereby perpetuating stress reactivity and difficulties with emotion regulation. Indeed, increased peer victimization has been associated with increased report of loneliness and more negative evaluation of social networks in adolescents between 10 and 16 years (León-Moreno et al., 2019). Further, some evidence suggests that adolescent loneliness actually increases risk for further exposure to interpersonal violence and abuse (Barnes et al., 2022), suggesting that shifts in the perception of the social environment may contribute to re-victimization and further perpetuate adverse effects of IVE. Given the developmental shifts in social, neural, and behavioral processes in adolescence, it is critical to understand how IVE shapes the way adolescents view their social networks and relationships, and whether an increased vigilance to social threat also shapes affective and behavioral responses via altered emotion regulation.

The combination of increased sensitivity to social threats stemming from both IVE and loneliness may significantly impact how individuals regulate their emotions. Indeed, lonely individuals have been shown to use distinct patterns of emotion regulation, characterized by increased use of strategies such as catastrophizing or emotion suppression and decreased use of cognitive reappraisal strategies (Preece et al., 2021). This evidence suggests that loneliness may

shape the way individuals leverage emotional and contextual information to direct emotion and behavior. Loneliness has also been identified as mediator between IVE and health outcomes more broadly. For example, loneliness has been found to mediate the relationship between adolescent IVE and recurrent headaches, such that lonelier individuals were more likely to suffer somatic effects (Stensland et al., 2014a). Similarly, loneliness has been found to mediate the relationship between shame and health in adolescents and young adults with a history of childhood IVE (Thoresen et al., 2018). This evidence suggests that loneliness may be one potential pathway by which physical and mental health risk increases following violence exposure. Other evidence has shown that loneliness specifically modulates emotion regulation following IVE. A study of Chinese adolescents found that loneliness partially mediated the relationship between difficulties in emotion regulation, depression, and cyberbullying - a form of peer victimization (Jiang et al., 2022). However, evidence linking loneliness to emotion regulation outcomes following IVE is more limited, leaving a gap in our understanding of how IVE and loneliness interact to shape adolescent emotion regulation. Importantly these studies demonstrating contributions of loneliness to responses to IVE utilize a single time point measurement of loneliness and are unable to assess how IVE and loneliness occur over time.

As experiences of IVE accumulate, threat-relevant information is stored and integrated into a schema of the social world, directing social processes, and manifesting in altered perceptions of social threat. Yet the complex interactions between perception of social threat, and emotional, physiological, and behavioral responses in adolescents has yet to be fully described. While IVE has been linked to both difficulties with emotion regulation and loneliness, the way these phenomena interact is not yet clear, particularly as they unfold over time. Therefore, the current study builds on prior work to assesses how IVE across adolescence is

related to the trajectory of emotion regulation abilities and how individual differences in adolescent functioning are shaped by loneliness and individual stress physiology. To assess the trajectories of IVE and loneliness I utilize the MI-STAR dataset, which is a rich longitudinal dataset that uses a combination of data collection methods to track outcomes in a population of adolescent girls exposed to interpersonal violence. Using physiological, emotional, and behavioral measures obtained across an 18-month period, I assessed the unique response patterns across individuals over time and consider individual contextual factors. It is critical to understand the individual differences that drive the spectrum of trajectories following IVE in order to identify individuals most at risk and to create effective targeted interventions.

Consistent with prior work, I predicted that higher IVE reported at the first study visit would be associated with greater difficulties in emotion regulation and more trauma symptoms. Based on evidence linking loneliness to childhood trauma, intimate partner violence, and community violence I also expected that greater exposure to IVE would be associated with a greater likelihood of being lonely. Building from these already established relationships, I predicted that individuals with both increasing loneliness and additional instances of IVE during this 18-month period would demonstrate decreased emotional regulation, more difficulties with emotion regulation, and greater trauma symptoms. I expected that these relationships will be modulated by loneliness and resting parasympathetic activity, such that individuals with higher loneliness and higher IVE and individuals with lower resting parasympathetic activity and higher IVE will both experience the greatest difficulties with emotion regulation and the most trauma symptoms at the start of the study and across the study period.

3.2 Methods

3.2.1 Participants

Participants are a sample of adolescent girls (N = 93) ages 10-15 years. Mean age at baseline was 12.9 (SD = 1.15). The majority of the sample identified as African American/Black (76.3%). Mean parental income was \$38,000 (SD = \$32,000). See Table 1 for demographic information. Participants were recruited from Detroit area high schools, adolescent health clinics, and community agencies. Inclusion criteria included adolescent age of 11-17 years, fluency in English, and obtained parental consent and adolescent assent. Adolescents mental and interpersonal health was assessed at three in-person lab visits spaced 9 months apart (Time 0, Time 1, and Time 2). All measures in the current study were assessed at each time point, and all visits for the proposed study took place at the research lab of PI Simon in Detroit, MI.

3.2.2 Questionnaire Measures

Interpersonal Violence Exposure

Interpersonal violence was derived from responses to the UCLA PTSD Reaction Index Trauma Screener, the Adverse Childhood Experiences Scale, the Conflict in Adolescent Dating Relationships Inventory, the Multidimensional Peer Victimization Scale, and the American Association of University Women Survey of Sexual Harassment in America's Schools. Items were included in the composite score if participants and/or their caregivers answered yes to the teenager having experienced the potentially traumatic event. Data was collected at each time point, allowing for assessment of additional exposures between each time point (e.g., number of exposures between Time 1 and Time 2). I considered two measures of IVE: Time 0 IVE and additional IVE. Time 0 IVE was calculated as the total number of exposures reported at the Time 0 visit. Additional IVE was calculated as the number of additional exposures between Time 0-Time 1 and Time 1-Time 2, respectively.

Loneliness

Loneliness was assessed via a 1-item measure included in the Child Depression Inventory (CDI; Kovacs, 1985). The item asked participants to rate how alone they felt in the last two weeks on a Likert scale ranging from 0 (I do not feel alone), to 2 (I feel alone all the time). Responses were treated as a binary variable to assess whether participants were lonely (responded with 1 or 2) or not lonely (responded 0). Single-item measures of loneliness have been found to be highly correlated with longer scales (e.g. UCLA-Loneliness Scale) and demonstrate reliability and validity in assessing loneliness (Mund et al., 2023).

Emotion Regulation

Emotion regulation strategies were assessed using the Emotion Regulation Questionnaire – Short Form (ERQ-S; John & Gross, 2004). The ERQ-S consists of 6 items measuring two distinct emotion regulation strategies: cognitive reappraisal and expressive suppression. Cognitive reappraisal involves reframing the meaning of emotional stimuli to alter emotional responses, while expressive suppression involves inhibiting emotional expressions. Participants rated each item on a Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree), indicating the extent to which they typically use each emotion regulation strategy. Higher scores on the cognitive reappraisal subscale reflect greater use of cognitive reappraisal, while higher scores on the expressive suppression subscale reflect greater use of expressive suppression. The scale showed moderate internal consistency ($\alpha = 0.72$).

Difficulties with Emotion Regulation

Emotion regulation difficulties were assessed using the Difficulty in Emotion Regulation Scale (DERS; Gratz & Roemer, 2004). The DERS comprises 36 items that measure multiple facets of emotion regulation, including awareness and understanding of emotions, acceptance of emotional responses, ability to engage in goal-directed behavior when experiencing negative

emotions, and the ability to control impulsive behaviors driven by emotions. A 9-item subset of this scale was used to assess goal-directed behaviors, access to emotion regulation strategies, and impulse control. Participants rated each item on a Likert scale ranging from 1 (almost never) to 5 (almost always), indicating the frequency of experiencing various emotion regulation difficulties. Higher total scores on the DERS reflect greater difficulties in emotion regulation. The scale showed high internal consistency ($\alpha = .90$).

Trauma Symptoms

Trauma symptoms were assessed using the UCLA PTSD Reaction Index, a widely used measure for screening and evaluating posttraumatic stress disorder (PTSD) symptoms in children and adolescents. The UCLA PTSD Index includes items covering 5 domains of trauma-related experiences: intrusive thoughts, avoidance behaviors, negative changes in cognition and mood, arousal symptoms, and experiences of dissociation. Participants responded to items based on the frequency of symptoms experienced in the past month. Responses were rated on a Likert scale ranging from 0 (none of the time) to 4 (most of the time), with higher total scores indicating a higher severity of trauma symptoms. The scale showed high internal consistency between subscales ($\alpha = .87$).

Resting Parasympathetic Activity

At each visit, resting parasympathetic cardiac control was measured during a 5-minute period during which the participant was instructed to rest. Cardiovascular measures of parasympathetic cardiac control were derived from an electrocardiogram (high frequency (0.12 - 0.40 Hz) heart rate variability (HF HRV)). HF HRV, an index of vagally mediated rhythmic fluctuations in heart rate during respiration, is a pure measure of parasympathetic cardiac control (Berntson et al., 1997). The electrocardiogram (ECG) was collected using a standard lead II

configuration and measured using a Bionex system (MindWare Technologies LTD, Gahanna, OH). Analysis of the ECG signal was completed with Mindware Technology's HRV software, (Version 3.2.11). Data was visually inspected minute-by-minute and manually edited to remove artifacts. HF HRV was derived from ECG using spectral analysis of the interbeat interval series, sampled at 4 Hz. The interbeat interval series were detrended and end-tapered before being submitted to a fast Fourier transform and integrated over the respiratory frequency band (0.12 - 0.40 Hz).

3.2.3 Data Analytic Strategy

The relationships between IVE and emotion regulation, difficulties with emotion regulation, and trauma symptoms at Time 1 was assessed using Ordinary Least Squares (OLS) multiple regression. IVE was treated as a continuous variable, and loneliness was treated as a binary factor. All models were run with and without outliers (defined as values above or below 3 standard deviations from the mean). Moderation effects were assessed using loneliness and resting PNS activity as separate interaction terms. To probe interactions, the emmeans (Lenth, 2022) and sjPlot (Lüdtke, 2021) packages were used to run simple-slopes analyses and pairwise contrasts for marginal effects. A Generalized Linear Model (GLM) was employed to predict loneliness as a binary factor with IVE as a continuous predictor. In this analysis, loneliness was coded as a binary variable, such as "1" for individuals reporting loneliness and "0" for those not reporting loneliness. A mediation analysis was conducted to explore the indirect effects of IVE on emotion regulation, difficulties with emotion regulation, and trauma symptoms at Time 1 through loneliness as a mediator. The mediate package (Tingley et al., 2014) was utilized for this analysis. The analysis assessed the indirect effect of IVE on the outcome variables through loneliness, controlling for relevant covariates. Effect sizes and significance levels of the indirect

effects were examined to understand the extent to which loneliness mediated the relationship between IVE and the outcomes of interest at Time 1.

Hierarchical linear model modeling (HLM) techniques were used to assess changes in emotion regulation, trauma symptoms, loneliness, and resting parasympathetic activity over the course of the 18-month period. HLM is a complex form of ordinary least squares (OLS) regression which is used to analyze variance in outcome variables when the predictor values are clustered at different levels (Woltman et al., 2012). Because HLM accounts for variance in hierarchically structured data, these models are well-suited for longitudinal data, where observations are nested within time and grouped within each subject. For binary outcome variables, a generalized linear mixed model (GLMM) using a binomial distribution (logit link function) was employed to examine the relationship between binary outcomes and continuous predictors, while accounting for the nested structure of the data. This approach accounts for variation in observed outcomes across individuals over time and handles missing data without need for imputation. RStudio (R version 4.1.2) (RStudio Team, 2020) was used to fit all models. All variables were z-scored ($M = 0$, $SD = 1$) prior to analysis so that coefficients could be used to estimate effect sizes (Lorah, 2018). Models reported below all include covariates age and race, unless otherwise noted. All models were run both with and without outliers identified as 3 standard deviations above and below the mean.

3.3 Results

Initial Violence Exposure History and Emotion Regulation

I first examined the relationship between individuals' history of violence exposure and emotion regulation at Time 0. As expected, greater Time 0 IVE was related to more reported difficulties in emotion regulation ($\beta = 2.57$, $SE = 0.97$, $p = .01$) and more trauma symptoms ($\beta =$

8.94, SE = 2.60, $p = .01$) at Time 0. The utilization of emotion regulation strategies participants reported using at Time 0 were not related to Time 0 IVE ($\beta = 0.10$, SE = 0.61, $p = .88$).

Next, I examined how violence exposure, and emotion regulation changed during the 18-month study period. Violence exposure increased across the study period ($\beta = 0.35$, SE = 0.02, $p < .001$), and individuals who had higher Time 0 IVE reported higher numbers of exposures at all time points ($\beta = 0.61$, SE = 0.14, $p < .001$). I expected my indices of emotion regulation to reflect more difficulties with emotion regulation across the study period. However, contrary to expectations, I found that across the study period difficulties in emotion regulation ($\beta = -1.80$, SE = 0.62, $p = .004$) and trauma symptoms ($\beta = -3.36$, SE = 1.34, $p = .01$) both decreased, while utilization of emotion regulation strategies did not significantly change ($\beta = -0.07$, SE = 0.35, $p = .85$).

Next, I assessed whether individual's prior history of violence exposure predicted changes in emotion regulation across the 18-month period. I found main effects for Time 0 IVE predicting difficulties with emotion regulation ($\beta = 2.52$, SE = 0.87, $p = .004$) and trauma symptoms ($\beta = 7.13$, SE = 2.05, $p < .001$), such that higher Time 0 IVE was associated with greater difficulties and symptoms across all time points. However, Time 0 IVE did not interact with timepoint to predict changes in difficulties with emotion regulation ($\beta = -0.30$, SE = 0.41, $p = 0.46$), trauma symptoms ($\beta = -1.15$, SE = 0.91, $p = .21$), or utilization of emotion regulation strategies ($\beta = -0.07$, SE = 0.28, $p = 0.82$).

Additional Violence Exposure and Emotion Regulation

Next, I examined associations between additional exposure to interpersonal violence during the study period and changes in emotion regulation during the same period. Here, additional IVE was considered as a time-varying predictor. Time 0 IVE was also included as an

additional covariate to control for baseline differences in exposure prior to this study. Additional IVE was associated with changes in trauma symptoms across the program ($\beta = 4.17$, $SE = 1.19$, $p < .001$), such that individuals with fewer additional violence exposures reported no change in trauma symptoms across the study period, while those with more additional exposures reported increases across the same period of time (Figure 5). A simple slopes analysis at one standard deviation above and below the mean for additional IVE was conducted to probe the interaction effect. At lower levels of additional IVE (one SD below the mean), trauma symptoms significantly decreased across time ($\beta = -7.89$, $SE = 1.59$, $p < .001$, 95% CI [-11.03, -4.76]). At higher levels of additional IVE (one SD above the mean), the effect was not significant ($\beta = 0.60$, $SE = 2.14$, $p = .78$, 95% CI [-3.63, 4.83]). Pairwise comparisons indicated a significant difference in these slopes (contrast estimate = 8.49, $SE = 2.29$, $p < .001$).

For difficulties with emotion regulation, there was a main effect of Time 0 IVE ($\beta = 2.04$, $SE = 0.79$, $p = .01$) in predicting difficulties with emotion regulation, but additional IVE did not interact with timepoint to predict changes in difficulties with emotion regulation ($\beta = 0.64$, $SE = 0.62$, $p = .31$) across the study period. Additional IVE also did not interact with timepoint to predict changes in utilization of emotion regulation strategies across the study period ($\beta = -0.08$, $SE = 0.42$, $p = .84$).

Violence Exposure History and Loneliness

Next, I examined the relationship between individual's initial history of violence exposure and loneliness both at Time 0 and across the 18-month study period. As expected, greater Time 0 IVE was associated with a higher likelihood of being lonely at Time 0 ($\beta = 0.81$, $SE = 0.29$, $p = .006$) (Figure 6). The odds ratio (OR) for Time 0 IVE was 2.25 (95% CI [1.30, 4.19]), indicating that for each one-unit increase in violence exposure, the odds of experiencing

loneliness increased by approximately 2.25 times. The likelihood that an individual reported feeling lonely did not significantly change across time points ($\beta = -0.005$, $SE = 0.02$, $p = 0.84$). Time 0 IVE did not predict changes in loneliness across the study period ($\beta = -0.002$, $SE = 0.01$, $p = 0.85$). Additional IVE was also not associated with changes in loneliness across the study period ($\beta = 0.004$, $SE = 0.011$, $p = 0.73$).

Next, I ran separate interaction models to assess whether loneliness moderated associations between violence exposure and emotion regulation at Time 0. I found a significant main effect of loneliness ($\beta = 8.37$, $SE = 02.33$, $p < .001$) on difficulties with emotion regulation, such that lonely individuals reported more overall difficulties with emotion regulation than non-lonely individuals, regardless of Time 0 IVE (Figure 7). However, loneliness did not moderate the relationship between Time 0 IVE and difficulties with emotion regulation at Time 0 ($\beta = -0.94$, $SE = 1.94$, $p = .63$). Loneliness also did not moderate the relationship between Time 0 IVE and trauma symptoms ($\beta = 0.72$, $SE = 4.93$, $p = .88$) or utilization of emotion regulation strategies ($\beta = 1.90$, $SE = 1.32$, $p = .16$).

Next, I ran separate interaction models to assess whether Time 0 loneliness moderated associations between Time 0 IVE and changes in emotion regulation across the 18-month study period. Time 0 loneliness did not interact with Time 0 IVE to predict changes in difficulties with emotion regulation ($\beta = -0.19$, $SE = 1.02$, $p = .85$), trauma symptoms ($\beta = -.41$, $SE = 2.00$, $p = .84$), or utilization of emotion strategies ($\beta = 0.83$, $SE = 0.69$, $p = .23$) across the study period.

Then I allowed all predictors to vary across time to assess how changes in IVE interact with changes in loneliness across time to shape emotion regulation outcomes. I found a significant two-way interaction between time and loneliness ($\beta = -4.35$, $SE = 1.37$, $p = .002$) in predicting difficulties with emotion regulation, as well as main effects for both loneliness ($\beta =$

8.95, SE = 1.87, $p < .001$) and Time 0 IVE ($\beta = 1.58$, SE = 0.72, $p = .03$). Here, lonely individual reported more difficulty with emotion regulation and higher Time 0 IVE was related to more difficulties with emotion regulation, regardless of additional exposures during the study period. A simple slopes analysis for loneliness (lonely vs. not-lonely) was conducted to probe the interaction effect. For lonely individuals difficulties with emotion regulation significantly decreased across time ($\beta = -4.83$, SE = 1.19, $p < 0.001$, 95% CI [-7.19, -2.47]). For not-lonely individuals, difficulties in emotion regulation did not change with time ($\beta = -0.41$, SE = 0.73, $p = 0.57$, 95% CI [-1.85, 1.03]). Pairwise comparisons indicated a significant difference in these slopes (contrast estimate = 4.42, SE = 1.29, $p < 0.001$).

I also found main effects of both loneliness ($\beta = 9.19$, SE = 3.43, $p = .008$) and Time 0 IVE ($\beta = 4.07$, SE = 1.59, $p = .01$) in predicting changes in trauma symptoms across time. Again, loneliness and greater initial IVE were independently associated with greater overall trauma symptoms. However, changes in loneliness did not interact with additional IVE to predict change trajectories of difficulties with emotion regulation over time ($\beta = -0.94$, SE = 1.28, $p = .47$), trauma symptoms ($\beta = 1.68$, SE = 2.46, $p = .50$) or utilization of emotion regulation strategies ($\beta = -1.05$, SE = 0.87, $p = .23$) over time.

Violence Exposure History and Resting PNS Activity

Next, I examined the relationship between individual's initial history of violence exposure and their resting PNS activity both at Time 0 and across the 18-month study period. Time 0 IVE was not associated resting PNS activity at Time 0 ($\beta = -0.12$, SE = 0.13, $p = .36$) or across the study period ($\beta = 0.08$, SE = 0.06, $p = .22$). Resting PNS activity did not change significantly across the three time points ($\beta = 0.04$, SE = 0.09, $p = .61$). Additional IVE did not predict changes in resting PNS activity across the study period ($\beta = 0.04$, SE = 0.09, $p = .67$).

Next, I ran separate interaction models to assess whether resting PNS activity moderated associations between violence exposure and emotion regulation at Time 0. Resting PNS activity significantly moderated the relationship between Time 0 IVE and emotion regulation strategies ($\beta = -1.11$, $SE = 0.50$, $p = 0.03$), such that individuals with lower resting PNS activity and higher Time 0 IVE reported increased use of emotion regulation strategies (Figure 8). This effect appeared to be driven by use of cognitive reappraisal ($\beta = -0.68$, $SE = 0.35$, $p = .05$), rather than use of emotion suppression ($\beta = -0.43$, $SE = 0.31$, $p = .18$). Resting PNS activity did not moderate the relationship between Time 0 IVE and difficulties with emotion regulation ($\beta = -0.94$, $SE = 0.84$, $p = .27$) or trauma symptoms ($\beta = -0.15$, $SE = 2.29$, $p = .95$) at Time 0.

A simple slopes analysis at one standard deviation above and below the mean for resting PNS activity was conducted to probe the interaction effect. At lower levels of resting PNS activity (one SD below the mean), IVE significantly predicted increased use of emotion regulation strategies ($\beta = 1.59$, $SE = 0.78$, $p = .045$, 95% CI [0.04, 3.14]). At higher PNS activity levels (one SD above the mean), the effect was not significant ($\beta = -0.56$, $SE = 0.77$, $p = .47$, 95% CI [-2.10, 0.99]). Pairwise comparisons indicated a significant difference in these slopes (contrast estimate = 2.15, $SE = 0.99$, $p = .03$).

Next, I ran separate interaction models to assess whether Time 0 resting PNS activity moderated associations between Time 0 IVE and emotion regulation across the 18-month study period. I found a significant two-way interaction between Time 0 resting PNS activity and Time 0 IVE in the model predicting use of emotion regulation strategies ($\beta = -0.89$, $SE = 0.41$, $p = .03$). While the overall interaction was significant, simple slopes analysis indicated that Time 0 IVE did not predict emotion regulation strategies at either lower (one SD below the mean; $\beta = 2.31$, $SE = 1.43$, $p = 0.11$, 95% CI [-0.53, 5.15]) or higher (one SD above the mean; $\beta = 1.73$, SE

= 1.07, $p = 0.11$, 95% CI [-0.39, 3.86]) levels of resting PNS activity. Pairwise comparisons did not indicate a significant difference in these slopes (contrast estimate = 0.58, SE = 0.36, $p = 0.11$).

Additionally, Time 0 resting PNS activity did not interact with Time 0 IVE to predict change trajectories of difficulties with emotion regulation ($\beta = 0.12$, SE = 0.38, $p = .75$), trauma symptoms ($\beta = 0.01$, SE = 0.87, $p = .99$), or utilization of emotion regulation strategies ($\beta = 0.38$, SE = 0.28, $p = .17$).

Then I allowed all predictors to vary across time to assess how changes in IVE interact with changes in resting PNS activity across time to shape emotion regulation outcomes. Changes in resting PNS activity did not interact with additional IVE to predict changes in difficulties with emotion regulation ($\beta = 0.79$, SE = 0.66, $p = .23$), trauma symptoms ($\beta = 0.09$, SE = 1.26, $p = .94$), or utilization of emotion regulation strategies ($\beta = -0.42$, SE = 0.42, $p = .33$) across time.

Loneliness and Resting PNS Activity as Time 1 Mediators

Finally, I conducted a mediation analysis to examine the role of loneliness in mediating the association between IVE and difficulties with emotion regulation. The analysis, employing nonparametric bootstrap confidence intervals, revealed a significant total effect of IVE at T0 on difficulties with emotion regulation ($\beta = 4.19$, $p < 0.001$), indicating that higher levels of interpersonal violence exposure were associated with increased difficulties in emotion regulation. The indirect effect (ACME) demonstrated that Loneliness significantly mediated the association between IVE at T0 and difficulties with emotion regulation (ACME = 1.13, 95% CI [0.01, 2.81], $p = .05$). In other words, individuals who experienced greater interpersonal violence were more likely to feel lonely, which, in turn, contributed to their difficulties in regulating

emotions (Figure 9). Importantly, even after accounting for this mediation effect, the direct effect of IVE at T0 on difficulties with emotion regulation remained significant (ADE = 3.05, 95% CI [0.48, 2.46], $p = .006$). Approximately 27% of the total effect was mediated by Loneliness (Prop. Mediated = 0.27, $p = .05$). When covariates were included in the model, the total effect mediated by Loneliness was 29% however the effect became marginally significant (Prop. Mediated = 0.29, $p = .076$).

The indirect effect of Loneliness on trauma symptoms through IVE at T0 was marginally significant (ACME = 1.64, $p = 0.10$), and Loneliness did not mediate the relationship between initial IVE and utilization of emotion regulation strategies (ACME = 0.15, $p = .50$).

3.4 Discussion

Regulating emotions is critical for effectively navigating complex and dynamic social situations, which often require a capacity for flexible and nuanced affective and behavioral responses. Exposure to violence is linked to emotion regulation abilities, particularly in adolescence. However, the relationship between violence exposure and loneliness in contributing to variability in emotion regulation abilities in adolescents has yet to be fully elucidated. This study used a longitudinal approach to examine how both lifetime and recent IVE interact with loneliness to shape emotion regulation in adolescent girls over an 18-month period. I found that greater lifetime history of violence exposure is associated with increased likelihood of experiencing loneliness. Loneliness and higher cumulative life history of IVE were also both associated with increased difficulties with emotion regulation overall. Study participants reported significant increases in exposure to violence across study visits, yet difficulties with emotion regulation and trauma symptoms decreased across the same period. Additionally, resting PNS activity interacted with history of IVE to predict the use of emotion regulation strategies. However, there was no evidence that either loneliness or resting PNS activity modulated how

individuals responded to additional exposures to violence across the course of the study.

Together, this evidence suggests that early life violence exposure and loneliness contribute to emotion regulation in adolescent girls.

The current findings add to the existing literature linking violence exposure to loneliness. My finding that greater IVE reported at the first study visit was associated with loneliness is consistent with evidence linking both childhood trauma (Barnes et al., 2022; Wang et al., 2022) and adult exposure to violence (Tung et al., 2019a) to loneliness. The current findings may be explained by the way exposure to violence shifts perception of social information, which can lead to feelings of social isolation. Indeed evidence shows that experience of early life stress (e.g. physical abuse) shifts perceptual processes towards the detection of cues of social threat (e.g. facial expressions of anger; Pollak & Tolley-Schell, 2003). Similarly, lonely individuals demonstrate biases towards the detection and processing of negative social information (Bangee et al., 2014; J. eun Shin & Kim, 2019; Spithoven et al., 2017). Current frameworks of loneliness suggest that increased vigilance for social threat can perpetuate loneliness by increasing expectations of negative social experiences and creating a feed-forward cycle of perceived social isolation (Hawkey & Cacioppo, 2010b; Spithoven et al., 2017). Notably, while I found that lifetime history of IVE was associated with loneliness, I did not find that additional exposures to violence predicted loneliness across the study period. Because IVE reported at the first study visit was a cumulative measure of exposure to violence in childhood and adolescence, it likely captures different aspects of violence exposure than more recent exposures. In particular, earlier violence exposure, in childhood as opposed to adolescence, is likely to have more profound effects on psychological functioning. Indeed, studies that find greater risk of adverse psychological outcomes for earlier violence exposure in childhood than for more recent violence

exposure in adolescence (Dunn et al., 2013, 2017). In combination with my findings, this evidence suggests that IVE earlier in life may be most impactful for adolescent loneliness.

My study also reveals a connection between interpersonal violence and increased difficulties in emotion regulation among violence-exposed adolescents, with loneliness emerging as a significant pathway through which this relationship unfolds. Specifically, I observed that loneliness partially mediates the relationship between a history of violence exposure and difficulties in regulating emotions. Trauma symptoms exhibited a similar trend, although the mediation effect of loneliness did not reach significance. These findings align with prior research indicating that loneliness acts as a partial mediator between violence exposure and subsequent health risk (Stensland et al., 2014b; Thoresen et al., 2018). I also found that lonely individuals faced overall more difficulties with emotion regulation across different time points in the study. These findings may reflect both the increased vigilance for threat that lonely individuals experience (Spithoven et al., 2017) and the differential use of emotion regulation strategies employed by lonely individuals (e.g. increased rumination and catastrophizing; Preece et al., 2021), resulting in a perception of less ability to regulate emotions. However, while I found that exposure to violence increased across the study period, I also observed improvement difficulties with emotion regulation across the same time period. While IVE at Time 0 was strongly associated with both more difficulty regulating emotions and more trauma symptoms, increased exposure to violence was not paralleled by increased difficulties in these areas across the study. One possible explanation for this finding is that adolescents are developing more mature and effective coping skills and emotion regulation strategies during this time.

Indeed, emotion regulation strategies have been shown to develop across adolescence and into adulthood (McRae et al., 2012), and during adolescence individuals begin to implement new

emotion regulation strategies more effectively (e.g. cognitive reappraisal; Silvers, 2022). Therefore, subjects in the current study may have been following a normal developmental trajectory of expanding their abilities to regulate emotions. However, I did not observe increases in self-report of the two emotion regulation strategies assessed in the current study - cognitive reappraisal and emotion suppression. This finding may indicate that the reduction in difficulties with emotion regulation was related to other emotion regulation strategies not captured here. For example, participants may have engaged in more help-seeking behaviors, allowing them to access the emotional or material resources necessary to cope with additional violence exposure. Indeed, adolescents who seek help from friends, caregivers, or teachers following IVE experience fewer trauma symptoms (Tummala-Narra et al., 2014). Other forms of emotion regulation that may have changed include decreases in rumination, catastrophizing, and withdrawal, or increases in active approach strategies (Garnefski & Kraaij, 2007). Another explanation for these findings is that individuals exposed to higher levels of IVE over time shift the way they categorize what constitutes a “social threat,” calibrating future expectations based upon prior experience. In this case, individuals with high IVE may have a higher threshold for what is considered a social threat. This shift in perception of social threat may in part explain the observed increased risk of re-victimization for individuals with a history of high IVE (Auslander et al., 2018; Frugaard Stroem et al., 2019). Additionally, while overall trauma symptoms decreased across the study, I found that individuals who experienced more violence exposures during the study period also reported more increases in trauma symptoms. This is consistent with prior work showing that recent exposure to violence is associated with subsequent increased risk for PTSD (Hedtke et al., 2008). Understanding the intricate relationship between loneliness,

emotion regulation difficulties, and trauma symptoms can inform targeted strategies to enhance mental health outcomes in individuals with histories of violence exposure.

Finally, my analysis revealed a relationship between violence exposure, resting parasympathetic activity, and use of emotion regulation strategies for adolescent girls. Initially, the expectation was that resting PNS activity would moderate the relationship between IVE and the use of emotion regulation strategies such that individuals with higher resting PNS activity and more IVE would employ greater use of emotion regulation strategies. Resting PNS activity has been associated with differences in emotion regulation and decision-making (Koenig, 2020; Porges, 2007; K. E. Smith & Pollak, 2022; Thayer & Lane, 2000), with higher resting PNS activity typically being associated with more flexible emotion regulation and less sensitivity to threat. Contrary to expectations, the current results revealed that individuals with lower resting PNS activity reported increased use of emotion regulation strategies. One explanation for this finding is that lower PNS activity might index increased sensitivity to threat for individuals with higher violence exposure. Indeed, IVE is linked to altered threat sensitivity (Kimble et al., 2013; Shackman et al., 2007; Weissman et al., 2020). An increased vigilance for threat may prompt individuals to employ more active emotion regulation strategies as a means of managing these emotional experiences effectively. Indeed, internalizing symptoms in adolescents are linked to lower resting PNS activity and is thought to be a risk factor for later development of depression (Koenig, 2020). A heightened vigilance towards threat may also lead to increased activation of emotion regulation mechanisms as a means of adapting to and mitigating the impact of perceived threats. Therefore, the observed pattern of increased use of emotion regulation strategies among individuals with lower resting PNS activity following violence exposure may reflect an adaptive response aimed at recalibrating expectations, managing threat sensitivity, and promoting

resilience in the face of ongoing challenges. Alternatively, these results may be reflective of more general variability in the relationship between resting PNS activity and regulatory processes during adolescence. Indeed, meta-analytic data show that the strength of associations between resting PNS activity and self-regulatory processes are greater for adults than youths (Holzman & Bridgett, 2017). However, more work is needed to disentangle the effects of violence exposure and the development of emotion regulation abilities, particularly related to autonomic physiology and coping strategies in adolescence.

The current study demonstrates several strengths. Firstly, the study benefits from a sample that includes a historically understudied population, with a majority of participants being Black and from urban areas. Secondly, the study employs a longitudinal design, aligning with current frameworks on loneliness that underscore the significance of temporal dynamics (Cacioppo & Hawkley, 2009; Qualter et al., 2015; Spithoven et al., 2017). These frameworks emphasize that the evolution of social perceptions over time is crucial for understanding how risk for adverse mental and physical health outcomes unfold over time. Moreover, while many studies examining violence exposure and related responses typically rely on a single time point, my prospective longitudinal design allows for a more nuanced exploration of how IVE, loneliness, and PNS activity change across time. Furthermore, the study utilizes a comprehensive measure of IVE that encompasses childhood experiences, peer interactions, and other forms of trauma. By incorporating a broader range of IVE experiences, my study provides a more holistic perspective on the relationship between IVE, loneliness, and related outcomes. These strengths not only enhance the utility of my findings but also contribute to a more nuanced understanding of the interplay between loneliness, violence exposure, and well-being among adolescent girls.

However, there are also limitations that should be acknowledged. Firstly, I was unable to distinguish between chronically lonely individuals and those experiencing more short-term loneliness, as My measure of loneliness assessed acute feelings (in the last two weeks). While I did examine changes over time, it may be useful for future work to differentiate between the effects of acute versus chronic loneliness. Additionally, my study utilized cumulative measures of IVE at each time point and relied on retrospective reports of violence exposures. Cumulative measures have been shown to reliably predict outcomes following violence and stress exposures, however additional explanatory power may be gained from more nuanced measures (e.g. measures of perception; (K. E. Smith & Pollak, 2020). Future research that delves into the specific types and timing of IVE could offer deeper insights into its effects on loneliness and related outcomes. Last, my sample consisted of a primarily Black, low-income population, which limits the generalizability of My findings. Researching these questions with a more representative sample can assist in evaluating if they are comparable across various populations.

Overall, this study unravels the interplay among IVE, emotion regulation difficulties, loneliness, trauma symptoms, and resting parasympathetic activity in adolescent girls. It highlights loneliness as a significant mediator between violence exposure and challenges in regulating emotions, shedding light on a critical pathway in mental health outcomes. The findings suggest a complex dynamic where adolescents may develop enhanced coping skills despite increased violence exposure, possibly due to adaptive responses to threat sensitivity. Finally, resting PNS activity may be one marker of coping via emotion regulation strategies in the face of violence exposure, however further research is needed to fully elucidate these relationships. In conclusion, my findings highlight the importance of considering both individual

and contextual factors in understanding the effects of violence exposure on emotional and psychological well-being in adolescence.

3.5 Appendix B: Chapter 3 Figures

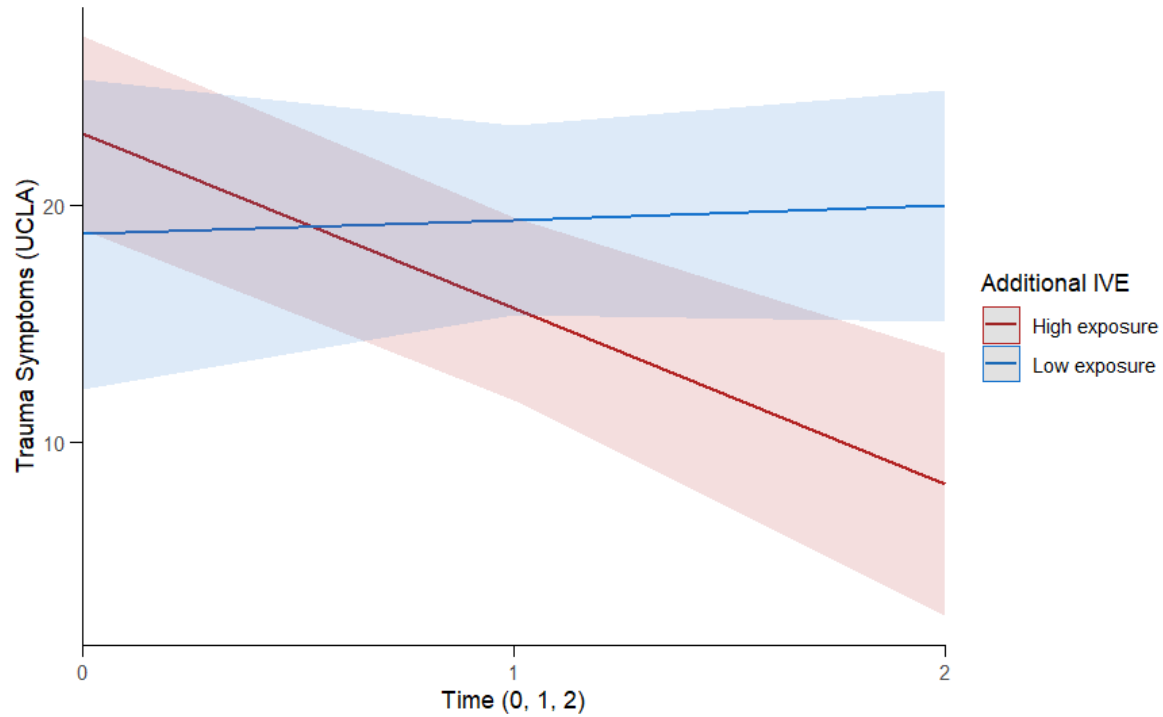


Figure 5. *Additional IVE and trauma symptoms.*

Increases in exposure to violence were associated with changes in trauma symptoms across the study period ($\beta = 4.17$, $SE = 1.19$, $p < .001$). Time 0 was the first study visit, Time 1 was 9 months later, and Time 2 was 18 months after the first visit. Higher levels of additional exposure (+1SD) were not associated with changes in trauma symptoms ($\beta = 0.60$, $SE = 2.14$, $p = .78$, 95% CI [-3.63, 4.83]), while lower additional violence exposure (-1SD) was associated with decreasing symptoms ($\beta = -7.89$, $SE = 1.59$, $p < .001$, 95% CI [-11.03, -4.76]).

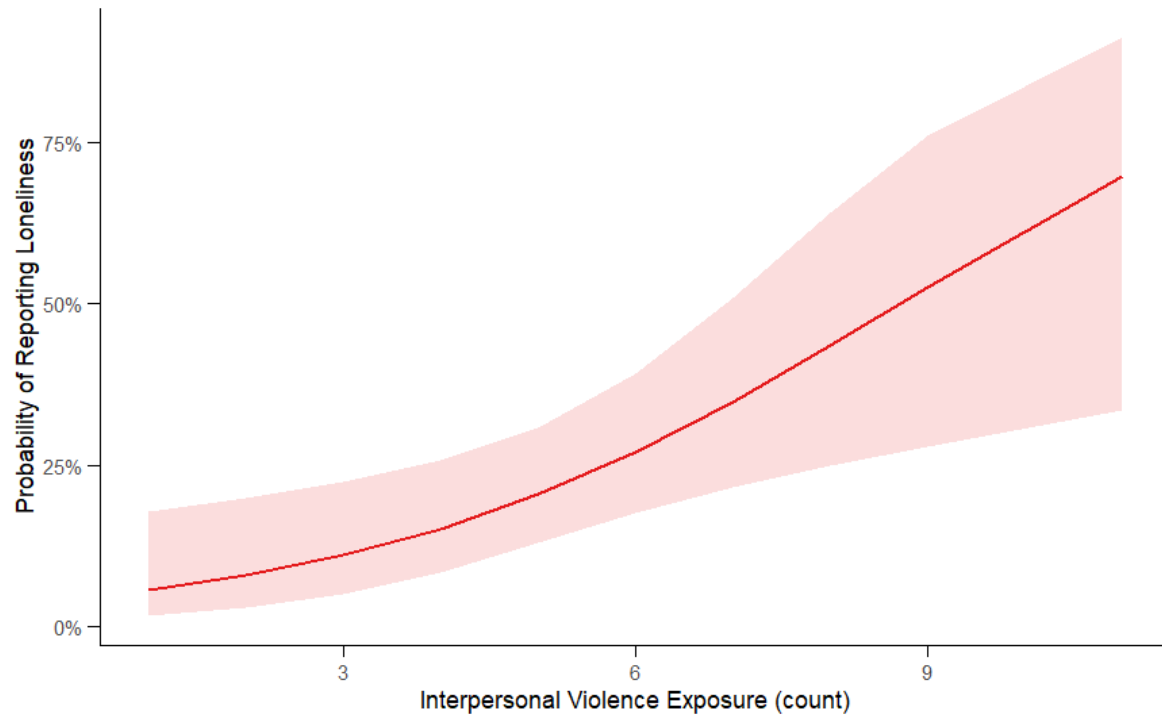


Figure 6. *Relationship between IVE and loneliness at Time 0.*
At Time 0 (the first study visit) greater history of violence exposure was associated with increased likelihood of reporting loneliness ($\beta = 0.81$, $SE = 0.29$, $p = .006$).

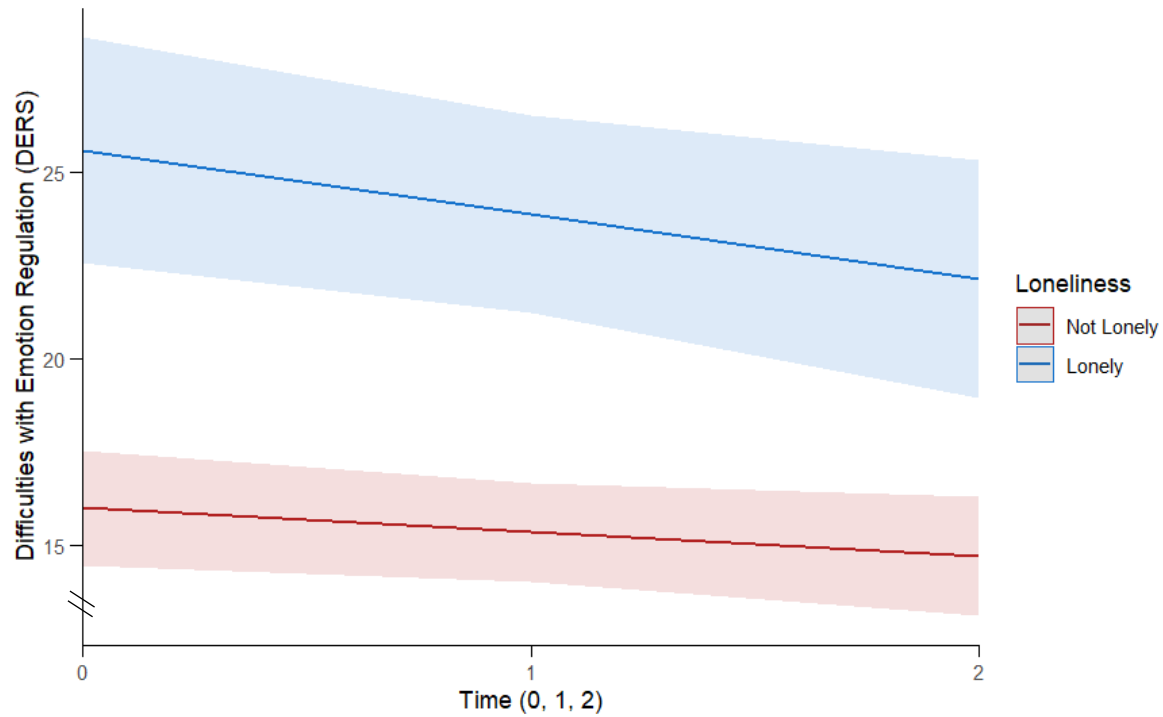


Figure 7. *Time 0 Loneliness and difficulties with emotion regulation across time points.* Loneliness reported at Time 0 (the first study visit) had a significant main effect on difficulties with emotion regulation ($\beta = 8.37$, $SE = 2.33$, $p < .001$). Individuals who reported being lonely at Time 0 had greater difficulties with emotion regulation across the study period at Times 1 (9 months after the first study visit) and 2 (18 months after the first study visit).

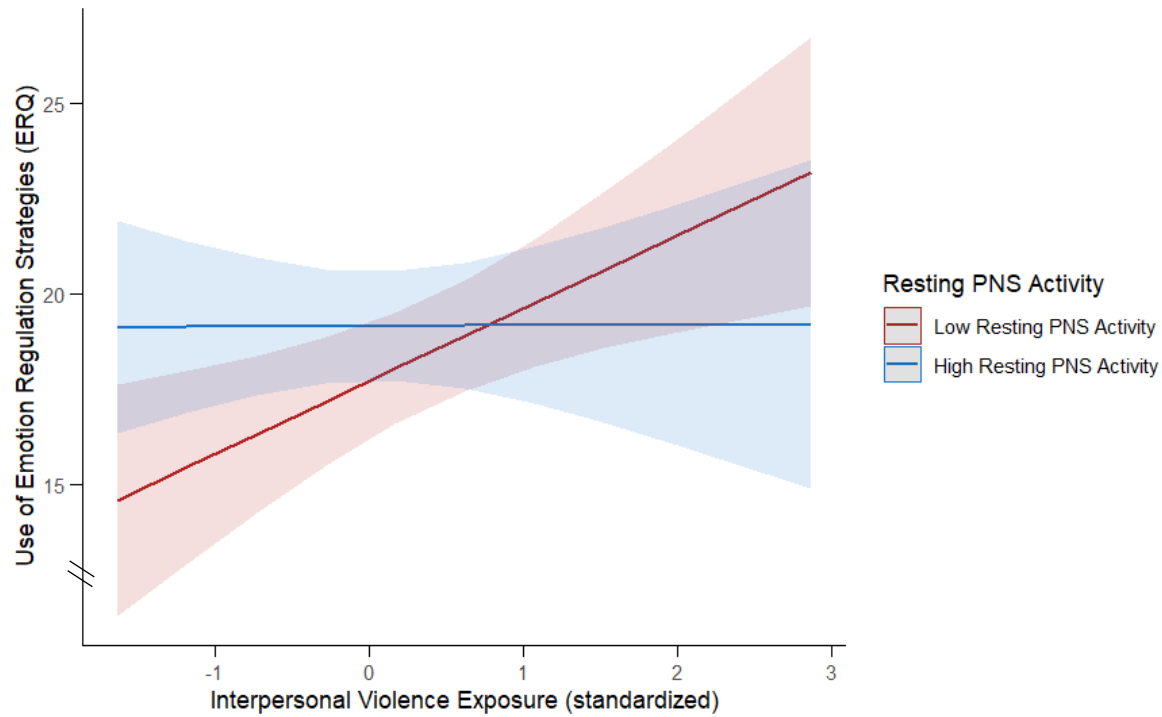


Figure 8. *History of interpersonal violence exposure, resting parasympathetic activity, and use of emotion regulation strategies*

At Time 0 (the first study visit) resting PNS activity interacted with history of IVE to predict utilization of emotion regulation strategies ($\beta = -1.11$, $SE = 0.50$, $p = 0.03$). Lower resting PNS activity (-1SD) predicted an increase in the use of emotion regulation strategies with increases in IVE ($\beta = 1.59$, $SE = 0.78$, $p = .045$, 95% CI [0.04, 3.14]). Higher resting PNS activity was not associated in differences in use of emotion regulation strategies as IVE increased ($\beta = -0.56$, $SE = 0.77$, $p = .47$, 95% CI [-2.10, 0.99]).

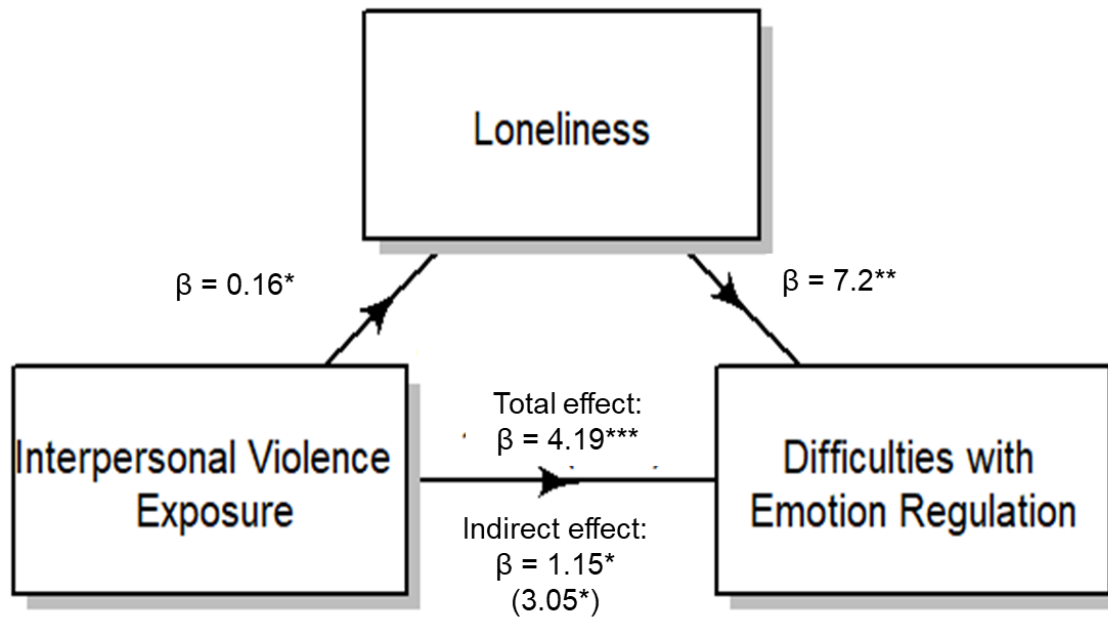


Figure 9. Loneliness mediates the relationship between IVE and Difficulties with Emotion Regulation.

The effect of history of IVE on difficulties with emotion regulation was partially mediated via the loneliness at Time 0 (the first study visit). As Figure 9 illustrates, the regression coefficient between IVE and difficulties with emotion regulation and the regression coefficient between loneliness and difficulties with emotion regulation was significant. The indirect effect (ACME) was $(.16) \times (7.2) = 1.15$. The significance of this indirect effect was tested using bootstrapping procedures. The bootstrapped unstandardized indirect effect was 1.15, and the 95% confidence interval ranged from .001 to 2.81. Thus, the indirect effect was statistically significant ($p = .05$). The average direct effect (ADE) is shown in parentheses, demonstrating the direct effect of IVE on difficulties with emotion regulation when controlling for loneliness. Note, * $p < .05$, ** $p < .01$, *** $p < .001$.

Chapter 4: Autobiographical Memory Following Social Threat

4.1 Introduction

In our daily lives, we often turn to memories of our past to calibrate expectations of stressful situations and guide our responses. Drawing upon prior personal experiences – autobiographical memories – can facilitate effective stress responses by integrating information about the past with current need states to generate dynamic and efficient responses. Importantly, autobiographical memories are not direct replications of past events, but are flexibly constructed when retrieved (Addis et al., 2007; Holland & Kensinger, 2010). Stress has been shown to modify the way these memories are reconstructed (Debeer et al., 2012a; Schwabe & Wolf, 2010), and disruptions to the process of retrieving and reconstructing autobiographical memories has been associated with the development of psychopathology, such as post-traumatic stress disorder (PTSD; Brown et al., 2013). In addition to calling upon past experiences, we can also generate imagined future scenarios to calibrate expectations and behavior. Termed episodic future thinking, the simulation or imagination of future experiences uses overlapping cognitive mechanisms and brain networks as the retrieval of autobiographical memory (Addis et al., 2007; Szpunar, 2010). Some evidence suggests that episodic future thinking may be similarly impacted by stress (Hallford et al., 2018; Lalla & Sheldon, 2021a), but there remains a need to fully elucidate how acute stress shapes the way individuals imagine future events. Investigation of the relationships between acute stress and both past and future-oriented memory processes can provide insight into how individuals use prior experiences and expectations of the future to direct behavior. Here, I investigate how acute psychosocial stress affects different stages of memory

retrieval and future simulation of events. Specifically, I consider how the effects of acute stress are shaped by individual stress responses, measured by physiological reactivity.

Acute Stress and Episodic Memory

Acute stress has been found to affect episodic memory across stages, including memory encoding, consolidation, and retrieval (Buchanan & Tranel, 2008; Wolf, 2017). Both the timing of stress and emotion affect how memory is impacted. While stress at encoding often enhances memory, and particularly memory for details relevant to the stressor, stress during retrieval has generally been shown to impair memory (de Quervain et al., 2017; Gagnon & Wagner, 2016). Without the presence of stress, memories that are highly negative or highly positive are more easily accessed and recalled (Holland & Kensinger, 2010; Kensinger & Ford, 2020). However acute stress during or prior to retrieval attenuates these effects, resulting in larger impairment for emotionally valenced content than for neutral content (Shields et al., 2017). For example, induction of acute psychosocial stress reduces free recall of positive and negative words (Kuhlmann et al., 2005). Importantly, many of the same brain regions that are involved in memory processes (e.g. hippocampus, amygdala, and prefrontal cortex) are also involved in generating and modulating stress responses (de Quervain et al., 2017; A. P. Yonelinas & Ritchey, 2015).

Stress effects on memory are facilitated by two primary stress response systems – the sympathetic nervous system (SNS) and the hypothalamic-pituitary-adrenal (HPA) axis. When stress occurs around the time of encoding, SNS activation is generally thought to contribute to memory enhancement, while cortisol release from the HPA axis contributes to memory impairment (Gagnon & Wagner, 2016). At retrieval SNS activity is linked to impaired retrieval of long-term memories (Buchanan & Tranel, 2008; de Quervain et al., 2017; Smeets, 2011).

Moreover, stress-induced increases in noradrenergic activity are linked to impaired executive function, such as working memory and cognitive flexibility, in areas associated with memory retrieval (Arnsten, 2009; Gagnon & Wagner, 2016; Shields et al., 2017). Thus, there is a close relationship between stress and memory processes, which has implications for how individuals are able to access and use information about their past when confronted with novel stressors.

Acute Stress and Autobiographical Memory

Importantly, stress can also affect autobiographical memory. Like all episodic memories, autobiographical memories are actively and dynamically reconstructed at retrieval, leaving them prone to memory biases and modification. Initial findings of overgeneralized autobiographical memories in clinical populations support the idea that stress may affect autobiographical memory specificity (Buss et al., 2004; J. M. G. Williams & Broadbent, 1986). Other forms of chronic stress, such as childhood trauma, have also been linked to overgeneral autobiographical memory recall (Aglan et al., 2010; Crane et al., 2014). Similarly, acute stress is thought to reduce the specificity, or amount of detail, in retrieval of autobiographical memories. For example, individuals exposed to an acute psychosocial stressor provide more overgeneral autobiographical memories after the stressor as compared to the level of detail for memories they provide prior to a stressor (Debeer et al., 2012). Other evidence demonstrates no difference in memory specificity for autobiographical memory retrieval immediately following acute stress (Sheldon et al., 2018; Tollenaar et al., 2009). Findings related to the effects of stress on reconsolidation of autobiographical memories are also mixed. Sheldon and colleagues (2018) found increased memory specificity for negatively valenced memories for individuals in the stress condition following a 3–4-day delay. The authors of the study suggest that acute stress impairs autobiographical memory accessibility in the moment but increases accessibility of these

memories over time by boosting encoding/reconsolidation of memories. However Schwabe and Wolf (2010) found that stress following retrieval of autobiographical memory has the opposite effect and impairs memory following reconsolidation (Schwabe & Wolf, 2010). Together this evidence suggests that the effects of stress on autobiographical memory depend on timing of stress and valence of content.

Deficits in memory detail have the potential to impact individual ability to utilize past information for adaptive responding. For example, overgeneral autobiographical memory has been linked to reduced problem solving ability (J. Evans et al., 1992; J. M. G. Williams et al., 2006), particularly on social problem solving tasks (Sutherland & Bryant, 2008). An impaired ability to effectively use past experiences to guide future behaviors and navigate complex social situations is likely to contribute to difficulties with emotion regulation and altered threat calibration associated with psychopathology. Indeed, overall reductions in autobiographical memory specificity have been found to predict mental health outcomes, including depression and PTSD (Kleim & Ehlers, 2008). However further research is needed to more fully elucidate the mechanisms that underlie the modification of memory recall under acute stress, including how valence of memories interacts with stress to amplify or reduce memory detail.

Episodic Future Thinking

The ability to imagine future events that have not yet occurred is thought to be adaptive, allowing individuals to adjust behavior flexibly and problem solve effectively (Madore & Schacter, 2014). Episodic future thinking relies on similar processes as the retrieval of past events and allows individuals to generate and mentally rehearse novel scenarios. For example, fMRI studies have found similar patterns of neural activation when individuals remember past events and imagine future ones (Addis et al., 2007; Benoit & Schacter, 2015). This suggests that

the ability to call on details from the past may increase one's ability to project details into the future. Indeed, individuals with high specificity in autobiographical memory also show higher specificity in episodic future thinking (Khan & Haque, 2022). Future events tend to be imagined with less specificity (J. M. G. Williams et al., 1996) and contain more positive content than past events (Salgado & Berntsen, 2020). Moreover, future positive events are rated as more detailed and easier to access than negative future events (Gallo et al., 2011). Further, the ability to think about a more detailed and vivid future is related to overall well-being (MacLeod & Conway, 2007), and envisioning positive future events aids coping following acute stress (Zheng et al., 2021). Future thinking may therefore be thought of as a form of emotion regulation, allowing individuals to modulate affective states and cope with current or future stressors.

Because the anticipatory simulation of future events relies on the same mechanisms as autobiographical memory, it is likely impacted by acute stress in a similar manner. Indeed, evidence suggests stress is related to the specificity and availability of imagining future events (A. D. Brown et al., 2014). For example, decreased specificity in future episodic thinking is associated with stress-related disorders, including PTSD (Ward, 2016), depression (Hallford et al., 2020) and anxiety (Miloyan et al., 2016). More generally, higher life stress has been associated with increased difficulty in accessing positive scenarios (past and future) and lower self-reported likelihood of participating in new positive future experiences (Lalla & Sheldon, 2021b). Differences in daily affect have also been associated with specificity of memory for the past as well as specificity in anticipating future events. Individuals with a greater bias towards negative past-oriented rumination show reduced specificity in day-to-day thinking about both the past and future (Beaty et al., 2019). Together this evidence suggests that stress, and the associated differences in cognitive and affective processes, shape imagination of the future.

However, the effect of acute stress on episodic future thinking has yet to be fully explored, and few studies have directly investigated a manipulation of acute stress in relation to the simulation of future events. This line of research may be fruitful, considering the associations between memory and acute stress.

The Current Study

For the current study I build upon prior work to examine how acute psychosocial stress shapes memory for personal experiences and the generation of imagined futures. To do this, I employed a longitudinal study design to observe how emotional valance, stress, and timing affects these personal events. First, all participants completed a modified version of the Autobiographical Memory Test (AMT; Figure 10) and provided memories and imagined future events without the presence of stress. Then, I used a psychosocial stress induction to examine how the detail and difficulty of generating the same personal past and future events changed immediately following acute stress. Finally, I explored how stress shapes reconsolidation of events by having participants return after a delay (several days later). Importantly, this study requires participants to generate events prior to the acute stress manipulation, ensuring that participants are able to pull from the same pool of memories, thereby allowing me to examine the effects of stress on memories that are matched for detail and difficulty. Because stress has been shown to impair memory for valanced emotional information, prior work demonstrating no differences in autobiographical memory specificity following acute stress may be due to participants having access to different memories rather than stress modifying the memories themselves. Having participants generate initial events without stress allows me to determine whether any differences observed following an acute stressor are due to the effect of stress on accessing memory details as opposed to limiting access to certain kinds of memories. For

example, if I observe reduced memory specificity following an acute stressor as compared to control, I will provide evidence that stress is impairing access to memory detail.

The primary goal of the study was to explore how autobiographical memory retrieval and future episodic thinking event generation are sensitive to states of acute stress. First, I expected that an acute psychosocial stressor would impair the ability to retrieve or generate memory details immediately following stress. I expected this impairment to be more pronounced for positive and neutral memories as compared to negative memories. Second, I expected memories recalled following a stressor was recalled with more specificity after a delay, and that this effect would be most pronounced for negative memories. Finally, I expected that stress would have a similar impact on the generation of future events as it does on autobiographical memories.

Ultimately, insight into how stress shapes future episodic thought may also be relevant to our understanding of psychopathology. Investigation of the relationship between stress and past and future-oriented memory processes, and their associated psychophysiological correlates, can provide insight into how individuals use prior experiences to direct future behaviors and may help guide future interventions for individuals most at risk.

4.2 Methods

4.2.1 Participants

Seventy-three participants (65.8% female) between the ages of 18-27 ($M = 20.1$; $SD = 1.74$; Race: 28.8% White Non-Hispanic; 23.3% Asian; 11.0% Black/African American; 37% Multiracial or Other) were tested. All participants were fluent in English. Participants provided informed consent prior to participation in the study and were compensated monetarily or with course credit. This study was approved by the University of Chicago Institutional Review Board.

4.2.2 Experimental Design

Participants in this study completed a modified version of the AMT, which required them to generate events and provide qualitative ratings at three timepoints. At Time 0, participants

completed baseline questionnaires. They then completed the AMT task in which they were presented with cue words (Table 1) which varied by valence (positive, negative, neutral) and asked to generate a personal title for each. Each cue was paired with instructions to think of either a true past personal event or a likely future personal event, limited to one year in the past and one year in the future. Following a 1-2-day delay, participants attended an in-person lab session at Time 1 where they completed a psychosocial stress induction, followed by the same AMT task, with the addition of a speaking component in which participants described previously generated events. Following a 3–4-day delay, participants returned and completed the same AMT task. All lab sessions were held in the same testing room and within the same time range each day (11 AM to 4 PM). Electrocardiogram and Impedance Cardiography measures were also collected at each in-person time point, beginning with a baseline period, and then measured throughout all tasks.

Time 0: Online Survey

Prior to coming into the lab, all participants completed six questionnaires; the UCLA Loneliness Scale (Russell, 1996), a 20-item scale assessing perceived social isolation; the Perceived Stress Scale (PSS) (S. Cohen et al., 1983), a 10-item scale assessing perception of stress related to life events in the past month; the Center for Epidemiological Studies Depression Scale (CESD) (Radloff, 2016), a 20-item scale assessing feelings of depression; the State and Trait Anxiety Index (STAI) (Spielberger et al., 1983), a 20-item scale assessing individual levels of state and trait anxiety; the Trauma History Questionnaire (THQ), a 24-item self-report measure of potentially traumatic life events (Hooper et al., 2011), and the Childhood Trauma Questionnaire (CTQ), a 28-item self-report measure of abuse and neglect in childhood (Bernstein et al., 2003).

Following this, participants completed an event generation task modeled after the AMT, in which they were presented with 12 cue words, which varied by valence (positive, negative, neutral; see Supplemental for words). Each cue was paired with instructions to think of either a true past personal event or a likely future personal event, limited to one year in the past and one year in the future. Instructions directed participants to think of a specific event (occurring in a particular location with a duration of less than one day). Participants were asked to limit events to one year in the past or future. Participants were then given one minute to think of each event and then were asked to provide a brief (2-5 word) title for the event. Finally, participants provided subjective ratings of valence, specificity, and availability of the event. Separate ratings for positivity and negativity were obtained in line with the evaluative space model of emotion (Norris et al., 2010). All ratings were given on a visual analog scale (VAS; 0-100). Each participant in this study received two event cues from each of the six categories: positive/future, negative/future, neutral/future, positive/past, negative/past, and neutral/past. The event cues were presented in a random order to each participant. Half of the participants will received each cue as a future event and the other half received it as a past event. The randomization of cue valence and future/past orientation were counterbalanced across participants to minimize the potential effects of order and sequence.

Time 1: Stress Protocol

In the first in-lab session, participants were randomized to either the stress condition or the no-stress condition. Stress was induced using the Trier Social Stress Task (TSST), a widely used laboratory procedure designed to induce acute psychological stress in participants (A. P. Allen et al., 2017). During the TSST, participants were instructed to prepare and deliver an impromptu speech in front of an audience (in this case, a camera) and were informed that their

performance would be evaluated later. In my study, participants in the experimental group were positioned in front of a webcam where they could see themselves, which further added to the social-evaluative component of the task. Participants in the stress condition were told that they were accused of cheating a statistics exam and had to defend themselves. Following standard protocol (Kirschbaum et al., 1993), participants were told behavioral analysts would later judge the video on their speech, intelligibility, clarity, and quality of content. They were then given 2 minutes to prepare a speech. After the anticipatory period, participants performed a 5-minute speech. Throughout the task, an experimenter remained present, providing minimal interaction but ensuring that the participant stayed engaged and speaking for the entire duration. Participants in the no-stress condition were instructed to perform a neutral speech describing either their morning routine or the interior of their house. Additionally, no-stress participants were not told they would be evaluated, to remove the social evaluative threat portion of the task. This structured protocol, combined with physiological and self-report measures, allows for a comprehensive assessment of stress responses in controlled laboratory conditions.

Time 1 and 2: Autobiographical Memory Task

For the final portion of each in-person lab session (Time 1 and Time 2), participants completed a second version of the modified AMT. Participants were presented with the event titles they provided at Time 0. Each event title was displayed on a screen for 5 seconds, and then participants were given minute to describe the event out loud. Again, they were reminded to describe specific events, which occur in a specific location and have a duration of less than one day. This task also includes providing ratings of specificity, availability, and valence of events using a visual analog scale (0-100). Rumination between sessions was assessed by asking participants how often they thought of that event since the last session. Presentation of event

titles was again randomized. Audio (but not video) was collected for both sessions and transcribed.

4.2.3 Physiological Measures

Cardiovascular measures of parasympathetic cardiac control were derived from an electrocardiogram (high frequency (0.12 - 0.40 Hz) heart rate variability (HF HRV)). HF HRV, an index of vagally mediated rhythmic fluctuations in heart rate during respiration, is a pure measure of parasympathetic cardiac control (Berntson et al., 1997). The electrocardiogram (ECG) was collected using a standard lead II configuration and measured using a Bionex system (MindWare Technologies LTD, Gahanna, OH). Analysis of the ECG signal was completed with Mindware Technology's HRV software, (Version 3.2.11). Data was visually inspected minute-by-minute and manually edited to remove artifacts. HF HRV was derived from ECG using spectral analysis of the interbeat interval series, sampled at 4 Hz. The interbeat interval series was detrended and end-tapered before being submitted to a fast Fourier transform and integrated over the respiratory frequency band (0.12 - 0.40 Hz).

Pre-ejection period (PEP), the period between the electrical stimulation of the left ventricle and the opening of the aortic valve, was used as a measure of sympathetic cardiac control (Berntson et al., 1991, 1994). A four-spot electrode configuration was used to collect PEP (Sherwood et al., 1990). MindWare software was used to generate the dZ/dt waveform and obtain PEP from impedance. PEP was quantified as the time interval in milliseconds from the onset of the electrocardiogram Q wave to the B point of the dZ/dt wave (Sherwood et al., 1990).

4.2.4 Data Analysis Plan

To examine initial differences in ratings of subjective ratings of events generated at Time 0, mixed measures analyses of variance (ANOVA) were performed, using a 2 (group: stress vs. non-stress) x 3 (cue-type: positive, negative, vs. neutral) x 2 (future, past) design to examine

differences in ratings of negativity, positivity, difficulty in accessing events, and detail of events. Similar analyses were run at Times 1 and 2 to test predictions about how stress affects specificity and availability of memory for past and future events of different valences. To examine differences in memory detail between time points, 2 (time: Time 0 v Time 1, Time 1 v Time 2, Time 0 v Time 2) x 2 (group: stress vs. control) x 3 (cue-type: positive, negative, neutral) repeated measures ANOVA were performed for each of the subjective ratings of events. All analyses were performed with and without outliers (identified as plus or minus 3SD from the mean). Gender and race were included as covariates.

4.3 Results

Group Demographics

Table 2 shows the baseline characteristics of participants in the stress and no-stress conditions collected at Time 1 prior to either the stress induction or control speaking task. Of note, there were no differences in mean anxiety (STAI) or perceived stress (PSS) scores. There were also no group differences in resting parasympathetic (HF-HRV) or sympathetic (PEP) activity. Table 3 shows characteristics of participants in the stress and no-stress conditions at Time 1 following administration of the stress induction paradigm. Confirming our manipulation, participants in the stress condition reported significantly higher negative affect (PANAS) following the TSST ($t(67.07) = -4.90, p < .001$). There were no differences in PNS reactivity between participants in the stress condition and participants in the no stress condition ($t(33.07) = -0.44, p = .66$). SNS reactivity also did not differ significantly between groups ($t(45.26) = 1.76, p = .09$), but the effect was trending such that participants in the stress condition had a greater increase in SNS activity. While this did not reach significance, the trending effect is in the expected direction (i.e. increased SNS activation with stress induction).

Time 0: Initial Event Generation

Event Valence

To confirm that cue type was reflected in the events generated prior to the in-lab sessions, I ran a mixed measures ANOVA condition, valence, and tense as factors. This resulted in a main effect of valence on positivity ratings, $F(2,134) = 410.64$, $p < .001$, partial $\eta^2 = 0.86$ (Figure 11). Post hoc pairwise comparisons using Tukey's method indicated substantial differences in positivity ratings among valence groups. Participants rated stimuli with a negative valence significantly lower in positivity than those with a neutral valence (contrast estimate = -36.10, SE = 2.29, $t(67) = -15.76$, $p < .0001$), as well as significantly lower than those with a positive valence (contrast estimate = -62.2, SE = 2.34, $t(67) = -26.59$, $p < .0001$). Similarly, stimuli with a neutral valence received significantly lower positivity ratings compared to those with a positive valence (contrast estimate = -26.10, SE = 1.88, $t(67) = -13.88$, $p < .0001$). The mixed design ANOVA with condition, word valence, and word tense as factors resulted in a main effect of valence on negativity ratings, $F(2, 130) = 402.60$, $p < .001$. Post hoc analyses using Tukey's method revealed that participants rated negative words significantly higher in negativity than neutral (contrast estimate = 46.1, SE = 2.62, $t(65) = 17.59$, $p < .0001$) and Positive words (contrast estimate = 61.5, SE = 2.23, $t(65) = 27.56$, $p < .0001$). Additionally, Neutral words received significantly higher negativity ratings than Positive words (contrast estimate = 15.4, SE = 1.85, $t(65) = 8.33$, $p < .0001$). As expected, there was no difference in positivity ($F(1,67) = 0.05$, $p = .83$, partial $\eta^2 < 0.001$) or negativity ($F(1,65) = 0.91$, $p = .34$, partial $\eta^2 = 0.01$) ratings by condition.

Next, I examined whether the availability or specificity of initial events generated differed by valence (Figure 12). There was main effect of valence on difficulty ratings, $F(2,138) = 9.76$, $p < .001$, partial $\eta^2 = 0.12$. Post hoc pairwise comparisons using Tukey's method

indicated that participants rated stimuli with a negative valence significantly less difficult to remember than those with a neutral valence (contrast estimate = -9.88, SE = 2.35, $t(69) = -4.21$, $p < .001$), as well as significantly less difficult than those with a positive valence (contrast estimate = -5.48, SE = 2.13, $t(69) = -2.57$, $p = .03$). Stimuli with a neutral valence did not differ from stimuli with a positive valence in difficulty ratings (contrast estimate = 4.40, SE = 2.24, $t(69) = 1.97$, $p = .13$). There was also a main effect of valence on detail ratings, $F(2, 138) = 7.44$, $p < .001$, $\eta^2 = .097$. Post hoc results revealed significant differences between negative and neutral detail ratings, with negative words being rated significantly higher in detail than neutral words (contrast estimate = 8.82, SE = 2.46, $t(69) = 3.59$, $p = .002$). However, there were no significant differences between negative and positive detail ratings (contrast estimate = 3.70, SE = 2.14, $t(69) = 1.73$, $p = .20$), nor between neutral and positive detail ratings (contrast estimate = -5.12, SE = 2.28, $t(69) = -2.24$, $p = .07$). As expected, there was no difference in difficulty ($F(1,69) = 3.20$, $p = .08$, partial $\eta^2 = 0.04$) or detail ($F(1,69) < 0.001$, $p = .95$, partial $\eta^2 < 0.001$) ratings by condition.

Event Tense

Next, I examined how detail and difficulty ratings differed based on whether the event was in the past (autobiographical memory) or future (episodic future thinking). The main effect of tense on difficulty ratings was not significant, $F(1, 69) = 0.47$, $p = .49$, partial $\eta^2 = 0.007$, indicating that there were no significant differences in difficulty ratings for autobiographical memories as compared to imagined future events (Figure 13). Similarly, the main effect of tense on detail ratings was not significant ($F(1, 69) = 0.51$, $p = .48$, partial $\eta^2 = 0.007$) indicating that there were no significant differences in detail ratings. Additionally, there was no interaction between tense and valence in predicting detail ratings ($F(2, 138) = 2.30$, $p = .10$, partial $\eta^2 =$

0.032) or difficulty ratings ($F(2, 138) = 1.79, p = .17, \text{partial } \eta^2 = 0.025$). To examine whether ratings of detail for past events corresponded to detail ratings for future events, I ran an OLS linear model. This analysis revealed that detail ratings for past events are positively associated with detail ratings for imagined future events ($\beta = 0.47, SE = 0.04, p < .001$).

Time 1: Effects of Stress on Retrieval

Event Valence

Following the stress protocol at Time 1, the first in-lab session, mixed measures ANOVA with condition, valence, and tense as factors again revealed a main effect of valence on positivity ratings ($F(2,142) = 399.81, p < .001, \text{partial } \eta^2 = 0.85$) and negativity ratings ($F(2,142) = 451.63, p < .001, \text{partial } \eta^2 = 0.86$). Post hoc testing revealed that the effect of valence on these ratings followed the same stepwise patterns as at Time 0. Additionally, there was also a main effect of valence on difficulty ($F(2,140) = 5.42, p = .005, \text{partial } \eta^2 = 0.07$) of events retrieved at Time 1. Post hoc analyses revealed that participants rated neutral events as significantly more difficult to generate as compared to negative (contrast estimate = -4.70, $t(70) = -2.55, p = .03$) and positive (contrast estimate = 5.79, $t(70) = 2.93, p = .01$) events. However, no significant difference was observed in difficulty ratings for negative and positive valence (contrast estimate = 1.08, $t(70) = 0.61, p = .82$).

To examine whether stress impacted negativity and positivity ratings I examined the main effect of condition (stress, no-stress). Condition did not have a significant effect on positivity ratings ($F(1, 71) = 0.13, p = .72, \text{partial } \eta^2 = .002$) or negativity ratings ($F(1, 71) = 0.47, p = .50, \eta^2 = .007$). Additionally, neither difficulty ratings ($F(1, 71) = 0.86, p = .357, \text{partial } \eta^2 = .012$) nor detail ratings differed by condition ($F(1, 71) = 0.52, p = .471, \eta^2 = .007$) (Figure 14). Valence did not interact with condition to predict negativity ($F(2,142) = 0.97, p = .38, \text{partial } \eta^2 = .01$),

positivity ($F(2,142) = 0.55$, $p = .58$, partial $\eta^2 = .008$), difficulty ($F(2,140) = 2.25$, $p = .11$, partial $\eta^2 = .03$) or detail ($F(2,142) = 0.17$, $p = .85$, partial $\eta^2 = .002$) ratings.

Next, I performed a repeated measures ANOVA with condition, valence, and time as factors to examine whether specificity and availability of events changed from Time 0 to Time 1, and whether any changes differed by condition. Neither detail ratings ($F(1, 59) = 0.59$, $p = .45$, $\eta^2 = .01$) nor difficulty ratings ($F(1, 55) = 1.18$, $p = .28$, $\eta^2 = .021$) changed significantly between these timepoints, and there was no interaction with time and condition for detail ($F(1, 59) = 0.20$, $p = .66$, $\eta^2 = .003$) or difficulty ($F(1, 55) = 1.92$, $p = .17$, $\eta^2 = 0.03$) ratings. Finally, the three-way interaction between condition, valence, and timepoint was not significant for detail ($F(2,118) = 0.71$, $p = .49$, partial $\eta^2 = 0.01$) or difficulty ratings ($F(2,110) = 0.03$, $p = .97$, partial $\eta^2 < 0.001$).

Event Tense

Next, I examined how detail and difficulty ratings differed following the stress induction based on whether the event was in the past (autobiographical memory) or future (episodic future thinking). There was no main effect of tense on difficulty ($F(1,70) < 0.001$, $p = .95$, partial $\eta^2 < 0.001$) or detail ($F(1,70) = 0.96$, $p = .33$ partial $\eta^2 = 0.01$) ratings. Additionally, condition did not interact with word tense to predict difficulty ($F(1,70) = 0.24$, $p = .63$, partial $\eta^2 = 0.003$) or detail ($F(1,70) = 0.12$, $p = .73$, partial $\eta^2 = 0.002$) ratings. Next, I performed a repeated measures ANOVA with condition, tense and time as factors to examine whether specificity and availability of events changed from Time 0 to Time 1, and whether any changes differed by condition. The three-way interaction between condition, valence, and timepoint was not significant for detail ($F(1,59) = 0.83$, $p = .37$, partial $\eta^2 = 0.01$) or difficulty ratings ($F(1,55) = 0.04$, $p = .85$, partial $\eta^2 < 0.001$).

Time 2: Effects of Stress on Reconsolidation

Next, I examined the effects of stress on reconsolidation of generated events, and whether these effects differed by valence or whether the events happened in the past or were imagined in the future. Mixed measures ANOVA analyses at Time 2 revealed that condition interacted with tense to predict difficulty ($F(1,69) = 4.65, p = 0.04, \text{partial } \eta^2 = 0.07$) and detail ($F(1,69) = 4.84, p = 0.03, \text{partial } \eta^2 = 0.06$) ratings. Post hoc pairwise comparisons using Tukey's method indicated that participants in the no-stress condition rated past events as marginally more difficult to generate than future events (contrast estimate: $-4.03, SE = 2.20, t(69) = -1.83, p = .07$). However, for ratings of detail, participants in the no-stress condition did not report significant differences between ratings for past and future events (contrast estimate: $2.46, SE = 1.95, t(69) = 1.26, p = 0.21$). Participants in the stress condition did not differ in difficulty ratings of past and future events (contrast estimate: $2.37, SE = 1.99, t(69) = 1.19, p = 0.24$), but did report marginally more detail for past events as compared to future (contrast estimate: $-3.33, SE = 1.77, t(69) = -1.89, p = 0.06$). Due to the lack of significant differences, it is not possible to fully interpret the interaction between condition and word tense.

There was no main effect of condition on ratings of positivity ($F(1, 69) = 0.14, p = .71, \text{partial } \eta^2 = .002$), negativity ($F(1, 69) = 0.01, p = .91, \eta^2 < 0.001$), difficulty ($F(1, 69) = 0.22, p = .64, \text{partial } \eta^2 = .003$) or detail ($F(1, 69) = 0.35, p = .56, \text{partial } \eta^2 = 0.005$) (Figure 15). Additionally, condition did not interact with word valence to predict ratings.

4.4 Discussion

In the current study, I assessed how acute psychosocial stress shapes retrieval and reconsolidation of both autobiographical memories and events generated through episodic future thinking. Stress, both acute and chronic, has been associated with differences in the amount of detail accessed in autobiographical memory (A. D. Brown et al., 2014; Crane et al., 2014).

Specifically, acute stress has been linked to impaired retrieval of emotionally arousing memories (Gagnon & Wagner, 2016; Shields et al., 2017) and overgeneral autobiographical memory retrieval (Debeer et al., 2012b). However, evidence suggests that stress may enhance memory for emotionally salient autobiographical memories following reconsolidation (Sheldon et al., 2018). Given the overlap between mechanisms underlying retrieval of past personal events – autobiographical memory – and simulation of future events – episodic future thinking (Addis et al., 2007; Benoit & Schacter, 2015), I expected that stress would exert similar effects on both the generation of future events and retrieval of past events, both immediately after stress and following a delay. I found that prior to stress participants provided similar initial ratings for the availability and specificity of both past and future personal events. Following induction of stress, there were no differences in the way participants in the stress condition rated events immediately after stress or following reconsolidation. Together these findings suggest that acute social stress does not impact the way individuals believe they are able to access and generate information about past and future events.

Experiences that are more intense and emotional at the time they occur tend to be more durable over time, and this effect is particularly strong for negative memories (Kensinger & Schacter, 2006; S. E. Williams et al., 2022). This durability is reflected in my findings that negative events were easiest to access at baseline, and that both negative and positive events were reported to be more detailed than neutral events. This finding is also in line with prior work showing that highly arousing emotional content is more readily retrieved (Holland & Kensinger, 2010). I also replicated work from Gallo and colleagues (2011) which found no differences in subjective ratings of detail and difficulty for autobiographical memories of negative and positive events. I extend this finding to demonstrate that both negative and positive events were rated as

more detailed than neutral events. These findings suggest that the emotional intensity of events plays a significant role in their long-term retention and accessibility in memory.

When comparing the availability and specificity of generating future events as compared to recalling past memories, memory for past personal experiences tends to be rated as more detailed and less difficult to generate than future experiences (D'Argembeau & Van Der Linden, 2004a; McDonough & Gallo, 2010). Additionally, studies of emotional valence have demonstrated a bias towards greater detail for positive future scenarios over negative future scenarios as assessed by both subjective and objective measures (Gallo et al., 2011; Lalla & Sheldon, 2021b). However, I did not find support for differences in ratings of detail or difficulty of past and future events, and this did not differ by emotional valence of cues. One explanation for this finding is that the subjective measures I used are indexing how participants felt about generating events as opposed to quantifying the actual amount of detail or effort. That is, participant ratings may reflect greater confidence relative to the number of specific details retrieved. Indeed, subjective ratings of autobiographical memories do not always correspond with objective measures of memory detail (Gallo et al., 2011; Sheldon et al., 2018). This may also reflect differences in how stress impacts different dimensions of memory retrieval differently. Indeed familiarity, a feeling of having encountered a memory without recalling specific information, and recollection, the actual knowledge of the details of a personal experience are dependent on different neural mechanisms (Gagnon & Wagner, 2016; A. Yonelinas et al., 2024). Recollection, which depends on hippocampal-dependent mechanisms is thought to be more sensitive to lower levels of stress than the cortical mechanisms that underly familiarity (Gagnon & Wagner, 2016). Notably, participants in the current study did not report differences in arousal for past and future events, which may in part explain the comparable

specificity between types of events. For example, McDonough and colleagues (2010) found that past events were rated as more detailed, more arousing, and easier to access than future events.

Another important consideration that may explain the comparable ratings between past and future events is the temporal constraint placed on the events reported by participants. By limiting participants to events that occurred within one year in the past or future, I aimed to examine the impact of stress on memories or events from a similar timeframe. Research suggests that the temporal distance of an event can significantly affect the amount of detail and ease with which it is recalled or imagined (Addis & Schacter, 2008; Berntsen & Bohn, 2010). Construal level theory posits that events in the near future are construed with more concrete, detailed information, while events in the distant future are construed with more abstract, general features (Trope & Liberman, 2010). By limiting events to a relatively short timeframe, the study may not have captured potential differences that could arise with more temporally distant events. For example, D'Argembeau and Van Der Linden (2004b) found that individuals tend to provide less detailed and more abstract descriptions for future events that are farther away in time, compared to those that are nearer. The one-year constraint might have homogenized the ratings for past and future events, obscuring differences that might be more pronounced over longer temporal spans. Future research could explore the impact of varying temporal distances on the specificity and perceived difficulty of past and future events by including events that span several years or even decades to further understand how the timing of personal events shapes retrieval and elaboration processes.

My finding that acute stress at retrieval did not result in differences in ratings of detail or difficulty for events overall is consistent with prior findings. Sheldon et al. (2018) found no differences in either participant ratings of autobiographical memory vividness or amount of

internal or external details included, suggesting that acute stress at retrieval does not impact the amount of detail accessed. However, while Sheldon and colleagues did find that participants in the stress condition were slower to access memories (indexed by reaction time), the current findings do not reflect this difference in access to memory, as difficulty ratings did not differ. Here too, participant ratings are indicative of their perception or confidence in their own memory access, which may not map onto more objective measures of memory accessibility, like reaction time. I extend this work in the current study to future thinking and find that ratings of detail and difficulty for episodic future thinking do not differ following acute stress. Another possible explanation for these findings is that the intensity of the stressor was either too weak or too strong to affect the retrieval of details. Prior work has demonstrated an inverted U-shape relationship between stress reactivity, indexed by cortisol, and memory recollection (McCullough et al., 2015), where both low and high reactivity were associated with lower recall. While the current work did not investigate differences in individual responses or reactivity to stress induction, future work may consider the intensity of the stressor when assessing how acute stress shapes specificity and difficulty of retrieving or simulating personal events.

Finally, I find that acute stress does not impact the retrieval of events following a 3-4-day delay. While prior work has demonstrated that acute stress enhances (Sheldon et al., 2018) or reduces (Schwabe & Wolf, 2010) reconsolidation of autobiographical memory detail depending on the timing of the stress, I find no differences. This suggests that the timing and nature of the stressor, as well as individual differences in stress responses, could play crucial roles in these outcomes. However, previous research, including Sheldon et al. (2018), found no significant effect of stress on subjective ratings of reconsolidated memories, which aligns with my findings here. Again, the current study reveals that this effect, or lack thereof, extends to episodic future

thinking, suggesting that the generation of both past and future events operates similarly, and these events are subject to comparable evaluations. This aligns with the constructive episodic simulation hypothesis, which posits that similar cognitive processes underlie both memory recall and future event simulation (Schacter et al., 2007).

The current work can be expanded on in several ways. First, while my sample expanded upon prior work by not limiting the gender of participants, the sample was fairly skewed towards women, which limited my ability to examine differences in memory and stress by gender. Importantly, the effects of stress on memory have been shown to vary by gender (Andreano & Cahill, 2009; Shields et al., 2017). Replication in a sample with a more representative gender breakdown is necessary to determine if the effects found here are generalizable across men and women. Second, the findings reported here rely entirely on participant-provided ratings of events. Discrepancies in self-report of memory detail (i.e. “subjective” measures) and quantification of detail amount by experimenters (i.e. “objective” measures) have been reported in studies of autobiographical memory (Gallo et al., 2011; Sheldon et al., 2018), suggesting that participant ratings should be interpreted with caution. Future work, both with the current dataset and in future studies, should obtain both participant report of detail and specificity as well as quantification of details provided. Additionally, Future work should consider not only the valence of cues given to participants but also how participants rate the negativity and positivity of each memory. These participant ratings can help explain additional variability that cue-valence alone cannot account for. Although negativity and positivity ratings generally align with cue-type in this study, there is variability in how participants rated each cue. Frameworks of emotion, such as the evaluative space model, support the idea that positivity and negativity are not always reciprocal and can exert independent or co-active effects (Norris et al., 2010).

Therefore, future studies should explore how these two rating dimensions contribute independently to understanding emotional responses. For example, events that are both extremely negative and extremely positive (e.g., the bittersweet feeling of winning silver at the Olympics) may be impacted differently by stress than events that are only highly negative or highly positive.

In conclusion, my results offer novel insights into the effects of stress on memory for past personal events and the generation of future imagined events. Specifically, these findings suggest a parallel functioning of autobiographical memory and episodic future thinking concerning individuals' perceptions of their ability to vividly envision personal experiences. This alignment underscores the interconnectedness of past recollection and future expectations in the context of stress. Ultimately, this work contributes to the literature informing how experiences of social threat contribute to our past recollection and future expectations, which may contribute to different forms of stress-related psychopathology.

4.5 Appendix C: Chapter 4 Tables and Figures

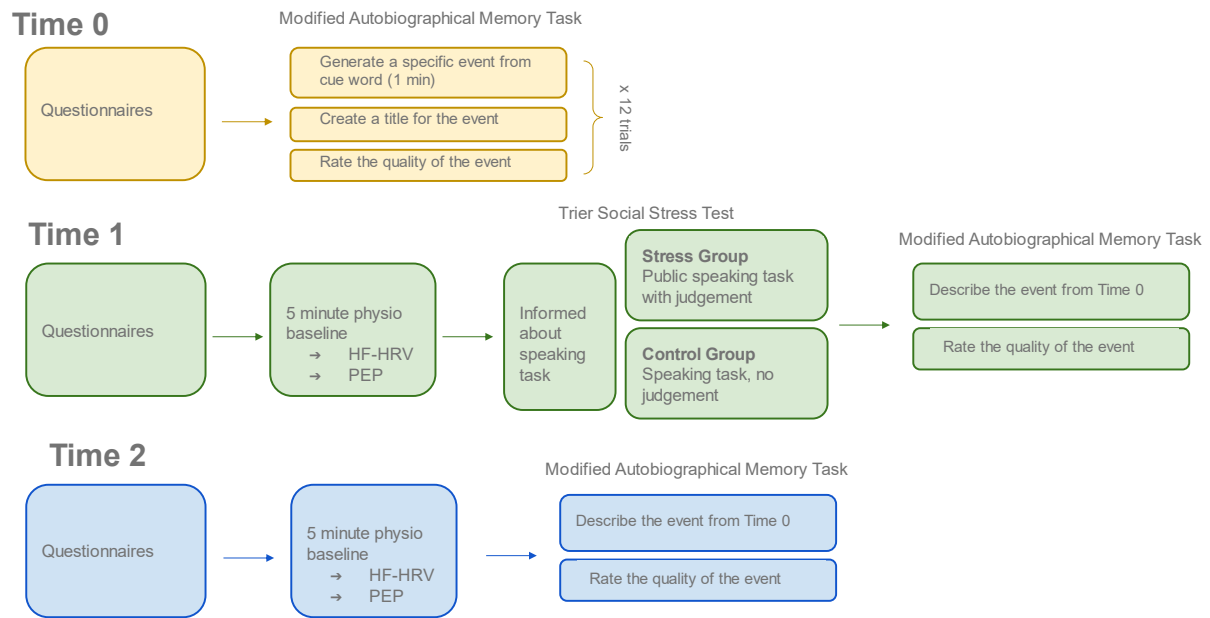


Figure 10. A schematic of the protocol used in this study.

Neutral	Positive	Negative
Pencil	Achieve	Stress
Seat	Pleased	Pain
Cabinet	Delight	Sad
Bowl	Laugh	Panic

Table 1. Cue words by valence.

	Control (N=32)	TSST (N=41)	P-value
Loneliness (UCLA)			
Mean (SD)	42.5 (8.87)	42.6 (8.94)	0.949
Median [Min, Max]	43.0 [26.0, 61.0]	43.0 [27.0, 63.0]	
Anxiety (STAI)			
Mean (SD)	39.7 (9.71)	40.0 (8.03)	0.902
Median [Min, Max]	38.0 [26.0, 65.0]	41.0 [25.0, 62.0]	
Perceived Stress (PSS)			
Mean (SD)	18.8 (7.24)	18.5 (5.46)	0.865
Median [Min, Max]	18.5 [2.00, 29.0]	18.0 [7.00, 29.0]	
Resting PNS Activity (HF-HRV)			
Mean (SD)	6.02 (1.38)	6.08 (1.32)	0.884
Median [Min, Max]	6.11 [2.14, 8.48]	6.31 [4.00, 8.30]	
Resting SNS Activity (PEP)			
Mean (SD)	97.6 (17.3)	101 (10.4)	0.387
Median [Min, Max]	97.0 [58.0, 133]	100 [82.8, 119]	

Table 2. Baseline participant characteristics at Time 1, before stress induction paradigm.

	Control (N=32)	TSST (N=41)	P-value
Positive Affect			
Mean (SD)	25.0 (7.07)	25.6 (6.80)	0.73
Median [Min, Max]	25.0 [13.0, 46.0]	26.0 [13.0, 38.0]	
Negative Affect			
Mean (SD)	14.2 (4.43)	20.8 (6.92)	<0.01
Median [Min, Max]	13.0 [10.0, 29.0]	19.0 [12.0, 41.0]	
PNS Reactivity			
Mean (SD)	-0.436 (1.29)	-0.292 (0.854)	0.66
Median [Min, Max]	-0.0143 [-3.03, 1.69]	-0.214 [-1.74, 1.69]	
SNS Reactivity			
Mean (SD)	-3.71 (5.55)	-6.32 (5.09)	0.085
Median [Min, Max]	-2.80 [-19.5, 7.40]	-6.15 [-20.3, 3.90]	

Table 3. Participant characteristics by condition following stress (TSST) or no-stress (placebo speaking task). Participants in the stress condition reported significantly higher negative affect following stress induction.

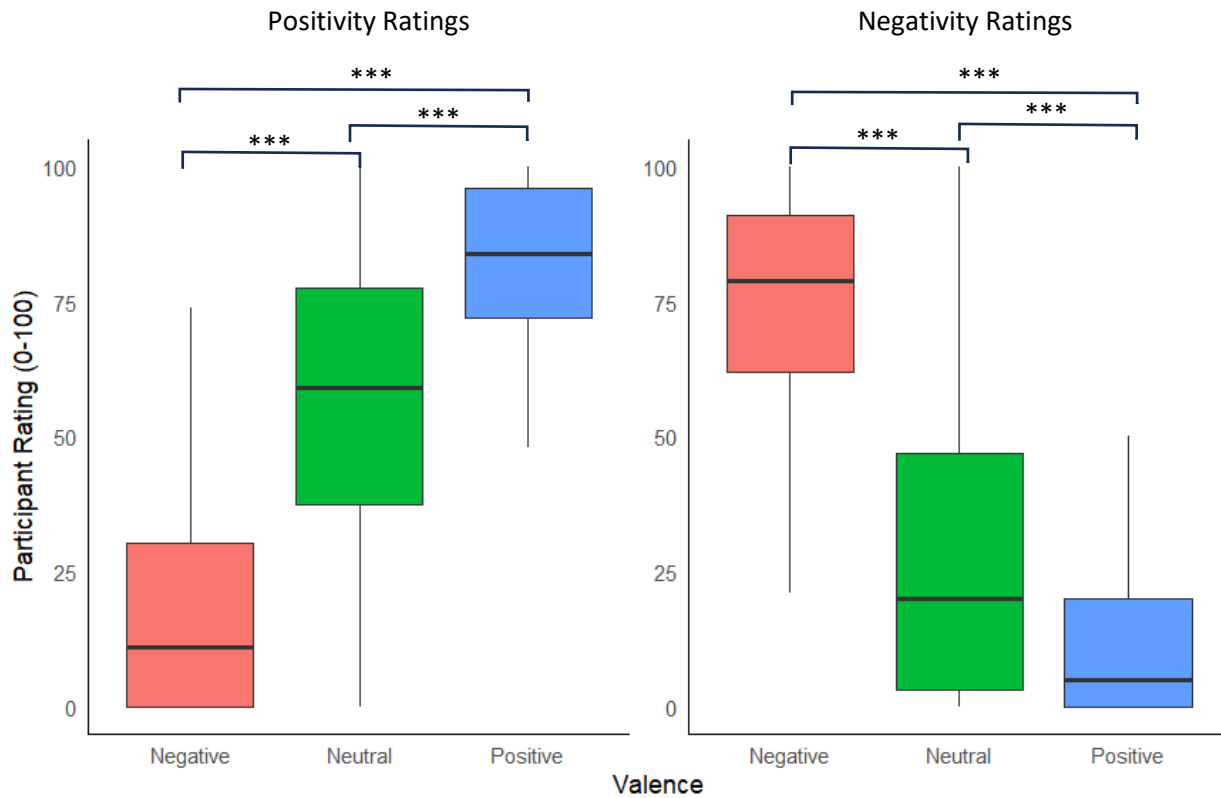


Figure 11. *Positivity and negativity ratings by word valence at Time 0.*

At Time 0 valence had a significant main effect on positivity rating, $F(2,130) = 402.60$, $p < .0001$, partial $\eta^2 = 0.86$. Post hoc Tukey's tests showed negative stimuli were rated lower in positivity than neutral ($t(67) = -15.76$, $p < .0001$) and positive stimuli ($t(67) = -26.59$, $p < .0001$), and neutral stimuli were rated lower than positive ($t(67) = -13.88$, $p < .0001$). Valence also affected negativity ratings, $F(2,130) = 402.60$, $p < .0001$. Negative words were rated higher in negativity than neutral ($t(65) = 17.59$, $p < .001$) and positive words ($t(65) = 27.56$, $p < .0001$), with neutral words rated higher than positive ($t(65) = 8.33$, $p < .0001$). There were no condition effects on positivity ($F(1,67) = 0.05$, $p = .83$) or negativity ($F(1,65) = 0.91$, $p = .34$).

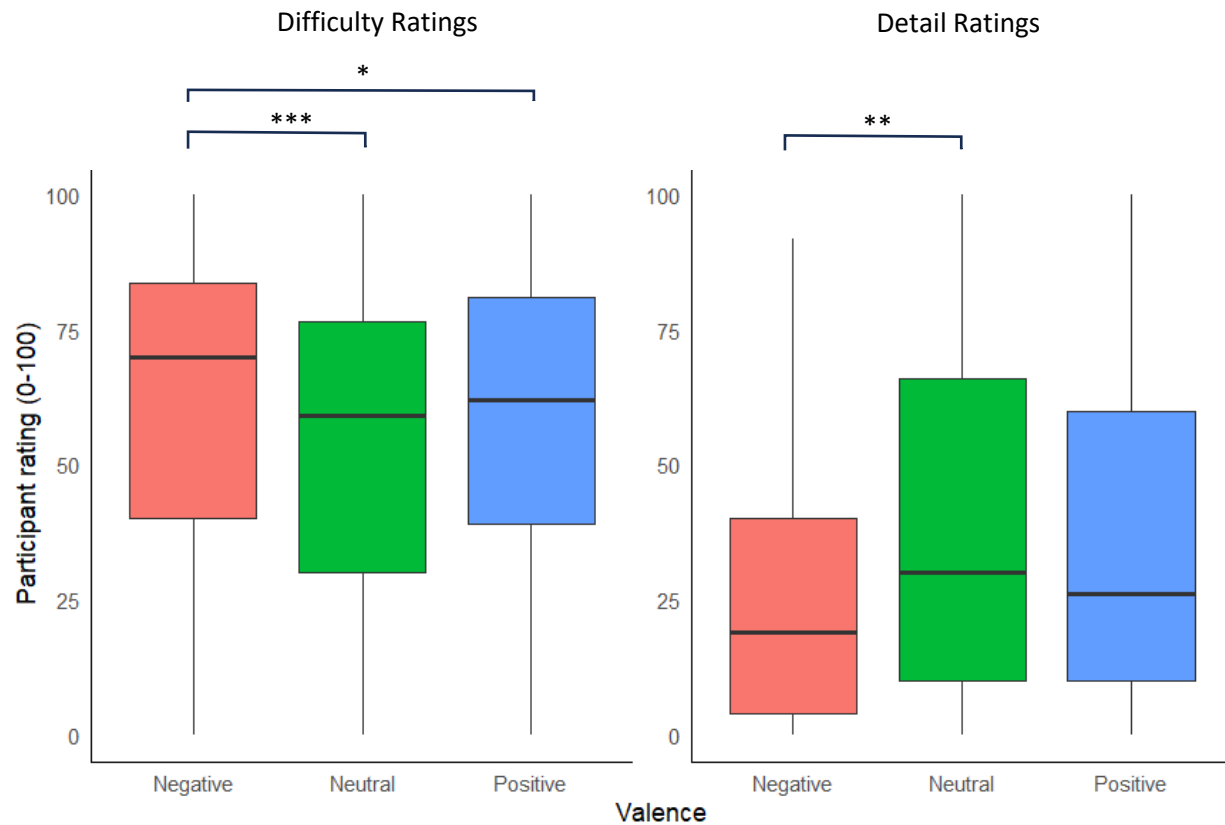


Figure 12. *Difficulty and detail ratings by word valence at Time 0.*

At Time 0 valence had a significant main effect on difficulty ratings, $F(2,138) = 9.76$, $p < .001$, partial $\eta^2 = 0.12$. Post hoc Tukey's tests showed negative stimuli were rated less difficult than neutral ($t(69) = -4.21$, $p < .001$) and positive stimuli ($t(69) = -2.57$, $p = .03$), while neutral and positive stimuli did not differ ($t(69) = 1.97$, $p = .13$). Valence also affected detail ratings, $F(2,138) = 7.44$, $p < .001$, partial $\eta^2 = .097$. Negative stimuli were rated higher in detail than neutral ($t(69) = 3.59$, $p = .002$), with no significant differences between negative and positive ($t(69) = 1.73$, $p = .20$) or neutral and positive ($t(69) = -2.24$, $p = .07$) stimuli

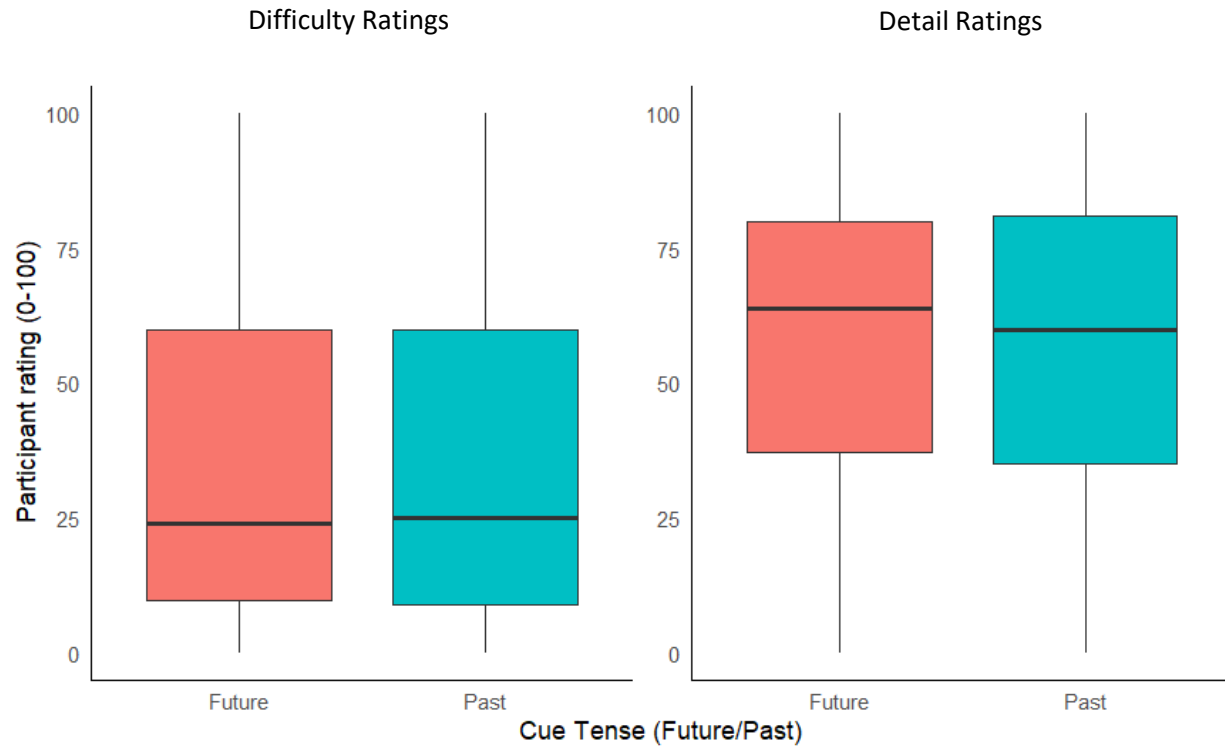


Figure 13. *Detail and difficulty ratings of past and future events at Time 0.*

At Time 0 the main effect of tense on difficulty ratings was not significant, $F(1, 69) = 0.47$, $p = .49$, partial $\eta^2 = 0.007$, indicating that there were no significant differences in difficulty ratings for autobiographical memories as compared to imagined future events. The main effect of tense on detail ratings was also not significant ($F(1, 69) = 0.51$, $p = .48$, partial $\eta^2 = 0.007$) indicating that there were no significant differences in detail ratings.

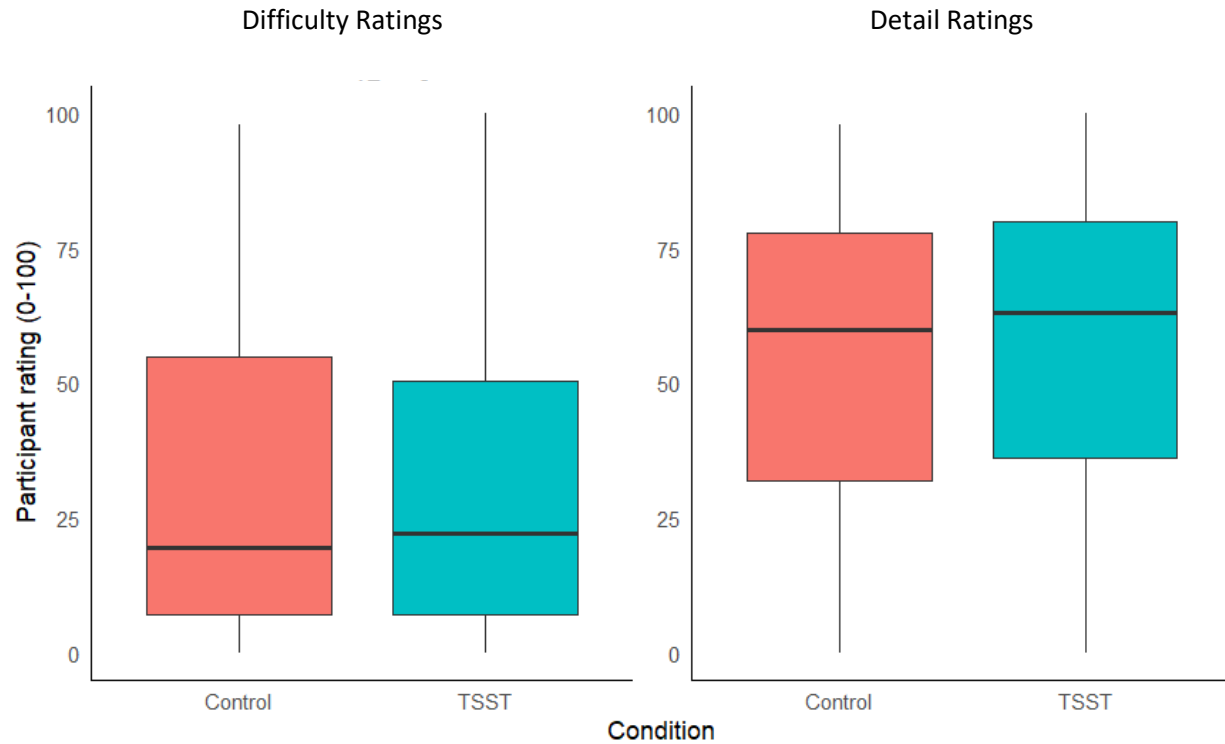


Figure 14. *Time 1 difficulty and detail ratings for stress (TSST) and no-stress (Control) participants.*

At Time 1, no differences were observed between conditions in difficulty ($F(1, 71) = 0.86, p = .357$, partial $\eta^2 = .012$) or detail ratings ($F(1, 71) = 0.52, p = .471, \eta^2 = .007$). Valence did not interact with condition to predict difficulty ($F(2,140) = 2.25, p = .11$, partial $\eta^2 = .03$) or detail ($F(2,142) = 0.17, p = .85$, partial $\eta^2 = .002$) ratings.

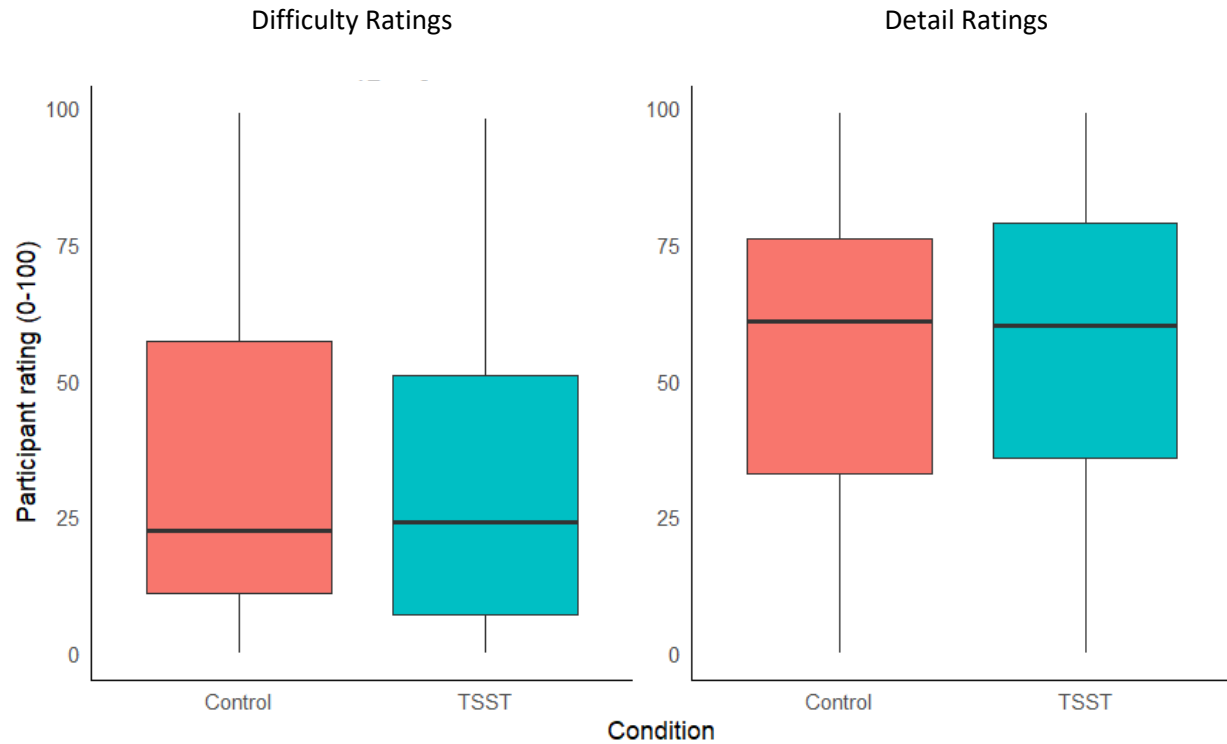


Figure 15. *Time 2 difficulty and detail ratings for stress (TSST) and no-stress (Control) participants.*

At Time 2 no differences were observed in difficulty or detail ratings between conditions. There was no main effect of condition on ratings of difficulty ($F(1, 69) = 0.22, p = .64, \text{partial } \eta^2 = .003$) or detail ($F(1, 69) = 0.35, p = .56, \text{partial } \eta^2 = 0.005$). Additionally, condition did not interact with word valence to predict ratings.

Chapter 5: General Discussion

The social world is an essential component of well-being for social species like humans (Baumeister & Leary, 2017; J. T. Cacioppo & Hawkley, 2003; Clair et al., 2021). Evolution has sensitized us to the social environment as a way of surviving and avoiding total isolation (J. T. Cacioppo et al., 2013; Pamela Qualter et al., 2015). The ability to form and maintain social relationships relies on complex processes involving cognitive, emotional, and physiological systems (Holt-Lunstad, 2018; Spithoven et al., 2017). Indeed, the capacity to adapt and be flexible across these systems allows social species to navigate the social world effectively. However, despite the benefits of social connections, existing within social networks also entails the risk of encountering social threats such as rejection, abuse, or violence, which can significantly impact mental and physical health (Doan et al., 2014; C. A. McEwen & McEwen, 2017; Shonkoff et al., 2009). Loneliness, interpersonal violence, and early life stress are particularly potent forms of social threat that contribute to adverse health outcomes across the lifespan, including depression, anxiety, cardiovascular disease, and immune dysfunction (Danese & J Lewis, 2017; Holt-Lunstad et al., 2015; B. S. McEwen & Gianaros, 2011). Understanding the factors that increase an individual's susceptibility to these negative effects is crucial for developing targeted interventions. To this end, our evolutionary history has endowed us with an incredible capacity to sense social threats, update social schemas based on experiences, and modify behavior to navigate social environments more effectively. The work described in this dissertation examines the complex and dynamic ways that individuals respond to social threat, as well as the psychological and physiological processes that underlie them.

This dissertation describes three studies that examine how individuals vary in their perception of, and responses to, social threat. Chapter 2 used a novel statistical framework to

examine how the predictability of the early environment contributes to differences in child self-regulatory behaviors. Many of the most impactful stressors for children are experiences that put social bonds (e.g., relationships with caregivers) at risk. The types of experiences often considered to be adverse or traumatic for children also tend to be social in nature, such as physical abuse and emotional neglect (Bernstein et al., 2003; Felitti et al., 1998; Porges, 2007). Additionally, adversity in childhood is often characterized by unpredictability (Ellis et al., 2022), which has been consistently linked to negative child outcomes (Davis & Glynn, 2024; Glynn et al., 2018; Howland et al., 2021). Results from Chapter 2 showed that the statistical components of unpredictability in the types of stressors children experience are differentially predictive of child behavioral outcomes. Specifically, unpredictability indexed by the Color of Noise is associated with greater behavioral improvement, while unpredictability indexed by the Coefficient of Variation and Changepoints in Variance is associated with slower improvement. These findings contribute to the expanding literature on the unpredictability of childhood environments and add to our understanding of how measures of unpredictability relate to one another and shape outcomes (Doom et al., 2024; Frankenhuis et al., 2019).

The development of social frameworks that begins in childhood continues to evolve into adolescence, where individuals begin to navigate increasingly complex social situations (Blakemore, 2008; Lodder et al., 2016). In particular, adolescents are at high risk of exposure to interpersonal violence (Finkelhor et al., 2015), which has been associated with difficulties with emotion regulation (Jiang et al., 2022; Rigterink et al., 2010a; Stevens et al., 2013). Results from Chapter 3 demonstrated that a history of violence exposure is related to both greater difficulties with emotion regulation and a greater likelihood of being lonely, while more recent exposures to violence are not related to these psychological outcomes. This highlights the long-term impact of

early social threat on emotional well-being and social integration, indicating that early interventions may be crucial to mitigate these long-term effects.

Finally, experiences of social threat can alter behavior by changing expectations for the future based on past experiences. The ability to retrieve autobiographical memory is influenced by stress (Schacter, 2012), and episodic future thinking (i.e., our expectations of what is to come) relies on similar processes (Szpunar et al., 2014). Additionally, drawing upon memories, or imagined futures, can serve as a form of emotion regulation when faced with social threat, allowing individuals to influence the emotions they experience (Holland & Kensinger, 2010). Chapter 4 revealed similarities in individuals' assessments of their own memory for past events and imagination of future events. Importantly, acute stress did not shift how individuals rated their abilities to access and picture personal events from the past or future at retrieval or following reconsolidation. This stability suggests a robust mechanism underlying the integration of past experiences and future expectations, even in the face of acute stressors. Understanding these processes is essential for comprehending how individuals navigate social environments and adapt to ongoing challenges, particularly those involving social threat.

For humans, the majority of our major life stressors come from social relationships (Sheldon Cohen et al., 2019; Holmes & Rahe, 1967). In order to manage social threats and simultaneously form and maintain social bonds, we spend a considerable amount of energy thinking about, or attempting to anticipate, social scenarios. Indeed, anticipatory responses are a hallmark of psychological stress, allowing us to prepare for potential future social threats and cope with uncertainty about the future (Brosschot et al., 2017; Grupe & Nitschke, 2013). These studies presented in this dissertation collectively explore how expectations of the future are shaped by both prior and recent experiences with social threats, ranging from early life through

young adulthood. In the first study, findings align with the statistical learning theory of unpredictability (Frankenhuis et al., 2019), where children use environmental unpredictability as a gauge for the certainty and reliability of their world. This unpredictability influences their self-regulatory behaviors, with different patterns of unpredictability (e.g., color of noise, changepoints in variance) leading to varying developmental outcomes (Ellis et al., 2022; Davis & Glynn, 2024). This suggests that children's expectations about the stability and predictability of their environment play a crucial role in their ability to regulate behavior and emotions effectively. The second study reveals that previous experiences of interpersonal violence significantly impact adolescents' responses to social stress, manifesting in heightened loneliness and difficulties with emotion regulation (Jiang et al., 2022; Rigterink et al., 2010b). These adolescents' expectations of social interactions are likely colored by their past traumatic experiences, leading them to anticipate social rejection or harm, which in turn affects their emotional and social functioning. This highlights the long-term influence of early social threats on shaping future expectations and stress responses. Although the third study did not demonstrate an effect of stress on the generation of future or past events, it provides important insights into the relationship between autobiographical memory and future expectations. Individuals with more specific and detailed autobiographical memories tend to have greater specificity in their expectations of future events, indicating that the ability to recall past experiences in detail is linked to the ability to anticipate future events accurately (Schacter, 2012; Szpunar et al., 2014). This suggests that cognitive mechanisms involved in memory and future thinking are crucial for preparing for potential future social threats. The ability to draw on past experiences and generate simulations of the future with greater specificity may actually decrease feelings of uncertainty. These findings align with the allostatic model of stress, which posits that

stress responses are often anticipatory, aimed at avoiding or coping with potential future harm (McEwen, 1998). In the context of social threats, stress responses are crucial for detecting and responding to cues that signal potential social rejection or harm. The anticipatory nature of these responses underscores their adaptive function, as they help individuals prepare for and mitigate future social challenges. By understanding how early experiences and environmental factors shape these anticipatory stress responses, we can develop targeted interventions to support individuals at risk of adverse outcomes due to early life stress and social threats.

This theoretical framework emphasizes the importance of early intervention and highlights the interconnectedness of cognitive, emotional, and physiological responses to social threats. It underscores the need for a multi-level, context-dependent approach to understanding how individuals navigate social environments and adapt to ongoing challenges. Learning how to accurately identify and anticipate changing social cues is a critical component of identifying social threats (Bangee et al., 2014; Spithoven et al., 2017). Indeed, responding to social threat requires modulation of emotion that is both flexible and dynamic (Gross, 2015). Together, these studies integrate to form a cohesive narrative about the complex interplay between social threat, emotional regulation, and cognitive processes, highlighting the importance of early experiences and the need for targeted interventions to mitigate long-term adverse outcomes. Ultimately, these studies contribute to a deeper understanding of how expectations about the future, shaped by past experiences and current environmental predictability, influence stress responses and overall psychological well-being across the lifespan.

The work described in this dissertation provides evidence of coordination among physiological, affective, and cognitive mechanisms that give rise to the perception of social threat and responses to real or potential future social threats. Taken together these three studies

highlight the complex and dynamic nature of social processes, which rely on the integration of current need states and perception of social stressors with existing frameworks of the social world to direct behavior. This research highlights the integrative nature of coordinated stress responses which give rise to complex social phenomena. The implications of this research extend to interventions targeting at-risk populations, emphasizing the importance of early intervention strategies to mitigate the negative impact of social threat experiences on psychological well-being. Future work will seek to further elucidate and disentangle the mechanisms by which perception of social threat changes throughout the development.

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