Title

Behavioral and Biological Markers of Sensory-Over-Responsivity in Youth With Early Caregiving Adversity: Associations With Social-Emotional Development

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Publication Date

2022

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA
RIVERSIDE

Behavioral and Biological Markers of Sensory-Over-Responsivity in Youth With Early Caregiving Adversity: Associations With Social-Emotional Development

A Dissertation submitted in partial satisfaction
of the requirements for the degree of

Doctor of Philosophy

in

Education

by

Laura Alicia Alba

June 2022

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Acknowledgements

I would like to express my heartfelt gratitude to my advisor, Dr. Shula Green for her guidance and tenacity in helping complete this dissertation and for truly believing in me. I would also like to thank my advisor Dr. Austin Johnson and Dr. Marsha Ing for their encouragement, mentorship, and advice, as well as all of the individuals who have served as committee members and offered feedback on this work: Dr. Jennifer Silvers and Dr. Stephanie Moore. I also wish to thank my family (Mi mama, Mariela, Melanie, and Elise), my friends, my SCAN labmates, and especially my partner, Matt, for their support, love, and compassion as I went through this educational journey.

Study 1: As a portion of this manuscript is a version of the following article, the author would like to thank the co-authors for their contributions: Méndez Leal, A.*, **Alba, L. A.** *, Cummings, K., Jung, J., Waizman, Y., Guassi Moreira, J., Saragosa-Harris, N., Ninova, E., Waterman, J., Langley, A., Tottenham, N., Silvers, J.+, Green, S.+ (in press). Sensory processing differences as a novel link between early caregiving experiences and mental health. *Development and Psychopathology.* As joint first authors, Méndez Leal, A. and Alba, L. A. contributed equally to the development of this manuscript in terms of: Research questions, Methodology, Pre-registration of Methodology, Investigation, Formal Analysis, as well as Manuscript writing. Priori hypotheses and data analytic plan were pre-registered on the Open Science Framework. The principal investigators for this study were Shulamite A. Green, Ph.D., and Jennifer Silvers, Ph.D.

Dedication

Para Antonia Alba (aka Mami!), gracias por tu apoyo, por estar siempre conmigo, y por hacerme una mejor persona. Tu apoyo incondicional ha sido fundamental a través de estos años, desde que era travesía y ya de adulto. Tu resiliencia me da fuerzas y me saco adelante. Eres mi maestra de vida, y no pude haber tenido una mejor.

ABSTRACT OF THE DISSERTATION

Behavioral and Biological Markers of Sensory Over-Responsivity in Youth With Early Caregiving Adversity: Associations with Social-Emotional Development

by

Laura Alicia Alba

Doctor of Philosophy, Graduate Program in Education
University of California, Riverside, June 2022
Dr. Shulamite A. Green, Co-Chairperson
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Early caregiving adversity (e.g., abuse, witnessing domestic violence, caregiver deprivation) has a profound impact on behavior and social-emotional development, as well as causing alterations in corresponding stress physiology (McEwen & Morrison, 2013; Tottenham, 2012). Heightened stress-related symptomatology increases the susceptibility for sensory processing challenges, especially sensory over-responsivity (SOR), an intense overaction to sensory stimuli, in these populations (Wilbarger et al., 2010). Yet, the link between SOR and early caregiving adversity is not well understood. This dissertation aimed to provide evidence for sensory processing challenges and their link with emotion dysregulation and physiological responses in youth with early caregiving adversity. Study 1 investigated sensory processing challenges among two distinct groups (adopted from either foster care or those previously institutionalized in orphanage care) of youth with early caregiving adversity. We examined how broad sensory processing challenges generally, and SOR specifically, was associated with mental health. Results showed that youth with early caregiving adversity show heightened sensory processing challenges, including SOR, that in turn partially influenced elevated mental health symptoms. Study 2 investigated the differences in HR responses to mildly aversive sensory stimuli in youth adopted from foster care (AFC) and nonadopted comparison youth. Particularly, this study investigated how SOR and emotion dysregulation influenced HR responses to sensory stimuli in AFC youth. Results showed that AFC participants with higher parent-reported, and experimenter-observed SOR displayed increased HR responses to sensory stimuli relative to AFC participants with lower SOR. Yet, emotion dysregulation only predicted HR responses to some sensory stimuli, suggesting that this hyper-physiological arousal during aversive sensory stimulation is specific to SOR-related dysregulation. Overall, findings show that sensory processing atypicalities are common in youth with early caregiving adversity and are linked to heightened physiological arousal to sensory stimulation and greater mental health challenges. Study results are discussed in terms of their educational implications.

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Figure 8. Inter-beat Interval (IBI) change from the 5-second before stimulus onset for each timepoint after stimulus onset is shown on the x-axis for the visual sensory stimuli **a)** AFC participants with higher SOR showed reduced IBI orientation during the Round-and-Round game; **b)** AFC participants with higher SOR showed reduced IBI orientation during the Sparkles game.

I. Introduction

Early adversity is often defined as exposure to environmental stressors during early childhood that have a significant impact on development, and which may surpass a child's ability to regulate behavior and emotions (Bick et al., 2015; Bruce et al., 2013; Hanson et al., 2015; Lupien et al., 2009; McEwen & Morrison, 2013; Tottenham & Sheridan, 2009; Shonkoff et al., 2012; van IJzendoorn et al., 2011). Children and adolescents with early caregiving adversity, in particular, have varied experiences that often occur within the family environment, and which include the absence of a caregiver, the inability of a caregiver to keep the child safe, and/or abuse directly from a caregiver (Essex et al., 2011; Humphreys et al., 2015; Kessler et al., 2010; Shaw & De Jong, 2012; Zeanah & Humphreys, 2018). Both youth adopted from domestic foster care (AFC) and those from previous institutionalized in orphanage care (PI) often experience high levels of caregiving instability that vary in duration and severity (Tottenham, 2012). While there is noteworthy heterogeneity in the type of caregiving adversity, all of these experiences can bestow susceptibility to stress-related symptomatology (Green et al., 2010; McLaughlin et al., 2012; Méndez Leal & Silvers, 2020; Pine et al., 2005). As such, difficulties in regulating and processing emotional and sensory information have been found among youth with early caregiving adversity (Cicchetti & Toth, 2016; Green et al., 2010; Mendéz Leal et al., 2022, Palmieri & La Salle, 2017; Toth & Manly, 2019; Wilbarger et al., 2010). Specifically, atypical brain development in regions recruited for emotion, sensory, and behavior regulation markedly affect daily living, particularly in their social interactions, school readiness, and mental health (Bick et al., 2015; Blair, 2002; Blair & Raver, 2015; Dennis & Thompson, 2013; Koss et al., 2014; Posner & Rothbart, 2000).

Despite being adopted into committed families, AFC and PI children and adolescents have significant emotion dysregulation and mental health challenges across development (Brand et al., 1999; Clausen et al., 1998; Hussey et al., 2012; Leslie et al., 2005; Pecora et al., 2009; Zill & Bramlett, 2014). Although the impact of early caregiving adversity on mental health symptoms is well-documented in the literature, sensory processing challenges are under-studied in these populations. Sensory processing challenges may be conveyed as under-responsivity such as being unaware or having a delayed response to sensory stimuli (e.g., failing to respond to a school fire alarm), or over-responsivity, such as having an exaggerated response to sensory input most people tolerate (e.g., extreme dislike of certain clothing fabrics), or sensory seeking, such as frequently searching for sensory input (e.g., mouthing on non-food items) (Miller et al., 2007). However, there is some empirical evidence suggesting that early caregiving adversity (e.g., PI youth), as well as other forms of environmental stress (e.g., exposure to war), show high rates of sensory processing challenges, including SOR (Lin et al., 2005; Wilbarger et al., 2010). Yet, the extant literature has primarily focused on sensory processing challenges among youth with autism spectrum disorder (ASD), a heterogenous group with marked inter-individual differences in the presentation of mental health symptoms and sensory processing challenges (Ben-Sasson et al., 2009; White et al., 2014). A major focus of the studies presented in this dissertation was to examine sensory processing challenges, particularly SOR, (e.g., Green et al., 2010), in a heterogenous group of youth with early caregiving adversity.

Studies among youth with ASD have found SOR to be interrelated with unique patterns of behavior, such as emotion dysregulation and internalizing symptoms, as well as biology, such as increased physiological and neural responses to sensory stimuli (e.g., Ben-Sasson et al., 2009; Green & Ben-Sasson, 2010; Jung et al., 2021; White et al., 2014; Green et al., 2015; 2019). Many of these behavioral and emotional challenges, as well as atypical patterns of brain development, are also commonly observed in youth with early caregiving adversity (e.g., Blair & Raver, 2016; McLaughlin et al., 2015; Tottenham, 2012).

Biological research has since provided important insights into the association between early life adversity and socioemotional challenges in children and adolescents (Appelhans & Luecken, 2006; Mehta et al., 2009; McEwen, 2004; Tottenham et al., 2010, 2011). For example, reduced heart rate variability (HRV, i.e., less variability between heart beats), as well as faster heart rate, have been observed in youth with early caregiving adversity and/or mental health symptomatology, and thus may serve as a potential stress marker (Appelhans & Luecken, 2006; Lane et al., 2009; Thayer et al., 2006). Indeed, increased HRV to emotional stimuli is commonly found among children and adults with greater stress resiliency (Michels, et al., 2013). There is evidence to suggest that reduced HRV is significantly linked with elevated anxiety, emotion dysregulation, and hypervigilance among populations with a history of abuse and neglect (Bunford et al., 2017; Krypotos et al., 2011; Porges et al., 1994; Thayer & Brosschot, 2005). Moreover, increased inter-beat intervals (IBIs), that is more heart beats per second and thus an alternate way to look at HRV within a shorter time frame (Task Force of, ESC/NASPE, 1996), shows overall increased physiological arousal in youth with ASD and high SOR (Jung et al., 2022). Moreover, neurobiological research has also shown that early caregiving adversity is associated with atypical brain development in limbic structures (e.g., amygdala) and related regulatory regions (e.g., prefrontal cortex, anterior cingulate cortex), which may lead to heightened internalizing and externalizing symptoms, (e.g., Gee et al., 2013; Gunnar & Quevedo, 2007; Lupien et al., 2009; McEwen, 2004; Tottenham, 2012) as well as play a key role in SOR (Green et al., 2015, 2019). Emotion dysregulation linked to early caregiving adversity and SOR are both considered to be prompted by altered amygdala development, a brain region recruited for detecting and processing emotional information (Green & Wood, 2019; Silvers et al., 2017), which may suggest that youth with early caregiving adversity are susceptible to heightened sensory processing challenges, including SOR. Therefore, exploration of the underlying biology of SOR in youth with early caregiving adversity could explain the notably high emotion dysregulation and risk for psychiatric disorders.

The role of SOR in emotion dysregulation and related mental health challenges among youth with early caregiving adversity warrants further investigation to inform intervention and ecologically valid assessment practices. AFC and PI youth are ideal groups to extend findings on emotion dysregulation and SOR following adverse caregiving because of the variability in adverse caregiving experiences and heightened risk of social-emotional and behavioral challenges, as well as high prevalence of psychiatric diagnoses (e.g., ADHD, anxiety; De Bellis et al., 2011; De Yong et al., 2011; Kavanaugh et al., 2017; Pechtel & Pizzagalli, 2011). Perhaps, SOR may be an overlooked association in understanding emotion dysregulation in children exposed to early caregiving adversity, which could provide insight into how to improve adaptive and school functioning for these youth. Moreover, physiological arousal to tactile, visual, and auditory stimuli have been linked to some SOR-related brain regions among a heterogeneous group of children with ASD (e.g., left sensory cortical regions; Jung et al., 2021). Thus, studying physiological arousal, such as HR, in response to sensory stimuli could provide some insight into the biological mechanisms underlying exposure to early caregiving adversity that may lead to greater risk of SOR.

Childhood abuse, neglect, and trauma, among other forms of adversities, are common problems encountered by school professionals (Jankowaska et al., 2015; Palmieri & La Salle, 2017; Romano et al., 2015). Yet there is limited training and exposure to empirical research about youth with early caregiving adversity among school professionals (Jankowaska et al., 2015). As such, negative views often arise in school professionals, in which previous research shows that they often interpret their social-emotional response to early adversity as avoidance, and/or lack of motivation, and/or poor academic performance (Hertel & Johnson, 2013; Porche, Costello, & Rosen-Reynoso, 2016). In addition, the paucity of research in education examining the developmental outcomes among youth with early caregiving adversity may lead to overrepresentation in special education (nearly 50% receive or are eligible), as well as a lack of access to educationally related services (O'Connor et al., 2003). Given that the school environment can be particularly sensory stimulating which, along with increased learning demands and decreased control of the environment, it could lead to greater emotional dysregulation or other mental health challenges (Miller & Summers, 2001; Sheridan & McLaughlin, 2016) Thus, school professionals should be aware of the high rates of sensory processing challenges among youth with early caregiving adversity as well as potential targeted intervention strategies.

This dissertation aimed to address the gap in the literature examining the behavioral and biological mechanisms underlying emotion dysregulation and SOR among children and adolescents with early caregiving adversity. Ultimately, the goal of this dissertation was to inform understanding of the associations between early caregiving adversity, mental health challenges, and physiological responses that may influence daily living. I also aimed to provide potential recommendations for targeted assessment for sensory processing challenges and mental health to improve school success for children and adolescents with adverse life experiences.

Early Caregiving Adversity and Prevalence

Adopted children and adolescents commonly experience significant caregiving adversity or the absence of a stable caregiving early in life, which in turn impacts critical development and places them at risk for mental health symptomatology (Tottenham, 2012). This dissertation focused on two groups of adopted youth who were either adopted from domestic foster care or previous institutionalized orphanage care. Despite, the differences in early caregiving experience in these two groups, research has postulated similar vulnerabilities to mental health symptoms and psychiatric diagnoses (Smith et al., 2007; Turney & Wildeman, 2016; Wiik et al., 2010), as well as altered biological response to emotional stimuli (Hodel et al., 2015; Hostinar et al., 2012; Tottenham et al., 2010). The following sections provide prevalence rates, as well as common experiences for youth adopted from foster care and previous institutionalized orphanage care.

Foster Care

In 2020, an estimated 407, 493 children and adolescents were in the foster care system with about 28% of them awaiting adoption (U.S. Department of Health and Human Services [HHS], Administration for Children and Families [AFCARS], 2021). Foster care is part of the U.S. child welfare system and was designed to protect children and adolescents from adverse home environments and is considered a temporary intervention (Child Trends, 2019). Most children and adolescents are removed from their home of origin due to caregiving adversity in the form of neglect (physical and emotional; 64%), followed by prenatal substance exposure (35%), caretake inability to cope (13%), physical abuse (13%), and housing instability (9%) (HHS, AFCARS; 2021; Oswald, Heil, & Goldbeck, 2010). Some children are also removed because of one or a combination of the following: parents' response to child behavior problems (e.g., not taking them for appropriate psychiatric care; 8%), parental incarceration (7%), abandonment (5%), parental substance and alcohol abuse (5%), sexual abuse (4%), child drug use (2%), child disability (2%), safe surrender (1%), and parent death (1%) (HHS, AFCARS; 2021; Turney & Wildeman, 2017). Removal of a child from their home of origin and thus, separation from caregivers, even when done in the interest of safety is a major adverse event and often a source of trauma in itself (English et al., 2015; Turney &

Wildeman, 2017). Indeed, youth removed from their caregivers exhibit a heightened risk for developing behavioral and mental health issues later in life (Curtis et al., 1999; Lawrence et al., 2006).

Previously Institutionalized Orphanage Care

Youth adopted from previously institutionalized orphanage care also experience varying early caregiving adversity. Approximately 278,745 children were adopted in 2019 into the U.S. from abroad (United States Department of State, retrieved from http://adoption.state.gov). PI children's early caregiving experiences differ in many ways from the experiences of AFC youth. For example, the quality of the caregiving environment in orphanage care may include rotating caregiving staff, high child-caregiver ratios, disruption of attachment relationships with staff, poor nutrition, and exposure to infection and unsanitary conditions (Gunnar, Bruce, & Grotevant, 2000; Gunnar & van Dulmen, 2007; Merz & McCall, 2010; Nelson et al., 2007; Smyke et al., 2007). Given that most orphanages are located abroad, adoptive parents often have little or unreliable information about the experiences of their children during orphanage living, which further adds to the difficulty in examining developmental outcomes (Groark & McCall, 2011; Groark, McCall, & Fish, 2011; Tirella, Chan, & Cermak, 2008; Vorria et al., 2003).

Despite the improvements in the caregiving environment, the long-term impact of early caregiving adversity for both youth adopted from foster care and institutionalized orphanage care continues to influence outcomes across development (Callaghan & Tottenham, 2016; Tottenham, 2012). For example, many children and adolescents often have numerous psychiatric disorders and mental health symptoms that emerge as a consequence of early adversity and are often observed in school settings (Kessler et al., 2005, 2007; McLaughlin et al., 2012). Thus, the varying outcomes among youth with early caregiving adversity warrant further exploration to provide critical school-based assessment and interventions. Although the literature suggesting that children and adolescents with early caregiving adversity are at risk for emotion dysregulation and maladaptive outcomes is vast, less is known about the role of sensory processing challenges, particularly SOR, in these population, especially among youth with early caregiving adversity. Most importantly, there is little to no research characterizing the biological mechanisms implicated for emotion regulation and sensory modulation in these populations, which contributes to the challenge in designing effective assessment strategies and subsequent intervention. Thus, understanding the role of SOR in emotion regulation among youth with early caregiving adversity may inform clinicians and school professionals in developing individualized interventions using a trauma-informed lens.

Emotion Regulation Development

Emotion regulation is essential to navigating school successfully, as it supports students' ability to adapt to the school environment and interact with peers and teachers (Aspinwall & Taylor, 1997; Cole et al., 2004; Graziano et al., 2007; Healey & Fisher, 2011; Panlilio et al., 2018; Yiend, 2010). For instance, the school environment may result in heightened emotion dysregulation, that is difficulty regulating behavioral responses to emotional information, due to the increased social-emotional and sensory demands (Miller & Summers, 2001). Hence, effective emotion regulation to meet the emotional demands of a sensory-driven school environment has been shown to be a predictor of school readiness, as well as academic success and normative social-emotional development (Blair, 2002; Blair & Raver, 2015; Denham, 2006; Eisenberg et al., 2010; Harrington et al., 2020; Raver, 2002). The Gross process model of emotion regulation indicates that engagement in emotion regulation starts after identifying and processing whether an emotion is helpful or harmful (Gross, 2015). Emotion regulation has been hypothesized as an acquired rapid and nonlinear developmental process that actively attempts to involve, maintain, and change emotions encountered in one's environment (Giedd, et al., 1999; Gross, 1998; Thompson, 1994). Per se, our emotions give us information about the environment we are interacting with and allow us to make decisions about how to process and deal with emotional and sensory input (Campos et al., 2004; Campos et al., 1994; Gross, 2008). The ability to regulate emotions is important to both increase positive emotional valence to promote learning, as well as to buffer negative emotions and heightened arousal that prevent the attainment of encoding novel information (Thompson, 1994).

Notably, emotion regulation is prompted in the context of parent-child interactions in which several components of emotional development are taught and shaped by a child's caregiver (Thompson, 1994; Tottenham, 2012). Much scientific literature has proposed that the presence of a caregiver in a child's life may mitigate or even decrease emotional stress responses to negative information in the environment, providing a sense of safety (Bowlby, 1963; Callaghan & Tottenham, 2016; Gunnar & Donzella, 2002; Hofer, 1994; Tottenham, 2012). Consequently, the absence of a caregiver drives children to adapt independently to survive the demands of a suboptimal environment filled with emotional and sensory information, which results in elevated emotion dysregulation (Gunnar et al., 2000; Tottenham, 2012). Emotion dysregulation is a hallmark challenge that contributes to increased mental health issues among youth with a history of caregiver deprivation, as well as caregiver abuse and neglect (Cicchetti et al., 1995; Ellis, Fisher & Zaharie, 2004; Green et al., 2010; Tottenham, 2012; Waizman et al., 2020). The National Comorbidity Survey indicated that childhood adverse experiences explained an estimated 32% of psychiatric disorders with 44% of these disorders having an onset in childhood (Green et al., 2010). When adverse caregiving experiences occur in childhood, they pose a threat to a human's ability to process and regulate emotions and sensory information which in turn increases the risk for mental illness (Cicchetti et al., 1995; Ellis et al., 2004; Green et al., 2010; Kessler et al., 2010; Maughan & Cicchetti, 2002; Thompson et al., 2008; McLaughlin et al., 2015; Tottenham et al., 2010).

Children and adolescents with early caregiving adversity often exhibit increased levels of anxiety, depression, and attention-deficit hyperactivity disorder (ADHD) relative to children living with their family of origin (Craig et al., 2020; Heneghan et al., 2013; Kocôvská et al., 2012; Bederian-Gardner et al., 2018; Garland et al., 2001; Laurent et al., 2015; Lehmann et al., 2013; McGuire et al., 2018; Pilowsky & Wu, 2006; Oswald et al., 2010). In a sample of 82 AFC children in Los Angeles, results indicated that neglect, physical and sexual abuse were linked to externalizing behaviors, such as elevated aggression and engagement in delinquent behavior (Tung et al., 2018). Other studies have also shown that children who experience multiple foster care placements prior to adoption exhibit more externalizing symptoms and poorer self-regulation relative to children who only had one foster care placement (Lewis et al., 2007; Smith-McKeever, 2006). Despite the number of foster care placements, youth were at an increased risk for mental health symptomatology (Lewis et al., 2007; Smith-McKeever, 2006). These findings highlight the importance of carefully considering the early life experiences of youth with early caregiving adversity, including age of placement and number of prior placements when exploring how early caregiving adversity impacts mental health.

Sensory Over-Responsivity and Emotion Regulation

A potential missing factor in understanding the mechanisms underlying emotion dysregulation may be sensory over-responsivity (SOR), an impairing condition in which individuals display an extreme sensitivity to environmental stimuli such as sudden loud noises, noisy environments, bright lights, scratchy clothing, or being touched (Haigh et al., 2016; Tomchek & Dunn, 2007). This condition is most commonly studied among individuals on the autism spectrum (ASD) and has been linked with difficulties in social-emotional development (Ben-Sasson et al., 2008; Glod et al., 2015). In a recent review, heightened scores on parent reported measures of SOR were shown to influence challenges, that is differences, in interpreting social interaction, particularly verbal and nonverbal communication, in children on the autism spectrum (Glod et al., 2015). In addition, neuroimaging research shows that high SOR in ASD populations relates to hyper-reactivity and decreased habituation in the amygdala, sensory, cognitive, and limbic (e.g., amygdala, hippocampus, PFC) regions in response to aversive sensory stimulation (Green et al., 2013, 2015). Moreover, youth with ASD *without* SOR exhibit abnormally high prefrontal down-regulation of the amygdala, which may indicate that they are utilizing additional energy to impede dysregulated behavioral sensory responses, such as having tantrums or becoming irritable (Green et al., 2015, 2019). While the extant literature characterizing SOR has focused on ASD, sensory processing challenges are not limited to ASD populations and are commonly observed in other clinical populations (e.g., ADHD, anxiety disorders, fragile X syndrome, post-traumatic stress disorder, learning disabilities; Cheung & Siu, 2009; Ermer & Dunn, 1998; O'Brien et al., 2009; Rogers et al., 2003; Yochman & Pat-Horenczyk, 2020).

There is some preliminary evidence suggesting that heightened sensory processing challenges in children with early caregiving adversity and/or other forms of adversity (e.g., exposure to war) relate to enhanced mental health symptoms (Lin et al., 2005; Yochman & Pat-Horenczyk, 2020; Wilbarger et al., 2010). In a study among a sample of 134 children previously exposed to repeated missile attacks in Israel, results showed that children with higher post-traumatic stress symptoms had significantly higher levels of sensory processing challenges, particularly in tactile sensitivity, relative to children with no post-traumatic stress symptoms (Yochman & Pat-Horenczyk, 2020). Furthermore, research in PI children have also revealed that prolonged institutional care was associated with more sensory aversions and sensory-seeking behaviors relative to children adopted early (before the age of 8 months) and those with no history of institutional rearing (Wilbarger, Gunnar, Schneider, & Pollak, 2010). However, Wilbarger et al. did not include participants adopted from domestic foster care, who are often removed from their homes on average around the age of 8 years (AFCARS; 2021).

Thus, further work is needed to understand sensory processing challenges among youth with various forms of early caregiving adversity. Moreover, alterations in sensory, cognitive, and limbic brain regions have also been observed among children and adolescents with early caregiving adversity, particularly PI youth (Cohen et al., 2013; Tottenham, 2012). Much work in early caregiving adversity have provided strong evidence for atypical amygdala development and amygdala-prefrontal connectivity in populations exposed to abuse, neglect, and caregiver deprivation (Gee et al., 2013; Green et al., 2016; Tottenham, 2012; Tottenham et al., 2010, 2011; VanTieghem & Tottenham, 2017). Such early atypical amygdala development may place youth exposed to early caregiving adversity at risk for atypical activation in sensory processing regions.

As such, there is emerging evidence that SOR may be an early indicator of subsequent mental health challenges, such as risk of developing sleep problems, anxiety symptoms, and irritability (Carpenter et al., 2019; Green & Carpenter, 2012). Indeed, evidence from cross-sectional and longitudinal studies suggest that parents who report elevated levels of SOR in their children also report elevated levels of internalizing, externalizing, and emotion dysregulation symptoms (Ben-Sasson et al., 2009; Carpenter et al., 2019; Green et al., 2013; Goldsmith et al., 2006). Studies also indicate that children with ADHD and anxiety often experience emotion dysregulation and SOR (Ben-Sasson et al., 2017; Lane & Reynolds, 2019; Parush et al., 2007; Reynolds & Lane, 2008, 2009). Susceptibility to high internalizing symptoms (e.g., anxiety) and externalizing symptoms (e.g., ADHD) in children and adolescents with early caregiving adversity, may make them prone to high prevalence rates of SOR. While the vast literature provides evidence about the pervasiveness of SOR across high-risk groups, less is known about the effect of environmental risk factors on elevated SOR among populations exposed to adversity. Perhaps, it is likely that youth with early caregiving adversity are at increased risk for SOR because of their early environmental exposure to abuse, neglect, witnessing violence, caregiver deprivation, and other forms of maltreatment (AFCARS; United States Department of Health and Human Services [USDHSS], 2020, Tottenham, 2012). Therefore, a main focus of this dissertation was to identify the level of SOR among youth with early caregiving adversity and how it linked with emotion dysregulation and related mental health challenges.

Psychophysiological Correlates and Emotion Regulation

Empirical evidence suggests that the body's physiological reactions activate in response to emotionally salient stimuli (Cohen et al., 2007; Danese & McEwen, 2012; Lane et al., 2009). Of particular interest is the physiological response of the heart which causes sympathetic activity to increase and parasympathetic activity to decrease in response to information in the environment (Appelhans & Luecken, 2006; Lane et al., 2009; Brosschot et al., 2006). Thereby, the ability of the autonomic nervous system to quickly regulate our heart rate is important for successful emotional processing (Appelhans & Luecken, 2006). Hence, when increases in heart rate (HR) occur, they are often in response to the interaction between emotions and the environment being navigated (Danese & McEwen, 2012). For example, when a child encounters a stressful situation, such as when presenting in front of their class, heart rate increases in response to the anxious feelings of the child. In this example, the body is responding to the shifts in emotions due to the new demands of the environment and thus the automatic nervous system needs to regulate the child's heart rate to successfully complete the task (Appelhans & Luecken, 2006).

Several studies have shown that heart rate variability (HRV) offers critical information about automatic flexibility and emotion regulation (Appelhans & Luecken, 2006; Porges, 2001; Michels et al., 2013; Thayer et al., 2012; Thayer & Lane, 2000). HRV measures the degree to which cardiac activity can be regulated to the changing environmental demands and is examined by measuring the variation between each heartbeat (Appelhans & Luecken, 2006; Fujimura & Okanoya, 2012; Thayer & Lane, 2000; Thayer et al., 2012). Among children and adolescents with high levels of stress, alterations in HRV to emotional stimuli are often observed (de Veld et al., 2014; Li, Chwo, & Pawan, 2013; Michels et al., 2013; Thayer et al., 2012). Generally, reduced HRV, that is less variability in each heartbeat, has been shown to be a characteristic of emotion dysregulation, behavioral inflexibility, and mental health challenges (Appelhans & Luecken, 2006; Bunford et al., 2017; Krypotos et al., 2011; Porges et al., 1994; Thayer & Brosschot, 2006). Moreover, reduced HRV had been observed among children and adults with heightened hypervigilance, disinhibition, and symptoms of post-traumatic stress disorder (PTSD) and anxiety (Blechert et al., 2007; Bunford et al., 2017; Friedman, 2007; Vögele et al., 2010). In a study examining the association between HRV and parent-reported emotion dysregulation in a sample of 104 children with and without ADHD, lower HRV was associated with more emotion dysregulation above and beyond an ADHD diagnosis (Bunford et al., 2017). Comparably, Michels et al. (2013) examined the association between HRV and emotional dysregulation in a sample of 523 children between the ages of 5-10 years and found that that low HRV and high frequency (HF) spectral power (higher power in the frequency band of HRV; Burr, 2007) were related to higher stress and negative emotions (e.g., anger, anxiety, and sadness). Studies in adults and children provide evidence that reduced HRV response, that is more beats per millisecond, is linked to PTSD symptoms and early life adversity (Cohen et al., 1998; Michels et al., 2013; Sammito et al., 2015).

Furthermore, physiological responses to adverse sensory stimuli and emotion dysregulation, particularly among ASD populations, has recently begun to be explored. Among these research studies, findings indicate that youth with ASD exhibit elevated physiological responses, particularly in inter-beat intervals (IBIs), which measure gaps between heart beats in a short duration of time and is similar to HRV responses (Task Force of, ESC/NASPE, 1996), when exposed to aversive sensory stimuli relative to neurotypical populations (Bizzell et al., 2019; Jung et al., 2021; Keith et al., 2019; Woodard et al., 2012). Indeed, Jung et al. (2021) examined mean HR and IBI responses to aversive sensory stimuli and related them to parent reported measures of SOR among ASD and neurotypical children and adolescents. Results revealed that ASD participants with high parent-reported SOR showed increased HR responses to aversive sensory stimuli relative to neurotypical and ASD participants with low SOR. In another study with children on the autism spectrum, Keith et al. (2019) found that more anxiety and auditory SOR (e.g., police sirens) were correlated with increased HR responses to a memory task paired with aversive sounds in youth with ASD relative to neurotypical participants. These studies highlight the unique relationship between physiological responses to aversive sensory stimulation in heterogenous clinical populations (e.g., ASD). Youth with early caregiving adversity, particularly AFC and PI youth, are also heterogenous groups with elevated risk to mental health symptomatology and increased HR responses to novel emotional stimuli. Accordingly, exploring HR responses to aversive sensory stimulation in children and adolescents with early caregiving adversity, particularly AFC youth, may provide information about the high rates of SOR in this population, as well as the link between SOR and emotion dysregulation.

Implications for Schools

Despite the large number of children and adolescents with early caregiving adversity, research has shown that school professionals often feel underprepared to support these students, due to the unreliability of early health information and educational histories (Miller et al., 2007; Saiman et al., 2001; Schulte et al., 2002). Moreover, teachers indicate that a lack of graduate training and limited support from school leaders, make them feel unprepared to meet the educational needs of students in foster care or those with a history of adversity (Zetlin et al., 2012). The limited understanding among school professionals has led to some teachers to misinterpret the behavior of students exposed to adversity, in which these children's behavior is often reported to be negative and problematic (Palmieri & LaSalle, 2017; Pears & Fisher, 2005a, 2005b), resulting in more office discipline referrals (Scherr, 2007).

In addition to shortcomings in teacher training and administrative support, educators face further challenges in building positive relationships with students with early caregiving adversity and identifying effective pathways for cultivating academic achievement in this population due to frequent changes in foster care placements, unstable caregiving, and increased school absences (Sattler et al., 2018; Tyrell et al., 2019; Zetlin & Weinberg, 2004; Zorc et al., 2013). These gaps in school staff knowledge and inadequate relationships likely spur issues of disproportionality and access to equitable services. For instance, youth in foster care are overrepresented in special education, with almost 50% of foster youth receiving or being eligible for special education services in school (Watson & Kabler, 2012; Zeitlin et al., 2004). However, the converse is also apparent, in which some youth may have limited or inadequate access to school-based services and often go unidentified for individual specialized instruction (Gallegos & White, 2013; Gamble & Lambros, 2014; Hirsch et al., 2018). As noted by Kendrick-Dunn et al. (2020), children and adolescents in foster care often experience systemic disadvantages in the school environment, including limited access to services that promote successful academic performance.

To deter undesirable outcomes for students in foster care, teachers and school-based mental health professionals should be made aware that the experience of starting school for a child may elicit the manifestation of sensory processing challenges and emotion dysregulation as the social and physical environment of school is often more stimulating than their homes (Miller & Summers, 2001; Sheridan & McLaughlin, 2016). Many children with a history of adverse caregiving come into the school environment with significant emotional dysregulation and mental health symptomatology that may be further exacerbated by this environment (Allen & Vacca, 2010; Zorc et al., 2013).

Unfortunately, a limited understanding of sensory processing challenges in this population of students may result in further emotion dysregulation and missed opportunity for early intervention.

Collectively, the behavioral and biological research previously described provides a rich foundation for the potential implications of emotion regulation in daily functioning for youth with early caregiving adversity. In addition to informing behavioral observations in the school environment, findings from biological sciences may enable the development of improved intervention strategies. That is, intervention design may take into consideration information about how our bodies react to emotionally salient cues in the environments we navigate. One goal of this dissertation was to add to this rich literature by examining the behavioral and biological mechanisms of sensory processing and emotion dysregulation among a population of children susceptible to struggling in the school environment, and then contextualize the information gleaned exclusively within educational and school psychological service delivery.

More specifically, given that sensory processing challenges, particularly SOR, have been understudied among children with a history of early caregiving adversity, school practitioners may not be aware that this is an area of concern. Therefore, characterizing the prevalence of SOR and how it relates to emotion dysregulation may facilitate the provision of important information to practitioners about the presentation of these symptoms. Understanding when SOR is the underlying cause for emotional and behavioral challenges in school may help teachers and school practitioners respond and support this behavior accordingly if the information developed here can be readily assessed by school-based personnel and appropriate targeted interventions subsequently applied.

This dissertation attempted to characterize the socioemotional and behavioral development, particularly sensory processing challenges, in a sample of children and adolescents with varying early caregiving adversities. Findings from this dissertation may not only add to the existing literature of early life adversity but may also inform the implementation of graduate teacher training in supporting the educational needs of students exposed to adversity and in screening for sensory processing challenges, particularly sensory over-responsivity.

School professionals may benefit from an increased understanding of developmental research which identifies behavioral and social-emotional development exhibited in youth exposed to adversity and how adverse experiences impact subsequent neural and physiological mechanisms needed to navigate the environment. As the field of education continues to intersect with research on the biological bases of behavior, it is prudent to not only characterize behavior but to explore how adversity impacts physiological responses to the sensory environment to better understand the context and possible causes of observed social-emotional behaviors and sensory processing challenges in the classroom.

Dissertation Studies

This dissertation examined the behavioral and biological mechanisms of SOR and their associations with emotion dysregulation in children and adolescents with early caregiving adversity. The analyses undertaken herein are framed as two investigations:

Aim 1. The first study sought out to explore the links between early caregiving adversity and sensory processing challenges, particularly SOR in two heterogenous groups of youth exposed to early caregiving adversity adopted from domestic foster care (AFC) and those previously institutionalized orphanage care (PI) in contrast to a non-adopted comparison (NAC) group. This study also investigated whether sensory processing challenges mediated the relationship between early caregiving adversity and internalizing and externalizing symptoms.

Aim 2. The second study aimed to investigate psychophysiological responses, particularly heart rate (HR), to aversive sensory stimulation in AFC and comparison non-adopted youth. This study also examined how HR responses to aversive sensory stimulation related to behavioral indices of SOR and emotion dysregulation in AFC youth.

II. Research Studies

Rationale for Study 1

Although the development of mental health symptoms and subsequent psychiatric diagnoses are commonly studied among children and adolescents with early caregiving adversity, there is some research postulating that early adversity confers increased sensory processing challenges in these populations. Sensory processing challenges, particularly SOR, have been shown to increase internalizing symptoms (e.g., anxiety) among clinical populations which in turn are related to biological mechanisms (e.g., amygdala) responsible for interpreting and processing emotional information. Given that early caregiving adversity also alters brain and physiological developmental of emotional processing, it likely makes these children and adolescents susceptible to heightened sensory processing challenges that impede daily living. However, the literature examining the risk of sensory processing challenges, especially SOR, among populations with early caregiving adversity is sparse and no study has characterized the prevalence of sensory processing challenges in these populations. Thus, this study aimed to bridge this gap in the literature by examining whether broad sensory processing challenges, and SOR in particular, are prevalent at high rates across two distinct groups with varying types of early caregiving adversity. These two groups consisted of youth adopted from either domestic foster care (AFC) or previous institutionalized orphanage care (PI). In addition, this study also identified how sensory processing challenges, particularly SOR, influenced the association between early caregiving adversity and subsequent mental health symptomatology.

Study 1: Sensory processing differences as a novel link between early caregiving experiences and mental health

Abstract

Background: Early caregiving adversity (ECA) is associated with elevated psychological symptomatology. While neurobehavioral ECA research has focused on socioemotional and cognitive development, ECA may also increase risk for “low-level” sensory processing challenges. However, no prior work has compared how diverse ECA exposures differentially relate to sensory processing, or, critically, how this might influence psychological outcomes.

Methods: We examined sensory processing challenges in 183 8-17 year-old youth with and without histories of institutional (orphanage) or foster caregiving, with a particular focus on sensory over-responsivity (SOR), a pattern of intensified responses to sensory stimuli that may negatively impact mental health. We further tested whether sensory processing challenges are linked to elevated internalizing and externalizing symptoms common in ECA-exposed youth.

Results: Relative to non-adopted comparison youth, both groups of ECA-exposed youth had elevated sensory processing challenges, including SOR, and also had heightened internalizing and externalizing symptoms. Additionally, we found significant indirect effects of ECA on internalizing and externalizing symptoms through both general sensory processing challenges and SOR, covarying for age and sex assigned at birth.

Conclusion: These findings suggest multiple forms of ECA confer risk for sensory processing challenges that may contribute to mental health outcomes, and motivate

continuing examination of these symptoms, with possible long-term implications for screening and treatment following ECA.

Please note: Méndez Leal, A.*, Alba, L. A. *, Cummings, K., Jung, J., Waizman, Y., Guassi Moreira, J., Saragosa-Harris, N., Ninova, E., Waterman, J., Langley, A., Tottenham, N., Silvers, J.+, Green, S.+ (in press). Sensory processing differences as a novel link between early caregiving experiences and mental health. *Development and Psychopathology.*

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Early caregiving adversity (ECA) is characterized by environmental features that directly disrupt the caregiver–child relationship– for example, exposure to abuse, neglect, parent mental illness, parent substance abuse, or institutional (e.g., orphanage) care (Tottenham, 2020). Exposure to ECA has profound implications for socioemotional, cognitive, and behavioral development, and is a significant risk factor for the development of adolescent mental health disorders (Callaghan & Tottenham, 2016a, 2016b; Kessler et al., 2010; McLaughlin, DeCross, Jovanovic, & Tottenham, 2019; Shaw & De Jong, 2012; Shonkoff et al., 2012; Witt et al., 2016; Zeanah & Humphreys, 2018). Though ECA exposures can be quite heterogeneous, youth with histories of ECA share an increased risk for stress-related symptoms in both the internalizing (anxiety, depression, and somatic) and externalizing (rule-breaking, aggression) domains (Blake, Ruderman, Waterman, & Langley, 2021; Busso, McLaughlin, & Sheridan, 2017; Heleniak, Jenness, Vander Stoep, McCauley, & McLaughlin, 2016; Humphreys et al., 2015; McLaughlin, Colich, Rodman, & Weissman, 2020; McLaughlin et al., 2012, 2015; Witt et al., 2016). Much of the neurobehavioral research on ECA has thus focused on how exposures may impact the development of high-level cognitive and socioemotional capabilities that, if disrupted, increase risk for psychopathology (Callaghan & Tottenham, 2016b; Chen & Baram, 2016; Heleniak et al., 2016; McLaughlin et al., 2020; McLaughlin, DeCross, et al., 2019; McLaughlin, Weissman, & Bitrán, 2019). However, emerging evidence – including causal connections in primates (Schneider et al., 2017, 2008) – suggests that ECA also confers increased risk for lower-level sensory processing challenges that may also contribute to mental health outcomes (Armstrong-Heimsoth, Schoen, & Bennion, 2021; Howard, Lynch, Call, & Cross, 2020; Joseph, Casteleijn, van der Linde, & Franzsen, 2021; Lin, Cermak, Coster, & Miller, 2005; Schneider et al., 2017, 2008; Wilbarger, Gunnar, Schneider, & Pollak, 2010).

Sensory processing challenges like those observed in youth with histories of ECA profoundly disrupt daily functioning and are linked to psychological symptomatology in both typically developing and clinical populations. These challenges often manifest in the way individuals modulate (experience and then respond to) sensory input. For example, sensory over-responsivity (SOR) is a prevalent and disruptive sensory processing challenge characterized by heightened or prolonged reactivity to sensory stimuli (e.g., bright lights, loud sounds, being touched; Ben-Sasson et al., 2009; Miller et al., 2007; Reynolds & Lane, 2008; Tomchek & Dunn, 2007). Other common examples of atypical sensory processing and reactivity include sensory under-responsivity, an unawareness of or delayed response to salient sensory stimuli (e.g., reduced pain responses, not reacting to novel sounds), and sensation seeking, which typically involves searching for sensory input (e.g. seeking out deep pressure; mouthing non-food items; Miller et al., 2007; Tomchek & Dunn, 2007). In addition to contributing to family impairment and socialization challenges (Ben-Sasson, Carter, et al., 2009; Carpenter et al., 2019; Carter, Ben-Sasson, & Briggs-Gowan, 2011; Dellapiazza et al., 2020, 2018), these sensory symptoms have implications for mental health. Though the directionality of the relationship between sensory processing challenges and developmental psychopathology warrants further investigation, sensory processing challenges in general, and SOR in particular, prospectively predict later internalizing symptoms (Carpenter et al., 2019), and (to a lesser degree) are linked to externalizing behaviors (Gunn et al., 2009). While sensory processing challenges occur in otherwise typically developing youth, they are over-represented in individuals with neurodevelopmental disorders or psychopathology (Ben-Sasson, Hen, et al., 2009; Ben-Sasson & Podoly, 2017; Ben-Sasson, Soto, Heberle, Carter, & Briggs-Gowan, 2017; Gunn et al., 2009; McMahon, Anand, Morris-Jones, & Rosenthal, 2019; Parham, Roush, Downing, Michael, & McFarlane, 2019). Furthermore, within clinical populations, higher levels of sensory processing challenges are associated with greater levels of symptoms from the primary diagnosis, suggesting that sensory processing challenges may exacerbate other clinical outcomes (Ben-Sasson & Podoly, 2017; Conelea, Carter, & Freeman, 2014; Engel-Yeger, Muzio, Rinosi, Solano, & Serafini, 2016; Hannant, Cassidy, Tavassoli, & Mann, 2016; Kern et al., 2006).

Theoretical Connections Between ECA and Sensory Processing Challenges

There is both theoretical and empirical evidence to suggest that ECA can produce sensory processing challenges, which in turn may contribute to the later development of psychopathology.

Caregivers guide numerous features of development, ranging from early attention and language acquisition to affective processes including self-regulation, and may similarly shape sensory development (Callaghan & Tottenham, 2016a; Gee, 2016; Hoff, 2006; Kuhl, 2007; Méndez Leal & Silvers, 2022; Tamis-LeMonda, Kuchirko, & Song, 2014). Theoretically, the absence of stable caregiving early in life may alter sensory processing development through reduced caregiver scaffolding of initial sensory responses, regulation of affective reactions to sensory stimuli, or both. This is consistent with emerging neurodevelopmental theories of sensory over-responsivity that argue that SOR symptoms may reflect bottom-up differences in encoding of sensory stimuli – through either altered sensory perception or initial affective responses to sensory input – or alternatively, may be the result of disrupted top-down regulation of sensory responses (Green & Wood, 2019).

In early life, the environment tunes experience-dependent neural and behavioral development (e.g. perceptual narrowing; Scott et al., 2007). Neural and behavioral evidence suggests that this tuning process is guided by attentional biases towards socially relevant stimuli (Johnson et al., 1991; Simion et al., 2008; Vouloumanos et al., 2010), and towards stimuli that are jointly viewed with others (a caregiver, for example; Hoehl, Michel, Reid, Parise, & Striano, 2014; Lloyd-Fox, Széplaki-Köllőd, Yin, & Csibra, 2015; Parise, Reid, Stets, & Striano, 2008; Suarez-Rivera, Smith, & Yu, 2019). In typical development, primary caregivers scaffold the salience of environmental cues, guiding the interpretation of sensory signals and providing context for what is otherwise a jumble of sights and sounds. It follows that navigating unpredictable or stressful environments without a stable primary caregiver may require heightened sensitivity, which may eventually manifest as SOR. Empirically, youth with histories of ECA have heightened behavioral and neural vigilance and threat sensitivity, perhaps reflecting increased attunement to salient environmental cues (Machlin et al., 2019; McLaughlin et al., 2016; Muhammad et al., 2012; Silvers et al., 2016, 2017). Notably, both these ECA-linked phenotypes and SOR are thought to be induced by altered development of the amygdala, the brain region most commonly implicated in the detection and appraisal of emotional stimuli (Gee, 2016; Green & Wood, 2019; Silvers et al., 2017).

Another way that the absence of a stable caregiver may evoke SOR is by altering regulation of sensory systems. Given the crucial role that caregivers play in the development of affective regulation systems and the well-documented impact of ECA on these processes (Callaghan & Tottenham, 2016a, 2016b; Gee, 2016; Méndez Leal & Silvers, 2022), it is possible that the absence of stable caregiving disrupts regulation of affective responses to sensory stimuli to produce sensory processing challenges, including SOR. In line with this possibility, ECA alters the development of prefrontal regulation of amygdala responses to affective and non-affective stimuli, producing poor behavioral self-regulation (Callaghan & Tottenham, 2016b; Chen & Baram, 2016; Cohodes, Kitt, Baskin-Sommers, & Gee, 2020; Heleniak et al., 2016; Jenness et al., 2020; Tottenham et al., 2010). The effects of ECA on these prefrontal-amygdala circuits and associated affective and self-regulatory processes are theorized to underlie the high prevalence of psychopathology (particularly internalizing disorders) in youth exposed to ECA (Callaghan & Tottenham, 2016b; Gee et al., 2013; Silvers et al., 2017; VanTieghem & Tottenham, 2018; Weissman et al., 2019).

Given this evidence and that development is hierarchical, it may be that changes to neural circuitry induced by a lack of stable caregiving first manifest as sensory processing challenges in childhood, before evolving into the broader psychological symptom profiles observed in youth with these experiences. Theoretically, ECA may act directly upon sensory processing first, given that the sensory cortices are developing rapidly in the first few years of life, and this in turn could have ripple effects on other aspects of development down the road. In line with this, empirical evidence in other populations suggests that sensory processing challenges emerge prior to and prospectively predict internalizing and externalizing symptoms (Carpenter et al., 2019; Green, Ben-Sasson, Soto, & Carter, 2012; McMahon et al., 2019). For example, cross-lag analyses in youth with autism suggest that SOR emerges early and predicts later increases in anxiety, while anxiety does not predict later SOR (Green et al., 2012). While it is possible that ECA independently causes sensory processing challenges, and later in development, internalizing and externalizing problems, this seems unlikely given that treating sensory processing challenges attenuates the development of other psychopathology in humans and neuroendocrine and behavioral correlates of early life stress in rodents (Kentner, Scalia, Shin, Migliore, & Rondón-Ortiz, 2018; Warner, Spinazzola, Westcott, Gunn, & Hodgdon, 2014).

Support for the theoretical model that ECA causes sensory processing challenges that in turn confer elevated risk for psychopathology ought to meet two criteria: first, sensory processing challenges ought to be prevalent in groups exposed to varied forms of ECA, and second, sensory symptoms ought to predict psychopathology in ECA-exposed youth. Several studies have reported that institutional (e.g. orphanage) caregiving elevates risk for sensory processing challenges (Armstrong-Heimsoth et al., 2021; Howard et al., 2020; Lin et al., 2005). However, institutional care is an increasingly rare form of ECA characterized both by reduced caregiving and a unique social and sensory deprivation driven by a reduction in novelty. Establishing that ECA in general contributes to the development of sensory processing challenges therefore requires comparison with other forms of ECA beyond institutionalization. Wilbarger et al. (2010) found that internationally adopted youth with histories of prolonged previous institutional caregiving experienced elevated sensory processing challenges relative to non-adopted youth and *internationally* adopted youth with short-term experiences of foster care, implying that institutional caregiving may confer a unique risk for sensory processing challenges. However, it is unclear from Wilbarger et al. whether the group differences in sensory processing challenges are related to *type* of ECA or simply to *severity.* Therefore, comparing sensory processing challenges in youth internationally adopted from institutional care to other groups with comparably severe ECA experiences – for example, youth in the United States adopted from *domestic* foster care (who have varied and often, more prolonged ECA experiences) may further clarify this finding. Although experiences surrounding placement into institutional and foster care have commonalities (e.g. separation from primary caregivers, lack of stable caregiving, and uncertainty about the future), these distinct types of caregiving adversity also typically differ on several important dimensions, including family circumstances leading to placement, the large-scale political or economic systems that determine the types of caregiving available, and qualitative features of the caregiving itself (Berens & Nelson, 2015; van IJzendoorn et al., 2020). Given that varied ECA exposures have been implicated in alterations of prefrontal-amygdala circuitry thought to underlie SOR (Callaghan & Tottenham, 2016b; Green et al., 2019; Green, Hernandez, Bowman, Bookheimer, & Dapretto, 2018; Green & Wood, 2019; Silvers et al., 2017, 2016), we would expect that diverse forms of ECA likely increase the risk of SOR. The present study allows us to test this possibility. Lastly, explicitly probing SOR and examining ties between sensory processing and mental health in middle childhood and adolescence (when most psychopathology begins to emerge; Solmi et al., 2021) may clarify the importance of sensory processing in long-term outcomes in youth with histories of ECA.

Current Study

The current study examined whether two broad categories of ECA (experiences surrounding previous institutionalization or placement in domestic foster care) are associated with elevated sensory processing challenges in children and adolescents. Specifically, we explored links between ECA and sensory processing challenges in general and SOR in particular, given the latter's relationship with clinical outcomes in other populations (Carpenter et al., 2019; Green et al., 2012). We also examined whether sensory processing challenges are related to internalizing and externalizing symptoms, which are common in youth with ECA exposures. Given that varied forms of ECA exert similar deleterious effects on development in other domains, we hypothesized that both youth adopted from foster care (AFC) and previously institutionalized (PI) youth would have greater sensory processing challenges (including SOR) relative to non-adopted comparison youth, and did not have specific between-group hypotheses regarding sensory processing challenges. Additionally, we hypothesized that we would find significant indirect effects for the positive relationship between ECA and internalizing and externalizing symptoms through both general sensory processing challenges and SOR specifically. Lastly, we predicted that sensory processing challenges would be higher in participants who were placed into adoptive homes later in life (due to prolonged ECA exposure), consistent with a dose-response relationship between ECA and both sensory and psychopathology symptoms in some samples (Julian, 2013; Lin et al., 2005; Pitula et al., 2014; Wilbarger et al., 2010). Our a priori hypotheses and data analytic plan were pre-registered on the Open Science Framework (*to comply with journal requirements, link to be added in unblinded submission given recruitment details included in the text of the pre-registration)*.

Methods

Participants

Data were drawn from two projects examining the neurobehavioral sequelae of ECA in AFC, PI, and non-adopted comparison children and adolescents. Informed consent and assent were obtained from legal guardians and study participants, and study procedures were approved by the Institutional Review Board. During study visits, parents/guardians were asked to complete assessments of sensory processing challenges and psychological symptomatology for their child.

As outlined in our pre-registration, child and adolescent participants were excluded from the study if they had a diagnosis of bipolar disorder, schizophrenia, autism spectrum disorder, or any known genetic conditions. While most parents completed all measures during one session, after pre-registration we discovered that psychological symptomatology measures were collected during a separate clinical intake for 7 AFC youth. Although most of these participants completed both assessments within a two-year period, one child with a larger gap between sensory and symptomatology assessments was excluded. Lastly, 6 youth in the pre-registered PI sample were later discovered to have been adopted internationally from foster (and not institutional) care and were thus excluded from the final analyses.

34 PI, 37 AFC, and 112 comparison youth aged 8-17 years had usable data and were included in analyses. Additional details about recruitment and exclusion are reported in the supplement.

Demographic Information

Chi-square analyses were performed to explore group differences in sex assigned at birth, race, and ethnicity. ANOVAs were used to assess group differences in child age, age at placement into adoptive home, and child IQ (measured using the *Wechsler Abbreviated Intelligence Scale, Second Edition;* WASI-II). Group differences in demographic information are presented in Table 1.

Measures

To characterize sensory experiences following ECA, we used a general measure of sensory processing challenges focused on sensory modulation (Short Sensory Profile) and a targeted assessment of SOR symptoms (SP3D Inventory), given reported links between SOR and clinical outcomes (McIntosh, Miller, & Shyu, 1999; Schoen, Miller, & Green, 2008). Additional measure details, discussion of the advantages of using both scales, and correlations between similar subscales across measures are reported in the supplement.

General sensory processing challenges. The *Short Sensory Profile* (SSP; McIntosh et al., 1999) assesses a child's struggles with sensory processing. For example, parents indicate to what extent their child reacts emotionally to or avoids intense sensory stimuli (e.g., touch, sound, light, tastes), seeks out touch/movement to a disruptive degree, or is affected by sensory distractors. SSP total scores are derived from parent ratings of their child's sensory processing on all 38 items, each scored from 1 (*Always*) to 5 (*Never*). The SSP items are divided into seven subscales: Tactile Sensitivity, Taste/Smell Sensitivity, Movement Sensitivity, Visual/Auditory Sensitivity, Underresponsive/Seeks Sensation, Auditory Filtering, and Low Energy/Weak. Previous research suggests that the SSP subscales have reliability estimates in the moderate to excellent range (McIntosh et al., 1999). Lower SSP scores reflect less typical processing, with clinical categories characterized as typical sensory processing (190 to 155), or probable (154 to 142) or definite (141 to 31) sensory processing challenges.

Sensory over-responsivity. The Sensory Processing 3-Dimensions Scale Sensory Inventory (SP3D) assesses a child's responses to common, potentially aversive sensory stimuli (Schoen et al., 2008). Parents reported how bothered their child is by individual stimuli on a Likert scale ranging from 1 (*Not bothered/never avoids*) to 5 (*Extremely bothered/always avoids*) on 42 questions. For example, parents report to what extent the sound of fluorescent lights, clothes swishing, toilets flushing, and sirens bother their child. Tactile, visual, and auditory subscales were used and combined to create a total SOR score. Previous findings have shown that the SP3D total score has high internal consistency ($\alpha = .89$; Schoen et al., 2017). SP3D scores range from 42 to 210, with higher scores corresponding to higher levels of SOR (greater impairment).

Clinical symptomatology. Internalizing symptoms and externalizing problems were measured using the Child Behavior Checklist, a parent-reported measure of mental health and behavioral symptoms for youth between the ages of 6-18 years (CBCL; Achenbach & Rescorla, 2001). On the CBCL, parents report their child's clinical symptoms on 118 questions (rated 0 = *Not True*, 1 = *Somewhat or Sometimes True*, or 2 = *Very True or Often True*). The internalizing subscale combines anxious/depressed, withdrawn/depressed, and somatic complaint scores. The externalizing problems subscale sums rule-breaking and aggressive behavior items. These subscales have strong evidence for reliability and both discriminant and convergent validity: there is excellent test-retest reliability for the internalizing symptoms (r = .91) and externalizing symptoms (r = .92), as well as good criterion-related validity and construct validity (Achenbach & Rescorla, 2001). Due to IRB constraints, the CBCL suicidality questions were not collected, and thus were omitted from score calculations. As a result, CBCL Internalizing subscale scores were calculated without question 91, while all other subscale scores of interest were calculated as usual. To prevent truncation (Achenbach & Rescorla, 2001), all analyses used raw subscale scores rather than t-scores.

Data Analytic Plan

Statistical analyses were conducted using SPSS Version 27.0 (SPSS Inc., USA). Path analyses were conducted using the PROCESS macro (Hayes, 2017), using 95% percentile bootstrap confidence intervals (5,000 bootstraps). In line with recommendations (Lemmer & Gollwitzer, 2017; Thoemmes, 2015), we did not test alternative path models by flipping the M and Y variables, and only ran statistical tests for the pre-registered path analyses that aligned with our theoretical model.

We conducted two ANCOVAs to probe differences in sensory processing between the PI and AFC groups, and to determine whether they should be examined separately or as one ECA group. We set group (AFC or PI) as the independent variable and SSP total score (general sensory processing challenges) and SP3D total score (SOR) as the respective dependent variables, with age and sex assigned at birth as covariates.

Given demonstrated relationships between ECA and both SOR and internalizing symptoms, we used two primary path analysis models to examine the impact of ECA, a multicategorical predictor (two ECA groups relative to the comparison group), on internalizing symptoms (CBCL) through sensory processing challenges, while covarying for age and sex assigned at birth. The two models respectively tested the indirect effects of our two sensory measures: SOR (SP3D score) and general sensory processing challenges (SSP score). In both models, we first examined group differences in SOR and sensory processing challenges using the path between ECA and the sensory measure of interest. We then probed indirect effects of ECA on internalizing symptoms through the two sensory measures, respectively.

Since links between sensory processing challenges and externalizing symptoms are less well-documented, we conducted two exploratory path analyses examining indirect effects of ECA on externalizing symptoms through the sensory measures, covarying for sex and age.

Our pre-registered analyses aimed to examine relative total effects (the sum of direct and indirect effects) of ECA group on psychological symptoms using these path analyses. However, because some participants had asynchronous sensory and psychological assessments, we covaried for different ages on different paths of our models. This required four multiple regressions to evaluate the total effects of ECA group (AFC or PI relative to non-adopted comparison) on internalizing and externalizing symptoms, respectively (covarying for age and sex). We also conducted a multiple regression within the combined ECA group (PI and AFC) to examine the effect of age at placement into a final adoptive home (predictors) on SOR, while covarying for sex.

To provide additional confidence in the reported findings, multiple post-hoc analyses focused on age and sex are reported in the supplement, including reanalysis of a smaller sample with age-matched groups. These results do not differ in any meaningful way from the original analyses, aside from observed differences in SOR between smaller age-matched AFC and comparison samples, which were marginally significant, presumably due to reduced statistical power.

Given the exploratory nature of our questions and that the populations in this study are very challenging to recruit (limiting statistical power), we did not correct for multiple comparisons. For this reason, we distinguished between our primary and exploratory questions of interest in both our pre-registration and below, to strike a balance between limiting multiple comparisons within the primary questions of interest while also providing as much useful descriptive data as possible on the sensory measures collected. In addition, given our use of bootstrapping, we did not exclude outliers in our pre-registered analyses in order to preserve statistical power in a small, hard to recruit sample from a population with high inter-individual variability (Tottenham, 2012). All findings reported below therefore include all eligible participants. Post-hoc analyses excluding participants with SP3D or SSP scores more than three standard deviations from the overall sample mean (excluding 4 AFC and 2 PI participants for the SP3D and 3 AFC participants for the SSP) found nearly identical patterns of effects as those reported below. These analyses are reported in the supplement.

Results

Descriptive Results

Sample demographic information is reported in Table 1, and descriptive statistics for all measures are presented in Table 2. While all subjects completed all primary measures, IQ was not collected in 14 AFC participants, and 5 AFC youth did not provide race/ethnicity information. Both the SP3D and the SSP measures had high internal consistency reliability in this sample ($\alpha_{SP3D} = .91$, $\alpha_{SSP} = .94$). Further information on parent-reported ECA experienced by the PI and AFC groups is reported in the supplement.

Differences in Sensory Processing Challenges Between ECA Groups

We found no differences between ECA groups on SP3D scores ($F(3,71) = 0.76$, $p = .39$). However, the AFC group had significantly more sensory processing challenges on the SSP than the PI group ($F(3,71) = 10.00$, $p = .002$). The AFC and PI groups were therefore examined separately in all analyses, with ECA dummy coded and non-adopted comparison youth as the reference group.

Sensory Processing Challenges Following ECA

As expected, youth in both ECA groups had significantly elevated sensory processing challenges (Figure 1; Table 2). Youth in the PI (a_{PI_SP3D} = 10.72, *SE* = 2.57, t = 4.18, 95% CI [5.65, 15.78], $p < .001$) and AFC (a_{AFC_SP3D} = 9.82, *SE* = 2.45, t = 4.02, 95% CI [5.14, .65], $p <.001$) groups had higher SP3D scores (higher SOR) than the non-adopted comparison group, covarying for age and sex. Consistent with this finding, youth in both the PI (a_{PI_SSP} = -11.09, *SE* = 3.10, t = -3.56 , 95% CI [-17.22, -4.97], $p <.001$) and AFC (a_{AFC_SSP} = -31.21, *SE* = 2.97, t = -10.56 , 95% CI [-37.05, -25.38], $p < .001$) groups had significantly heightened general sensory processing challenges on the SSP (lower scores), relative to non-adopted comparison youth. This suggests that youth with histories of ECA experience elevated general sensory processing challenges and increased SOR, relative to comparison youth.

A post-hoc chi-square analysis showed a moderate association ($\varphi = 0.57$, $p < .001$) between group membership (PI, AFC, and comparison) and the distribution of participants in SSP clinical categories ($\chi^2(4) = 60.19$, $p <.001$). Of the non-adopted comparison youth, 5.36% were classified as having probable and 1.7% as having definite sensory processing challenges, consistent with previous findings in younger children (Tomchek & Dunn, 2007). PI youth displayed more evidence of sensory processing challenges, with approximately 15% classified as having probable and 3% as having definite sensory processing challenges. Notably, 19% of AFC youth were considered to have probable, and an additional 40% to have definite sensory processing challenges.

Group differences on the SSP and SP3D subscales are reported in the supplement for reference.

Psychological Symptomatology following ECA

There were significant total effects of ECA on both internalizing and externalizing symptoms. Both PI ($c_{PI\_INT} = 6.26$, *SE* = 1.21, *t* = 5.17, 95% CI [3.87, 8.67], $p < .001$) and AFC ($c_{AFC\_INT} = 8.32$, *SE* = 1.27, t = 6.54, 95% CI [5.81, 10.83], $p < .001$) youth had higher internalizing symptom scores than comparison youth, covarying for age and sex. Similarly, both PI ($c_{PI\_EXT} = 4.16$, *SE* = 0.89, *t* = 4.70, 95% CI [2.41, 6.91], $p < .001$) and AFC ($c_{AFC\_EXT} = 12.51$, *SE* = 1.36, *t* = 9.17, 95% CI [9.81, 15.21], $p < .001$) youth had higher externalizing symptoms than comparison youth, covarying for age and sex. These results are consistent with those reported in other PI and AFC samples (e.g. Humphreys et al., 2015).

Sensory Processing Challenges and Links to Psychological Symptomatology

Findings from the path analyses were consistent with our theoretical framework, which posits that ECA inflates risk for psychological symptomatology in part through increased sensory processing challenges. First, we explored how SOR might contribute to links between ECA and internalizing symptoms. Covarying for age and sex assigned at birth, we found significant indirect effects of ECA on elevated internalizing symptoms through SOR, for both PI ($ab_{PI\_SP3D\_INT} = 1.37$, 95% CI [0.36, 2.63]) and AFC ($ab_{AFC\_SP3D\_INT} = 1.26$, 95% CI [0.29, 2.44]) youth (Figure 2A). In a second model that examined general sensory processing challenges as a link between ECA and internalizing symptoms, we again found significant indirect effects through sensory processing challenges for both PI ($ab_{PI\_SSP\_INT} = 1.65$, 95% CI [0.67, 3.04]) and AFC participants ($ab_{AFC\_SSP\_INT} = 4.64$, 95% CI [2.66, 6.95]), relative to comparison youth (Figure 3A).

We also conducted two exploratory path analyses to examine how sensory processing challenges might explain the relationship between ECA and externalizing symptoms. The first examined SOR as a link between ECA and externalizing symptoms (Figure 2B). We found significant indirect effects of PI and AFC status on externalizing symptoms through SOR (PI: $ab_{PI\_SP3D\_EXT} = 1.28$, 95% CI [0.10, 2.75]; AFC: $ab_{AFC\_SP3D\_EXT} = 1.17$, 95% CI [0.06, 2.6]). Similarly, we found a significant indirect effect of ECA on externalizing symptoms through sensory processing challenges (Figure 3B; PI: $ab_{PI\_SSP\_EXT} = 1.98$, 95% CI [0.73, 3.76]; AFC: $ab_{AFC\_SSP\_EXT} = 5.57$, 95% CI [2.78, 9.08]).

These findings support our hypothesis that sensory processing challenges and SOR symptoms may contribute to ECA-associated internalizing and externalizing symptoms.

SOR and Age at Placement into Final Adoptive Home

Our results were not consistent with a dose-response relationship between pre-adoption ECA duration and SOR ($B_{\text{Placement}} =$ -0.11, $t(70) = -1.47$, 95% CI [-0.26, 0.04], $p = .15$). Post-hoc exploratory analyses showed age at placement was not associated with SOR within the PI ($B_{\text{Placement\_PI}} =$ -.13, $t(33) = -0.77$, 95% CI [-0.48, 0.22] $p = .45$) or AFC groups ($B_{\text{Placement\_AFC}} =$ -0.13, $t(36) = -1.27$, 95% CI [-0.33, 0.08], $p = .21$). Additional analyses found no associations between age and SOR symptoms across both ECA groups, as reported in the supplement.

Discussion

This study examined the impact of ECA on sensory processing challenges in youth adopted from institutional (e.g., orphanage) or foster care. We found that relative to non-adopted comparison youth, children and adolescents adopted from institutional or foster care display elevated sensory processing challenges, including SOR. This suggests that ECA-linked sensory processing challenges persist into adolescence, in contrast with age-related reductions in sensory symptoms reported in typically developing and clinical samples of youth without known ECA (Kern et al., 2006; Little, Dean, Tomchek, & Dunn, 2018; Van Hulle, Lemery-Chalfant, & Goldsmith, 2015). Our results also suggest that sensory processing challenges, including SOR, may contribute in part to elevated internalizing and externalizing symptoms observed in youth with histories of ECA. Taken together, our findings point to a commonality of sensory processing challenges among youth exposed to severe forms of ECA, with possible implications for mental health. Further work should examine whether similar effects are observed following more common, less severe forms of ECA.

That we observed sensory processing challenges in both PI and AFC youth both replicates and contradicts findings from a previous study, which reported sensory processing challenges (assessed using the SSP) in PI, but not AFC youth (Wilbarger et al., 2010). These discrepant findings in AFC youth could be explained in part by differences in time prior to placement in a final adoptive home between the current and prior studies, given that youth in the prior AFC sample were very young at adoption (M_{Age} = 4.5 months, range = 1-8 months) relative to our AFC sample (M_{Age} = 37.59 months, range = 0-108 months). However, as our current results do not suggest a dose-response relationship between duration of pre-adoption ECA and sensory processing difficulties, these differences merit further exploration of how ECA severity impacts outcomes in future work employing more targeted metrics.

Developmental heterogeneity after ECA exposure

Though the effects of ECA have primarily been documented in cognitive and affective domains (Callaghan & Tottenham, 2016a, 2016b; Chen & Baram, 2016; McLaughlin, DeCross, et al., 2019; Pechtel & Pizzagalli, 2011), our results indicate that ECA also alters "lower-level" sensory processing. Our findings suggest that across two distinct forms of ECA, each with considerable experiential heterogeneity, there is a shared elevated risk for sensory processing challenges. Though circumstances surrounding placement in institutional and foster caregiving differ on several features, they often share core adversities, including separation from primary caregivers, frequent transitions, and a lack of stable caregiving. Notably, while we observed a shared risk for sensory processing challenges in both the PI and AFC groups, there was substantial variability in sensory processing within each of these cohorts. Relative to comparison youth, the range of SOR scores was 27% wider for the PI group and 59% wider for the AFC group. This variability is consistent with a broader literature suggesting that while ECA exposure probabilistically increases the risk for psychopathology, this link is not deterministic (Kessler et al., 2010; McLaughlin et al., 2012; Tottenham, 2012).

These observations speak to the diversity of exposures that youth with histories of ECA encounter. For example, for internationally adopted PI youth, institutional placements are often the result of political, societal or economic pressures (e.g., poverty, national policies, natural disasters), and not necessarily abuse or neglect (Gunnar, van Dulmen, & International Adoption Project Team, 2007; van IJzendoorn et al., 2020). As such, the initial family separation and qualitative features of the institutional rearing environment itself (including high child to caregiver ratios, rotating staff, and resultant lower quality caregiving) are often principal sources of ECA for these youth (Berens & Nelson, 2015; van IJzendoorn et al., 2020). By contrast, domestically adopted AFC youth have heterogeneous experiences that can include exposure to violence, neglect, removal(s) from their home of origin, and commonly, a larger number of placements prior to their final adoptive home (AFCARS, 2020; Almas et al., 2020). The heterogeneity of exposure AFC youth experience is consistent with the present AFC sample showing more variable sensory processing challenges than PI youth. Future work should examine whether specific features of ECA (e.g., trauma, unpredictability, degree of deprivation exposure, perceptions of experiences of ECA) contribute to variability in sensory development and specific sensory symptom profiles (Cohodes et al., 2020; McLaughlin & Sheridan, 2016; Smith & Pollak, 2021). Descriptive analyses in our sample (described in the supplement) are consistent with clearer links between ECA and SOR than other sensory processing challenges, but these tentative findings merit additional exploration in future work.

Potential mechanisms for development of sensory processing challenges after ECA exposure

Mechanistic pathways for the development of sensory processing challenges following ECA are not well characterized. However, key neural circuits thought to be impacted by ECA have also been implicated in the development of SOR. For example, preliminary neuroimaging evidence suggests that sensory symptoms may be driven by enhanced affective reactivity, altered top-down regulation of limbic circuitry, or both (Green et al., 2018, 2013), mirroring altered prefrontal-amygdala circuit activity observed following ECA. The present results imply that ECA-associated threat vigilance (linked to amygdala hyper-reactivity in ECA-exposed youth; Silvers et al., 2017) may extend to the sensory domain and contribute to symptoms of both SOR and anxiety (Green & Ben-Sasson, 2010). Likewise, diminished regulation of affective responses to sensory stimuli may contribute to sensory processing challenges. Lower emotion regulation capacity is linked to SOR symptoms (McMahon et al., 2019), and SOR is associated with both reduced amygdala habituation and prefrontal down-regulation of the amygdala during aversive sensory stimulation (Green et al., 2019, 2018, 2015; Green & Wood, 2019). These findings mirror observations of altered prefrontal regulation of limbic circuitry in youth with histories of ECA during both affective and non-affective self-regulation (Callaghan & Tottenham, 2016b; Chen & Baram, 2016; Cohodes et al., 2020; Heleniak et al., 2016; Jenness et al., 2020; Tottenham et al., 2010). While altered neurobehavioral vigilance and self-regulation profiles are likely adaptations to unpredictable or threatening environments, both phenotypes convey increased risk for internalizing symptoms among youth with histories of ECA (Callaghan & Tottenham, 2016b; Gee et al., 2013; Silvers et al., 2017; VanTieghem & Tottenham, 2018; Weissman et al., 2019). Testing mechanistic pathways could further clarify the connections between sensory processing challenges and internalizing (and externalizing) symptoms observed in the present study.

Clinical Implications

Regardless of developmental mechanisms, our results are consistent with findings in other clinical populations that indicate that sensory processing challenges increase risk for a broad range of psychological and behavioral symptoms (Carpenter et al., 2019; Gourley, Wind, Henninger, & Chinitz, 2013; Green et al., 2012; McMahon et al., 2019). This fact has led some researchers to advocate for the addition of a sensation and perception domain to future versions of the Research Domain Criteria (Harrison, Kats, Williams, & Aziz-Zadeh, 2019). These findings motivate further longitudinal exploration of sensory development in the context of ECA exposure to characterize developmental trajectories.

If replicated, the present findings motivate further work evaluating the impact of screening for sensory processing difficulties in clinical assessment and treatment in youth with histories of ECA. If additional longitudinal work establishes a directional relationship between sensory processing challenges and later psychopathology following ECA, it will be important to investigate whether monitoring or treating such challenges can support improved clinical outcomes. The present findings together with future work stand to have two implications. First, screening for sensory processing challenges could prove to be useful for early intervention in youth with histories of ECA. In some individuals, ECA-induced changes to psychosocial functioning (and underlying neural circuitry) may first manifest as sensory processing challenges -- which emerge in early childhood -- before evolving into broader psychological symptom profiles during adolescence, when psychopathology most commonly emerges (Ben-Sasson, Carter, et al., 2009; Carpenter et al., 2019; Carter et al., 2011; Green et al., 2012; McLaughlin et al., 2012; Román-Oyola & Reynolds, 2013; Solmi et al., 2021). In line with this reasoning, our findings suggest sensory processing challenges in ECA-exposed youth remain elevated in adolescence, and do not disappear following early childhood. Second, sensory processing-focused assessments and targeted treatments may improve clinical care for youth with histories of ECA. Sensory processing symptoms in populations exposed to ECA may lead to misinterpretation of behavioral and mental health symptoms by parents and clinicians alike (Conelea et al., 2014; Fernández-Andrés, Pastor-Cerezuela, Sanz-Cervera, & Tárraga-Mínguez, 2015; Harrison et al., 2019; Howe & Stagg, 2016). For instance, sensory processing challenges often manifest as tantrums, aggression, and both avoidance of and difficulty disengaging with stimulation. In addition to being psychologically taxing for youth, such responses cause distress, family impairment, and socialization challenges (Ben-Sasson, Carter, et al., 2009; Carpenter et al., 2019; Carter et al., 2011; Dellapiazza et al., 2020, 2018). As a result, sensory-informed assessments may lead to more accurate, targeted, and effective treatments of both sensory symptoms and psychological symptomatology.

Limitations

These findings suggest ECA is associated with altered sensory processing, and that sensory processing challenges may contribute to internalizing and externalizing symptoms. However, the present study has several limitations that should be addressed by future work. First, we have limited information about pre-adoption experiences for PI and AFC participants, including exposure to other adversities common in these populations (e.g., abuse, prenatal substance exposure). Though this precludes conclusions about the effects of specific exposures on sensory processing, that both ECA groups demonstrated elevated risk for sensory processing challenges despite heterogeneous experiences suggests that ECA generally confers risk for sensory challenges. Second, while previous findings in typically developing and clinical samples suggest SOR symptoms predict later development of psychological symptoms (Green et al., 2012; McMahon et al., 2019), our analyses used cross-sectional, observational data. Although our path analyses indicate covariation between sensory processing challenges and psychological symptomatology, we cannot draw definitive conclusions about causality or temporal ordering effects. In the present study, we tested the most theoretically plausible model but acknowledge that the directional relationships between our variables ought to be probed by future longitudinal developmental work, ideally from very early in life, including sensitive periods of sensory development, and extending through adolescence (given that most psychopathology emerges during this life stage). Lastly, this study exclusively used parent-reported measures of sensory processing challenges and psychological symptomatology. Future studies should build upon present methods to include self-reported and behavioral measures of sensory processing and psychological symptomatology, probe directionality using longitudinal or experimental (e.g., animal model) designs, and evaluate whether the observed pattern of findings extends to more common and/or less severe forms of ECA than circumstances leading to adoption.

Conclusion

We report increased sensory processing challenges in children and adolescents exposed to heterogenous ECA (PI and AFC), and associations between ECA-linked sensory processing challenges and internalizing and externalizing symptoms. These findings motivate future work assessing whether inclusion of sensory processing challenges during screening and treatment for youth with histories of ECA may support improved clinical outcomes.

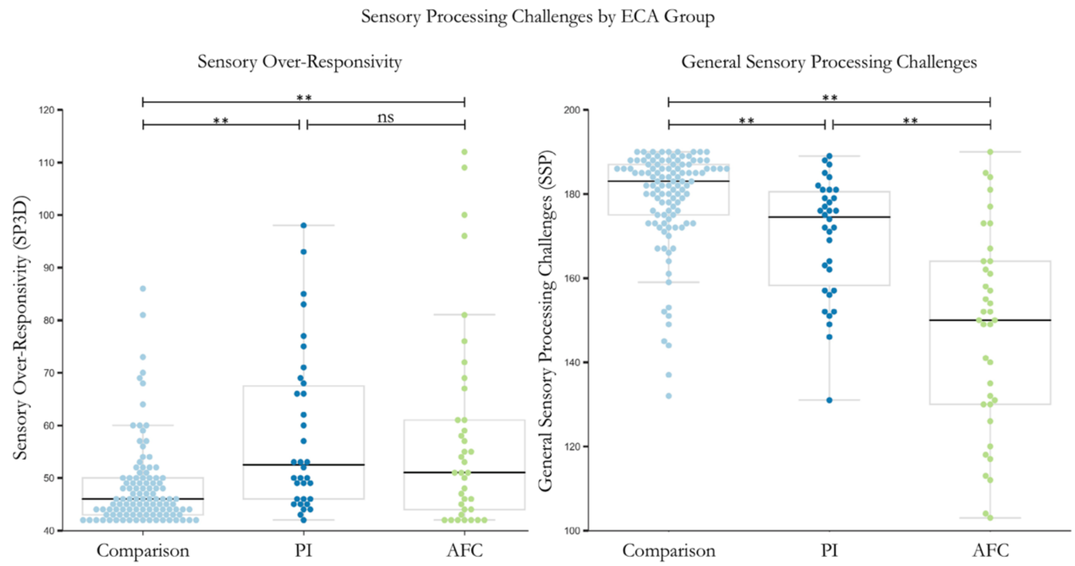
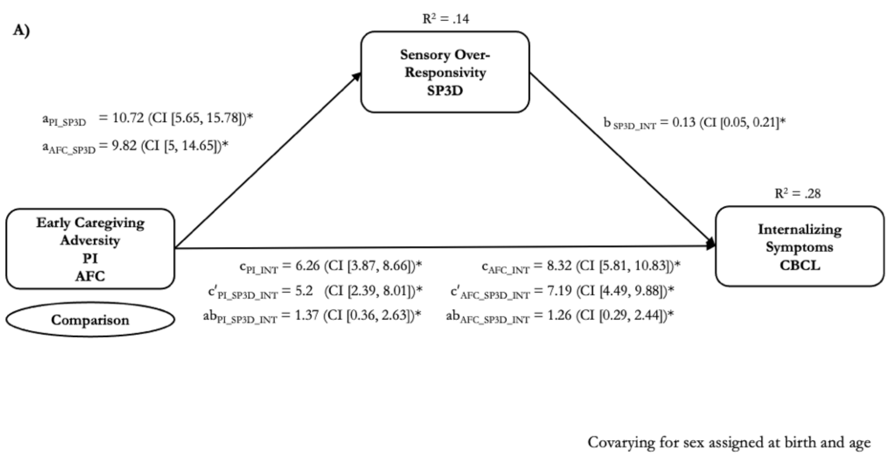


Figure 1. Left: PI and AFC participants show elevated levels of sensory over-responsivity (higher SP3D scores), relative to non-adopted, comparison youth. Right: PI and AFC participants show increased levels of general sensory processing challenges (lower SSP scores) relative to non-adopted, comparison youth. ***p* <.001, **p* <.05

Figure 2. a) 95% percentile bootstrapped regression coefficients for a path analysis model examining the association between ECA (predictor) and internalizing problems (outcome) through SP3D total score, while controlling for age and sex assigned at birth. b) 95% percentile bootstrapped regression coefficients for a path analysis model examining the association between ECA (predictor) and externalizing problems (outcome) through SP3D total score, while controlling for age and sex assigned at birth. As in OLS regression, R2 for each component of the path analysis can be interpreted as the proportion of the variance in the outcome explained by that model (e.g., proportion of SP3D variance explained by OLS with ECA group, sex, and age predictors) **p<.001, *p<.05



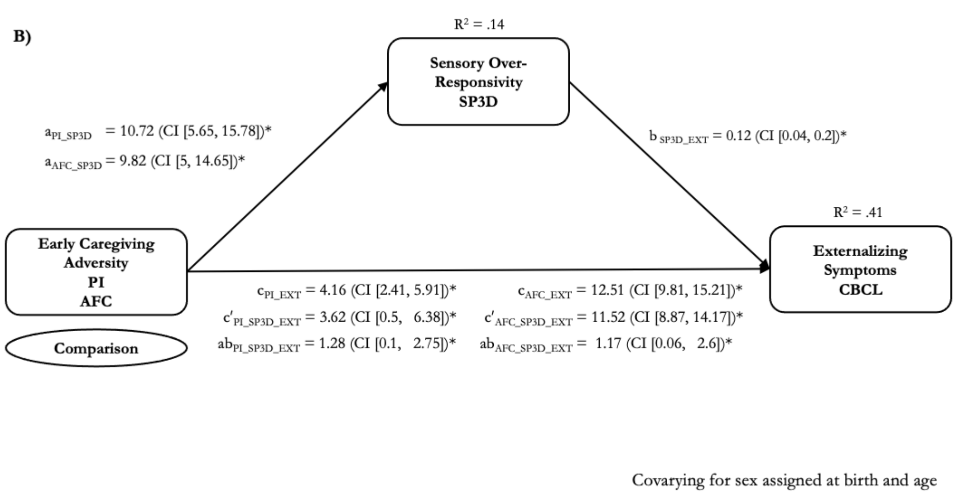


Figure 3. a) 95% percentile bootstrapped regression coefficients for a path analysis model examining the association between ECA (predictor) and internalizing problems (outcome) through SSP total score, while controlling for age and sex assigned at birth. b) 95% percentile bootstrapped regression coefficients for a path analysis model examining the association between ECA (predictor) and externalizing problems (outcome) through SSP total score, while controlling for age and sex assigned at birth. As in OLS regression, R^2 for each component of the path analysis can be interpreted as the proportion of the variance in the outcome explained by that model (e.g., proportion of SSP variance explained by OLS with ECA group, sex, and age predictors) ***p*<.001, **p*<.05

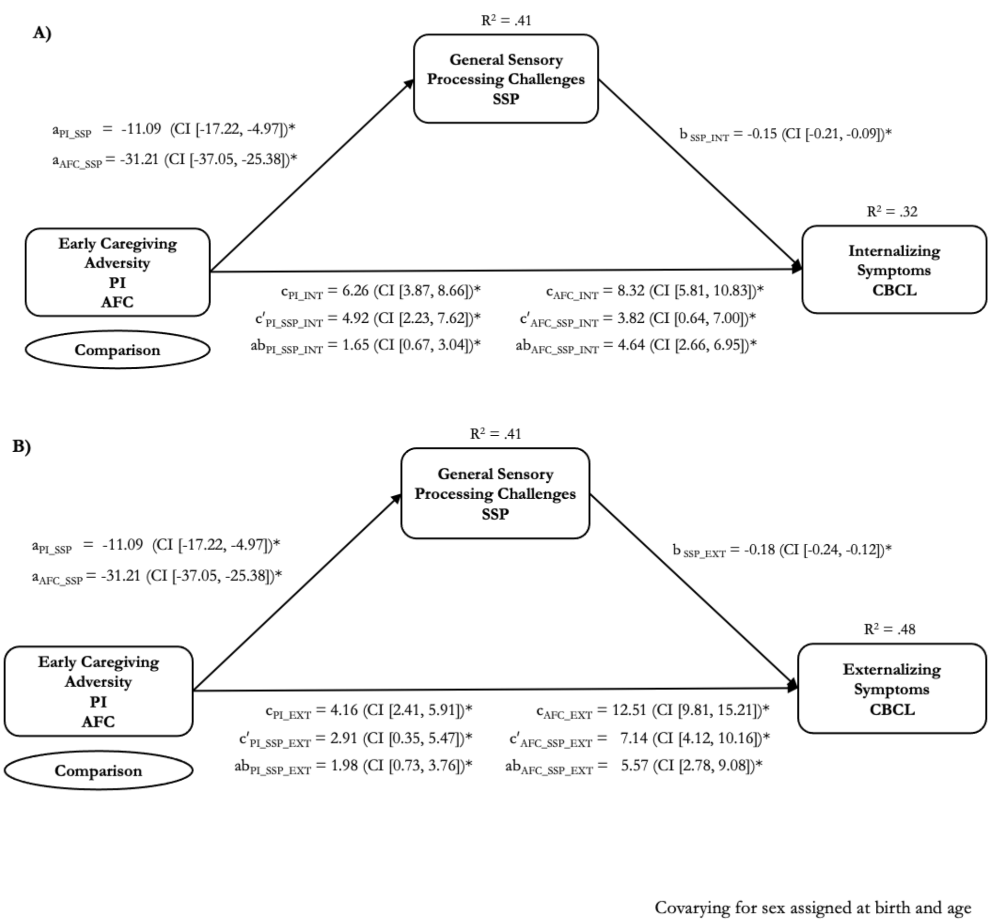


Table 1. *Demographic information.*

Note: AFC = adopted from foster care; PI = previously institutionalized. IQ was not collected in 14 AFC participants, and race/ethnicity is unknown for 5 AFC youth. Chi-square analyses were performed to explore group differences in sex assigned at birth, race, and ethnicity. ANOVA was used to explore group differences in IQ, child age, and age at placement into adoptive home. IQ was measured using the *Wechsler Abbreviated Intelligence Scale, Second Edition* (WASI-II; Wechsler, 2011). *p* values reflect the results of each chi-square or ANOVA.

Variable	**Comparison (N = 112)**	**PI (N = 34)**	**AFC (N = 37)**	
	Mean (Median; SD)	***Mean (Median; SD)***	***Mean (Median; SD)***	***p***
Age	13.37 years (13.17; 2.48)	14.94 years (15.17; 1.78)[a]	11.96 years (10.74; 2.81)[ac]	<.001
Age at Placement into Adoptive Home	---	19.46 mths (12.75; 16.03)	37.59 mths (30.0; 33.29)	<.001
IQ	115.64 (118.0; 14.15)	104.65 (105.0; 13.31)[a]	97.61 (99.0;11.35)[bc]	<.001
	Count (%)	***Count (%)***	***Count (%)***	***p***
Assigned Sex at Birth	Female: 50 (45%) Male: 62 (55%)	Female: 24 (71%) Male: 10 (29%)	Female: 19 (51%) Male: 18 (49%)	.03
Race				<.001
Black	9 (8%)	0 (0%)	11 (3%)	
Asian	15 (13%)	16 (47%)	0 (0%)	
white	64 (57%)	13 (38%)[a]	18 (49%)[b]	
Native Hawaiian or Pacific Islander	2 (2%)	0 (0%)	0 (0%)	
Multiracial	19 (17%)	1 (3%)[a]	3 (8%)[b]	
Other	3 (3%)	4 (12%)	0 (0%)	
Ethnicity				<.001
Latinx/e	26 (23%)	0 (0%)[a]	13 (41%)	

[a] Denotes higher rates/scores in the Comparison group than the PI group.
[b] Denotes higher rates/scores in the Comparison group than the AFC group.
[c] Denotes higher rates/scores in the PI group than the AFC group.
Abbreviations: Previously Institutionalized (PI); Adopted from Foster Care (AFC)

Table 2. *Descriptive statistics for sensory over-responsivity, general sensory processing challenges, and clinical symptomatology*

Scales	Comparison (N = 112)	PI (N = 34)	AFC (N = 37)
	Mean (Median; SD)	***Mean (Median; SD)***	***Mean (Median; SD)***
SOR SP3D Total Measure Range: 42-210	48.22 (46.00; 7.97) Range: 42-86	58.34 (52.50; 15.3)[a] Range: 42-98	58.24 (51.00; 19.26)[b] Range: 42-112
General Sensory Processing Challenges SSP Total Measure Range: 190-38	178.99 (183.00;11.79) Range: 190-132	169.76 (174.50; 14.10)[a] Range: 189-131	147.54 (150.00; 23.71)[bc] Range: 190-103
Internalizing Symptoms CBCL Internalizing Measure Range: 0-62	4.56 (3.00; 4.9) Range: 0-25	11.62 (9.5; 8.42)[a] Range: 0-32	12.49 (11.0; 9.67)[b] Range: 0-41
Externalizing Symptoms CBCL Externalizing Measure Range: 0-70	2.98 (1.00; 3.7) Range: 0-15	7.00 (6.00; 5.82)[a] Range: 0-20	15.96 (12.00; 12.44)[bc] Range: 0-50

Note: Reported CBCL scores are raw subscale scores. T-scores and clinical cutoffs for the CBCL are reported in the supplement.

[a] Denotes elevated symptoms in the PI group relative to the Comparison group.

[b] Denotes elevated symptoms in the AFC group relative to the Comparison group.

[c] Denotes elevated symptoms in the AFC group relative to the PI group.

Abbreviations: Previously Institutionalized (PI); Adopted from Foster Care (AFC)

Supplement

Additional Participant Information

Recruitment

Youth adopted from domestic foster care (AFC) were recruited from two adoption-related programs to participate in a study examining neurobiological and behavioral mechanisms underlying sensory processing challenges following ECA. Importantly, youth were not recruited based on the presence of sensory processing challenges. Study staff contacted AFC participants and their families by providing flyers to clinicians working with adopted children, presenting to adoptive families and clinicians, and posting on social media outlets. Non-adopted comparison participants in this sample were recruited through flyers posted throughout the community (schools, university campus, and around the metropolitan area), on social media, and from an active waiting list of families interested in participating in research. These comparison participants were initially recruited for a study examining sensory processing challenges in youth with autism spectrum disorders. Given that autism is most prevalent in individuals assigned male at birth, youth assigned male at birth were oversampled in this comparison group. Participants were between the ages of 8-17 years and had no known history of early caregiving adversity.

Internationally adopted previously institutionalized (PI) youth were originally recruited from adoption-related programs. The data used in this analysis was collected from PI and non-adopted PI-comparison youth as part of the fourth wave of an ongoing longitudinal study. These participants were originally recruited through a combination of flyers and word of mouth in various targeted communities, including international adoption family networks, online adoption family support groups, and adoption agencies. In addition, participants were recruited from local early childhood education centers, the campus, local public posting areas in the metropolitan area, and varied community institutions, including schools, religious organizations, community centers, professional offices, after-school facilities, community gatherings, and activity fairs.

The two comparison groups (from the AFC and PI studies, respectively) were equivalent on all demographic variables except for sex assigned at birth (in part because of over-recruitment of males in the AFC comparison sample) and were therefore combined to yield one joint comparison group prior to all analyses.

Pre-Adoption Experiences

Overall, AFC youth in this sample were adopted much later than PI youth and had a larger number of placements. For example, AFC youth had an average of 7 placements prior to arrival in their final adoptive home. In contrast, to our knowledge 86% of PI participants were placed in an institution within the first 18 months of life (> 50% within the first month) and adopted directly from the institution. Nearly all PI participants had only 1-2 placements (including the institution) prior to final adoption.

AFC:

We do not have information about why AFC participants were removed from their initial homes. However, a subset (N = 25) of AFC participants had their parents report additional detail about experiences of ECA prior to adoption, while 21 reported on the number of foster care placements. It should be noted that parents often do not have full information on their adopted children, so the below statistics should be considered examples of the types of adversity commonly experienced by this population but the percentages are likely not representative. For example, of the 65% who did not report prenatal exposure to substances, it does not mean these children were *not* exposed, but just that the adoptive parents lack this information:

Supplemental Table 1. Parent reported pre-adoption ECA for a subset of AFC youth

Type of ECA Experience	N (Total = 25)	% (of subset)
Neglect	16	70
Prenatal Exposure to Substances	8	35
Physical Abuse	4	17
Witnessing Violence in the Home	6	26
Sexual Abuse	13	57
Other	Experienced homelessness = 3 Malnutrition = 1 Failed finalized adoption = 1	22
	M (SD)	**Range**
Mean Number of ECA Experienced	2.09 (1.44)	1-5
Mean Number of Foster Care Placements	1.52 (1.72)	0-7

Abbreviations: Early Caregiving Adversity (ECA)

PI:

The countries that the PI youth in this study were adopted from are listed in the table below for all participants. In addition, 91.2% (N = 31) of parents reported having visited the institutions their children were living in, and provided their subjective impressions of the building quality, facility cleanliness, quantity of caregiving, and quality of caregiving in the institutions also reported below. In general, most parents reported moderate to high building quality and facility cleanliness. Average reports of quantity and quality of caregiving were middling, with a high degree of variability. Lastly, 62% (N = 21) of PI adoptive parents said they were told their child had a special relationship with a caregiver prior to adoption.

Supplemental Table 2. Parent reported caregiving history for PI youth

Country Adopted from:	
Azerbaijan	1
China	12
Kazakhstan	7
Russia	13
South Korea	1
Parental Impressions of Institution (1-10):	
Building Quality (1 = poor, 10 = nice)	6.73 (2.72; 1-10)
Facility Cleanliness (1 = poor, 10 = excellent)	8.05 (1.63; 4.5-10)
Quantity of Caregiving (1 = too few caregivers, 10 = many caregivers)	5.98 (3.09;1-10)
Quality of Caregiving (1 = very poor, 10 = very good)	6.50 (3.11, 1-10)
Parent Reported Placement History	
Caregiving Institution Only	
Placed in institution 0-1 months after birth, adopted from institution	18
Placed in institution 2-6 months after birth, adopted from institution	4
Placed in institution 7-18 months after birth, adopted from institution	4
Placed in institution >18 months after birth, adopted from institution	3
Caregiving Institution + Other Out of Home Placements	
Placed in institution , 6-9 months after birth, after extended hospital stay Adopted from institution	2
Placed in institution < 6 months after birth, in foster care for some period*	3

* one of these children also had an extended hospital stay (age 0-3 months)
Note: While all parents reported country of origin and a brief placement history (N = 34), parental impressions of the institution were available for 31/34 participants (91.2%)

Additional Information regarding Study Measures

Measure Selection

We included analysis of both the Short Sensory Profile and the SP3D checklist to provide a more complete assessment of links between ECA and sensory development. While there are some similarities between "sensitivity" items on the SSP and SOR items on the SP3D checklist, they assess these symptoms using different (but complementary) approaches.

The SSP provides a general measure of sensory issues across multiple aspects of functioning, including sensory seeking, sensory under-responsivity, and difficulty filtering sensory information, as well as SOR. In addition, the SSP has been extensively validated and is the measure most commonly used in developmental research on sensory processing challenges (including work on early adversity). This measure therefore provides a helpful point of comparison with other relevant work. Importantly, the SSP focuses primarily on affective expressions of responses to sensory stimuli, asking parents to report on patterns of behavior and including both physical and social stimuli (e.g., grooming, being touched, responding to name).

We administered the SP3D checklist as a more tailored estimate of SOR. We were most interested in SOR a priori because we felt SOR was most likely to be impacted in youth with histories of ECA given the neurodevelopmental mechanisms we believe underlie the emergence of sensory differences in this population, and because SOR symptoms have been most clearly linked to mental health outcomes. We therefore selected the SP3D because it was developed with the primary goal of providing more specific assessment of a child's response to their regular sensory environment, with an explicit focus on assessing SOR from the perspective of multiple sensory modalities. As a result, it was designed in a checklist format, with parents asked to what extent their children were bothered by commonly encountered stimuli.

Supplemental Analyses

Descriptions of supplemental analyses conducted as part of this study are included below. Unless otherwise noted, these analyses were included in the original pre-registration.

Correspondence Between Measures of Sensory Over-Responsivity

To examine consistency across measures, an SSP SOR composite score (intended as a parallel to the SP3D SOR measure) was calculated using the Tactile Sensitivity and Visual/Auditory Sensitivity subscales. In addition, to examine whether observed differences in general processing challenges on the SSP were solely the result of overlap between SOR items across measures, we also calculated an SSP total score that omitted items from the two SSP subscales with overlap with the SP3D (the SSP Tactile Sensitivity and Visual/Auditory Sensitivity subscales). Neither of these composite scores were used in any primary analyses.

We conducted a series of linear regressions to examine concordance between different measures of sensory over-responsivity (the SSP and SP3D) across sensory modalities. Specifically, we compared a composite measure of the SSP Tactile and Visual/Auditory sensitivity scales to the SP3D total score, a measure of tactile, visual, and auditory SOR. In addition, we compared symptoms reported on the SSP and SP3D subscales for each of these sensory modalities. As expected, we found high correspondence between all SP3D measures and analogous SSP scores, as shown in *Supplemental Table 3*.

Supplemental Table 3. Concordance between SSP and SP3D Subscales

Scales	β	*t*	*p*
SSP Tactile Sensitivity vs SP3D Tactile SOR	-.45	-6.78	< .001
SSP Visual/Auditory Sensitivity vs SP3D Auditory SOR	-.62	-10.55	< .001
SSP Visual/Auditory Sensitivity vs SP3D Visual SOR	-.29	-4.00	< .001
SSP SOR Composite (Tactile + Vis/Aud) vs. SOR SP3D Total	-.60	-10.07	< .001
SSP Total vs. SOR SP3D Total	-.53	-8.47	< .001

Note: Concordance was assessed in the whole sample (N = 183). The SSP sensitivity score was derived using the Tactile Sensitivity and Visual/Auditory Sensitivity subscales to create a comparable score to the SP3D total.
Abbreviations: Short Sensory Profile (SSP); Sensory Processing 3-Dimensions Checklist (SP3D); Sensory Over-Responsivity (SOR)

An unregistered exploratory analysis of the SSP that excluded the two subscales with overlap with the SP3D (the SSP tactile sensitivity and visual/auditory sensitivity subscales) revealed very similar results to the SSP findings reported in the main text (although with decreased effect sizes). There were still group differences between the AFC and PI groups on total non-SOR SSP score ($F(3,71) = 9.71$ $p = .003$), so we again analyzed the two ECA groups separately. Consistent with this finding, youth in both the PI ($a_{PI\_SSP} = -7.57$, $SE = 2.22$, t =

-3.42, 95% CI [-11.95, -3.20], $p < .001$) and AFC (a_{AFC_SSP} = -21.29, *SE* = 2.11, *t* = -10.08 , 95% CI [-25.45, -17.12], $p < .001$) groups had significantly heightened general sensory processing challenges on the SSP (lower scores), relative to non-adopted comparison youth. In a model that examined general sensory processing challenges as a link between ECA and internalizing symptoms, we again found significant indirect effects through non-SOR general sensory processing challenges for both PI ($ab_{PI\_SSP\_INT} = 1.51$, 95% CI [.57-2.81]) and AFC participants($ab_{AFC\_SSP\_INT} = 4.24$, 95% CI [2.26-6.53]), relative to comparison youth. Similarly, we found a significant indirect effect of ECA on externalizing symptoms through non-SOR sensory processing challenges (PI: $ab_{PI\_SSP\_EXT} = 1.73$, 95% CI [.62-3.31]; AFC: $ab_{AFC\_SSP\_EXT} = 4.86$, 95% CI [2.48-7.78]).

These findings suggest that the general sensory processing challenges reported in the main text are not purely driven by SOR items.

Sensory Measure Subscales by Group

Sensory measure subscale score distributions for each group are documented in *Supplemental Table 5.*

Supplemental Table 4 and *Supplemental Table 5.*

Supplemental Table 4. SP3D subscale scores for total, auditory, visual, and tactile domains in comparison, PI, and AFC participants.

SP3D Subscales	***Comparison*** ***N = 112***	***PI*** ***N = 34***	***AFC*** ***N = 37***	***p***
Total Score	48.22 (7.97) Range: 42 - 86	58.35 (15.3)[a] Range: 42 - 98	58.24 (19.26)[b] Range: 42 - 112	< .001
Tactile SOR	20.77 (4.76) Range: 17 - 42	25.09 (8.04)[a] Range: 17 - 49	24.51 (10.06)[b] Range: 17 - 61	< .001
Visual SOR	5.34 (1.02) Range: 5 - 11	6.15 (2.87)[a] Range: 5 - 18	6.24 (2.49)[b] Range: 5 - 15	.01
Auditory SOR	22.12 (3.84) Range: 20 - 45	27.12 (9.63)[a] Range: 20 - 63	27.49 (10.73)[b] Range: 20 - 68	< .001

ANOVA was used to explore group differences in subscale scores, and associated p values are reported in the table. Pairwise group differences were then probed using t-tests:
[a] Denotes that the PI group has higher scores (higher SOR) than the Comparison group.
[b] Denotes that the AFC group has higher scores (higher SOR) than the Comparison group.
Abbreviations: Sensory Processing 3-Dimensions Checklist (SP3D); Sensory Over-Responsivity (SOR); Previously Institutionalized (PI); Adopted from Foster Care (AFC).

Supplemental Table 5. *Mean SSP subscale scores for total, tactile sensitivity, auditory filtering, movement sensitivity, visual/auditory sensitivity, taste sensitivity, sensory under-responsivity, and low energy/weakness domains among comparison, PI, and AFC participants.*

SSP Subscales	*Comparison* *N = 112*	*PI* *N = 34*	*AFC* *N = 37*	*p*
Total Score	178.99 (11.79) Range: 190 - 132	169.76 (14.1)[a] Range: 189 - 131	147.54 (23.71)[bc] Range: 190 - 103	< .001
Tactile Sensitivity	28.16 (5.59) Range: 35 - 18	33.48 (3.13) Range: 35 - 7	32.35 (2.6)[bc] Range: 35 - 27	< .001
Visual Auditory Sensitivity	24.19 (1.67) Range: 25 - 16	22.12 (3.83)[a] Range: 25 - 13	19.59 (5.21)[bc] Range: 25 - 9	< .001
Sensory Underresponsivity	32.83 (3.47) Range: 35 - 19	31.24 (4.95)[a] Range: 35 - 12	25.59 (7.03)[bc] Range: 35 - 12	< .001
Taste Sensitivity	18.14 (3.33) Range: 20 - 4	17.91 (3.21) Range: 20 - 5	16.38 (3.74) Range: 20 - 8	.018
Auditory Filtering	26.87 (3.13) Range: 30 - 18	23.53 (4.16)[a] Range: 30 - 11	19.03 (4.82)[bc] Range: 30 - 10	< .001
Movement Sensitivity	14.27 (1.62) Range: 15 - 3	14.21 (1.39) Range: 15 - 9	13.05 (2.11)[bc] Range: 15 - 9	< .001
Low Energy	29.21 (2.24) Range: 30 - 17	28.41 (3.2) Range: 30 - 15	25.73 (5.6)[bc] Range: 30 - 13	< .001
SOR Composite (Tactile + Vis/Aud Sensitivity)	57.67 (3.84) Range: 60 - 32	54.47 (5.55)[a] Range: 60 - 40	47.76 (10.01)[bc] Range: 60 – 27	<.001

ANOVA was used to explore group differences in subscale scores, and associated p values are reported in the table. Pairwise group differences were then probed using t-tests:

[a] Denotes that the PI group has lower scores (greater general sensory processing challenges) than the Comparison group

[b] Denotes that the AFC group has lower scores (greater general sensory processing challenges) than the Comparison group, suggesting more sensory symptoms.

[c] Denotes that AFC group has lower scores (greater general sensory processing challenges) than the PI group

Abbreviations: Short Sensory Profile (SSP); Sensory Over-Responsivity (SOR); Previously Institutionalized (PI); Adopted from Foster Care (AFC)

SSP Categories by Group

Supplemental Table 6. Sample SSP Clinical Categories by Group

ECA Group	**Typical**	**Probable Sensory Processing Challenges**	**Definite Sensory Processing Challenges**
Comparison N = 112	92.86%	5.36%	1.79%
PI N = 34	82.35%	14.7%	2.94%
AFC N = 37	40.54%	18.9%	40.54%

Note: Probable Sensory Processing Challenges and Definite Sensory Processing Challenges categories correspond to the Probable and Definite Difference categories from the SSP
Abbreviations: Early Caregiving Adversity (ECA); Short Sensory Profile (SSP); Previously Institutionalized (PI); Adopted from Foster Care (AFC)

Descriptive Statistics for CBCL T-Scores by Group

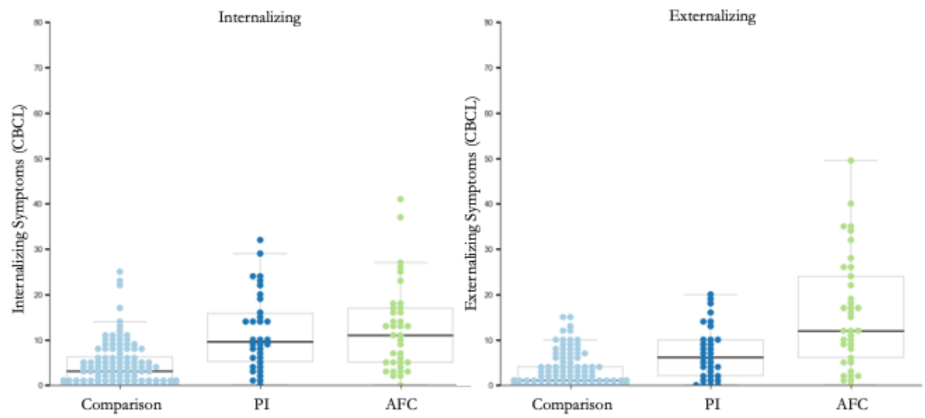
Descriptive statistics for CBCL T-scores are provided in *Supplemental Table 7* and visualized in *Supplemental Figure 1* and *Supplemental Figure 1.*

Supplemental Table 7. Sample Clinical Descriptive Statistics

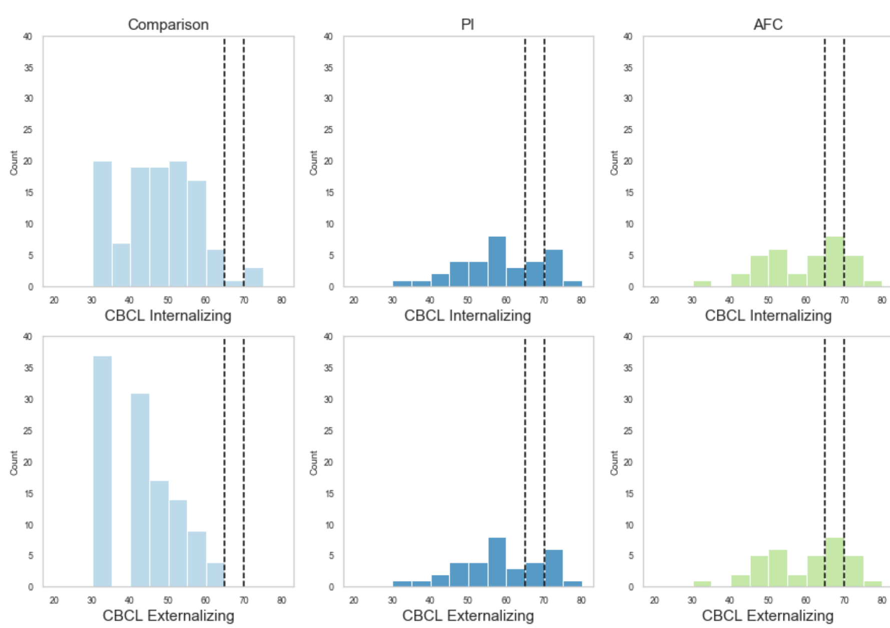
Scales	***Comparison N = 112 Mean (Median; SD)***	***PI N = 34 Mean (Median; SD)***	***AFC N = 37 Mean (Median; SD)***
CBCL Internalizing T-Scores Range: 33 - 100	47.24 (9.74) Range: 33-71	57.76 (10.84) Range: 33-76	59.78 (11.57) Range: 33-84
CBCL Externalizing T-Scores Range: 33 - 100	43.03 (8.52) Range: 33-63	50.76 (9.43) Range: 34-66	60.43 (12.38) Range: 34-86

Note: CBCL internalizing T-scores in this sample may underestimate symptoms, because raw scores were calculated without question 91. Internalizing and externalizing T-scores above 70 are considered to be in the clinical range; scores between 65 and 70 are considered to be in the borderline clinical range.
Abbreviations: Child Behavior Checklist (CBCL); Previously Institutionalized (PI); Adopted from Foster Care (AFC)

Supplemental Figure 1. Visual representation of CBCL internalizing and externalizing scores for comparison, PI, and AFC participants.



Supplemental Figure 2. Visual representation of CBCL internalizing and externalizing scores with clinical cutoffs for comparison, PI, and AFC participants. T-scores above 70 are considered to be in the clinical range; scores between 65 and 70 are considered to be in the borderline clinical range.



Zero-Order Correlations Between Sensory Symptoms and Psychopathology

Supplemental Table 8. Zero-Order Correlations Between Sensory Symptoms and Psychopathology

	Whole Sample (N = 183)	**Comparison (N = 112)**	**PI (N = 34)**	**AFC (N = 37)**
SP3D-INT				
R (Beta)	.36	.33	.17	.20
t	5.21	3.69	.96	1.21
p	<.001	<.001	.34	.23
SP3D-EXT				
R (Beta)	.36	.2	.11	.3
t	5.14	2.08	.65	1.84
p	<.001	.04	.52	.08
INT-EXT				
R (Beta)	.60	.49	.57	.51
t	10.08	5.84	3.93	3.53
p	<.001	<.001	<.001	.001
SSP-INT				
R (Beta)	-.47	-.25	-.54	-.26
t	-7.23	-2.71	-3.59	-1.62
p	<.001	.008	.001	.114
SSP-EXT				
R (Beta)	-.64	-.38	-.56	-.43
t	-11.25	-4.26	-3.78	-2.81
p	< .001	< .001	< .001	.008
SSP-SP3D				
R (Beta)	-.53	-.33	-.48	-.59
t	-8.47	-3.60	-2.82	-4.36
p	< .001	< .001	.008	.001

Abbreviations: Previously Institutionalized (PI); Adopted from Foster Care (AFC)

Early Caregiving Adversity, Age, and Sensory Processing Challenges

Based on previous findings, we predicted that sensory processing challenges would decrease with age. With this in mind, we pre-registered an analysis of age-SOR associations within the larger ECA group (AFC +PI). We chose not to conduct a moderation analysis given we predicted the same (negative) relationship between age and symptoms in the two ECA groups. Instead, we performed a planned linear regression examining the relationship between age and SOR symptoms within the overall ECA group (PI and AFC). Given age differences between the AFC and PI groups in the updated sample, we performed a post-hoc linear regression within each of the individual ECA groups.

SOR symptoms in PI and AFC youth were not correlated with age, covarying for sex assigned at birth (B_{Age} = -.68, *t*(70) = -0.93, 95% CI [-2.14-0.78], p = .36). Post-hoc exploratory follow-up analyses showed no association between age and SOR in either the PI (B_{Age_PI} = 0.23, *t*(33) = 0.15, 95% CI [-2.92-3.37], p = .89) or AFC groups (B_{Age_AFC} = -1.54, *t*(36) = -1.42,95% CI [-3.74 -0.67], p = .17).

Post-Hoc Exclusion of Outliers and Reanalysis

We made the decision when pre-registering our exclusion criteria to not exclude outliers, in order to preserve statistical power in a relatively small sample for a hard to recruit population that has documented high inter-individual variability (Tottenham, 2012). All primary analyses were conducted using bootstrap resampling to provide greater confidence in our estimate of the examined effect sizes.

To provide additional confidence that our findings were not the result of influential outliers, all SP3D SOR analyses were re-run (post-hoc), excluding participants with SP3D SOR total scores greater than (or less than) 3 SDs from the overall sample mean of 49.23 (SD = 8.83).

The remaining sample (N = 145) included 33 AFC participants (4 excluded), 32 PI participants (2 excluded) and 112 comparison participants (0 excluded). All SP3D SOR analyses remained significant in the direction of the original results.

Specifically:

- As before, we found no differences between ECA groups on SP3D scores ($F(3, 64) = 1.95$, $p = .168$). Again, the AFC group had significantly more sensory processing challenges on the SSP than the PI group ($F(3, 64) = 10.5$, $p = .002$).
- Youth in the PI (a_{PI_SP3D} = 7.87, SE = 1.97, t = 4.00, $p < .001$, 95% CI [3.97-11.75]) and AFC (a_{AFC_SP3D} = 4.82, SE = 1.90, t = 2.53, p = .01, 95% CI [1.07-8.58]) groups had higher SP3D scores (higher SOR) than the non-adopted comparison group, covarying for age and sex
- Covarying for age and sex assigned at birth, we found significant indirect effects of ECA on elevated internalizing symptoms through SOR, for both PI ($ab_{PI\_SP3D\_INT} = 1.38$, $SE = .55$, 95% CI [.37- 2.51]) and AFC ($ab_{AFC\_SP3D\_INT} = 0.85$, $SE = .46$, 95% CI [.08-1.86]) youth.
- We found significant indirect effects of PI and AFC status on externalizing symptoms through SOR (PI: $ab_{PI\_SP3D\_EXT} = 1.16$, SE = .54, 95% CI [0.29 , 2.41]; AFC: $ab_{AFC\_SP3D\_EXT} = .71$, $SE = 0.43$, 95% CI [0.07 , 1.72]).

Likewise, all SSP analyses were re-run (post-hoc), excluding participants with SSP total scores less than (or greater than) 3 SDs from the overall sample mean of 170.92 (SD = 19.58).

The remaining sample (N = 180) included 34 AFC participants (3 excluded), 34 PI participants (0 excluded) and 112 comparison participants (0 excluded).

Specifically:

- As before, we found no differences between ECA groups on SP3D scores (F(3,67) = 1.08, p = .30). Again, the AFC group had significantly more sensory processing challenges on the SSP than the PI group (F (3,67) = 9.69, p = .003).

- Youth in the PI (a_{PI_SP3D} = 10.12, SE = 2.36, t = 4.29, p < .001,95% CI [5.47-14.78]) and AFC (a_{AFC_SP3D} = 7.32 , SE = 2.31, t = 3.17, p = .002, 95% CI [2.77-11.87]) groups had higher SP3D scores (higher SOR) than the non-adopted comparison group, covarying for age and sex. Consistent with this finding, youth in both the PI (a_{PI_SSP} = -10.63, SE = 2.93, t = -3.63, 95% CI [-16.40, -4.85], p < .001) and AFC (a_{AFC_SSP} = -27.94, SE = 2.86, t = -9.77, 95% CI [-33.59, -22.3], p < .001) groups had significantly heightened general sensory processing challenges on the SSP (lower scores), relative to non-adopted comparison youth.

- Covarying for age and sex assigned at birth, we found significant indirect effects of ECA on elevated internalizing and externalizing symptoms through SOR, for both PI ($ab_{PI\_SP3D\_INT} = 1.56$, $SE = .64$, 95% CI [.38- 2.93]; $ab_{PI\_SP3D\_EXT} = 1.31$, SE =

.56, 95% CI [0.31- 2.52) and AFC ($ab_{AFC_{SP3D_{INT}}} = 1.13, SE = 0.54$, 95% CI [.20-2.32]; $ab_{AFC\_SP3D\_EXT} = 0.95, SE = .51$, 95% CI [.14-2.13]) youth.

- Covarying for age and sex assigned at birth, we found significant indirect effects of ECA on elevated internalizing and externalizing symptoms through general sensory processing challenges, for both PI ($ab_{PI\_SSP\_INT} = 1.80, SE = 0.70$, 95% CI [.65-3.36]; $ab_{PI\_SSP\_EXT} = 2.11, SE = 0.82$, 95% CI [0.77- 3.94) and AFC ($ab_{AFC_{SSP_{INT}}} = 4.74, SE = 1.24$, 95% CI [2.59-7.41]; $ab_{AFC\_SSP\_EXT} = 5.55, SE = 1.56$, 95% CI [2.95-9.00]) youth.

Post-Hoc Reanalysis in an Age-Matched Sample

To provide additional confidence that our findings were not the result of age differences between groups, all analyses were re-run (post-hoc) using only participants between ages 11 and 18. This age range ensured that the resultant sample had no differences between ages across groups, while maximizing sample size.

The remaining sample (N = 144) included 20 AFC participants (17 excluded), 34 PI participants (0 excluded) and 90 comparison participants (22 excluded). Our findings are summarized below:

Differences in Sensory Processing Challenges Between ECA Groups: As before, we found no differences between ECA groups on SP3D scores ($F(3,53) = 1.93$, $p = .17$). However, the AFC group had significantly more sensory processing challenges on the SSP than the PI group ($F(3,53) = 8.52$, $p = .005$). The AFC and PI groups were therefore examined separately in all analyses, with ECA dummy coded and non-adopted comparison youth as the reference group.

Sensory Processing Challenges Following ECA:

- As before, age-matched PI youth had higher SOR (higher SP3D scores; a_{PI_SP3D} = 10.06, *SE* = 2.27, t = 4.44, 95% CI [5.58 -14.54], $p < .001$) and heightened general sensory processing challenges (lower SSP scores; a_{PI_SSP} = -10.79, *SE* = 2.99, *t* = -3.61 , 95% CI [-16.70, -4.88], $p < .001$) than the non-adopted comparison group, covarying for age and sex.

- As before, age-matched AFC youth had heightened general sensory processing challenges (lower SSP scores; a_{AFC_SSP} = -27.31, *SE* = 3.57, *t* = -7.65, 95% CI [-34.37, -20.25], $p < .001$) than the non-adopted comparison group, covarying for age and sex. However, although the direction of the effect remained the same, the age-matched AFC sample of AFC youth no longer had significantly elevated SOR (higher SP3D scores; a_{AFC_SP3D} = 4.84, *SE* = 2.71, *t* = 1.79 , 95% CI [-0.52 -10.19], $p = .08$) than the non-adopted comparison group, covarying for age and sex.

Psychological Symptomatology following ECA: As in the original analysis, there were significant total effects of ECA on both internalizing and externalizing symptoms. Both PI (c_{PI_INT} = 6.28, *SE* = 1.3, *t* = 44.84, 95% CI [3.71, 8.84], $p < .001$) and AFC (c_{AFC_INT} = 8.34, *SE* = 1.57, *t* = 5.23, 95% CI [5.22 – 11.46], $p < .001$) youth had higher internalizing symptom scores than comparison youth, covarying for age and sex. Similarly, both PI (c_{PI_EXT} = 4.30, *SE* = 0.91, *t* = 4.75, 95% CI [2.51, 6.1], $p < .001$) and AFC ($c_{AFC_{EXT}}$ = 9.99, *SE* = 1.32, *t* = 7.55, 95% CI [7.34 – 12.62], $p < .001$) youth had higher externalizing symptoms than comparison youth, covarying for age and sex.

Sensory Processing Challenges and Links to Psychological Symptomatology:

- Age-matched PI youth: covarying for age and sex assigned at birth, we again found significant indirect effects of previous institutionalization on elevated internalizing and externalizing symptoms through SOR ($ab_{PI\_SP3D\_INT}$ = 1.76, 95% CI [0.56-3.19]; $ab_{PI\_SP3D\_EXT}$ = 1.06, 95% CI [0.14 -2.09]) and through general processing challenges ($ab_{PI\_SSP\_INT}$ = 1.90, 95% CI [0.7-3.63]; $ab_{PI\_SSP\_EXT}$ = 1.45, 95% CI [0.51-2.85]), relative to comparison youth.
- Age-matched AFC youth: covarying for age and sex assigned at birth, we again found significant indirect effects of AFC status on elevated internalizing and externalizing symptoms through general processing challenges ($ab_{AFC\_SSP\_INT}$ = 4.82, 95% CI [2.45-8.01]; $ab_{AFC\_SSP\_EXT}$ = 3.68, 95% CI [1.62-6.37]), but not SOR ($ab_{AFC_{SP3D_{INT}}}$ = .85, 95% CI [-0.12-2.1]; $ab_{AFC\_SP3D\_EXT}$ = .51, 95% CI [-0.08 -1.51]), relative to comparison youth.

Early Caregiving Adversity, Age, and Sensory Processing Challenges within the age matched sample: SOR symptoms in PI and AFC youth were not correlated with age, covarying for sex assigned at birth (B_{Age} = .62, *t*(53) = -.60, 95% CI [-1.44-2.67], *p* = .55). Unregistered exploratory follow-up analyses showed no association between age and SOR in either the PI (B_{Age_PI} = 0.23, *t*(33) = .15, 95% CI [-2.92-3.37], *p* = .89) or AFC groups (B_{Age_AFC} = 1.68, *t*(19) = -.12, 95% CI [-2.72 – 3.06], *p* = .90).

Examination of Sex Differences Between Groups

Individuals assigned female at birth are often over-represented in internationally adopted previously institutionalized samples as a result of varied political and social factors that impact both circumstances leading to placement in an institution and the process of international adoption. Consistent with this, individuals assigned female at birth are disproportionately represented in our PI sample (~71%). The comparison and AFC groups have approximately even proportions of individuals assigned male and individuals assigned female at birth.

All analyses covaried for assigned sex at birth. In the primary models (which included group membership), sex was not significantly associated with SOR symptoms in (B_{Female_SOR} = -1.09, t = -.58, p = 0.56, CI = [-4.85 – 2.65]). Sex was significantly associated with SSP scores in the primary models (B_{Female_SSP} = 4.79, t = -.86, p = .39, CI = [0.25 – 9.32]), indicating that individuals assigned male at birth had more elevated sensory processing challenges than individuals assigned female at birth. Given this and that limited data suggest sensory symptoms are more common in males than females in youth with and without experiences of ECA (Wilbarger et al., 2010), if anything the over-representation of females in the PI group may be resulting in underestimation of the impact of PI experiences on sensory symptoms.

Relationship between SSP Auditory Filtering Score and ADHD Symptoms

In addition to our focal analyses of the CBCL internalizing and externalizing subscale, we calculated ADHD subscale scores for all participants as part of our assessment of the relationship between measures. While the SSP is the most commonly used questionnaire index of sensory processing challenges in youth, critics of the measure argue that it may conflate sensory processing issues with symptoms of ADHD. In order to parse these effects in the context of ECA, we conducted an exploratory multiple regression. ADHD symptoms were significantly associated with more atypical SSP auditory filtering ($\beta = -0.50$, $t(182) = -8.70$, $p < .001$).

Rationale for Study 2

Overall, Study 1 established that sensory processing challenges in general, including SOR, are heightened for youth with early caregiving adversity relative to non-adopted comparison youth. Additionally, findings from Study 1 also showed that sensory processing challenges may even partially account for elevated mental health symptomatology in these populations. Specifically, broad sensory processing challenges and SOR in particular, may exacerbate increased mental health symptomatology in youth with early caregiving adversity. Given these findings and previous research showing links between elevated physiological arousal to aversive sensory stimuli and SOR among clinical populations, the aim of this study was to examine physiological arousal in SOR using heart rate responses to mildly aversive tactile, visual, and auditory sensory stimuli in a group of children and adolescents with early caregiving adversity. This study also examined parent reported measures of SOR and emotion dysregulation in order to compare the extent to which SOR versus more general emotion dysregulation related to hyper-physiological arousal during sensory stimulation in youth adopted from foster care (AFC) participants. Given the importance of using observations, particularly as part of school-based assessments, to assess behavior, we also examined how experimenter-observed SOR during sensory stimulation related with HR responses to mildly aversive sensory stimuli in AFC participants.

Study 2: Heart Rate Responses to Sensory Stimuli and their link to Sensory Over-Responsivity and Emotion Dysregulation in Youth Adopted from Foster Care

Abstract

Background: Youth adopted from foster care (AFC) are highly susceptible to developing elevated sensory processing challenges, including sensory over-responsivity (SOR), an impairing condition marked with intense sensitivity and dysregulation to sensory input, that in turn may lead to high mental health symptoms. To date, no study has examined the physiological underpinnings of SOR and how they relate to behavioral indices of SOR and emotion dysregulation among youth with early caregiving adversity. This study examined heart rate (HR) responses to mildly aversive sensory stimuli in AFC youth and non-adopted comparison (NAC) participants. In addition, we investigated how HR responses to sensory stimulation were associated with symptoms of SOR and emotion dysregulation among AFC participants.

Methods: Children and adolescents between the age of 7-17 years (n=26 AFC; n=30 NAC) experienced mildly aversive tactile, visual, and auditory stimuli using the Sensory Processing 3-Dimensions Assessment while measuring heart rate (HR) responses. Specifically, mean HR across time, as well as inter-beat interval (IBI) responses to sensory stimulation were examined. Parents also reported on their child's SOR and emotion dysregulation symptoms on questionnaires. During assessment, an experimenter also rated participants' reactions to sensory stimuli as an observed measure of SOR symptoms. Parent-reported and experimenter-observed SOR, as well as parent-reported emotion dysregulation were examined as predictors of HR responses within the AFC group.

Results: No significant AFC versus NAC group differences in mean HR and IBI responses to mildly aversive tactile, visual, or auditory sensory stimuli were found. Results revealed that within the AFC group, both parent-reported and experimenter-observed SOR were related to greater HR during sensory stimulation across multiple sensory modalities. In contrast, emotion dysregulation predicted fewer HR responses, indicating that these heightened HR responses may be more specific to SOR symptoms than to general dysregulation.

Conclusion: Our results suggest that hyper-physiological arousal to sensory stimulation is not observed generally across children and adolescents with early caregiving adversity; rather it is specific to those with high SOR symptoms.

Youth adopted from foster care (AFC) are at heightened risk for emotion dysregulation (Witt et al., 2016; Zeanah & Humphreys, 2018), which in turn makes them susceptible for elevated sensory over-responsivity (SOR), an extreme avoidance or reaction to sensory stimuli such as being touched and/or noisy environments. Sensory processing challenges have been commonly observed among clinical populations and may in turn increase mental health symptoms (Ermer & Dunn, 1998; O'Brien et al., 2009; Rogers et al., 2003; Yochman & Pat-Horenczyk, 2020). Specifically, SOR has been shown to exacerbate mental health symptomatology in youth with autism spectrum disorder (ASD), attention-deficit hyperactive disorder (ADHD), and anxiety (Green & Ben-Sasson, 2010; Reynolds & Lane, 2009). However, little is known about SOR symptoms among samples of children and adolescents with early caregiving, who also have elevated mental health symptomatology (Zeanah & Humphreys, 2018). Notably, there is emerging research showing an increased risk of sensory processing challenges, including SOR, among youth with early caregiving adversity (e.g., Méndez Leal, Alba, et al., in press; Wilbarger et al., 2010) For example, Méndez Leal, Alba et al. (in press) showed increased risk for SOR and other broad sensory processing challenges among youth adopted from foster care and institutionalized orphanage care on parent reported measures. Results showed that heightened SOR and broad sensory processing challenges in these groups in part accounted for heightened internalizing and externalizing symptomatology relative to nonadopted comparison youth. These findings along with previous research suggest that sensory processing atypicalities may contribute to heightened emotion dysregulation and subsequent psychiatric diagnoses.

Although research on parent reported behavioral measures of sensory processing challenges provides critical information about the level of these symptoms in youth with early caregiving adversity, the underlying biology of SOR has only recently been explored among clinical populations. As such, little to no research has examined how biological mechanisms in youth with early caregiving adversity, specifically those adopted from domestic foster care, influence increased sensory processing challenges and emotion dysregulation. The physiological response of the heart to sensory stimulation is particularly of interest given the automatic nervous system's ability to modulate bodily functions to emotional and/or sensory information quickly (Appelhans & Luecken, 2006). Heightened heart rate (HR) responses to emotionally salient information have been observed among children and adolescents with high levels of stress and risk for elevated mental health symptomatology (de Veld et al., 2014; Li, Chwo, & Pawan, 2013; Michels et al., 2013; Thayer et al., 2012).

In regard to sensory processing challenges specifically, youth with autism spectrum disorder (ASD) display elevated heart rate responses when exposed to aversive sensory stimuli relative to neurotypical populations (Bizzell et al., 2019; Keith et al., 2019; Woodard et al., 2012). In particular, HR responses to aversive sensory stimuli has been shown to be a sensitive indicator of SOR among participants with ASD (Jung et al., 2021), suggesting that heart rate may provide objective information about how SOR is linked to the body's physiology. Jung et al. (2021) examined mean HR and inter-beat interval (IBI) responses to aversive sensory stimuli in a sample of youth with and without ASD. Results showed higher mean HR among ASD participants with higher SOR relative to those with lower SOR. On further analysis, the authors found that heighted mean HR responses to sensory stimulation were explained by greater HR acceleration (faster heart rate), as measured by IBI, during the first few seconds after stimulus onset. Also, there was a trending effect in which ASD participants with high SOR displayed reduced IBI orientation to sensory stimuli, as indicated by increased IBI heart rate deceleration directly after the onset of the stimulus. This could indicate that heightened SOR may have been contributing to difficulties in the initial effective processing and subsequent response to sensory stimuli. Reduced HR orientation to emotional and traumatic stimuli has also been observed in individuals exposed to traumatic events, suggesting elevated physiological arousal when under stress (Elsesser et al., 2004). Taken together these studies suggest that heart rate during sensory stimulation in youth with early caregiving adversity may provide objective information about heightened SOR and emotion dysregulation symptoms among a group particularly at risk for these challenges.

While the reviewed studies show evidence for the role of elevated heart rate in sensory over-responsivity, this association is not well documented among youth with early caregiving adversity, such as those adopted from foster care. Therefore, exploring HR responses to aversive sensory stimulation in children and adolescents in youth adopted from foster care (AFC), a group at high susceptibility to social-emotional and behavioral challenges, may provide critical information about the high rates of SOR and emotion dysregulation in this population. It may also support further understanding about common biological mechanisms underlying SOR and emotion dysregulation both in AFC youth and across clinical groups in order to highlight the importance of including observation of sensory processing challenges to inform individualized interventions targeting both SOR and emotion dysregulation.

Current Study

The current study aimed to investigate how heart rate responses to aversive sensory stimuli differs in youth adopted from foster care (AFC) and non-adopted, comparison youth (NAC). We also examined how HR responses to aversive sensory stimuli relate to emotion dysregulation and SOR in AFC youth. The following research questions were examined: 1) Are there group differences between AFC and NAC participants in mean heart rate (HR) and inter-beat interval (IBI) responses to mildly aversive tactile, auditory, and visual sensory stimuli? It was hypothesized that AFC participants would show heightened HR to sensory stimuli relative to the NAC group. Particularly, we expected the AFC group to show higher mean HR to sensory stimuli than the NAC group, as well as reduced IBI orienting, increased acceleration, and reduced habituation to sensory stimuli. 2) Is severity of SOR and emotion dysregulation associated with mean HR and IBI responses to mildly aversive tactile, auditory, and visual sensory stimuli within the AFC group? We hypothesized that higher mean HR, reduced IBI orienting, and greater IBI acceleration across sensory stimulation would be observed among AFC participants with high SOR and emotion dysregulation relative to AFC participants with low SOR.

Methods

Participants

A subsample of 26 AFC and 30 NAC children and adolescents with good psychophysiological data from a larger biological sciences study were included in this study. Participants ranged in age from 7 to 17 years of age (M_{age}= 12.34, *SD*=3.016) and all had cognitive ability estimates within the average range on the *Weschler Abbreviated Scales of Intelligence-II* (WASI-II; Weschler, 2011). For the current sample the estimated cognitive ability was significantly different across the two groups ($t(54)=5.24$, $p < .001$) in which the AFC group (*M*=98.69, *SD*=12.05) had lower scores than the NAC group (*M*=116.07, *SD*=12.63). The majority of participants in the AFC group were assigned female at birth (58%), while the majority of participants in the NAC group were assigned male at birth (73%) due to the NAC group being recruited specifically as a control group for an autism study, thus there were significant sex differences across the two groups (χ^2= 5.54, p= .02). Therefore, sex at assigned birth and Full-Scale Intelligence Quotient (FSIQ) were used as covariates in group level analyses. See Table 1 for demographic information.

Procedure

Institutional Review Board at the University of California, Los Angeles approved all study procedures. AFC participants were eligible to participate if they have had a finalized adoption or legal guardianship through the Department of Child and Family Services (DCFS), were between the ages of 7-17, had no diagnosis of an autism spectrum disorder or major mental illness (i.e., bipolar disorder or schizophrenia), and had no metal in their body (e.g., braces). AFC participants were recruited through two adoption-related programs in the Los Angeles area, UCLA TIES for Families and Adoption Promotion and Support Services (APSS).

UCLA TIES is an interdisciplinary program offering advocacy and therapeutic services to support the development of foster care and adopted youth from birth to 21 years of age. Clinicians at UCLA TIES were provided flyers to give to current eligible families and mailed out flyers to previous clients who had children currently eligible for the study. APSS also provides a variety of care services, including therapy, case management, and mentoring support for foster care and adopted youth. Clinicians at APSS were emailed and asked to provide their eligible clients with the study flyer. UCLA TIES clinicians also made presentations about the study at APSS meetings, requesting that clinicians provide the flyer to their eligible families.

Comparison, non-adopted participants were recruited from posting flyers throughout the community (schools, UCLA campus, and around the Los Angeles area), on social media including Facebook and Peachhead, and from an active waiting list of families interested in participating in research at UCLA. Comparison participants were included if between the ages of 7-17 years, had no history of adoption or DCFS involvement, and had no mental health diagnoses or learning disabilities. AFC and comparison participants were also included only if they had a full-scale IQ (FSIQ) >70 on the WASI-II.

Behavioral Measures

Demographic information. Parents of AFC youth provided demographic information about age placed in foster care, age removed from home of origin, age adopted from foster care, and child's assigned sex at birth. Race and ethnicity from both groups was also collected.

Full-Scale Cognitive Ability. The *Weschler Abbreviated Scales of Intelligence, Second Edition* (WASI-II; Weschler, 2011) was used to provide an estimate of cognitive ability. The WASI-II measures consist of four subtests in which participants verbally and non-verbally respond to questions about vocabulary and identifying patterns from visual stimuli.

Emotion dysregulation. The *Child Behavior Checklist* (CBCL; Achenbach & Rescorla, 2001) was used to measure emotion dysregulation. The CBCL is a widely used standardized 118-item parent-report measure assessing symptoms of mental health symptomatology in children and adolescents. The CBCL has two forms, one for ages 1.5 to 5 years (CBCL/1.5-5) and one for 6-18 years (CBCL/6-18). Parents are asked to define their child's behavior within the past 6 months using a 3-point scale (0= *Not True*, 1= *Somewhat or Sometimes True*, 2= *Very True or Often True*). The CBCL provides an Emotion Dysregulation Index (CBCL-EDI) which is comprised of 18 items (Samson et al. 2014). This index score was formed via an expert rating process for children between the ages of 6-18 years and has been reported to have high internal consistency ($\alpha = 0.90$). For this study, the following 18 items from the CBCL were used to create the CBCL-EDI score: argues a lot; clings to adults; cries a lot, destroys his/her own things;

destroys things belonging to his/her family or others; gets in many fights; nervous, high-strung, or tense; too fearful or anxious; physically attacks people; screams a lot; stubborn, sullen, or irritable; sudden changes in mood or feelings; temper tantrums or hot temper; threatens people; unhappy, sad, or depressed; worries. These items consist of questions included in the Internalizing Problems and Externalizing Problems subscale scores.

Sensory over-responsivity. The *Sensory Processing 3-Dimensions Inventory* (SP3-D; Schoen et al., 2008) is a parent-report measure, used to measure SOR. Parents rate their child's sensory over-responsivity in visual, tactile, and auditory domains by indicating the number of items in a checklist that bothers their child on a Likert scale ranging from 1 (*Not bothered/never avoids*) to 5 (*Extremely bothered/always avoids*) on 42 questions. A total SOR score, which was used for this study, is calculated by summing the tactile, visual, and auditory subscales scores.

Psychophysiological Behavioral Measures

The **Sensory Processing 3-Dimensional Assessment** (Mulligan et al., 2016) was used to examine responses to tactile, visual, and auditory sensory modulation items in children and adolescents. Participants were presented with visual, tactile, and auditory sensory stimuli designed to be ecologically valid such as viewing bright lights, listening to musical instruments, being touched with scratchy materials, and touching goo. The sensory paradigm is presented in E-Prime with stimuli presentation time between 30 seconds to 2 minutes in duration (depending on the stimulus) and with a 9-second fixation cross before each task. This study used the following tasks: Goo game (tactile; two 30sec blocks), Painting game (tactile; three 30 sec blocks), Round and Round game (visual; one 20sec block), Lightning Storm game (visual; one 20sec block), Sparkles game (visual; one 20sec block), and Orchestra time game (auditory; three 30sec blocks). During and directly after each task, participants were coded with a 0 (no SOR), OR 1 (SOR). Participants were coded a one when there is an adverse response such as a grimace, avoidance, or covering of eyes and/or ears. A total SP3D SOR score was calculated by summing the codes for each item. All codes were discussed and agreed upon with the principal investigator, who has extensive knowledge about sensory modulation in children and adolescents, and through trainings and consultations with one of the measure developers.

Physiological Data

Heart rate (HR) responses were obtained throughout participation in the Sensory Processing 3-Dimensional Assessment paradigm. One electrode is placed on the upper right chest under the collar bone and the other electrode between the left hipbone and bottom ribcage. HR is recorded using a standard limb electrocardiogram via connection to the BIOPAC bioamplifier (S75-01), which reports to a tachometer (S77-26) in order to plot beats per minute. Participants' vagal tone is measured via respiratory sinus arrhythmia (RSA), which is a noninvasive measure of cardiac vagal control described by increases in HR during inspiration and decreases in HR during post-inspiration.

Physiological data preparation. Physiological data was preprocessed using the Automatic Nervous System Laboratory (ANSLAB) software through MATLAB. Mean HR metrics were derived by extracting 10-second intervals from each sensory task to create a mean HR score for each of the 10 second blocks within each sensory task: tactile

(Goo and Painting game), auditory (Orchestra game), and visual (Round and Round game, Lightning storm and Sparkles game) stimuli. A 3-minute baseline was collected before presentation of the sensory paradigm and mean resting HR during this baseline was used as a covariate in analyses investigating mean HR to examine HR change from baseline to stimulus.

In subsequent analyses, we calculated inter-beat intervals (IBIs), measured in milliseconds, where higher values indicate slower HR (more time between heart beats). IBI is a measure calculated in milliseconds (ms) between consecutive R-wave peaks, to examine the temporal distance in HR (Task Force of, ESC/NASPE, 1996; Thayer & Lane, 2000). Higher R-waves values correspond to slower HR indicating more time between beats (.12 Hz - .40 Hz; Task Force of ESC/NASPE, 1996; Thayer & Lane, 2000). IBI was calculated for each of the following intervals after stimulus onset: 0-1, 1-2, 2-3, 3-4, 4-5, 5-10, 10-15, 15-20 seconds from visual sensory modality tasks which lasted 20 seconds each, and an additional calculated 20-25, 25-30 seconds were calculated from tactile and auditory stimuli which lasted 30 seconds. We then subtracted the mean IBI 0-5 seconds before stimulus onset for each interval. This allowed us to examine both immediate changes in IBI after the stimulus onset ("orienting" phase; 0-1 to 1-2 sec), subsequent HR acceleration ("acceleration" phase; 1-2 to 3-4 sec), and sustained IBI across the remaining seconds ("habituation" phase; 5-10 to 10-15, 15-20, 20-25, 25-30 sec).

Repeated-measure ANOVAs for each sensory modality (Tactile, Visual, and Auditory stimuli) with group as a between-subjects variable were conducted. Tactile sensory stimuli consisted of only the three Painting Game tasks for IBI analyses, given that the Goo game requires the participant to move their bodies, therefore making it challenging to detect small changes in HR unrelated to motion. In addition, Visual sensory stimuli only included the Round and Round Game and Sparkles Game, since the Lightning Storm Game requires the participant to move as well.

Data Analytic Plan for Study 2

To examine mean HR and IBI responses to mildly aversive tactile, auditory, and visual sensory stimuli in the AFC and NAC groups a series of repeated measures ANOVAs were performed using IBM SPSS version 27. Group analyses included sex assigned at birth and FSIQ as covariates. Analyses with mean HR included baseline HR as a covariate. The assumption of sphericity was assessed using the Mauchly's test of sphericity. If the assumption was violated, a Greenhouse-Geisser estimate was applied. Parent-reported SOR, experimenter-observed SOR, and CBCL EDI were tested as predictors of mean HR and IBI responses within the AFC group, and, where significant, a post-hoc analysis was conducted using a low and high median split group on the significant measure to interpret the direction of effects. One NAC participant was excluded due to being a significant outlier on SOR score. Therefore, the following HR analyses were conducted with 29 NAC and 26 AFC participants. Two AFC participants did not have CBCL-EDI data and thus were excluded from analyses examining emotion dysregulation (n= 24).

Results

Independent-sample t-tests were conducted to test for group differences in parent-reported measures of SOR (SP3D Parent Report) and emotion dysregulation, in addition to experimenter-observed SOR (SP3D Experimenter Observed). The AFC group was rated significantly higher in total SP3D Parent Report SOR scores ($t(52)=-2.14$, $p= .04$) and emotion dysregulation ($t(52)=-3.61$, $p=.001$) relative to the NAC group. There were no significant group differences in the SP3-D Experimenter Observed SOR scores ($t(52)=.163$, $p=.87$). Another independent samples t-test was performed to explore group differences in the mean 3-minute baseline HR and mean HR responses to each modality of stimulus (tactile, visual, and auditory). Results revealed no significant group differences. Overall descriptive statistics are displayed in Table 2. Pearson bivariate correlations within the AFC group showed a significant positive relationship between parent-reported SOR and emotion dysregulation ($r= .44$, $p= .04$), such that higher SOR was associated with higher emotion dysregulation. No other significant correlations were found among these symptoms measures or between SOR/emotion dysregulation and baseline HR, see Table 3. However, it should be noted that there was a slight trend towards higher experimenter-observed SOR being associated with higher baseline HR ($r=.29$, $p=.15$).

Psychophysiological Results

Mean Heart Rate

Group Analyses

We first examined group differences in mean HR responses to each sensory modality (Tactile, Visual, and Auditory) using a repeated-measures ANOVA with group as a between-subjects variable, stimulus type and time block (first, second, and third 10-sec blocks for tactile and auditory stimuli, and first and second 10-sec blocks for visual stimuli) as within-subjects variables, and baseline HR, sex assigned at birth, and FSIQ as covariates.

Tactile Sensory Stimuli

Results revealed no significant main effect of group or interactions with group, (p >.05), showing similar mean HR responses to tactile sensory stimulation were observed across the two groups.

Visual Sensory Stimuli

For visual stimuli, results showed a significant effect of time(linear), ($F(1,51)$= 9.16, p=.004), such that mean HR increased across time for all participants throughout visual sensory tasks. Results also showed a significant effect of visual sensory stimulus, ($F(1,49)$= 4.64, p=.04), showing that mean HR was greater during the Lightning Storm game relative to other forms of visual sensory stimulation across all participants. Results revealed no significant main effect of group or interactions with group, (p >.05), indicating similar mean HR responses to visual sensory stimulation across the two groups.

Auditory Sensory Stimuli

Results revealed a significant effect of time(quadratic), ($F(1,50)= 5.77$, p=.02), indicating that mean HR increased across time for all participants during the span of auditory stimuli tasks. A significant interaction between Time(quadratic)*FSIQ, ($F(1,50)= 5.25$, p=.03) was also found, such that HR changed over time differently depending on FSIQ. Results revealed no significant main effect of group or interactions with group, (p >.05).

Sensory over-responsivity and Emotion Dysregulation Correlations within the AFC Group:

Separate repeated-measure ANOVAs within the AFC group were also conducted for mean HR responses within each sensory modality with 1) parent-reported SOR; 2) experimenter-observed SOR; 3) parent-reported emotion dysregulation entered as between-group continuous covariates of interest and covarying for baseline HR.

Mean Heart Rate

Tactile Sensory Stimuli

Parent-reported SOR. Findings showed a significant 3-way interaction between tactile sensory stimuli*Time (quadratic)*SP3D SOR, ($F(1,22)= 5.71$, p=.03, $\eta^2 = .21$), indicating that the effect of SOR on mean HR responses differed over time across tactile sensory stimulation. Post-hoc analyses indicated that mean HR increased more across each stimulus block for participants with higher SOR relative to those with lower SOR, particularly during the Goo Game tasks. As shown in Figure 1a, AFC participants with higher SOR showed greater HR increases over time during tactile sensory tasks and greater overall HR during the goo game. This pattern held when taking into account baseline HR (Figure 1b).

Observed SOR. Results showed a significant 2-way interaction between tactile sensory stimuli*SP3-D SOR, (F(4,20)= 3.62, p=.02, $\eta^2 = .28$), such that the effect of SOR on mean HR differed by tactile stimuli. Post-hoc analyses revealed mean HR was greater for AFC participants with higher SOR during the Painting Game relative to other tactile stimulation, see Figure 2a. When accounting for baseline HR, AFC participants with higher SOR showed greater HR responses during the Painting game but lower HR responses (i.e., less change from baseline) during the Goo games; see Figure 2b.

Emotion Dysregulation. Results showed a significant 2-way interaction between Time(quadratic)*CBCL-EDI, (F(1,21)= 5.17, p=.03, $\eta^2 = .20$), indicating that the effect of emotion dysregulation on mean HR differed across time. Post-hoc analyses revealed that AFC participants with higher EDI showed significantly greater HR response increases across the stimulus blocks, likely accounted for responses during the Goo Games, see Figure 3b.

Visual Sensory Stimuli

Parent-reported SOR. No significant main effects or interactions with parent-reported SOR were found (p >.05).

Observed SOR. Results showed a significant interaction between Time(linear)*SP3-D SOR, (F(1, 22)= 5.09, p=.03, $\eta^2 = .19$), indicating that mean HR differed over time differently depending on experimenter-observed SOR scores. Post-hoc analyses showed that AFC participants with higher experimenter-observed SOR increased HR more across time during visual sensory stimulation compared to those with lower SOR, see Figure 4a. A significant interaction between visual sensory stimuli*SP3-D SOR, (F(1, 22)= 11.03 p=.003, η^2 =.33) was also found, indicating that the effect of SOR on mean HR differed by visual sensory stimuli. Post-hoc analyses revealed that mean HR was higher for AFC participants with higher SOR during the Round-and-Round Game specifically. This pattern was similar when accounting for baseline HR (Figure 4b), except that while AFC participants with higher SOR continued to show higher HR responses during the Round-and-Round game, they actually showed reduced responses (i.e., less change from baseline) compared to participants with lower SOR during the other two visual stimuli. However, higher SOR participants still showed greater increases in HR over time even after accounting for baseline HR.

Emotion Dysregulation. No significant interactions and main effects were observed (p>.05).

Auditory Sensory Stimuli

Parent-reported SOR. Results showed no significant main effects or interactions with parent-reported SOR (p >.05).

Observed SOR. Results showed a significant 3-way interaction between auditory sensory stimuli*Time (quadratic)*SP3-D SOR, (F(1, 23)=5.49, p=.03, η^2 =.19), indicating that the effect of SOR on mean HR differed over time across visual sensory stimuli. A significant 2-way interaction between Time(quadratic)*SP3-D SOR was also found, (F(1, 23)=7.04, p=.01, η^2 =.23), indicating that the effect of experimenter-observed SOR on mean HR differed across time. Post-hoc analyses revealed that AFC participants with higher SOR displayed higher mean HR during the 10-20 sec time block of the Cymbal and Stick task, see Figure 5 a and b. However, when accounting for baseline HR, AFC participants with lower SOR showed higher HR responses (i.e., greater change from baseline) during the Cymbal and Stick task and during the Whistle task.

Emotion Dysregulation. No significant main effects or interactions were found (p >.05).

IBI Results

Group Analyses

A series of repeated-measures ANOVAs were conducted for inter-beat interval (IBI) responses to each sensory modality (Tactile, Visual, and Auditory) with group as a between-subjects variable, stimulus type and time block as within-subjects variables, and sex assigned at birth and FSIQ as covariates. Results revealed no significant or trending main effects or interactions with group across tactile, visual, and auditory sensory stimuli (p <.05).

Sensory over-responsivity and Emotion Dysregulation Correlations within the AFC Group: Inter-Beat Intervals

Separate repeated-measure ANOVAs within the AFC group were also conducted for IBI within each sensory modality with 1) parent-reported SOR; 2) experimenter-observed SOR; and 3) parent-reported emotion dysregulation entered as between-group continuous covariates of interest.

Tactile Sensory Stimuli

Parent-reported SOR. There were no significant main effects or interactions with parent-reported SOR (p>.05).

Observed SOR. Similarly, there were no significant main effects or interactions with experimenter-observed SOR (p>.05).

Emotion Dysregulation. Results showed a significant interaction between tactile sensory stimuli*CBCL-EDI, F(1,22)=6.23, p=.008, $\eta^2 = .22$), such that the effect of emotion dysregulation on IBI responses differed across tactile sensory stimulation. As shown in Figure 6, post-hoc analyses revealed that IBI was greater for AFC participants with low emotion dysregulation across the Chapstick task of the Painting Game (p=.002). Thus, participants with higher emotion dysregulation showed faster heartbeats during the orienting, acceleration, and habituation phases (see Figure 8).

Visual Sensory Stimuli

Parent-reported SOR. Results revealed significant two-way interactions between Time* SP3D SOR, (F(7, 17)=4.81, p=.004. $\eta^2 = .66$), and visual sensory stimuli*SP3D SOR, (F(1, 23)=5.66, p=.03, $\eta^2 = .20$), and a three-way interaction between visual sensory stimuli*Time(linear)*SP3D SOR, (F(1,23)=6.00, p=.02, $\eta^2 = .21$), indicating that IBI responses differed over time across visual sensory stimuli differently depending on SOR scores. As shown in Figure 7, post-hoc analyses indicated that AFC participants with higher SOR displayed reduced (faster heart rate) IBI orientation (during the 0 to 2 seconds of stimulus onset) during the Round-and-Round game specifically. No other main effects or interactions were found (p>.05).

Observed SOR. A similar repeated measures ANOVA was conducted with SP3-D SOR Experimenter-Observed scores as a covariate. Findings showed a significant 3-way interaction between visual sensory stimuli*Time*SP3-D SOR, ($F(7,18)=2.62$, $p=.05$, $\eta^2=.50$), such that the effect of experimenter-observed SOR on IBI responses differed across time and across the different visual sensory stimuli. Similar to parent reported findings, AFC participants with higher SOR showed reduced IBI orientation during the Round-and-Round (Figure 8a) and Sparkles games (Figure 8b). There was also a two-way interaction between Time*SP3D SOR ($F(7,18)=3.16$, $p=.02$, $\eta^2=.55$), indicating an overall effect of experimenter-observed SOR on the orientation phase.

Emotion Dysregulation Results showed no significant main effects or interactions with emotion dysregulation ($p>.05$).

Auditory Sensory Stimuli

Parent-reported SOR. There were no significant main effects or interactions with parent-reported SOR ($p>.05$).

Observed SOR. Similarly, there were no significant main effects or interactions with observed SOR ($p>.05$).

Emotion Dysregulation. Results showed no significant main effects or interactions with emotion dysregulation ($p>.05$).

Discussion

This study examined group differences in heart rate (HR) responses to mildly aversive tactile, visual, and auditory sensory stimuli among youth adopted from foster care (AFC) and non-adopted comparison (NAC) participants. This study also examined how HR responses to mildly aversive sensory stimuli related to measures of SOR and emotion dysregulation within AFC youth. Findings indicated that AFC participants with higher SOR, both through parent-report and experimenter-observation, displayed hyper-physiological arousal during sensory stimulation relative AFC participants with lower SOR. Our results are consistent with previous work showing hyper-physiological arousal, especially in HR responses, to mildly aversive sensory stimulation in clinical populations, such as those with autism spectrum disorder (ASD) who also present with inter-individual differences in symptom presentation (Jung et al., 2021). The similar physiological patterns seen in other groups with SOR, such as those with ASD, could indicate a common biological marker for SOR across different populations. Moreover, our results also showed that AFC participants with higher SOR exhibited a reduced inter-beat interval (IBI) orientation to sensory stimuli, a similar HR response pattern as that observed among individuals with histories of trauma when presented to emotional and traumatic stimuli (Elsesser et al., 2004).

Our results showed no overall group differences in mean HR and inter-beat interval (IBI) responses to tactile, visual, or auditory sensory stimuli, suggesting that in this sample, both AFC and NAC participants display similar HR patterns. However, there was significant variability within the AFC group in SOR symptoms, and thus, these individual differences did predict HR responses to sensory stimulation, which is consistent with the heterogeneity of early caregiving adverse experiences, developmental trajectories, and mental health outcomes in these groups (McLaughlin et al., 2012; Tottenham, 2012). As such, the present study findings revealed a subset of AFC participants who present with higher SOR symptomatology and hyper-physiological arousal to sensory stimulation. Therefore, further research may want to examine whether *type* of early adverse caregiving experience predicts higher SOR and heightened HR responses to sensory information to identify groups of youth with heightened susceptibility to sensory processing challenges to inform targeted intervention.

In general, the extant literature, although sparse, has shown that youth with early caregiving adversity have higher sensory processing challenges, including SOR, on parent reported measures (e.g., Méndez Leal, Alba, in press; Wilbarger et al., 2010). Our study for the first time, showed heightened observable SOR during all types of sensory stimulation was linked with hyper-physiological arousal in a sample of youth with early caregiving adversity. However, when accounting for baseline HR, in some cases participants with lower experimenter-observed SOR actually increased more from baseline relative to those with higher SOR (though at times the opposite was true). In general, baseline HR was slightly higher for AFC participants with higher SOR symptoms possibly due to anticipation of the upcoming sensory stimuli, and then HR may have decreased *relative to baseline* during some of the sensory stimulation. However, HR was consistently higher for AFC participants with higher SOR across most sensory stimuli. Even when accounting for baseline HR, HR responses increased more during the Painting Game for those with higher SOR, a task most similar to some of the stimuli used in the Jung et al. (2021) study, which found similar results in ASD. This finding may indicate that tactile sensory stimuli are better at differentiating HR responses between AFC participants with low vs. high SOR. Notably, both HR responses and experimenter-observed SOR were collected at the same time and, thus, may correlate more highly relative to parent-reported SOR which may correlate better with HR responses to sensory stimuli outside of the lab environment, such as in the home. These findings highlight the importance of including real-time observations of sensory processing challenges in the environment of concern (e.g., school), to inform assessment and subsequent intervention supports for youth with early caregiving adversity. Combining parent-report measures and observations may provide insight into the generalizability of sensory processing challenges across structured and unstructured settings, which are both common practices in school-based assessments (McConaughy & Ritter, 2014; National Association of School Psychologists, 2016).

Our results also showed reduced IBI orientation and no increased IBI acceleration during visual sensory stimulation for AFC participants with higher SOR. Unlike prior research in ASD populations (Jung et al., 2021), we did not find overall higher HR responses during the orienting and acceleration phases of tactile and auditory sensory stimulation. This may suggest that this initial subconscious-level basic sensory processing cause of SOR could be more specific to youth with ASD whereas in AFC we could be seeing more of a general stress response that is less specific to the immediate onset of the stimuli. Interestingly, our results revealed that AFC participants with higher SOR showed reduced IBI orienting only to visual sensory stimuli, suggesting potential differences within this group during the initial processing of visual input. In general, inter-beat-intervals should increase (i.e., heart rate slowing) when presented with novel stimulus (e.g., Thayer & Lane, 2000), as we observed here in AFC participants with *lower* SOR severity. Indeed, these results are consistent with findings showing reduced HR orienting to stressful stimuli among populations with histories of stress (Elsesser et al., 2004; D'Andrea et al., 2013). It is possible that this type of visual sensory stimuli may differentiate levels of SOR during the first few seconds of stimulus presentation in youth with early caregiving adversity. However, visual sensory tasks in this study are less aversive than the scratchy and gooey materials presented during tactile stimulation and loud instruments during auditory sensory stimulation. It may be that the presentation of study instructions for visual sensory stimuli may not have prepared participants for the visual tasks and thus they may be perceived as more overwhelming. Also, it may be possible that this subset of AFC participants can tolerate and modulate loud noises whereas tactile items and visual stimulation may induce higher SOR symptoms. Overall, our research adds to the extant literature showing hyper-physiological arousal to novel stimuli in individuals with adverse life experiences by including a similar presentation pattern to emotion stimuli when introduced to sensory stimulation.

In contrast to SOR, our results showed that emotion dysregulation was less consistently related to HR responses to sensory stimuli within the AFC group, which may indicate that these hyper-physiological responses are specific to SOR rather than to early caregiving adversity or emotion dysregulation. In fact, results with emotion dysregulation showed that AFC participants with higher emotion dysregulation displayed decreased IBI (faster HR) during tactile sensory stimulation tasks (Chapstick task of the Painting Game). However, no other notable findings were observed in HR responses to sensory stimuli when including emotion dysregulation. Future work should examine how HR responses to emotional stimuli paired with sensory stimuli may relate to heightened emotion dysregulation in youth with early caregiving adversity.

Clinical Implications

Our results provide evidence for significant and observable SOR symptoms, as well as hyper-physiological arousal to sensory stimuli in a sample of youth with early caregiving adversity. Findings from this study and previous work in youth with early caregiving adversity (Méndez, Alba, et al., in press), show high sensory over-responsivity (SOR) symptoms in these populations. Furthermore, we not only showed high SOR from the perspective of parents and direct assessors, but also hyper-physiological responses to sensory stimuli. This provides even more evidence that SOR is impacting the daily experiences of youth with early caregiving adversity. Heightened SOR, and thus, hyper-arousal to sensory stimuli, may make it challenging for youth with early caregiving adversity to attend to the learning environment at school. As such, utilizing screening tools for sensory processing may further inform why a child with early caregiving adversity exhibits behavioral challenges that impact school performance and subsequent mental health difficulties. Thus, it is important for school-based and clinical professionals to screen for sensory processing during the first few seconds of stimulus presentation challenges, particularly SOR, among youth with early caregiving adversity.

In addition to screening for sensory processing challenges, our results showed that observed SOR symptoms during a structured setting significantly related to hyper-physiological arousal. Structured classroom observations by school-based professionals and clinicians may want to consider observing for possible sensory processing challenges in youth with early caregiving adversity, especially during times when sensory input is heightened in the classroom (e.g., during movement breaks with loud sounds). Heightened physiological arousal may further explain why school practitioners need to screen for sensory processing challenges to further explain youth's overreactions to the sensory input in the classroom environment (Ben-Sasson, Carter, et al., 2009; Carter et al., 2011). These sensory-informed assessments, such as parent report measures and observations, may in turn inform more targeted and effective classroom interventions for youth with early caregiving adversity.

Limitations

Despite our significant findings, the study did have a few limitations. First, the study's focus on SOR may have limited the scope in understanding how other types of sensory processing challenges influence HR response to sensory stimuli. Future research may consider examining the role of additional sensory processing atypicalities (e.g., sensory seeking, sensory underresponsivity, taste aversion) and relate them to psychophysiological responses toward mildly aversive sensory stimulation in youth exposed to early caregiving adversity. Second, the lack of group differences may have been the result of a structured lab setting, which may have reduced the level of discomfort compared to stimuli experienced in everyday life. Indeed, previous research has shown that predictability of exposure to school schedules or daily living activities are a protective factor among youth exposed to early caregiving adversity (Hedin et al., 2011; Sciaraffa et al., 2018). For example, Sciaraffa et al., 2018 noted that establishing predictable routines, including school schedules, structure, and planned transitions may serve as resilience factors as they reduce stress in youth exposed to childhood adversity. Thus, the preparation of sensory modulation activities by an experimenter during testing may have caused participants to decrease their HR responses. Future research may want to explore the differences in HR responses to mildly aversive sensory stimulation between a structured lab setting and naturalistic observation in youth exposed to early caregiving adversity to determine if context plays a role in HR differences between AFC and NAC participants. In addition, we only focused on youth adopted from foster care who were often adopted early in life, as well as having limited developmental history that may inform study results. Future studies with a larger sample could examine effects in early caregiving experience in AFC youth, such as, but not limited to prenatal substance exposure, abuse, neglect, and age of foster care placement.

Conclusion

Taken together, our findings provide novel insight into the role of SOR symptoms in HR responses to mildly aversive sensory stimuli among a sample of youth adopted from foster care and non-adopted comparison youth. While early caregiving adversity is a significant risk factor for SOR, hyper-responsiveness to sensory stimulation may not be a general characteristic of youth adopted from foster care, rather it may be related to variability of SOR symptom presentation. These results provide further evidence for school-based professionals and clinicians to screen for sensory processing challenges in youth with early caregiving adversity to inform adequate individualized intervention supports.

Table 1.

Demographic information on sample with available physiological data

Variable	**AFC** (*n* = 26)		**NAC** (*n* = 30)		
	%		%		χ^2
Assigned Sex Female	47%		33%		5.54*
Child Race/Ethnicity					19.84*
White	8%		28%		
Black	50%		0%		
Asian	0%		21%		
Multiracial	11%		21%		
Nonwhite Hispanic/Latinx	0%		3%		
White Hispanic/Latinx	31%		21%		
Declined to State	0%		6%		
	Mean	**SD**	**Mean**	**SD**	***t***
Age (years)	12.0	2.9	13.1	3.1	-.39
Full Scale IQ(FSIQ)	99.5	12.4	116.2	12.2	5.24**

Note: *p*<.05*, *p*<.001**

Table 2.

Group differences in variables of interest

	AFC (*n*=26)		**NAC** (*n*=30)		
Variable	***M***	***SD (range)***	***M***	***SD (range)***	***p***
		Behavioral Data			
CBCL-EDI score	7.73	6.38 (0-21)	2.63	3.90 (0-7)	<.001*[a]
SP3D SOR Parent Report	55.08	18.46 (42-109)	47.27	7.03 (43-73)	.04*[a]
SP3-D SOR Experimenter Observed	1.31	2.00 (0-6)	1.39	1.85 (0-7)	.87
Baseline HR	79.03	12.74 (58-103)	79.28	12.54 (57-104)	.94

Note: [a]*Levene's Test of Equal Variances = p < .05*, showing significant variances in scores.

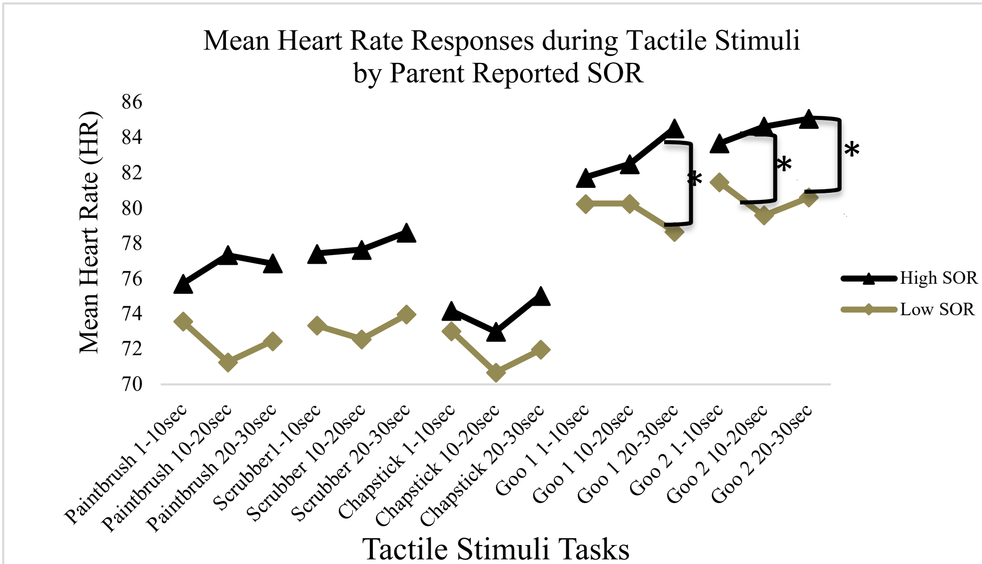
Table 3.

Pearson bivariate correlations within the AFC group

Variables	**1.**	**2.**	**3.**	**4.**
1.Baseline HR	--	.05	.29	.19
2. SP3D SOR Parent Report	--	--	-.08	.44*
3. SP3-D SOR Experimenter Observed	--	--	--	-.15
4. CBCL EDI	--	--	--	--

Note: * *p* <.05

A)



B)

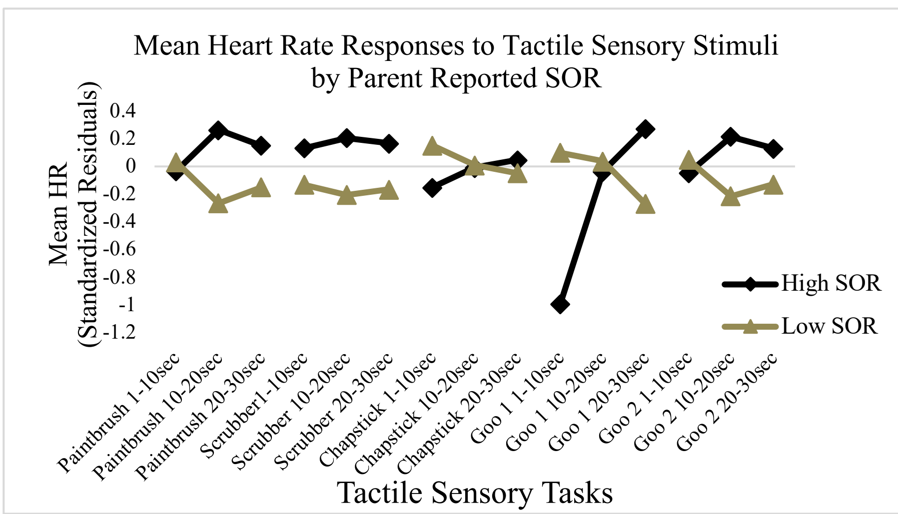
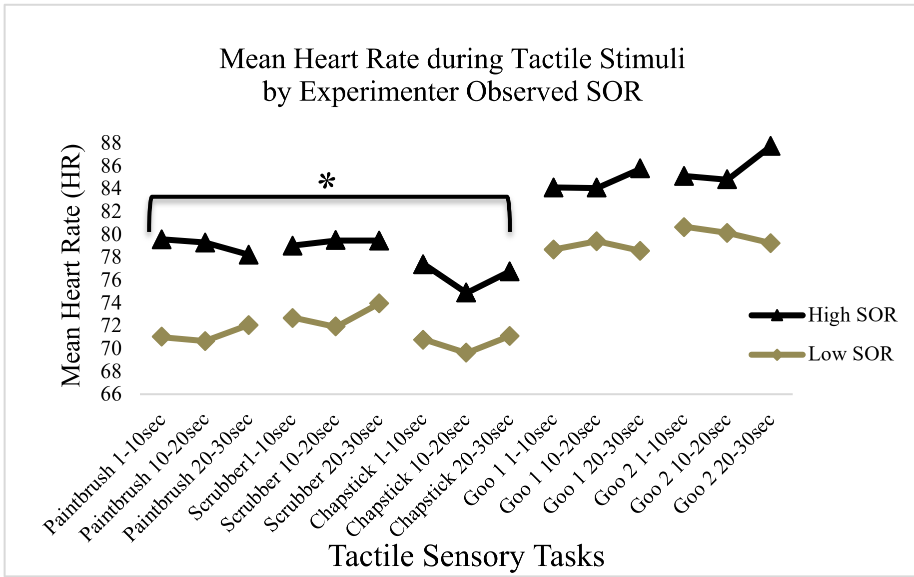


Figure 1. Mean HR responses across time for tactile sensory tasks by **parent reported SOR** scores within AFC participants. **a)** AFC participants with higher SOR showed higher mean HR responses during the Goo game and greater HR increases across stimulus blocks; **b)** The same pattern emerged when controlling for baseline HR. *Note:* Painting Game= Paintbrush, Scrubber, and Chapstick; Goo Game= Goo Part 1 and Goo Part 2 *p <.05

A)



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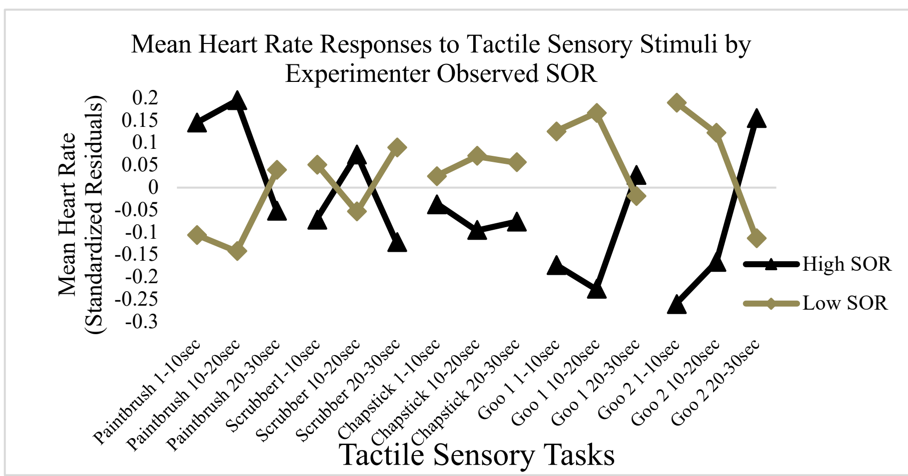
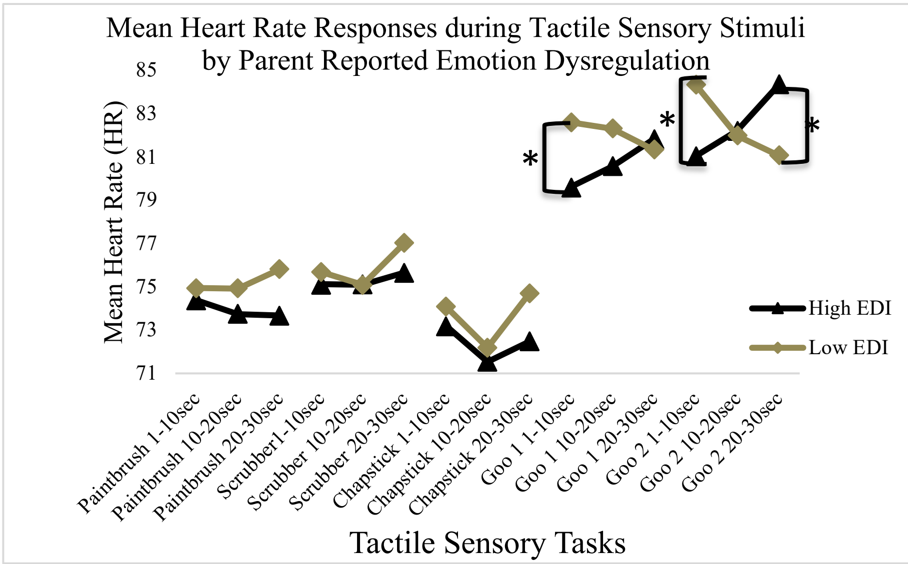


Figure 2. Mean HR responses to mildly aversive tactile sensory stimuli by **experimenter-observed SOR** within AFC participants. **a)** AFC participants with higher SOR showed higher mean HR during the Painting Game; **b)** When accounting for baseline heart rate, AFC participants with higher experimenter-observed SOR showed higher mean HR responses to the Painting Game tactile stimuli but lower responses (i.e., less change from baseline) during the Goo games. Standardized residuals scores are plotted, covarying for baseline heart rate. * $p < .05$

A)



B)

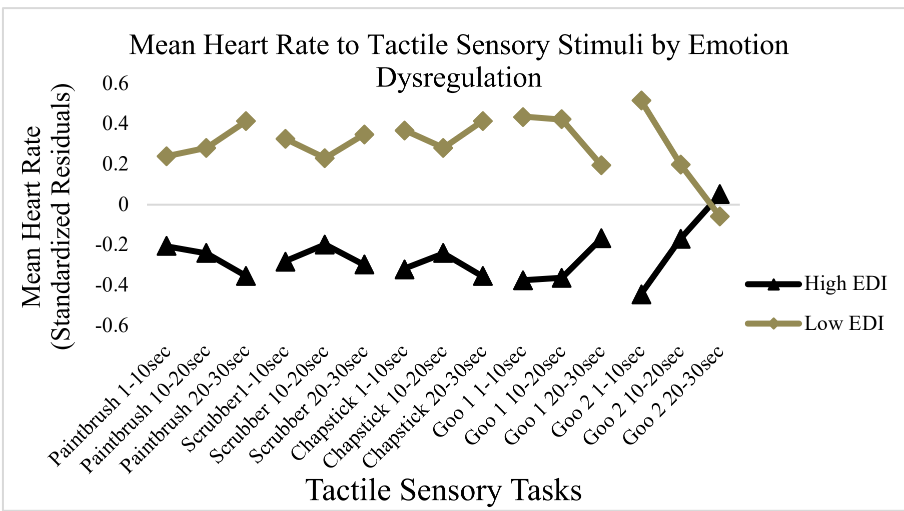
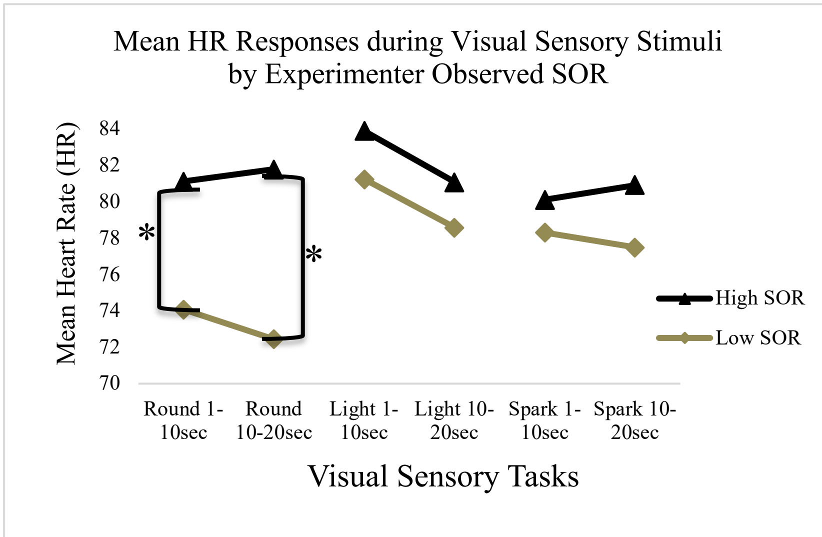


Figure 3. Mean HR responses varying across time for tactile sensory tasks by **emotion dysregulation** symptoms within AFC participants. a) AFC participants with higher emotion dysregulation showed higher HR increases during the two Goo games; b) Similarly, when accounting for baseline HR, AFC participants with higher emotion dysregulation showed greater mean HR response increases over time during the Goo game. *Note*: Painting Game= Paintbrush, Scrubber, and Chapstick; Goo Game= Goo Part 1 and Goo Part 2. **p* <.05

A)



B)

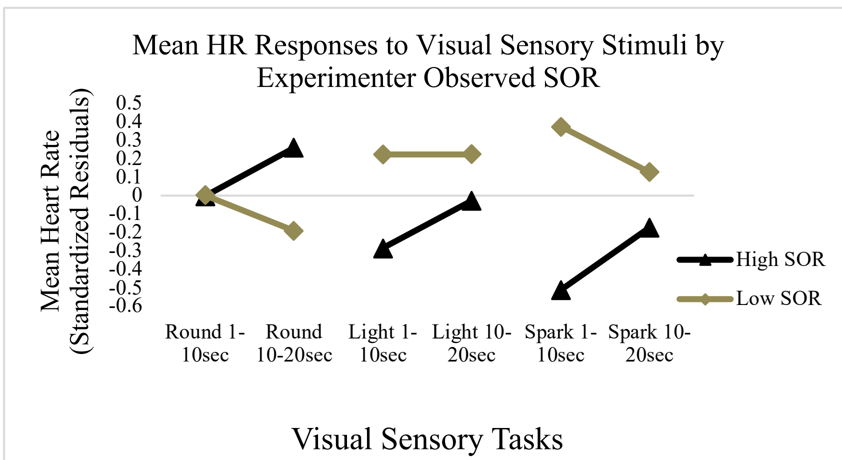
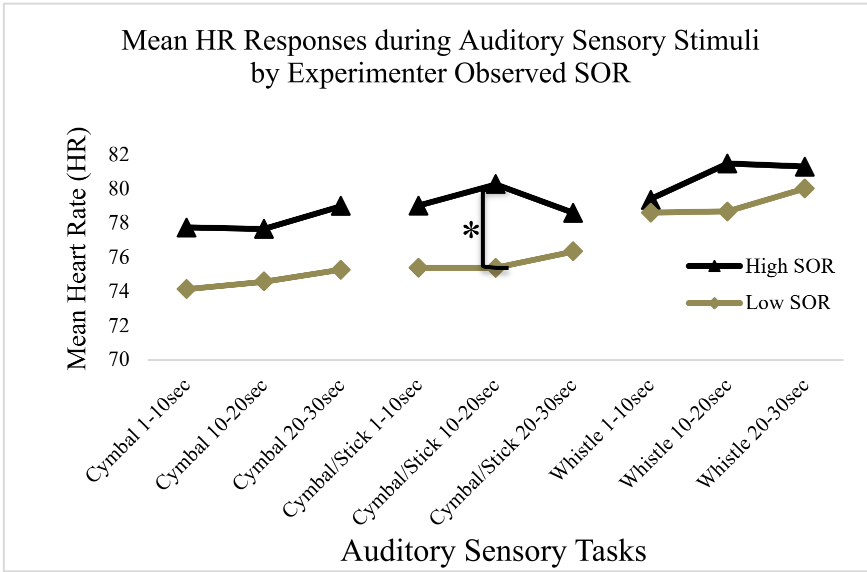


Figure 4. Mean HR responses to mildly aversive visual sensory stimuli by **experimenter-observed SOR** within AFC participants. **a)** AFC participants with higher SOR showed higher mean HR during the Round and Round game; **b)** When accounting for baseline heart rate, AFC participants with higher experimenter observed SOR had higher mean HR during the Round-and-Round Game but lower during the other visual stimuli. Participants with higher SOR showed greater HR increases across stimuli compared to those with lower SOR. Standardized residuals scores are plotted, covarying for baseline heart rate. *p <.05

A)



B)

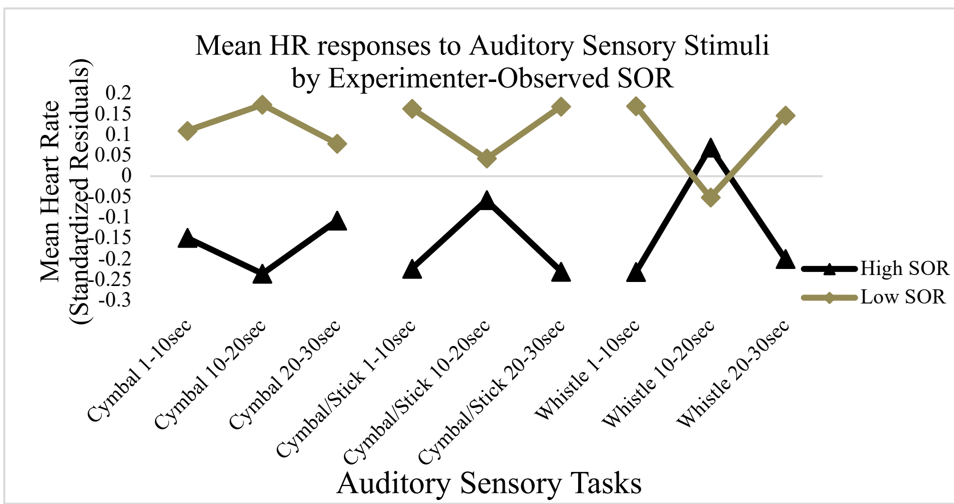


Figure 5. Mean HR responses to mildly aversive visual, and auditory sensory stimuli by **experimenter-observed SOR** within AFC participants. **a)** AFC participants with higher SOR showed higher mean HR during the first 10-20sec time blocks of the Cymbal and Stick task of the Orchestra Time Game; **b)** When accounting for baseline heart rate, AFC participants with lower experimenter observed SOR showed higher mean HR across time during auditory sensory stimulation. Standardized residuals scores are plotted, covarying for baseline heart rate. *$p < .05$

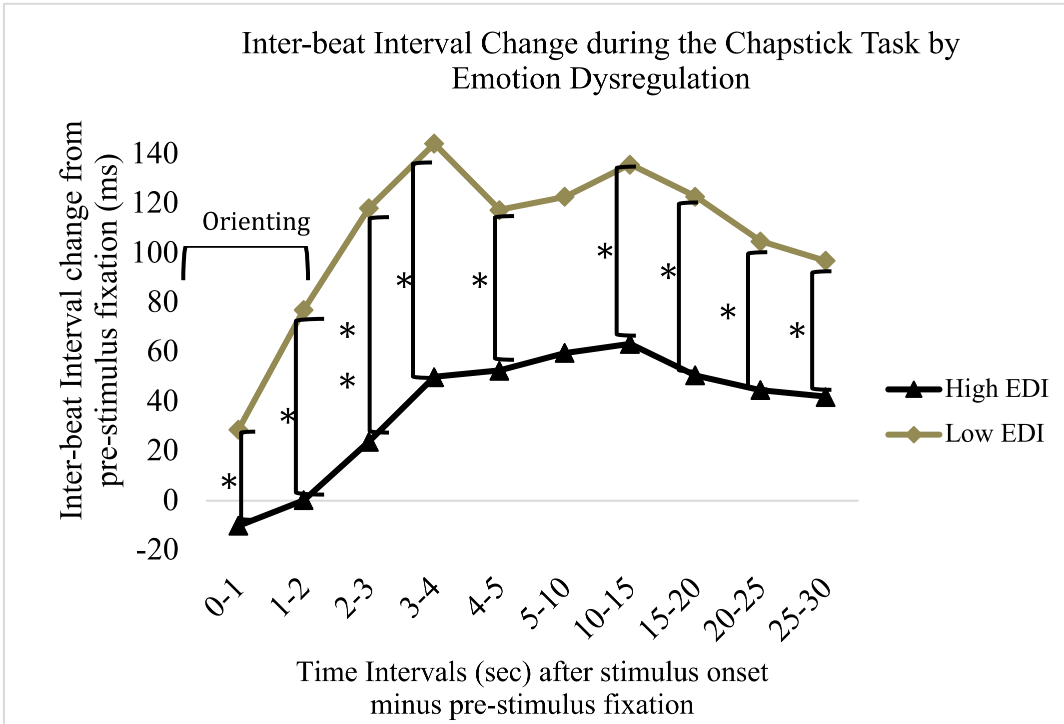


Figure 6. Inter-beat Interval (IBI) change from the 5-second before stimulus onset for each timepoint after stimulus onset is shown on the x-axis for the tactile sensory stimuli by **emotion dysregulation**. The first 5 timepoints show the orienting and acceleration phases across 1 second periods. The remaining 3 timepoints show sustained habituation across 5 second periods. AFC participants with higher emotion dysregulation showed higher IBI responses across time during the orienting, acceleration, and habituation phases of the ***Chapstick task from the Painting Game*** for all timepoints except during the beginning of the habituation phase (5-10 seconds) of stimulus onset. **p<.001, *p<.05

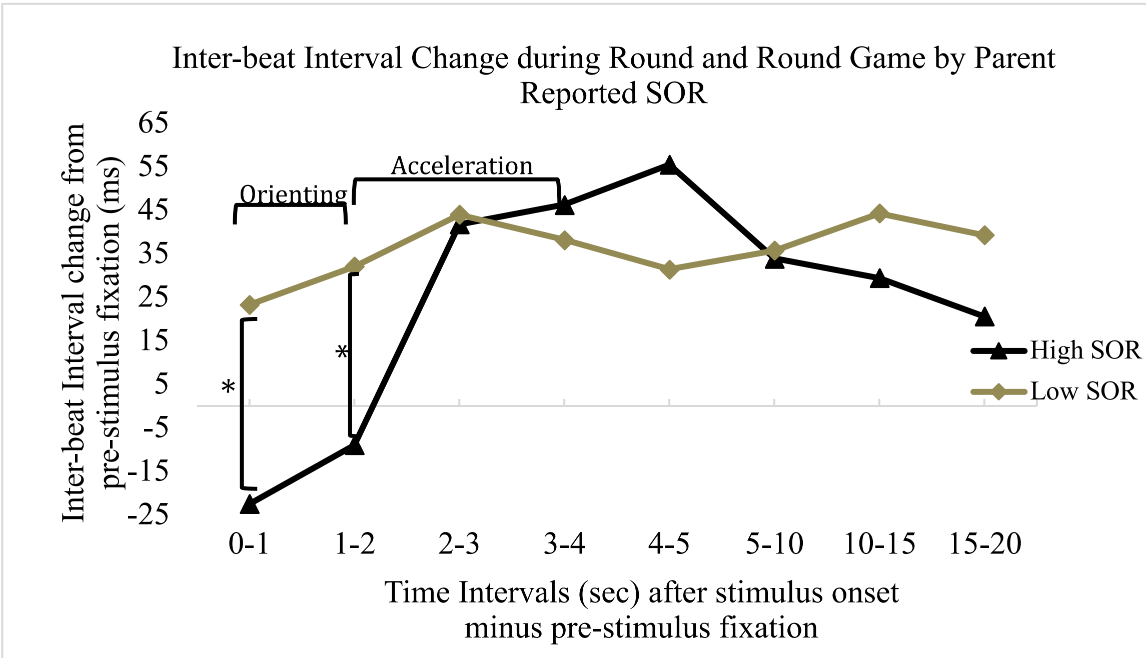
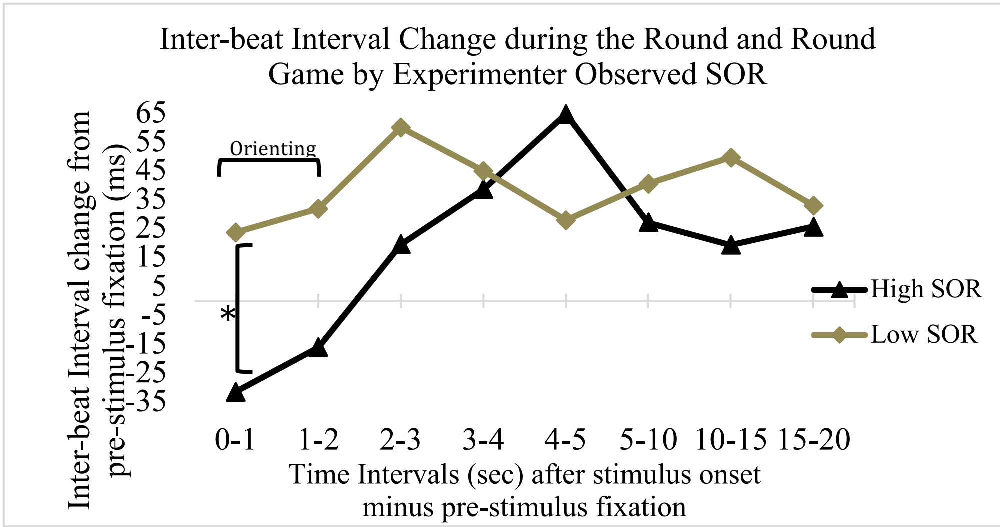


Figure 7. Inter-beat Interval (IBI) change from the 5-second before stimulus onset to each timepoint after stimulus onset is shown on the x-axis for the visual ***Round and Round Game*** for high versus low (median split) **parent-reported SOR**. The first 5 timepoints show the orienting and acceleration phases across 1 second periods. The remaining 3 timepoints show sustained habituation across 5 second periods. AFC participants with higher SOR showed reduced IBI orientation during the Round-and-Round game relative to other forms of visual sensory stimuli. *$p < .05$

A)



B)

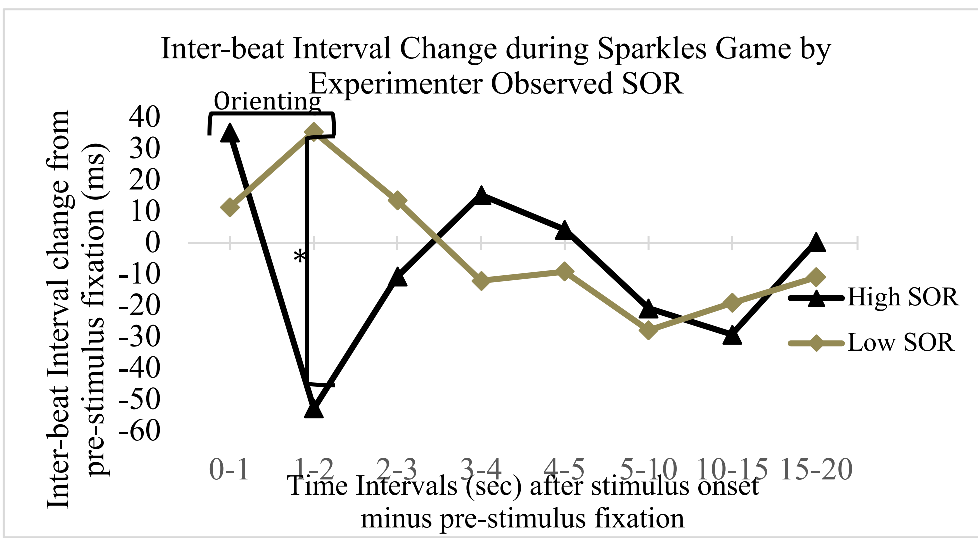


Figure 8. Inter-beat Interval (IBI) change from the 5-second before stimulus onset for each timepoint after stimulus onset is shown on the x-axis for the visual sensory stimuli **a)** AFC participants with higher SOR showed reduced IBI orientation during the Round-and-Round game; **b)** AFC participants with higher SOR showed reduced IBI orientation during the Sparkles game. *p <.05

I. General Discussion

Summary and Significance

Early caregiving adversity impacts the development of mental health challenges across childhood and adolescence, and also affects the biological mechanisms underlying processing of emotional and sensory stimuli. Central to each study was the question of whether early caregiving adversity was linked to sensory processing challenges, particularly sensory over-responsivity (SOR). As such, the first study demonstrated that youth adopted from domestic foster care (AFC) and previous institutionalized care (PI) showed elevated sensory processing challenges, including SOR, as well as influenced, at least in part, the link between early caregiving adversity and internalizing and externalizing symptoms. These findings were observed despite varying experiences and severity of early caregiving adversity. This further adds to the literature, suggesting stress-related symptoms are present across heterogenous adverse experiences (Green et al., 2010; McLaughlin et al., 2012; Méndez Leal & Silvers, 2020; Pine et al., 2005).

Overall, no prior work has examined HR responses to sensory stimulation in youth with early caregiving adversity. Study 2 built upon the findings from Study 1 by adding observed SOR and physiological responses to sensory stimuli among a sample of youth AFC. Although we did not find group differences in HR responses to sensory stimuli when comparing AFC youth to non-adopted comparison youth, it allowed us to look within the AFC group and to determine a subset of these youth with high SOR. For example, results revealed that SOR is not only observed retrospectively by caregivers but may also be observable during a standardized assessment of sensory processing objectively. Additionally, parent-reported, and experimenter-observed SOR was also related to greater physiological arousal in a subset of youth with early caregiving adversity and high SOR symptoms. This finding further provides evidence for the fight/flight autonomic reactivity responses to novel stimuli commonly observed in individuals with histories of stress or trauma (D'Andrea et al., 2013), in which a subset of AFC youth with high SOR also showed hyper-physiological arousal in initial responses to sensory stimulation. Taken together, these two studies provide novel insight about heightened sensory processing challenges in youth with early caregiving adversity and how they influence mental health and hyper-physiological arousal to sensory stimulation.

Limitations and Future Research

Despite significant findings across the two studies, there are limitations to be noted in regard to the present methods and results. Both studies used similar parent report measures of sensory processing challenges, including SOR, which may not have captured the nuanced presentation of these challenges among heterogenous groups of youth with early caregiving adversity. Therefore, future replication of this work should use observations of SOR during sensory stimulation in real-time, along with self-report and parent-report measures of sensory processing challenges. Given that previous research has shown how SOR may impact the development of brain regions, specifically the amygdala (Green et al., 2015, 2019), further work should include how neural correlates (e.g., amygdala) relate to behavioral indices of SOR in youth with early caregiving adversity. Replicating findings using neuroimaging methods may provide additional support for how sensory processing challenges influence daily functioning and mental health symptoms among populations with early caregiving adversity. As noted in the limitations of Study 2, only AFC youth were included when examining physiological responses to sensory stimulation. Future work should include other groups of youth with early caregiving adversity (e.g., those in previous institutionalized care) to provide more evidence about hyper-arousal to sensory stimuli in these populations.

Educational Implications

The results from this dissertation provide important educational implications for working with students exposed to early caregiving adversity. These studies demonstrated heightened levels of sensory processing challenges, particularly SOR, and emotion dysregulation among a heterogenous sample of youth with early caregiving adversity. Specifically, results from both studies bring awareness to the frequent occurrence of sensory processing challenges among heterogenous populations of youth with early caregiving adversity which may inform understanding of behavior we observed in the classroom environment. Notably, Study 2 provided evidence about observable SOR during a structured assessment in which hyper-physiological arousal to sensory stimuli was observed in AFC youth with high SOR relative to low SOR. Thus, using both parent report measures and naturalistic observations to determine level of SOR symptoms may be useful in understanding the rate of sensory processing challenges in these populations. As such, awareness of the presentation of sensory processing challenges in youth with early caregiving adversity may propel school-based professionals to consider screening for sensory processing challenges, along with overt classroom observations, among youth with early caregiving adversity to better explain the presentation of possible social-emotional and behavioral difficulties at school.

Along with screening procedures to measure sensory processing challenges, results from these two studies evidenced that youth with early caregiving adversity may need tailored interventions that target not only mental health symptoms, but also sensory processing challenges, including SOR. Our results showed that sensory processing challenges partially mediated the relationship between early caregiving adversity and internalizing and externalizing symptoms. These findings further provide evidence about the possibility of sensory processing challenges exacerbating mental health symptoms and/or being perceived as irritability, aggression, anxiety, and/or as a tantrum. As such, sensory processing challenges may be included when considering the usage of Positive Behavior Intervention Supports (PBIS; Sugai, Horner et al., 2000) in schools which include access to learning effective coping skills, tangible rewards, and movement breaks, as well as access to calming classrooms. In addition to PBIS strategies, these results also highlight the importance in working with interdisciplinary teams, such as occupational therapists who are experts in sensory processing interventions (e.g., sensory gym, noise cancelling headphones), to identify the needs of students with a history of early caregiving adversity to develop an individualized plan that may include supporting sensory processing challenges.

As observed in many schools across the nation and advocated by neurodivergent individuals with sensory processing challenges, access to sensory reducing areas are important environments for students to use in order to ameliorate the emotional and sensory overload of the classroom environment (e.g., Waisman et al., 2022; Warner et al., 2013). Indeed, school psychologists and special education educators can collaborate with occupational therapists who have vast knowledge about sensory environmental modification to provide essential recommendations for students with sensory processing challenges. For example, these modifications can look like elimination of extraneous visual stimuli, reduced noise level, alterations to lighting, compression vests, and/or the use of noise cancelling headphones (Champagne, 2006; Waisman et al., 2022; Warner et al., 2013; Watling et al., 2011).

Conclusion

Taken together, our findings underline the risk of sensory processing challenges, particularly sensory over-responsivity, among youth with various forms of early caregiving adversity. Specifically, these studies described the intersection between biological sciences and the behavior we often see in the classroom as teachers, school psychologists, and school-based professionals. Indeed, understanding the rate of sensory processing challenges and their link to emotion dysregulation in youth with early caregiving adversity provides critical information when conducting ecologically valid assessment, in developing appropriate school-based and clinical recommendations for intervention. Further work should partner educational and biological sciences in order to inform best practices in school psychological service delivery.

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