Sensory processing challenges as a novel link between early caregiving experiences and mental health

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Conflicts of Interest

None

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Abstract

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. 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. 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. 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.

Keywords: early caregiving adversity; sensory processing; sensory over-responsivity; mental health; adolescence

Abbreviations: SOR: sensory over-responsivity; ECA: early caregiving adversity; PI: previously institutionalized; AFC: adopted from foster care

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 & 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, Carter, & Briggs-Gowan, 2009; Miller, Anzalone, Lane, Cermak, & Osten, 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 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 et al., 2009; Ben-Sasson, Soto, Heberle, Carter, & Briggs-Gowan, 2017; Ben-Sasson & Podoly, 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 (Amso & Scerif, 2015; 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 attentional or 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 (Amso & Scerif, 2015; 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 through cognitive stimulation and providing context for what is otherwise a jumble of co-occurring sights and sounds (Rosen, Amso, & McLaughlin, 2019). 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 (Amso & Scerif, 2015; Green & Wood, 2019). Given the crucial role that caregivers play in the development of attentional and affective regulation systems, and the well-documented impact of ECA on these processes (Callaghan & Tottenham, 2016a, 2016b; Gee, 2016; Méndez Leal & Silvers, 2022; Rosen et al., 2019), it is possible that the absence of stable caregiving disrupts regulation of affective responses to sensory stimuli to produce sensory processing challenges, including SOR (Amso & Scerif, 2015; Green & Wood, 2019; Rosen et al., 2019). 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 regulatory circuits and associated attentional and affective self-regulatory processes are theorized to underlie the high prevalence of psychopathology (particularly internalizing disorders) in youth exposed to ECA (Amso & Scerif, 2015; Callaghan & Tottenham, 2016b; Gee et al., 2013; Johnson et al., 2021; Rosen et al., 2019; Silvers et al., 2017; VanTieghem & Tottenham, 2018; Weissman et al., 2019). Additionally, changes to sensory processing circuits induced by altered cognitive stimulation in the context of ECA may themselves produce changes to the development of prefrontal affective and attentional regulatory systems, and vice versa (see Rosen et al., 2019 for a relevant review).

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 (e.g. Rosen et al., 2019). 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 several small case studies suggest treating sensory processing challenges attenuates the development of other psychopathology in individuals with histories of ECA (Dowdy, Estes, Linkugel, & Dvornak, 2020; Fraser, MacKenzie, & Versnel, 2017; Haradon, Bascom, Dragomir, & Scripcaru, 1994; Lynch et al., 2021; Purvis, McKenzie, Cross, & Razuri, 2013; 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; Cermak & Daunhauer, 1997; Lin et al., 2005; Wilbarger et al., 2010). 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 cross-sectional 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 (osf.io/r9e8q).

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.

Table 1. *Sample demographic information*

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%)	

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.
[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)

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 only ran statistical tests for the pre-registered cross-sectional path analyses that aligned with our theoretical model (which posits that ECA causes sensory processing challenges that in turn confer elevated risk for psychopathology), and did not test alternative path models by flipping the M (sensory) and Y (psychological symptomatology) variables.

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 (α_{SP3D} = .91, α_{SSP} = .94). Parent-reported partial information on 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.

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	48.22 (46.00; 7.97)	58.34 (52.50; 15.3)[a]	58.24 (51.00; 19.26)[b]
Measure Range: 42-210	Range: 42-86	Range: 42-98	Range: 42-112
General Sensory Processing Challenges			
SSP Total	178.99 (183.00;11.79)	169.76 (174.50; 14.10)[a]	147.54 (150.00; 23.71)[bc]
Measure Range: 190-38	Range: 190-132	Range: 189-131	Range: 190-103
Internalizing Symptoms			
CBCL Internalizing	4.56 (3.00; 4.9)	11.62 (9.5; 8.42)[a]	12.49 (11.0; 9.67)[b]
Measure Range: 0-62	Range: 0-25	Range: 0-32	Range: 0-41
Externalizing Symptoms			
CBCL Externalizing	2.98 (1.00; 3.7)	7.00 (6.00; 5.82)[a]	15.96 (12.00; 12.44)[bc]
Measure Range: 0-70	Range: 0 -15	Range: 0-20	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); Sensory Processing 3-Dimensions Scale Sensory Inventory (SP3D); Short Sensory Profile (SSP); Child Behavior Checklist (CBCL)

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, 0.65], *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 ($\varphi = .57$, $p < .001$) between group membership (PI, AFC, and comparison) and the distribution of participants in SSP clinical categories (χ^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.

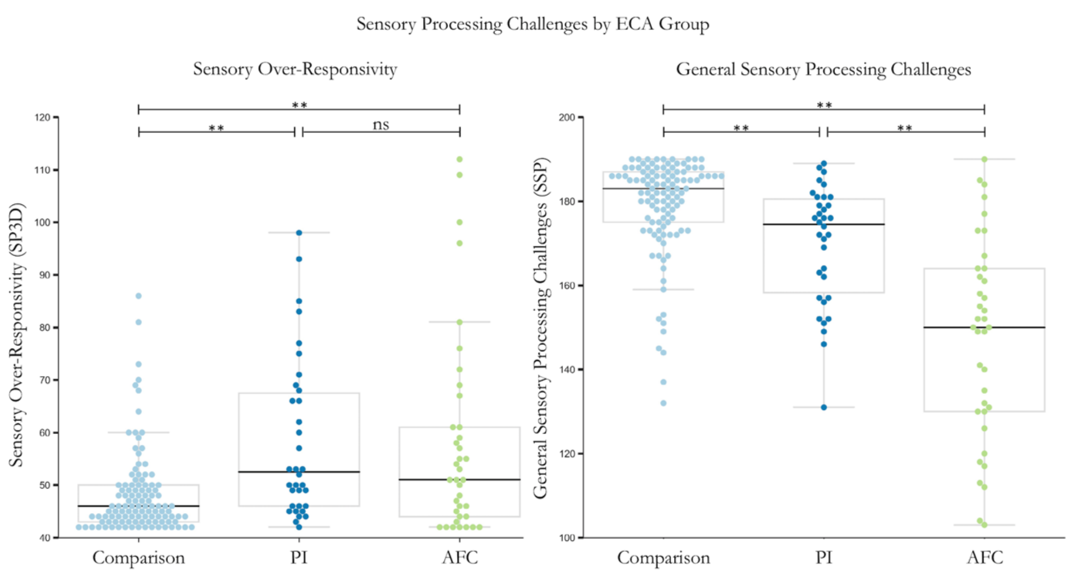


Figure 1. Left: PI and AFC participants show elevated levels of sensory over-responsivity (higher SP3D scores), relative to non-adopted, comparison youth. Right: PI and AFC participants show increased levels of general sensory processing challenges (lower SSP scores) relative to non-adopted, comparison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

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).

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

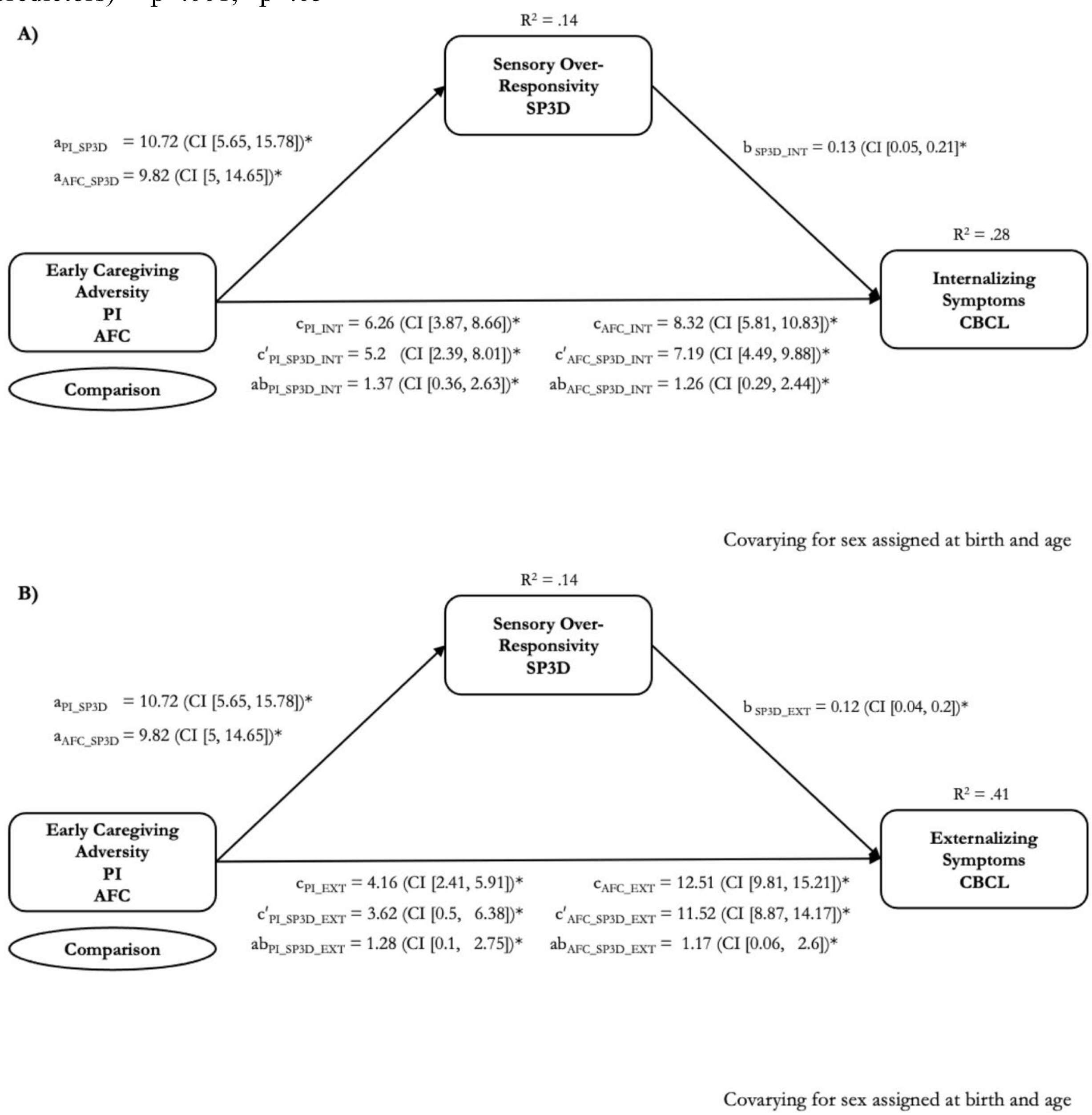
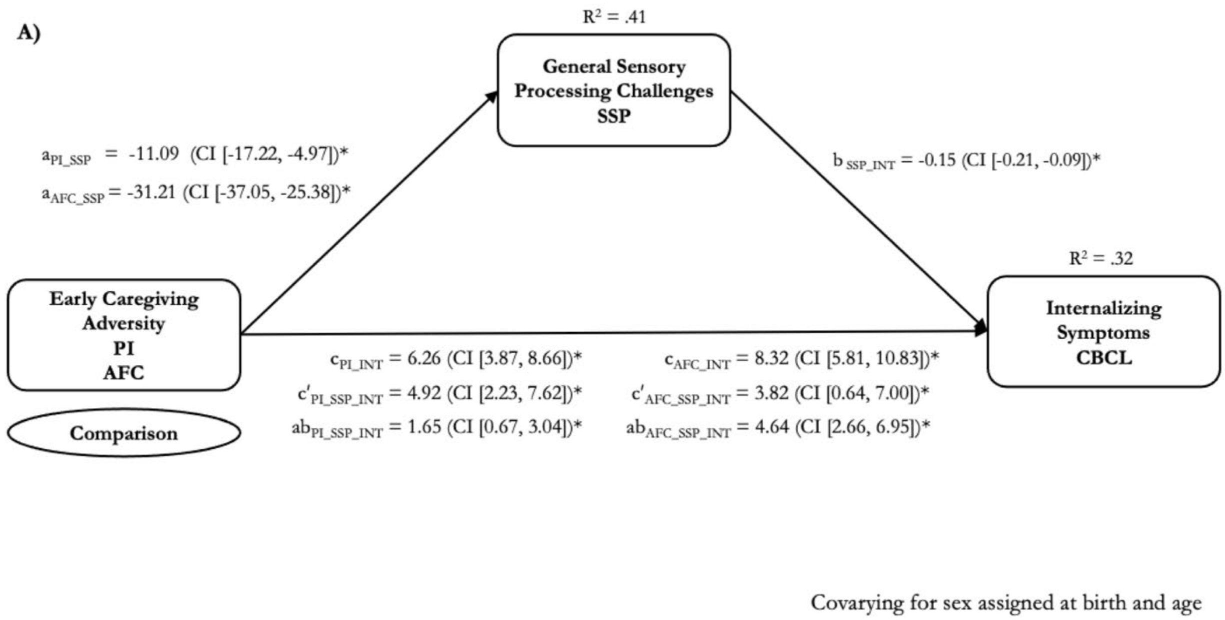
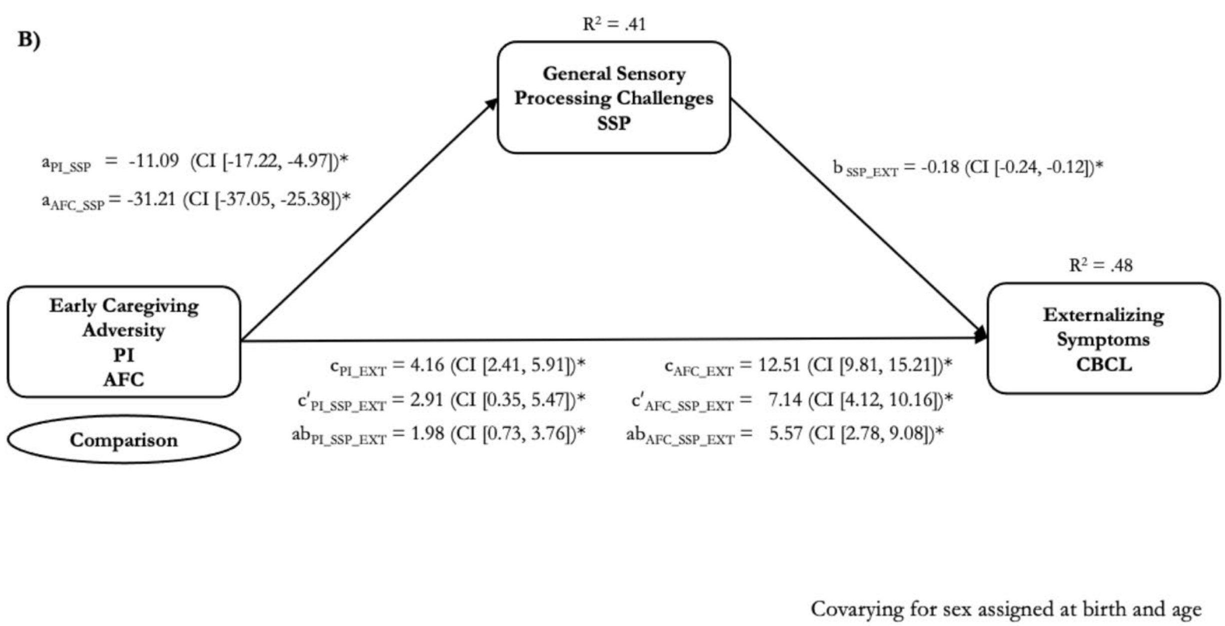


Figure 3. a) 95% percentile bootstrapped regression coefficients for a path analysis model examining the association between ECA (predictor) and internalizing problems (outcome) through SSP total score, while controlling for age and sex assigned at birth. b) 95% percentile bootstrapped regression coefficients 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





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 ($B_{\text{Placement\_PI}} = -0.13$, $t(33) = -0.77$, 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. Although our participant samples are not necessarily representative of all youth with similar paths to adoption, these 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 and varied experiences that, in addition to removal(s) from their home of origin themselves, may at times include exposure to violence, neglect (AFCARS, 2020), in addition to other systemic or family-level factors contributing to interaction with the welfare system and placement in foster care (e.g. systemic racism, poverty).

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 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 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. In addition, ongoing work should 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, potentially by characterizing early experiences using dimensional approaches (e.g. threat vs. deprivation), rather than categorical descriptors.

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.

References

Adoption and foster care analysis and reporting system (AFCARS). (2020). US Department of Health and Human Services, & US Department of Health and Human Services. (*FY 2019 Estimates as of June 2019. The AFCARS report*, *26*.)

Achenbach, T. M., & Rescorla, L. A. (2001). Manual for the ASEBA School-Age Forms & Profiles. *Burlington : University of Vermont, Research Center for Children, Youth, and Families*.

Almas, A. N., Papp, L. J., Woodbury, M. R., Nelson, C. A., Zeanah, C. H., & Fox, N. A. (2020). The Impact of Caregiving Disruptions of Previously Institutionalized Children on Multiple Outcomes in Late Childhood. *Child Development*, *91*(1), 96–109. https://doi.org/10.1111/cdev.13169

Amso, D., & Scerif, G. (2015). The attentive brain: Insights from developmental cognitive neuroscience. *Nature Reviews. Neuroscience*, *16*(10), 606–619. https://doi.org/10.1038/nrn4025

Armstrong-Heimsoth, A., Schoen, S. A., & Bennion, T. (2021). An Investigation of Sensory Processing in Children and Adolescents in Congregate Foster Care. *Occupational Therapy in Mental Health*, *0*(0), 1–17. https://doi.org/10.1080/0164212X.2021.1916418

Ben-Sasson, Ayelet, Carter, A. S., & Briggs-Gowan, M. J. (2009). Sensory Over-Responsivity in Elementary School: Prevalence and Social-Emotional Correlates. *Journal of Abnormal Child Psychology*, *37*(5), 705–716. https://doi.org/10.1007/s10802-008-9295-8

Ben-Sasson, Ayelet, Hen, L., Fluss, R., Cermak, S. A., Engel-Yeger, B., & Gal, E. (2009). A Meta-Analysis of Sensory Modulation Symptoms in Individuals with Autism Spectrum

Disorders. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-008-0593-3

Ben-Sasson, Ayelet, & Podoly, T. Y. (2017). Sensory over responsivity and obsessive compulsive symptoms: A cluster analysis. *Comprehensive Psychiatry*, *73*, 151–159. https://doi.org/10.1016/j.comppsych.2016.10.013

Ben-Sasson, Ayelet, Soto, T. W., Heberle, A. E., Carter, A. S., & Briggs-Gowan, M. J. (2017). Early and Concurrent Features of ADHD and Sensory Over-Responsivity Symptom Clusters. *Journal of Attention Disorders*. https://doi.org/10.1177/1087054714543495

Berens, A. E., & Nelson, C. A. (2015). The science of early adversity: Is there a role for large institutions in the care of vulnerable children? *The Lancet*, *386*(9991), 388–398. https://doi.org/10.1016/S0140-6736(14)61131-4

Blake, A. J., Ruderman, M., Waterman, J. M., & Langley, A. K. (2021). Long-term effects of pre-adoptive risk on emotional and behavioral functioning in children adopted from foster care. *Child Abuse & Neglect*, 105031. https://doi.org/10.1016/j.chiabu.2021.105031

Busso, D. S., McLaughlin, K. A., & Sheridan, M. A. (2017). Dimensions of Adversity, Physiological Reactivity, and Externalizing Psychopathology in Adolescence: Deprivation and Threat. *Psychosomatic Medicine*, *79*(2), 162–171. https://doi.org/10.1097/PSY.0000000000000369

Callaghan, B. L., & Tottenham, N. (2016a). The Neuro-Environmental Loop of Plasticity: A Cross-Species Analysis of Parental Effects on Emotion Circuitry Development Following Typical and Adverse Caregiving. *Neuropsychopharmacology*, *41*(1), 163–176. https://doi.org/10.1038/npp.2015.204

Callaghan, B. L., & Tottenham, N. (2016b). The Stress Acceleration Hypothesis: Effects of early-life adversity on emotion circuits and behavior. *Current Opinion in Behavioral Sciences*, *7*, 76–81. https://doi.org/10.1016/j.cobeha.2015.11.018

Carpenter, K. L. H., Baranek, G. T., Copeland, W. E., Compton, S., Zucker, N., Dawson, G., & Egger, H. L. (2019). Sensory Over-Responsivity: An Early Risk Factor for Anxiety and Behavioral Challenges in Young Children. *Journal of Abnormal Child Psychology*, *47*(6), 1075–1088. https://doi.org/10.1007/s10802-018-0502-y

Carter, A. S., Ben-Sasson, A., & Briggs-Gowan, M. J. (2011). Sensory Over-Responsivity, Psychopathology, and Family Impairment in School-Aged Children. *Journal of the American Academy of Child & Adolescent Psychiatry*, *50*(12), 1210–1219. https://doi.org/10.1016/j.jaac.2011.09.010

Cermak, S. A., & Daunhauer, L. A. (1997). Sensory processing in the postinstitutionalized child. *The American Journal of Occupational Therapy : Official Publication of the American Occupational Therapy Association*. https://doi.org/10.5014/ajot.51.7.500

Chen, Y., & Baram, T. Z. (2016). Toward Understanding How Early-Life Stress Reprograms Cognitive and Emotional Brain Networks. *Neuropsychopharmacology*, *41*(1), 197–206. https://doi.org/10.1038/npp.2015.181

Cohodes, E. M., Kitt, E. R., Baskin-Sommers, A., & Gee, D. G. (2020). Influences of early-life stress on frontolimbic circuitry: Harnessing a dimensional approach to elucidate the effects of heterogeneity in stress exposure. *Developmental Psychobiology*, *n/a*(n/a). https://doi.org/10.1002/dev.21969

Conelea, C. A., Carter, A. C., & Freeman, J. B. (2014). Sensory Over-Responsivity in a Sample of Children Seeking Treatment for Anxiety. *Journal of Developmental and Behavioral Pediatrics : JDBP*, *35*(8), 510–521. https://doi.org/10.1097/DBP.0000000000000092

Dellapiazza, F., Michelon, C., Oreve, M.-J., Robel, L., Schoenberger, M., Chatel, C., … ELENA study group. (2020). The Impact of Atypical Sensory Processing on Adaptive Functioning and Maladaptive Behaviors in Autism Spectrum Disorder During Childhood: Results From the ELENA Cohort. *Journal of Autism and Developmental Disorders*, *50*(6), 2142–2152. https://doi.org/10.1007/s10803-019-03970-w

Dellapiazza, F., Vernhet, C., Blanc, N., Miot, S., Schmidt, R., & Baghdadli, A. (2018). Links between sensory processing, adaptive behaviours, and attention in children with autism spectrum disorder: A systematic review. *Psychiatry Research*, *270*, 78–88. https://doi.org/10.1016/j.psychres.2018.09.023

Dowdy, R., Estes, J., Linkugel, M., & Dvornak, M. (2020). Trauma, Sensory Processing, and the Impact of Occupational Therapy on Youth Behavior in Juvenile Corrections. *Occupational Therapy in Mental Health*, *36*(4), 373–393. https://doi.org/10.1080/0164212X.2020.1823930

Engel-Yeger, B., Muzio, C., Rinosi, G., Solano, P. A. C., & Serafini, G. (2016). Extreme sensory processing patterns and their relation with clinical conditions among individuals with major affective disorders. *Psychiatry Research*. https://doi.org/10.1016/j.psychres.2015.12.022

Fernández-Andrés, M. I., Pastor-Cerezuela, G., Sanz-Cervera, P., & Tárraga-Mínguez, R. (2015). A comparative study of sensory processing in children with and without Autism

Spectrum Disorder in the home and classroom environments. *Research in Developmental Disabilities*, *38*, 202–212. https://doi.org/10.1016/j.ridd.2014.12.034

Fraser, K., MacKenzie, D., & Versnel, J. (2017). Complex Trauma in Children and Youth: A Scoping Review of Sensory-Based Interventions. *Occupational Therapy in Mental Health*, *33*(3), 199–216. https://doi.org/10.1080/0164212X.2016.1265475

Gee, D. G. (2016). Sensitive Periods of Emotion Regulation: Influences of Parental Care on Frontoamygdala Circuitry and Plasticity. *New Directions for Child and Adolescent Development*, *2016*(153), 87–110. https://doi.org/10.1002/cad.20166

Gee, D. G., Gabard-Durnam, L. J., Flannery, J., Goff, B., Humphreys, K. L., Telzer, E. H., … Tottenham, N. (2013). Early developmental emergence of human amygdala–prefrontal connectivity after maternal deprivation. *Proceedings of the National Academy of Sciences*, *110*(39), 15638–15643. https://doi.org/10.1073/pnas.1307893110

Gourley, L., Wind, C., Henninger, E. M., & Chinitz, S. (2013). Sensory Processing Difficulties, Behavioral Problems, and Parental Stress in a Clinical Population of Young Children. *Journal of Child and Family Studies*, *22*(7), 912–921. https://doi.org/10.1007/s10826-012-9650-9

Green, S. A., & Ben-Sasson, A. (2010). Anxiety Disorders and Sensory Over-Responsivity in Children with Autism Spectrum Disorders: Is There a Causal Relationship? *Journal of Autism and Developmental Disorders*, *40*(12). https://doi.org/10.1007/s10803-010-1007-x

Green, S. A., Ben-Sasson, A., Soto, T. W., & Carter, A. S. (2012). Anxiety and sensory over-responsivity in toddlers with autism spectrum disorders: Bidirectional effects across time.

Journal of Autism and Developmental Disorders, *42*(6), 1112–1119. https://doi.org/10.1007/s10803-011-1361-3

Green, S. A., Hernandez, L., Lawrence, K. E., Liu, J., Tsang, T., Yeargin, J., … Bookheimer, S. Y. (2019). Distinct Patterns of Neural Habituation and Generalization in Children and Adolescents With Autism With Low and High Sensory Overresponsivity. *The American Journal of Psychiatry*, *176*(12), 1010–1020. https://doi.org/10.1176/appi.ajp.2019.18121333

Green, S. A., Hernandez, L. M., Bowman, H. C., Bookheimer, S. Y., & Dapretto, M. (2018). Sensory over-responsivity and social cognition in ASD: Effects of aversive sensory stimuli and attentional modulation on neural responses to social cues. *Developmental Cognitive Neuroscience*, *29*, 127–139. https://doi.org/10.1016/j.dcn.2017.02.005

Green, S. A., Hernandez, L., Tottenham, N., Krasileva, K., Bookheimer, S. Y., & Dapretto, M. (2015). Neurobiology of Sensory Overresponsivity in Youth With Autism Spectrum Disorders. *JAMA Psychiatry*, *72*(8), 778–786. https://doi.org/10.1001/jamapsychiatry.2015.0737

Green, S. A., Rudie, J. D., Colich, N. L., Wood, J. J., Shirinyan, D., Hernandez, L., … Bookheimer, S. Y. (2013). Overreactive Brain Responses to Sensory Stimuli in Youth With Autism Spectrum Disorders. *Journal of the American Academy of Child & Adolescent Psychiatry*, *52*(11), 1158–1172. https://doi.org/10.1016/j.jaac.2013.08.004

Green, S. A., & Wood, E. T. (2019). The role of regulation and attention in atypical sensory processing. *Cognitive Neuroscience*, *10*(3), 160–162. https://doi.org/10.1080/17588928.2019.1592141

Gunn, T. E., Tavegia, B. D., Houskamp, B. M., McDonald, L. B., Bustrum, J. M., Welsh, R. K., & Mok, D. S. (2009). Relationship Between Sensory Deficits and Externalizing Behaviors in an Urban, Latino Preschool Population. *Journal of Child and Family Studies*, *18*(6), 653–661. https://doi.org/10.1007/s10826-009-9266-x

Gunnar, M. R., van Dulmen, M. H. M., & International Adoption Project Team. (2007). Behavior problems in postinstitutionalized internationally adopted children. *Development and Psychopathology*, *19*(1), 129–148. https://doi.org/10.1017/S0954579407070071

Hannant, P., Cassidy, S., Tavassoli, T., & Mann, F. (2016). Sensorimotor Difficulties Are Associated with the Severity of Autism Spectrum Conditions. *Frontiers in Integrative Neuroscience*, *10*. https://doi.org/10.3389/fnint.2016.00028

Haradon, G., Bascom, B., Dragomir, C., & Scripcaru, V. (1994). Sensory functions of institutionalized Romanian infants: A pilot study. *Occupational Therapy International*, *1*(4), 250–260. https://doi.org/10.1002/oti.6150010405

Harrison, L. A., Kats, A., Williams, M. E., & Aziz-Zadeh, L. (2019). The Importance of Sensory Processing in Mental Health: A Proposed Addition to the Research Domain Criteria (RDoC) and Suggestions for RDoC 2.0. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.00103

Hayes, A. F. (2017). *Introduction to Mediation, Moderation, and Conditional Process Analysis, Second Edition: A Regression-Based Approach*. Guilford Publications.

Heleniak, C., Jenness, J. L., Vander Stoep, A., McCauley, E., & McLaughlin, K. A. (2016). Childhood Maltreatment Exposure and Disruptions in Emotion Regulation: A Transdiagnostic Pathway to Adolescent Internalizing and Externalizing Psychopathology.

Cognitive Therapy and Research, *40*(3), 394–415. https://doi.org/10.1007/s10608-015-9735-z

Hoehl, S., Michel, C., Reid, V. M., Parise, E., & Striano, T. (2014). Eye contact during live social interaction modulates infants' oscillatory brain activity. *Social Neuroscience*, *9*(3), 300–308. https://doi.org/10.1080/17470919.2014.884982

Hoff, E. (2006). How social contexts support and shape language development. *Developmental Review*, *26*(1), 55–88. https://doi.org/10.1016/j.dr.2005.11.002

Howard, A. R. H., Lynch, A. K., Call, C. D., & Cross, D. R. (2020). Sensory processing in children with a history of maltreatment: An occupational therapy perspective. *Vulnerable Children and Youth Studies*, *15*(1), 60–67. https://doi.org/10.1080/17450128.2019.1687963

Howe, F. E. J., & Stagg, S. D. (2016). How Sensory Experiences Affect Adolescents with an Autistic Spectrum Condition within the Classroom. *Journal of Autism and Developmental Disorders*, *46*(5), 1656–1668. https://doi.org/10.1007/s10803-015-2693-1

Humphreys, K. L., Gleason, M. M., Drury, S. S., Miron, D., Nelson, C. A., Fox, N. A., & Zeanah, C. H. (2015). Effects of institutional rearing and foster care on psychopathology at age 12 years in Romania: Follow-up of an open, randomised controlled trial. *The Lancet Psychiatry*, *2*(7), 625–634. https://doi.org/10.1016/S2215-0366(15)00095-4

Jenness, J. L., Peverill, M., Miller, A. B., Heleniak, C., Robertson, M. M., Sambrook, K. A., … McLaughlin, K. A. (2020). Alterations in neural circuits underlying emotion regulation following child maltreatment: A mechanism underlying trauma-related psychopathology. *Psychological Medicine*, 1–10. https://doi.org/10.1017/S0033291720000641

Johnson, D., Policelli, J., Li, M., Dharamsi, A., Hu, Q., Sheridan, M. A., … Wade, M. (2021). Associations of Early-Life Threat and Deprivation With Executive Functioning in Childhood and Adolescence: A Systematic Review and Meta-analysis. *JAMA Pediatrics*, *175*(11), e212511. https://doi.org/10.1001/jamapediatrics.2021.2511

Joseph, R. Y., Casteleijn, D., van der Linde, J., & Franzsen, D. (2021). Sensory Modulation Dysfunction in Child Victims of Trauma: A Scoping Review. *Journal of Child & Adolescent Trauma*. https://doi.org/10.1007/s40653-020-00333-x

Julian, M. M. (2013). Age at Adoption from Institutional Care as a Window into the Lasting Effects of Early Experiences. *Clinical Child and Family Psychology Review*, *16*(2), 101–145. https://doi.org/10.1007/s10567-013-0130-6

Kern, J. K., Trivedi, M. H., Garver, C. R., Grannemann, B. D., Andrews, A. A., Savla, J. S., … Schroeder, J. L. (2006). The pattern of sensory processing abnormalities in autism. *Autism: The International Journal of Research and Practice*, *10*(5), 480–494. https://doi.org/10.1177/1362361306066564

Kessler, R. C., McLaughlin, K. A., Green, J. G., Gruber, M. J., Sampson, N. A., Zaslavsky, A. M., … Williams, D. R. (2010). Childhood adversities and adult psychopathology in the WHO World Mental Health Surveys. *The British Journal of Psychiatry*, *197*(5), 378–385. https://doi.org/10.1192/bjp.bp.110.080499

Kuhl, P. K. (2007). Is speech learning 'gated' by the social brain? *Developmental Science*, *10*(1), 110–120. https://doi.org/10.1111/j.1467-7687.2007.00572.x

Lemmer, G., & Gollwitzer, M. (2017). The "true" indirect effect won't (always) stand up: When and why reverse mediation testing fails. *Journal of Experimental Social Psychology*, *69*, 144–149. https://doi.org/10.1016/j.jesp.2016.05.002

Lin, S. H., Cermak, S., Coster, W. J., & Miller, L. (2005). The Relation Between Length of Institutionalization and Sensory Integration in Children Adopted From Eastern Europe. *American Journal of Occupational Therapy*, *59*(2), 139–147. https://doi.org/10.5014/ajot.59.2.139

Little, L. M., Dean, E., Tomchek, S., & Dunn, W. (2018). Sensory Processing Patterns in Autism, Attention Deficit Hyperactivity Disorder, and Typical Development. *Physical & Occupational Therapy In Pediatrics*, *38*(3), 243–254. https://doi.org/10.1080/01942638.2017.1390809

Lloyd-Fox, S., Széplaki-Köllőd, B., Yin, J., & Csibra, G. (2015). Are you talking to me? Neural activations in 6-month-old infants in response to being addressed during natural interactions. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *70*, 35–48. https://doi.org/10.1016/j.cortex.2015.02.005

Lynch, B. P., Brokamp, K. M., Scheerer, C. R., Bishop, M., Stauble, L., Hagedorn, B., & Endres, L. (2021). Outcomes of Occupational Therapy in Trauma-Informed Care. *Journal of Occupational Therapy, Schools, & Early Intervention*, *0*(0), 1–17. https://doi.org/10.1080/19411243.2021.2003733

McIntosh, D. N., Miller, L. J., & Shyu, V. (1999). *McIntosh, D. N., Miller, L. J., & Shyu, V. (1999). Development and validation of the short sensory profile.*

McLaughlin, K. A., Colich, N. L., Rodman, A. M., & Weissman, D. G. (2020). Mechanisms linking childhood trauma exposure and psychopathology: A transdiagnostic model of risk and resilience. *BMC Medicine*, *18*(1), 96. https://doi.org/10.1186/s12916-020-01561-6

McLaughlin, K. A., DeCross, S. N., Jovanovic, T., & Tottenham, N. (2019). Mechanisms linking childhood adversity with psychopathology: Learning as an intervention target. *Behaviour Research and Therapy*, *118*, 101–109. https://doi.org/10.1016/j.brat.2019.04.008

McLaughlin, K. A., Green, J. G., Gruber, M. J., Sampson, N. A., Zaslavsky, A. M., & Kessler, R. C. (2012). Childhood Adversities and First Onset of Psychiatric Disorders in a National Sample of US Adolescents. *Archives of General Psychiatry*, *69*(11), 1151–1160. https://doi.org/10.1001/archgenpsychiatry.2011.2277

McLaughlin, K. A., & Sheridan, M. A. (2016). Beyond Cumulative Risk: A Dimensional Approach to Childhood Adversity. *Current Directions in Psychological Science*, *25*(4), 239–245. https://doi.org/10.1177/0963721416655883

McLaughlin, K. A., Sheridan, M. A., Tibu, F., Fox, N. A., Zeanah, C. H., & Nelson, C. A. (2015). Causal effects of the early caregiving environment on development of stress response systems in children. *Proceedings of the National Academy of Sciences*, *112*(18), 5637–5642. https://doi.org/10.1073/pnas.1423363112

McLaughlin, K. A., Weissman, D., & Bitrán, D. (2019). Childhood Adversity and Neural Development: A Systematic Review. *Annual Review of Developmental Psychology*, *1*(1), 277–312. https://doi.org/10.1146/annurev-devpsych-121318-084950

McMahon, K., Anand, D., Morris-Jones, M., & Rosenthal, M. Z. (2019). A Path From Childhood Sensory Processing Disorder to Anxiety Disorders: The Mediating Role of Emotion Dysregulation and Adult Sensory Processing Disorder Symptoms. *Frontiers in Integrative Neuroscience*, *13*. https://doi.org/10.3389/fnint.2019.00022

Méndez Leal, A. S., & Silvers, J. A. (2022). Neuroscientific Approaches to the Study of Self and Social Emotion Regulation During Development. In D. Dukes, A. Samson, & E. Walle

(Eds.), *Oxford Handbook of Emotional Development.* Oxford University Press. https://doi.org/10.31234/osf.io/a2p9x

Miller, L. J., Anzalone, M. E., Lane, S. J., Cermak, S. A., & Osten, E. T. (2007). Concept evolution in sensory integration: A proposed nosology for diagnosis. *The American Journal of Occupational Therapy: Official Publication of the American Occupational Therapy Association*, *61*(2), 135–140. https://doi.org/10.5014/ajot.61.2.135

Parham, L. D., Roush, S., Downing, D. T., Michael, P. G., & McFarlane, W. R. (2019). Sensory characteristics of youth at clinical high risk for psychosis. *Early Intervention in Psychiatry*, *13*(2), 264–271. https://doi.org/10.1111/eip.12475

Parise, E., Reid, V. M., Stets, M., & Striano, T. (2008). Direct eye contact influences the neural processing of objects in 5-month-old infants. *Social Neuroscience*, *3*(2), 141–150. https://doi.org/10.1080/17470910701865458

Pechtel, P., & Pizzagalli, D. A. (2011). Effects of early life stress on cognitive and affective function: An integrated review of human literature. *Psychopharmacology*, *214*(1), 55–70. https://doi.org/10.1007/s00213-010-2009-2

Pitula, C. E., Thomas, K. M., Armstrong, J. M., Essex, M. J., Crick, N. R., & Gunnar, M. R. (2014). Peer Victimization and Internalizing Symptoms Among Post-Institutionalized, Internationally Adopted Youth. *Journal of Abnormal Child Psychology*, *42*(7), 1069–1076. https://doi.org/10.1007/s10802-014-9855-z

Purvis, K. B., McKenzie, L. B., Cross, D. R., & Razuri, E. B. (2013). A Spontaneous Emergence of Attachment Behavior in At-Risk Children and a Correlation With Sensory Deficits. *Journal of Child and Adolescent Psychiatric Nursing*, *26*(3), 165–172. https://doi.org/10.1111/jcap.12041

Reynolds, S., & Lane, S. J. (2008). Diagnostic Validity of Sensory Over-Responsivity: A Review of the Literature and Case Reports. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-007-0418-9

Román-Oyola, R., & Reynolds, S. (2013). Prevalence of Sensory Modulation Disorder among Puerto Rican Preschoolers: An Analysis Focused on Socioeconomic Status Variables. *Occupational Therapy International*, *20*(3), 144–154. https://doi.org/10.1002/oti.1353

Rosen, M. L., Amso, D., & McLaughlin, K. A. (2019). The role of the visual association cortex in scaffolding prefrontal cortex development: A novel mechanism linking socioeconomic status and executive function. *Developmental Cognitive Neuroscience*, *39*, 100699. https://doi.org/10.1016/j.dcn.2019.100699

Schneider, M. L., Moore, C. F., Adkins, M., Barr, C. S., Larson, J. A., Resch, L. M., & Roberts, A. (2017). Sensory Processing in Rhesus Monkeys: Developmental Continuity, Prenatal Treatment, and Genetic Influences. *Child Development*, *88*(1), 183–197. https://doi.org/10.1111/cdev.12572

Schneider, M. L., Moore, C. F., Gajewski, L. L., Larson, J. A., Roberts, A. D., Converse, A. K., & DeJesus, O. T. (2008). Sensory Processing Disorder in a Primate Model: Evidence From a Longitudinal Study of Prenatal Alcohol and Prenatal Stress Effects. *Child Development*, *79*(1), 100–113. https://doi.org/10.1111/j.1467-8624.2007.01113.x

Schoen, S. A., Miller, L. J., & Green, K. E. (2008). Pilot Study of the Sensory Over-Responsivity Scales: Assessment and Inventory. *American Journal of Occupational Therapy*, *62*(4), 393–406. https://doi.org/10.5014/ajot.62.4.393

Schoen, S. A., Miller, L. J., & Sullivan, J. (2017). The development and psychometric properties of the Sensory Processing Scale Inventory: A report measure of sensory modulation.

Journal of Intellectual & Developmental Disability, *42*(1), 12–21. https://doi.org/10.3109/13668250.2016.1195490

Scott, L. S., Pascalis, O., & Nelson, C. A. (2007). A Domain-General Theory of the Development of Perceptual Discrimination. *Current Directions in Psychological Science*, *16*(4), 197–201. https://doi.org/10.1111/j.1467-8721.2007.00503.x

Shaw, M., & Jong, M. D. (2012). Child abuse and neglect: A major public health issue and the role of child and adolescent mental health services. *The Psychiatrist*, *36*(9), 321–325. https://doi.org/10.1192/pb.bp.111.037135

Shonkoff, J. P., Garner, A. S., The Committee on Psychosocial Aspects of Child and Family Health, C. on E. C., Siegel, B. S., Dobbins, M. I., Earls, M. F., … Wood, D. L. (2012). The Lifelong Effects of Early Childhood Adversity and Toxic Stress. *Pediatrics*, *129*(1), e232–e246. https://doi.org/10.1542/peds.2011-2663

Silvers, J. A., Goff, B., Gabard-Durnam, L. J., Gee, D. G., Fareri, D. S., Caldera, C., & Tottenham, N. (2017). Vigilance, the Amygdala, and Anxiety in Youths With a History of Institutional Care. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *2*(6), 493–501. https://doi.org/10.1016/j.bpsc.2017.03.016

Silvers, J. A., Lumian, D. S., Gabard-Durnam, L., Gee, D. G., Goff, B., Fareri, D. S., … Tottenham, N. (2016). Previous Institutionalization Is Followed by Broader Amygdala–Hippocampal–PFC Network Connectivity during Aversive Learning in Human Development. *Journal of Neuroscience*, *36*(24), 6420–6430. https://doi.org/10.1523/JNEUROSCI.0038-16.2016

Smith, K. E., & Pollak, S. D. (2021). Rethinking concepts and categories for understanding the neurodevelopmental effects of childhood adversity. *Perspectives on Psychological Science*, *16*(1), 67–93. https://doi.org/10.1177/1745691620920725

Solmi, M., Radua, J., Olivola, M., Croce, E., Soardo, L., Salazar de Pablo, G., … Fusar-Poli, P. (2021). Age at onset of mental disorders worldwide: Large-scale meta-analysis of 192 epidemiological studies. *Molecular Psychiatry*, 1–15. https://doi.org/10.1038/s41380-021-01161-7

Suarez-Rivera, C., Smith, L. B., & Yu, C. (2019). Multimodal Parent behaviors within Joint Attention support Sustained Attention in infants. *Developmental Psychology*, *55*(1), 96–109. https://doi.org/10.1037/dev0000628

Tamis-LeMonda, C. S., Kuchirko, Y., & Song, L. (2014). Why Is Infant Language Learning Facilitated by Parental Responsiveness? *Current Directions in Psychological Science*, *23*(2), 121–126. https://doi.org/10.1177/0963721414522813

Thoemmes, F. (2015). Reversing Arrows in Mediation Models Does Not Distinguish Plausible Models. *Basic and Applied Social Psychology*, *37*(4), 226–234. https://doi.org/10.1080/01973533.2015.1049351

Tomchek, S. D., & Dunn, W. (2007). Sensory Processing in Children With and Without Autism: A Comparative Study Using the Short Sensory Profile. *American Journal of Occupational Therapy*, *61*(2), 190–200. https://doi.org/10.5014/ajot.61.2.190

Tottenham, N. (2012). Risk and Developmental Heterogeneity in Previously Institutionalized Children. *Journal of Adolescent Health*, *51*(2), S29–S33. https://doi.org/10.1016/j.jadohealth.2012.04.004

Tottenham, N. (2020). Neural meaning making, prediction, and prefrontal–subcortical development following early adverse caregiving. *Development and Psychopathology*, *32*(5), 1563–1578. https://doi.org/10.1017/S0954579420001169

Tottenham, N., Hare, T. A., Quinn, B. T., McCarry, T. W., Nurse, M., Gilhooly, T., … Casey, B. J. (2010). Prolonged institutional rearing is associated with atypically large amygdala volume and difficulties in emotion regulation. *Developmental Science*, *13*(1), 46–61. https://doi.org/10.1111/j.1467-7687.2009.00852.x

Van Hulle, C., Lemery-Chalfant, K., & Goldsmith, H. H. (2015). Trajectories of Sensory Over-Responsivity from Early to Middle Childhood: Birth and Temperament Risk Factors. *PLOS ONE*, *10*(6), e0129968. https://doi.org/10.1371/journal.pone.0129968

van IJzendoorn, M., bakermans-kranenburg, M., Duschinsky, R., Fox, N., Goldman, P., Johnson, D., … Sonuga-Barke, E. (2020). Institutionalisation and deinstitutionalisation of children 1: A systematic and integrative review of evidence regarding effects on development. *The Lancet Psychiatry*, *7*. https://doi.org/10.1016/S2215-0366(19)30399-2

VanTieghem, M. R., & Tottenham, N. (2018). Neurobiological Programming of Early Life Stress: Functional Development of Amygdala-Prefrontal Circuitry and Vulnerability for Stress-Related Psychopathology. In E. Vermetten, D. G. Baker, & V. B. Risbrough (Eds.), *Behavioral Neurobiology of PTSD* (pp. 117–136). Cham: Springer International Publishing. https://doi.org/10.1007/7854_2016_42

Warner, E., Spinazzola, J., Westcott, A., Gunn, C., & Hodgdon, H. (2014). The Body Can Change the Score: Empirical Support for Somatic Regulation in the Treatment of Traumatized Adolescents. *Journal of Child & Adolescent Trauma*, *7*(4), 237–246. https://doi.org/10.1007/s40653-014-0030-z

Weissman, D. G., Bitran, D., Miller, A. B., Schaefer, J. D., Sheridan, M. A., & McLaughlin, K. A. (2019). Difficulties with emotion regulation as a transdiagnostic mechanism linking child maltreatment with the emergence of psychopathology. *Development and Psychopathology*, *31*(3), 899–915. https://doi.org/10.1017/S0954579419000348

Wilbarger, J., Gunnar, M., Schneider, M., & Pollak, S. (2010). Sensory processing in internationally adopted, post-institutionalized children. *Journal of Child Psychology and Psychiatry*, *51*(10), 1105–1114. https://doi.org/10.1111/j.1469-7610.2010.02255.x

Witt, A., Münzer, A., Ganser, H. G., Fegert, J. M., Goldbeck, L., & Plener, P. L. (2016). Experience by children and adolescents of more than one type of maltreatment: Association of different classes of maltreatment profiles with clinical outcome variables. *Child Abuse & Neglect*, *57*, 1–11. https://doi.org/10.1016/j.chiabu.2016.05.001

Zeanah, C. H., & Humphreys, K. L. (2018). Child Abuse and Neglect. *Journal of the American Academy of Child & Adolescent Psychiatry*, *57*(9), 637–644. https://doi.org/10.1016/j.jaac.2018.06.007

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 [0.57-2.81]) 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 [0.62-3.31]; 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 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

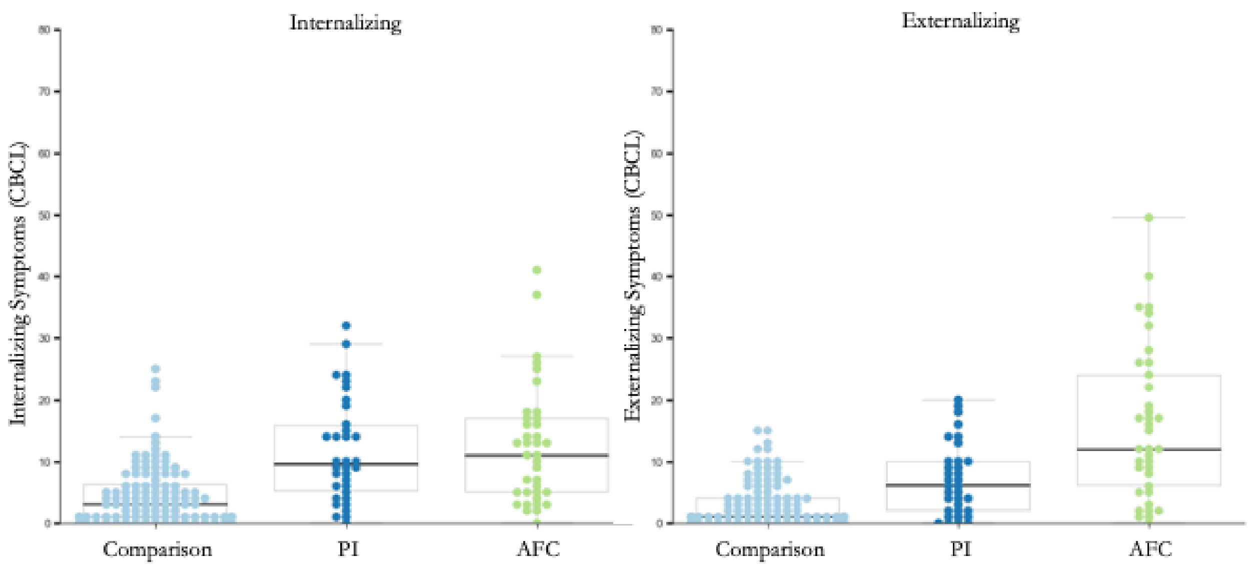
Descriptive statistics for CBCL T-scores are provided in *Supplemental Table 7* and visualized in *Supplemental Figure 1* and *Supplemental Figure 2.*

Supplemental Table 7. Sample Clinical Descriptive Statistics

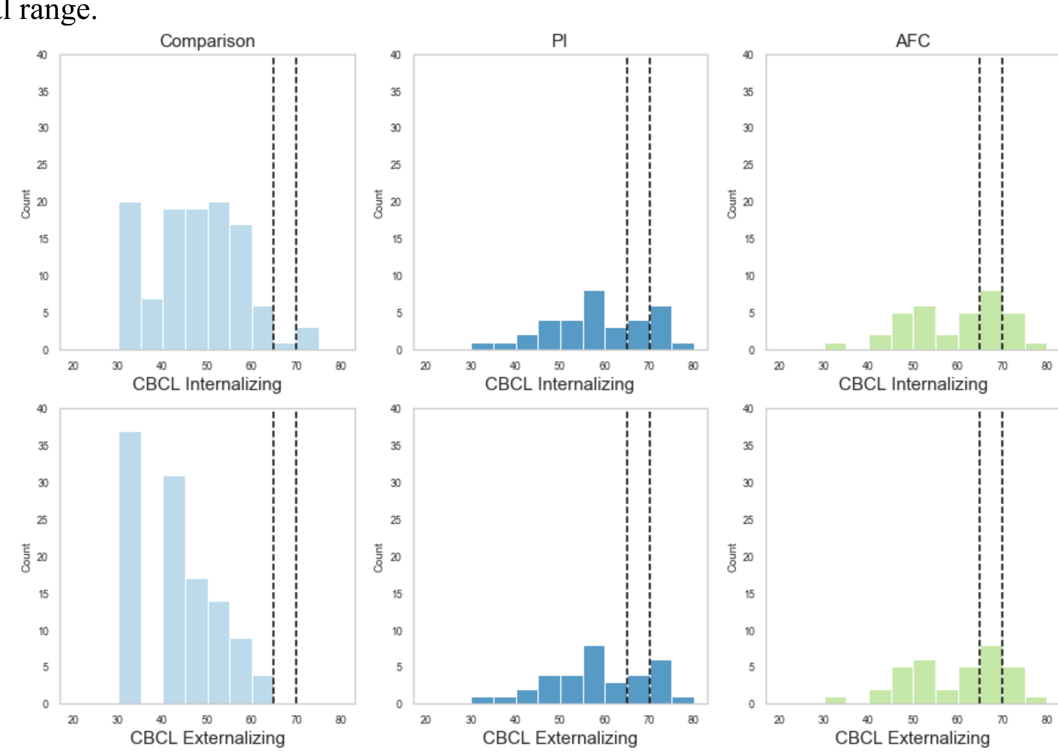
Scales	***Comparison N = 112 Mean (Median; SD)***	***PI N = 34 Mean (Median; SD)***	***AFC N = 37 Mean (Median; SD)***
CBCL Internalizing T-Scores Range: 33 - 100	47.24 (9.74) Range: 33-71	57.76 (10.84) Range: 33-76	59.78 (11.57) Range: 33-84
CBCL Externalizing T-Scores Range: 33 - 100	43.03 (8.52) Range: 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} = -0.68, *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 ($ab_{PI\_SP3D\_INT} = 1.38$, $SE = 0.55$, 95% CI [0.37- 2.51]) and AFC ($ab_{AFC\_SP3D\_INT} = 0.85, SE = 0.46$, 95% CI [0.08-1.86]) youth.
- We found significant indirect effects of PI and AFC status on externalizing symptoms through SOR (PI: $ab_{PI\_SP3D\_EXT} = 1.16$, SE = 0.54, 95% CI [0.29, 2.41]; AFC: $ab_{AFC\_SP3D\_EXT} = 0.71,\ SE = 0.43$, 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 ($ab_{PI\_SP3D\_INT} = 1.56$, $SE = 0.64$, 95% CI [0.38- 2.93]; $ab_{PI\_SP3D\_EXT} = 1.31$, $SE = 0.56$, 95% CI [0.31-2.52) and AFC ($ab_{AFC_{SP3D_{INT}}} = 1.13$, $SE = 0.54$, 95% CI [0.20-2.32]; $ab_{AFC\_SP3D\_EXT} = 0.95$, $SE = 0.51$, 95% CI [0.14-2.13]) 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 [0.65- 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 ($\mathrm{ab}_{\mathrm{AFC\_SSP\_INT}}$ = 4.82, 95% CI [2.45-8.01]; $\mathrm{ab}_{\mathrm{AFC\_SSP\_EXT}}$ = 3.68, 95% CI [1.62-6.37]), but not SOR ($\mathrm{ab}_{\mathrm{AFC_{SP3D_{INT}}}}$ = 0.85, 95% CI [-0.12-2.1]; $\mathrm{ab}_{\mathrm{AFC\_SP3D\_EXT}}$ = 0.51, 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 ($\mathrm{B}_{\mathrm{Age}}$ = 0.62, *t*(53) = -0.60, 95% CI [-1.44-2.67], *p* = .55). Unregistered exploratory follow-up analyses showed no association between age and SOR in either the PI ($\mathrm{B}_{\mathrm{Age\_PI}}$ = 0.23, *t*(33) = 0.15, 95% CI [-2.92-3.37], *p* = .89) or AFC groups ($\mathrm{B}_{\mathrm{Age\_AFC}}$ = 1.68, *t*(19) = -0.12, 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 = -0.58, p = .56, CI = [-4.85 – 2.65]). Sex was significantly associated with SSP scores in the primary models (B_{Female_SSP} = 4.79, t = -0.86, 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 (β = -0.50, $t(182)$ = -8.70, p < .001).