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ADVANCES IN PEDIATRIC RESEARCH

Latino children's autonomic nervous system reactivity moderates the relations between cumulative socioeconomic adversity in the first five years and externalizing behavior problems at seven years

Abbey Alkon [1], Sara F. Waters [2], W. Thomas Boyce [3], Megan M. Johnson [4], Kim G. Harley [4], Brenda Eskenazi [4]

1 University of California, San Francisco (UCSF) School of Nursing, San Francisco, CA, USA **2** Washington State University, Department of Human Development, Vancouver, Washington, USA **3** UCSF Division of Developmental-Behavioral Pediatrics, San Francisco, CA, USA **4** Center for Environmental Research and Children's Health (CERCH), University of California, Berkeley School of Public Health, Berkeley, CA, USA

Abstract

Background: Thirty-seven percent of Hispanic and Latino children under 5 years of age are living in poverty in the United States. Children growing up under conditions of cumulative adversity are at much greater risk for compromised psychosocial adjustment with long-lasting ramifications for mental and physical health. This study assessed whether the relations between adversity early in life and later externalizing behaviors was moderated by children's autonomic nervous system (ANS) reactivity for immigrant, poor, Mexican-American children.

Methods: A cumulative socioeconomic adversity index of children's exposure to poverty, father's absence, household crowding, mothers speaking Spanish, and poor housing condition at 6 months and 1, 3.5, and 5 years of age was calculated. At 5 years, ANS profiles during resting and social- and emotion-evoking challenges were calculated as combined parasympathetic and sympathetic difference scores. At 7 years, parents assessed children's externalizing behavior problems.

Results: Multiple regression models (n=220) showed that the relations between cumulative socioeconomic adversity and externalizing behaviors were moderated by children's ANS profiles of coactivation during a social, not emotion-evoking, challenge, controlling for relevant covariates.

Conclusions: Children living in adverse conditions early in life with specific psychobiologic responses to social challenges may be at risk for developing externalizing behavior problems later in life.

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* Email: abbey.alkon@ucsf.edu

Introduction

Hispanic and Latino children under five years of age in the United States (US) are disproportionately living in poverty [1]. Twenty-five percent of all children under 5 years of age are living in poverty while 37% of Hispanic and Latino children under 5 years of age are living in poverty. There are cultural and historical reasons why Latino-Americans are a unique population, thus highlighting the necessity of exploring the influences of adversity on mental health outcomes in-depth [2]. Despite the fast growing population of Latinos in the US, there is a dearth of pediatric research on the impact of stressors such as household crowding on their health.

Children living in poverty in the US often face a host of concomitant difficulties including household crowding, poor housing conditions, family separation, and less structure and routine in their daily lives [3]. Those growing up under these conditions of cumulative adversity are at much greater risk for compromised psychosocial adjustment and this early adversity has long-lasting ramifications for mental and physical health [4]. Thus, it is paramount to understand how adversity sets the stage for maladjustment issues like externalizing behavior problems among children at the greatest disadvantage. However, contextual and individual factors lead to differential responses to adversity, so that not all children growing up in negative circumstances develop behavior problems. In the current study, children's autonomic nervous system responses were examined as moderators of the relationship between earlier adversity and later externalizing behavior problems.

Children who develop externalizing behavior problems, including hostile, aggressive, oppositional, and defiant behaviors, are at elevated risk for other negative outcomes, including low academic achievement, internalizing symptoms, and poor interpersonal relationships [5]. There is a subset of young children, predominantly boys, with chronic or increasing externalizing behavior problems identified during early childhood [6–8] whose developmental trajectory continues into adulthood [9]. A large body of research has examined factors that are linked to externalizing behavior problems, neighborhood characteristics [10], parenting behaviors [11], and marital conflict [12]. In the few studies examining these associations in children living in low-income families, cumulative risk indices that capture the multiple adversities they are facing are often better predictors of later behavior problems than single risk indices [13,14]. Overall there is a paucity of longitudinal cohort studies that address the relationship between contextual socioeconomic factors and the development of externalizing behavior problems with a focus on multiple family adversities [4]. The current investigation directly addresses this gap in the literature.

Since not all children who grow up in adverse conditions develop behavior problems, researchers have investigated compounding risk factors as well as protective factors. One psychological factor that has emerged as a significant risk factor for young children growing up in poverty is maternal depression. Maternal depression occurs at high rates among Latino families [15,16], and has been shown to be related to economic hardship and child adjustment in immigrant families [17]. On the other hand, the quality of the mother-child relationship established early in life may be a protective factor. Indeed, some studies show that maternal nurturance [18], maternal responsiveness [19], or eating family meals together [20] can buffer the effects of adversity on developing behavior problems. Continuing to identify the protective and risk factors in young children's lives may help explain why children exposed to adversity differentially experience mental health problems later in life.

Another potential link between the context in which children live and the development of externalizing behavior problems is children's physiological reactivity. The biological sensitivity to context (BSC) theory posits that the developmental trajectories of children who exhibit strong physiological reactivity are highly influenced by contextual factors, whether those factors are positive or negative [21]. Highly reactive children who live in supportive, low adverse environments may experience few behavior problems, yet those living under adverse conditions are at high risk for developing behavior problems [22,23]. This perspective also suggests that children who do not exhibit strong physiological reactivity are relatively less influenced by their circumstances. The adaptive calibration model (ACM) extends the BSC

to children living under the conditions of extreme adversity to explain the association between extreme adversity and dampened physiologic responses [24]. In this model, children facing extreme adversity may exhibit lower or more dampened physiological responses than children facing moderate or high adversity. Thus, when one's circumstances involve multiple adversities cumulatively over time, this lack of sensitivity may be adaptive. This is an important distinction to make given the prevalence of multiple adversities over time in the current sample.

The BSC and ACM models include the ANS as an index of physiological reactivity. The ANS has two branches: the parasympathetic nervous system (PNS), which regulates recovery and restores the body to a state of homeostasis, and the sympathetic nervous system (SNS), which prepares the body for a 'fight or flight' response [25]. Respiratory sinus arrhythmia (RSA) reactivity indexes activation of the PNS while pre-ejection period (PEP) reactivity indexes activation of the SNS compared to a resting state. Reactivity in this case refers to changes in the ANS when an individual shifts from a resting state to engage in a specific task or challenge. Moderate levels of PNS inhibition and SNS activation (i.e., negative RSA and PEP reactivity scores) in response to a challenge are considered adaptive by showing physiologic arousal. PNS inhibition is synonymous with PNS withdrawal or the vagal brake. On the other hand, extreme levels of RSA or PEP reactivity or a blunted RSA or PEP response to a challenge (i.e., positive RSA or PEP reactivity scores) are considered ANS dysregulation.

Although ANS reactivity includes the simultaneous responses of the parasympathetic and sympathetic branches, the majority of studies examine only one ANS branch at a time. The concept of autonomic space was introduced by Berntson and colleagues [26] to show a two-dimensional model of autonomic control which conceptualizes PNS and SNS as flexible and responsive to each other. The few studies that have utilized this two-dimensional model in samples of children have found evidence that the discrete space or profile in which an individual falls is meaningful for their emotion regulatory abilities and aggressive tendencies [23, 27].

An additional consideration when examining children's ANS responses is that reactivity is tied intimately to the specific context eliciting that reaction [28,29]. According to the Polyvagal Theory [30], changes in RSA indicates activation of a multi-system social engagement system and thus RSA reactivity reflects the body's ability to regulate a shift from a resting state to social-emotional context [31]. PEP reactivity reflects the body's ability to shift from a resting state to an attention-demanding task or context [25]. Given the context-sensitive nature of ANS responses, the type of task or challenge used to elicit children's physiological reactivity protocols should be related conceptually to the constructs under study [32]. In studies of children's externalizing behavior problems, physiological reactivity tasks are often interpersonal in nature [12, 33] since these are the kinds of challenges these children tend to struggle with the most.

This study investigated the following research question: Do children's ANS profiles of reactivity moderate the relationship between cumulative socioeconomic adversities early in life and developing externalizing problems later in life? Repeated measures of multiple adversities over the first 5 years formed the cumulative socioeconomic adversity index and RSA reactivity and PEP reactivity in response to separate social and emotional challenges were examined through ANS profiles. Together these factors were used to predict externalizing behavior problems at age 7 years. The investigation was guided by the following hypotheses: Children who experience cumulative socioeconomic adversities in the first five years of life and who have the ANS profiles, co-activation or classic reactivity during the SC, will have the highest levels of externalizing behavior problems at 7 years of age. Children who experience cumulative socioeconomic adversities in the first five years of life and who have the ANS profiles, co-inhibition or reciprocal PNS activation and SNS inhibition during the EC, will have the highest levels of externalizing behavior problems at 7 years of age. Further, it was expected that maternal depression would operate as a risk factor, and a proxy of maternal nurturance (eating meals together) would operate as a protective factor in our models.

Methods

Participants

The participants were drawn from a larger birth cohort, The Center for the Health Assessment of Mothers and Children of Salinas (CHAMACOS), which examines the relations of pesticides and other environmental exposures on the health of pregnant women and their children. Women in the first half of their pregnancy were recruited between October 1999 and October 2000 from six prenatal clinics. Eligible women were 18 years of age or older, less than 20 weeks gestation, Spanish or English speaking, eligible for California's low-income health insurance program, Medi-Cal, and planning to deliver at the county hospital. Methods for the study have been described elsewhere [34,35].

Of the 601 women initially enrolled, 527 were followed through delivery and 428 of their infants were seen at the six-month old visit: 418 at 1 year, 330 at 3.5 years, 319 at 5 years, and 349 at 7 years of age. The largest drop-out rate occurred between enrollment and the 6-month visit and subsequently there was a 5%-10% drop-out rate for each consecutive visit. For the current investigation, children were excluded if they had a medical condition that could affect ANS measures (n = 6), were not 5 years of age when the reactivity protocol was administered (n = 2), did not complete the reactivity protocol (n = 54), or were missing data on one or more of the adversity measures, covariates, or parent-completed behavior measures (n = 67). The final sample included 220 children who had complete data. There were no significant differences in the demographic characteristics for the children in this investigation (n=220) and the full sample.

Procedures

The University of California (UC), Berkeley's and UC, San Francisco's institutional review boards approved the study protocols and consent forms. Prior to data collection at each time point, informed consent was obtained from one of the child's parents. Mothers were interviewed during pregnancy, after delivery, and when the children were 6 months and 1, 2, 3.5, 5, and 7 years of age by bilingual, bicultural interviewers in Spanish or English. Mothers provided information on demographic, social, family, and economic measures at each age, depression symptoms at the 1- and 3.5-year visits, and their child's behavior at the 7-year visit [34,36]. At the 5-year visit, children completed a 15-minute reactivity protocol involving resting states and social, cognitive, physical, and emotional challenges while continuous measures of the ANS were collected [37]. The protocol was administered by bilingual, bicultural staff in the child's language of choice and conducted in private rooms in a research office.

Measures

Cumulative socioeconomic adversity

Five indicators of socioeconomic adversity measured repeatedly during the first five years of the children's lives were: poverty status, household density, amount of English spoken by mother, father's absence from the home, and housing conditions. These factors were identified in the literature as adversities that impact a child's physiologic, physical or emotional development and the cutoffs used in previous studies were applied to this sample [33,38–41]. The factors were categorized into dichotomous groups and then a summary index was calculated. The poverty level for each family was calculated by dividing the total household income by the number of people supported by that compared to the federal poverty level (FPL) [1]. Poverty status was dichotomized at or below 100% the FPL (1) or above the FPL (0). Household density was determined by the number of people living in the household divided by the number of rooms, excluding bathrooms. Families with more than 1.5 adults per room were categorized as more adverse (1) than those families with fewer persons per room (0). Families where the mothers reported they spoke only Spanish at home (1) were categorized as more adverse compared to families where only English or a combination of languages were spoken by the mother (0). The father's presence in the household was assessed by the question, "Since our last visit, have you lived with the baby's father?" The mothers' responses were dichotomized as father not present at all (1) or present some, most, or all of the time (0). Housing conditions were measured by trained observers to assess the presence of mold, rot, water damage, musty odor, peeling paint, rodents, or

roaches. The number of housing problems was tallied and families living with more than 3 housing problems (1) were categorized as more adverse than families living with 3 or fewer housing problems (0).

First, the five specific adversities were summarized by frequency (percent) per age (Table 1). The 2-year-old measures were not consistent with the other years and thus, not included in the index. Next, the specific adversities were summarized across the ages by creating a mean of the dichotomous variables at the four time points (6 months, 1, 3.5, 5 years) for those children with complete data at two or more time points. Lastly, a cumulative socioeconomic adversity index was calculated for each child as a mean of the age-specific adversity indices.

Maternal depression

The 20-item Center for Epidemiologic Studies Depression Scale (CES-D) [42] was completed at the 1 and 3.5 year visits. Maternal depression was dichotomized at each visit using the US clinical cutoff of 16. Then, the depression index was dichotomized as depression at both time points (1), or depression at one time point or never depressed (0). There was missing data for 13 mothers at 1 year and 20 mothers at 3.5 years.

Family meal time

The Home Observation Measurement of the Environment (HOME) and the HOME-Short Form is a valid and reliable measure of the quality of a child's home environment [43]. The HOME was completed at the 6 month and 1 year visit and the HOME-Short Form was completed at the 3.5 and 5 year visits. The frequency of the item 'family meals with the child' was categorized as at least daily (1) versus less frequently than daily (0). A proxy for parent-child time spent together in the first five years of life was created by calculating a mean across the time points.

Bisphenol A exposure

Bisphenol A is an endocrine-disrupting compound used in the manufacture of polycarbonate plastics. Children's exposure to BPA is ubiquitous via plastic food and beverage containers, canned food, and dental sealants. An investigation of this cohort found girl's BPA to be positively related to their level of parent-rated externalizing behaviors at 7 years [44]. BPA was analyzed on 303 of the children at 5 years of age by spot urines collected and analyzed at the Centers for Disease Control and Prevention. Continuous urinary BPA concentrations were log-transformed to reduce the influence of outliers. Given that the current study is embedded in a larger study investigating environmental exposure to deleterious compounds such as BPA, BPA measured as µg/L was a covariate in the analyses predicting externalizing behavior problems.

Child externalizing behavior problems

Children's behaviors were assessed during the maternal interviews in English or Spanish at the 7-year visit with the standardized Behavior Assessment System for Children 2 (BASC-2) [45]. The 160 items ask how often the child exhibits certain behaviors in the home setting and each item is rated as never, sometimes, often or almost always. In this investigation, the externalizing behavior problems composite is used, which includes the aggression, conduct problems and hyperactivity subscales. Outliers with scores at 3 standard deviations above the sample mean were excluded from these analyses (n = 3).

Child ANS

Children participated in a standardized reactivity protocol where continuous measures of impedance cardiography, electrocardiography (ECG), and respirations were measured [37,46]. Four spot electrodes were placed on the neck and trunk to collect impedance and respiratory measures, and three spot electrodes were placed on the right clavicle, lower left rib, and right abdomen for electrocardiography (ECG) measures.

Table 1. Autonomic nervous system profile scores by PEP and RSA reactivity at 5 years of age

Autonomic Nervous System (ANS) Profile	ANS		Social Challenge (n=220)	Emotion Challenge (n=198)
	RSA reactivity	PEP reactivity	n (%)	n (%)
1. Coactivation of SNS and PNS	+	-	54 (25%)	38 (17%)
2. Coinhibition of SNS and PNS	-	+	57 (26%)	39 (18%)
3. Reciprocal PNS activation and SNS inhibition	+	+	17 (8%)	73 (33%)
4. Reciprocal SNS activation and PNS inhibition (Classic Reactivity)	-	-	92 (42%)	48 (22%)
Total			220 (100%)	198 (100%)

Note: + = Positive reactivity score; - = Negative reactivity score

Data were acquired using the Biopac MP150 to collect continuous ECG Z_o (basal impedance) and dZ/dt (first derivative of the impedance signal) waveforms. A 4-milliamp AC current at 100Hz was passed through the two current electrodes and Z_o and dZ/dt signals were acquired from the two voltage-recording electrodes.

Respiratory sinus arrhythmia (RSA), a measure of the PNS, is the periodic oscillation in sinus rhythm occurring at the frequency of respiration and manifested as an increase in heart rate (HR) with inspiration and a decrease during expiration. RSA indices were calculated using the interbeat intervals on the ECG reading, respiratory rates derived from the impedance (e.g. dZ/dt) signal, and a bandwidth range of 0.15 to 0.80 Hz [47,48]. As the parasympathetic influence on HR decreases, referred to as parasympathetic withdrawal/inhibition, the RSA index decreases.

Preejection period (PEP), an indirect noninvasive cardiac measure of the SNS, is the time interval in milliseconds of the onset of ventricular depolarization (Q point on the ECG wave) and the onset of left ventricular ejection (B point on the dZ/dt wave) [49]. As sympathetic activity increases, PEP decreases.

ANS data were filtered, extracted, and then scored using Mindware software (www.mindware.org). Minute-by-minute data cleaning procedures involved examining for artifact and a child's data were deleted if more than 25% of the task minutes were unscorable. Cleaning procedures also included checking for outliers and minutes with greater than 3 standard deviations from the sample mean; in this sample, there were no outliers. Five percent of the participants (n=15) who completed the reactivity protocol had missing data due to child or parent refusals, equipment failure, or noisy data due to child movement or electrode displacement.

Physiological responses to a context-specific task have been shown to be more sensitive to the conceptually-similar outcome than generalizing across different challenges [32,48]. Thus, of the four challenges included in the reactivity protocol (social, cognitive, physical, and emotional), this investigation included the social challenge (SC) and emotion challenge (EC) in predicting children's externalizing behavior problems. The SC was an interview by an adult who asked questions about the child's friends, favorite activities, and birthday. The SC was preceded by the adult reading a neutral story. The EC involved a fear-evoking video (boys walk on a railroad bridge and the train comes) and was preceded by a neutral video (child making a snowman).

Consistent with field standards [46,50], PEP and RSA reactivity scores were calculated as the mean response across the 2-minute SC task and the 2-minute EC task minus the preceding comparable 2-minute resting episodes. High RSA reactivity (i.e., negative RSA difference score) indicates the child

had parasympathetic inhibition or vagal withdrawal during the challenge compared to the resting state. High PEP reactivity (i.e., negative PEP difference score) indicates the child had sympathetic activation during the challenge compared to the resting state. Low RSA reactivity (i.e., positive RSA difference score) indicates the child had parasympathetic activation (i.e., more vagal input) during the challenge compared to the resting state. Low PEP reactivity (i.e., positive PEP difference score) indicates the child had sympathetic inhibition during the challenge compared to the resting state. Lastly, RSA and PEP positive and negative reactivity scores were dichotomized as activation or inhibition and then categorized into four ANS profiles: co-activation, co-inhibition, PNS activation/SNS not activated, or SNS activation/PNS inhibition (Table 1). ANS profiles were calculated for the SC and EC separately.

Data analysis

Analyses were conducted using Stata version 12.0 (StataCorp, College Station, Texas, US) and SPSS 21.0. Descriptive statistics were calculated for all demographic characteristics and variables in the regression models. Repeated measures analysis of variance using the raw values from resting and task in the SC and EC was conducted to determine whether participants exhibited significant change from resting to task. Spearman or Pearson correlations explored the relations between the independent variables in the regression models. Eight separate linear regressions were conducted to predict children's externalizing behavior problems from the cumulative socioeconomic adversity index, SC or EC ANS profiles, adversity X ANS profile interaction and relevant covariates (sex, child BPA, maternal depression, and family meal time). The adversity variable was centered before forming the interaction terms and the interaction term varied in each model: cumulative socioeconomic adversity by ANS profile (x4) for either the SC reactivity or EC reactivity. Interactive effects were examined using the simple slopes technique [51] by comparing the effect of high (i.e., 1 standard deviation above the mean) and low (i.e., 1 standard deviation below the mean) levels of cumulative socioeconomic adversity on externalizing behaviors for children with an ANS coactivation profiles and those without this profile. A priori levels of significance were set at $p < 0.05$ for models and main effects and $p < 0.10$ for interaction effects.

To understand potential differential impact for girls and boys, post-hoc analyses were stratified the significant model by sex. For significant models, post-hoc regression models included the individual adversities rather than the cumulative index (i.e. poverty status, maternal language, household density, father's absence, and housing condition) to identify significant interactions with ANS in predicting externalizing behavior problems.

Results

Sample characteristics

In the analytic sample of 220 families, 88% of mothers were born in Mexico and 100% self-identified as Latina. At the time of enrollment in the study, 72% of mothers were under 30 years of age, 80% had a high school education or less, and 45% had lived in the US for less than 5 years. The majority of children were girls (53%), born full-term (95%), and not their mother's first child (69%).

Descriptive statistics

The majority of children experienced multiple adversities over the first five years of life, with most of the children experiencing at least two adverse conditions at every time point ($M = 0.50$, $SD = 18$, range 0 to 1; Table 2). The majority of the children lived in poverty and had a mother who spoke only Spanish at home. Over the first five years, there was a 50% decrease in the number of crowded households and a 5% decrease in the households with housing problems. Complete father absence from the home was not as common as the other adversities.

Table 2. Frequency of children living with socioeconomic adversities by age (n=220)

SES Adversity	Age of child				
	6 months n (%)	1 year n (%)	3.5 years n (%)	5 years n (%)	Mean (SD)
Mother speaks only Spanish at home	174 (86%)	173 (80%)	170 (77%)	172 (78%)	0.80 (0.32)
At or below 100% of the Federal Poverty Line (FPL)	156 (71%)	154 (70%)	141 (64%)	133 (61%)	0.67 (0.32)
Household density (> 1.5 people per room)	101 (50%)	96 (48%)	97 (37%)	53 (25%)	0.39 (0.32)
Housing problems (>3 problems)	95(46%)	99 (48%)	92 (42%)	98 (45%)	0.45 (0.32)
Father not at home	33 (16%)	42 (19%)	48 (22%)	49 (22%)	0.20 (0.31)

There were 116 (53%) of mothers depressed at the 12 month visit, 105 (48%) at the 42 month visit, and 74 (34%) at both the 12 and 42 month visit. On average, the children only had meals with their parent(s) at one of the four timepoints of the study. The children's mean BPA levels were lower than the general US population [44] with a geometric mean BPA of 1.9 µg/L. The BASC-2 externalizing behavior problems for the sample was M = 135, SD = 22 with a range of 101 to 201.

There were no significant differences between the SC and EC for RSA or PEP resting values (p = 0.11 and 0.20, respectively). There was a significant difference between the SC and EC for RSA task values, $t(216)$ = -6.88, p < .001, with SC RSA lower (M = 6.55, SD = 1.22) than EC RSA (M = 6.91, SD = 1.12). Similarly, there was a significant difference between the SC and EC for PEP task values, $t(215)$ = -3.07, p = 0.002, with SC PEP lower (M = 77.38, SD = 7.49) than EC PEP (M = 77.89, SD = 7.90). For the SC, there was a significant decrease in RSA values from resting (M = 6.74, SD = 1.15) to task (M = 6.55, SD = 1.23), *Wilk's* λ = 0.52, $F(1, 219)$ = 15.14, p< 0.001, η_p^2 = 0.07. There was also a significant decrease in PEP values from resting (M = 78.03, SD = 7.47) to task (M = 77.44, SD = 7.43), *Wilk's* λ = 0.89, $F(1, 219)$ = 28.58, p < 0.001, η_p^2 = 0.12. For the EC, there was a significant decrease in RSA values from resting (M = 6.82, SD = 1.16) to task (M = 6.90, SD = 1.12), *Wilk's* λ = 0.97, $F(1, 215)$ = 6.33, p = 0.01, η_p^2 = 0.03. There was no significant decrease in PEP values from resting (M = 77.76, SD = 7.89) to task (M = 77.87, SD = 7.91). Thus, the SC activated both the SNS and PNS systems while the EC activated the PNS but not the SNS.

The distribution (n%) of the four ANS profiles differ by the SC and EC (Table 1). The most frequent ANS profile during the SC was classic reactivity. For the EC, the sample was distributed fairly evenly across the four profiles. In contrast to the low frequency in the SC, the reciprocal PNS activation and SNS inhibition was the most common profile in the EC. The distribution of the children's ANS profiles in the SC and EC were not significantly different (X^2 (9, N=198) = 12.69 p = 0.18).

Bivariate associations

There was no significant colinearity between the independent variables in the regression models since there were only weak bivariate associations between cumulative adversity, ANS profiles, and the relevant covariates. The correlations between the single adversity indices over time showed moderate, positive associations. Poverty level was positively and weakly associated with Spanish language spoken at home ($r(220)$ = 0.37, p < 0.001), household density ($r(220)$ = 0.19, p = 0.004), and housing conditions ($r(220)$ = 0.21, p = 0.001). Household density was positively and weakly associated with Spanish language spoken at home ($r(220)$ = 0.18, p = 0.007) and housing conditions ($r(220)$ = 0.33, p = 0.001).

Spanish language spoken at home was negatively, weakly associated with housing conditions ($r(220) = 0.22$, $p = 0.001$) and father absence, ($r(220) = -0.16$, $p = 0.02$). There was also a moderate, negative association between father absence and having daily family meals ($r(220) = -0.39$, $p < 0.001$).

Children's externalizing behavior problems

The model involving ANS coactivation, not classic reactivity, during the SC was significant, $F(7, 212) = 2.62$, $p = 0.01$ (Table 3). The relation between socioeconomic cumulative adversity and later externalizing behavior problems was moderated by the children's ANS coactivation profile during the SC, controlling for covariates ($F(7, 212) = 2.62$, $p = 0.01$; Table 3). There were significant main effects of child sex, maternal depression, and family meal time. Boys, children whose mothers had experienced depression, and children who spent less time eating together as a family during early childhood had higher levels of externalizing behavior problems at 7 years of age, controlling for cumulative adversities and ANS reactivity. The interaction of cumulative adversity and ANS coactivation was marginally significant. The children with a coactivation profile during the SC experienced the most externalizing behavior problems if they experienced frequent cumulative adversities compared to the other children (slope: $t(212) = 1.57$, $p = 0.08$) (Figure 1). On the other hand, the children with a coactivation profiles during the SC experienced the least externalizing behavior problems if they experienced few cumulative adversities.

The slope for children without the coactivation profile was not significant (slope: $t(212) = -0.84$, $p = 0.20$). The other ANS profiles during the SC did not moderate the relations between cumulative adversity and externalizing behavior problems.

Post-hoc analyses stratified by sex resulted in non-significant regression models. Post-hoc analyses of the regression models with interactions of individual adversities by SC coactivation showed that both household density ($F(7, 212) = 2.66$, $p = 0.01$) and father absence ($F(7, 212) = 3.06$, $p = 0.004$) yielded significant models. The household density interaction term was marginally significant ($\beta = 0.13$, $p = 0.08$, 95% CI = -2.72, 42.79) and there were significant main effects of child sex, maternal depression, and parent-child meal time. Graphing the interaction revealed the same moderating relationship found with the cumulative socioeconomic adversity index by SC coactivation.

Table 3. Parent-rated externalizing behavior problems (n=220)

Variable	b	SE	β	*t*-statistic	*p*-value	95% CI	
Child sex (0=boy)	-6.23	2.97	-0.15	-2.32	0.03	-12.47	-0.77
BPA µg/L	0.53	1.03	0.04	0.52	0.61	-1.50	2.56
Maternal depression	6.62	3.10	0.14	2.14	0.03	0.51	12.72
Family meal time	-11.74	5.31	-0.15	-2.21	0.02	-22.21	-1.28
Cumulative adversity	-7.67	9.18	-0.07	-0.84	0.40	-25.76	10.42
ANS SC coactivation	2.72	3.35	0.05	0.81	0.42	-3.88	9.32
Cumulative adversity X ANS coactivation	30.98	18.76	0.13	1.64	0.10	-6.01	67.97

Behavior problems were predicted by the interaction of socioeconomic cumulative adversity and ANS profile of SC coactivation, controlling for covariates
Note: b = unstandardized; β = standardized
Overall model: F(7,212)= 2.62, p=0.01

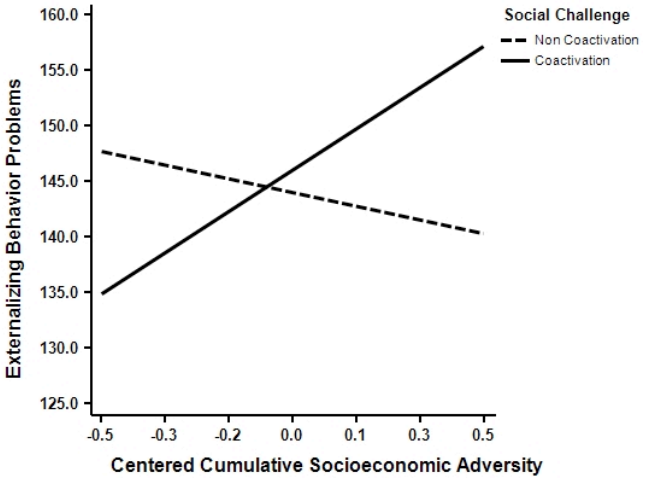

Figure 1. Children's ANS coactivation profile moderates the relationship between exposure to cumulative socioeconomic adversity and externalizing behavior problems

Namely, children with a coactivation profile demonstrated the most externalizing behavior problems if they lived in crowded housing (high household density) during the first five years of life (slope: $t(212) = 1.50$, $p = 0.07$). Those children without coactivation did not demonstrate this association (slope :$t(212) = -0.89$, $p = 0.19$).

The father's absence interaction term was significant ($\beta = 0.18$, $p = 0.02$, 95% $CI = 4.05, 46.17$). The same pattern emerged for the graph of the interaction. Children with the coactivation profile were most negatively affected by the absence of father from the home over time (slope: $t(212) = 2.20$, $p = 0.01$). Again, those children without coactivation did not demonstrate this association (slope: $t(212) = -0.81$, $p = 0.21$).

Children's ANS profiles during the EC did not moderate the relations between exposures to cumulative socioeconomic adversity and later externalizing behavior problems, controlling for relevant covariates.

Discussion

The current investigation found that the relationship between exposure to cumulative socioeconomic adversity in the first five years and the development of externalizing behavior problems at 7 years was moderated by children's coactivation of the parasympathetic and sympathetic nervous systems during a social challenge at 5 years of age. In a sample of highly vulnerable Latino children, a profile of coactivation in response to a social challenge, not an emotion-evoking challenge, increased children's likelihood of developing externalizing behaviors for those facing multiple socioeconomic adversities. The post-hoc analyses revealed that crowded living conditions and the lack of the father's consistent presence in the home were particularly salient adversities.

As hypothesized, the interaction between ANS reactivity and cumulative socioeconomic adversities corroborated the BSC theory [21]. Children who responded to the SC with a coactive profile had the highest levels of externalizing behaviors when also exposed to multiple adversities in the first five years of life but they had the lowest levels of externalizing behaviors when living in families with fewer adversities. In contrast, children who did not have the coactivation profile during the SC seemed to be buffered from the exposure to adversities, because the level of adversities in their lives did not relate to the level of externalizing behaviors at 7 years of age.

There were specific study hypotheses for the type of reactivity task and ANS response profile. The findings supported the hypothesis for children with a coactivation profile during the SC, but not for children with the classic reactivity profile. Other studies found that children with a classic reactivity profile living under adverse conditions had high externalizing problems, but those studies analyzed the mean ANS responses across a range of tasks and not one contextual task at a time [23,52]. Thus, this hypothesis may not be supported for specific reactivity tasks. The second hypothesis was not supported since neither the children with the coinhibition nor those with the reciprocal PNS activation and SNS inhibition during the EC had a differential response to their adverse living conditions in relation to externalizing behavior problems. Although some studies showed that children with dampened ANS reactivity [53] or cortisol reactivity [54] were at risk for later behavior problems and children living under adverse conditions had a

dampening of their ANS reactivity [55] or cortisol reactivity [56,57], this investigation did not find that children with dysregulation (dampened sympathetic reactivity) moderated the relations between cumulative adversity and later externalizing behaviors.

Autonomic nervous system reactivity to two different challenges, one social in nature and one emotional in nature, were used to examine the context-specific nature of ANS responses as they related to adversity and behavior problems. Responses to the SC moderated this relationship while, contrary to expectations, no significant results were obtained with ANS responses during the EC. The SC finding aligns with the results of other studies. For instance, in a study of socioeconomically diverse kindergarteners that used a comparable SC, children with low RSA reactivity during the task had more externalizing behavior problems under conditions of high marital conflict and fewer externalizing behavior problems under conditions of low conflict [48]. In a maltreated sample of preschoolers, children who had high RSA reactivity while completing a frustration task with their mothers had less inhibitory control compared to children who had low RSA reactivity and these results were not supported for tasks children completed without their mothers [32]. While other studies have used a comparable EC to successfully elicit PNS responses in 5-year-olds with meaningful links to externalizing problems [31], the EC did not evoke significant change in the SNS in the current sample. Thus the ANS profiles from the EC did not capture the range of PNS and SNS responses obtained from the SC and this may be one explanation for the null effect. Together these findings illustrate that the nature of the challenge used to elicit a physiologic response is an important consideration when investigating the relations between adversity and behavior.

The ANS profiles were used because they summarized the simultaneous responses of the parasympathetic and sympathetic nervous systems. The combination of dual branch activation was informative in this study, suggesting that the impact of ANS responses on behavior may be better captured through measures of changes in both branches rather than either the PNS or SNS alone. Few studies model the simultaneous effects of the PNS and SNS, especially in vulnerable samples, but the findings from this investigation align with a few studies. In a study of school-age children's exposure to marital conflict, children living in a home with marital conflicts who had the ANS profile of coactivation (i.e. the interaction of skin conduction reactivity as the measure of SNS and RSA baseline as the measure of PNS) during a verbal argument task had high levels of externalizing problems compared to children with coactivation and living in families with low marital conflict [12]. On the other hand, a small study of predominately white, middle-class 4–5-year-olds created an interaction of RSA baseline and PEP reactivity to characterize children with a coactivation profile to a SC, an interview [58]. Children with coactivation who were characterized with low temperamental surgency had poor emotional regulation in response to disappointment task. Thus, evidence from multiple studies indicates that coactivation of the PNS and SNS may be a physiological profile of risk for children facing other difficulties as well.

There were significant demographic characteristics and covariates in this investigation. Sex was a significant predictor of externalizing problems in this study and many other studies [59]. Maternal depression was highly prevalent in this and other studies of Mexican American mothers [16] and was related to higher levels of children's externalizing problems. On the other hand, family meal time was a protective factor for children. The benefits of family meals was explored in a review of 14 studies of adolescents in the US and it was related to children's quality time with adults, better nutrition, self-regulation skills, and less behavior problems [20]. Maternal depression is a risk factor yet having family meals is a protective factor for developing externalizing behavior problems during school-age. These findings highlight the importance of high quality parent-child interactions in buffering the effects of poverty on young children. Further, clinical implications can be drawn from such findings, as the treatment of maternal depression and/or coaching families to spend quality time with one another could alter the trajectory of health and development for young children. Sex, parental mental health, and family time are important factors to explore as

potential risk or protective factors for future studies of children's mental health problems.

While many studies show the risk and protective factors of different adversities early in life, there are several scientists who explain physiologic processes underlying these relationships. Children growing up in poor families with a heightened activation of the stress response system show different patterns of maturation in selected areas of the brain, such as the prefrontal cortex, depending on their mother's responsiveness [60]. In a neuroscience study of children living in poverty, the areas of the brain which were sensitive to childhood poverty were language, long-term memory, working memory and executive control [61]. In another study, the number of years a child lived in poverty from birth to 13 years of age was related to decreased working memory, but only for children who also experienced physiological stress (e.g. measured as blood pressure or cortisol) [62].

Socioeconomic disparities experienced by these children partially accounted for the variability in the developing amygdala and hippocampus [63]. The amygdala system functions to modulate cognition, behavior, and autonomic activity through afferent and efferent connections with cortical and subcortical structures. Chronic stress is related to low levels of glucocorticoids and gene transcription factors, which potentially can down-regulate the amygdala's reactivity to the threat response system [64]. These changes in physiology can dampen the body's sympathetic or fight/flight response to threat and increase the risk of health problems. It is also shown that children's stress response systems during early childhood exhibits plasticity under conditions of moderate adversity and changes in response to positive environmental factors, such as maternal sensitivity.

The timing of poverty has life-long effects on children's development and mental health. Children persistently living in poverty during early and late childhood have higher rates of antisocial behavior [65]. On the other hand, children whose families were able to get out of poverty had the same level of behavior problems by adolescence as children whose families were never poor. This illuminates the salience of critical ages in development when children face socioeconomic adversities. The first five years of life were the focus of this study because they are a time of rapid development and organization of the autonomic nervous system. Nevertheless, other sensitive periods may also be important, adolescence for example, and understanding when negative socioeconomic conditions are most impactful for children's risk of behavior problems will help inform future work to develop well-timed interventions to support these children.

Although this investigation included mother's language spoken at home as an adversity, some studies consider speaking only Spanish at home a protective factor associated with lower acculturation, decreased marital problems and lower child behavior problems [66]. On the other hand, school-age Mexican-American children who reported hassles related to their language abilities had more externalizing symptoms [67]. This relation differed based on the child's report of neighborhood cohesion with higher behavior problems for boys with language hassles and a lack of neighborhood cohesion. In a study of socio-economically diverse Mexican American 8–13-year-olds, children living with Spanish-speaking mothers had fewer conduct problems than English-speaking Mexican Americans [68]. Therefore, language is not a proxy for acculturation and thus should be studied as an independent factor that may affect a child's behavior, peer relationships, and academic achievement.

The father's absence is another adversity explored in this investigation and found to be a significant predictor of behavior problems for children with the coactive ANS profile. In a study of school-age Mexican-Americans that assessed family instability, divorce and/or parental separation, children who experienced family instability in 5th and 7th grades had higher rates of externalizing behavior problems in 7th grade than other children [69]. Mother-child relationships moderated the relations between family instability and behavior problems. Future research might examine family-related adversities more closely, as main effects and as part of a moderating influence on later behavior problems.

The social support structure of a Latino family's household is important to understand to try to disentangle the complexity of how these children

adapt to the American culture and norms. To understand the child's cultural orientation or acculturation for young children, studies include the language spoken at home [68]. In this investigation, the majority of mothers only spoke Spanish at home and only 22% of the mothers spoke some or only English at home by the time their children were 5 years of age. Since the majority of mothers were born in Mexico and had lived in the US less than 5 years at the time of the index pregnancy, these may be protective factors that need to be explored further along with cultural orientation and ethnic identification.

The ANS responses to the SC are similar to other studies of ethnically and socioeconomically diverse 5-6 year olds [48] and ethnically diverse 3–5-year-olds [37]. The modifying effect of ANS reactivity on the relations between early childhood adversity and children's behavior problems has been found in other studies, but not cohort studies of Latino families. There are many potential confounders or covariates not included in this investigation and other studies. Future studies of Latino families should explore the impact of neighborhood danger and cohesion, school environments, parent psychopathology, parental involvement and warmth, and cultural orientation or ethnic identity on children's mental health.

In contrast to the majority of studies that measure adversities at only one point in time, this investigation relied on a cohort design with multiple assessments of adversity exposure over the first five years of life. Repeated measurement of various indices of adversity over time strengthens the validity of the cumulative socioeconomic adversity construct. As the current findings indicate, many children remain in poverty year after year, with increasing risk for problem behavior and criminality in later life [65]. Individual indices of adversity may function differently in relation to behavioral responses. Thus, it is critical to measure various features of children's lives and not rely on a single index like family income for children living in poverty.

In addition to the behavioral problems studied here, ANS reactivity may modify the relationship between cumulative socioeconomic adversity and other outcomes including mental health problems and physical health. Risk for internalizing behavior problems such as anxiety and depression is elevated in children living in poverty and those living in families marked by conflict and upheaval. Greater attention to understanding the role of physiological reactivity in the associations between adversity and internalizing problems is warranted. Accumulated experiences of socioeconomic adversity "get under the skin" to alter physiological functions [70] in ways that can lead to later health related problems [52,71]. A large study of adults exposed to household dysfunction or abuse during childhood were at high risk for certain adult diseases, including ischemic heart disease, cancer, chronic lung disease, and skeletal fractures [72]. Lifespan longitudinal studies are needed to better understand how these early experiences of adversity erode health later in life. Early indicators of compromised health trajectories may already be present in young children facing extreme socioeconomic adversity and future research should investigate this more closely.

This investigation is the first cohort study of Latino families to examine the modifying effect of ANS reactivity on the relations between early childhood adversity and children's behavior problems over time. Nevertheless, there are several limitations. In order to meaningfully capture the combination of PNS and SNS responses, children were categorized into one of four profiles, which disallowed the investigation from exploring the children with more extreme positive or negative reactivity scores. The percentage of children exposed to socioeconomic adversities, such as poverty and crowding, at each time point was quite high such that there was a lack of variability in the sample's distribution which may underestimate our results.

Despite the various measures of adversity, there are likely to be other potential confounders or covariates not included in this investigation and other studies. Future studies of Latino families should explore the impact of neighborhood danger and cohesion, school environments, parent psychopathology, parental involvement and warmth, and cultural orientation or ethnic identity on children's functioning. Finally, the findings from this sample cannot be generalized beyond populations of impoverished, Latino populations living in the US.

Further studies with children experiencing a range of socioeconomic adversities or with purposive samples, using an extreme groups approach to contrast children from high and low socioeconomic families, might indicate larger effects of disadvantage on ANS reactivity in young children [70]. Future studies should include standardized specific laboratory challenges that are salient to the concepts being studied and related to the understanding of predicting which children are at risk for developing externalizing behavior problems. Further emphasis on protective factors should be explored with more sensitive measures of maternal-child relationships.

Conclusions

This investigation extends our understanding of the developmental interconnections between socioeconomic adversity, physiological responses, and psychosocial adjustment problems by focusing on a highly vulnerable and understudied population, Latino children growing up in the face of multiple socioeconomic adversities.

Latinos are the fastest growing minority population in the US and they comprise the largest majority of youth in California. It is important that we understand the adversities young Latinos face and how they respond to these challenges as such adversities can directly influence their health and well-being.

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