ENVIRONMENTAL IMPACT ON RESILIENCE TO TRAUMATIC LIFE EVENTS IN CHILDREN FROM THE ABCD STUDY

BY

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Abstract

Objectives: This study aims to identify which environmental factors are significantly associated with resilience and which maintain significance after accounting for complex ecological interactions. **Methods**: Data from 6,748 children aged 9-10 years were analyzed from the Adolescent Brain Cognitive Development (ABCD) Study. Resilience was operationalized using the residual method, quantifying variance in mental health outcomes unexplained by trauma exposure. From 327 environmental variables across 13 domains, 68 key variables were identified through exploratory factor analysis. Analytical approaches included univariate mixed-effects linear regression and Gaussian Graphical Model (GGM) network analysis with data partitioned into discovery (n = 4,498) and holdout (n = 2,250) datasets. **Results**: Twenty-two environmental factors showed significant associations with resilience in the discovery dataset, with 15 confirmed in the holdout dataset. Parental characteristics demonstrated the strongest associations: parental internalizing (β = -0.500), parental externalizing (β = -0.472), parental mental health history (β = -0.461), and parental strength (β = 0.379). Network analysis revealed only five factors directly associated with resilience, with just three (parental internalizing, subjective school environment, and parental ages at childbirth) demonstrating statistically stable connections. Insurance and care and family socioeconomic status emerged as central nodes integrating numerous environmental influences. **Conclusion**: The family microsystem, particularly parental mental health, constitutes a crucial influencing aspect in developing childhood resilience. The complex interplay between environmental factors underscores the need

for multilevel interventions targeting parental mental health support, school environment enhancement, and structural factors like healthcare access and socioeconomic inequalities to promote resilience in children facing adversity.

Keywords: Childhood resilience; Trauma; Environmental factors; Parental mental health; Ecological systems; Network analysis.

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Thesis Submission Declaration Form

THE EDUCATION UNIVERSITY OF HONG KONG
Department of Psychology
Thesis Submission Declaration Form

Student Name: ZHONG Jiajia
Student No.:
Title of Thesis: Environmental Impact on Resilience to Traumatic Life Events in Children from the ABCD Study
Course: PSY4075 Scientific Study in Psychology II: Honours Project
Programme: Bachelor of Social Sciences (Honours) in Psychology [BSocSc(Psy)]
Name of Supervisor: Dr. WONG Ting Yat

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1. Introduction

Resilience is a capability for positive adaptation to adversity that helps individuals recover from suffering and trauma, improving mental health and personal well-being (Kalisch et al., 2017). Developing resilient communities and global populations enables better risk management and resource utilization, making resilience important for both individuals and humanity as a whole (Ungar, 2011). From a developmental psychology perspective, the development of resilience during childhood has profound implications for shaping adolescent and lifelong resilience, as childhood represents a critical sensitive period for brain development and neuroplasticity, where early-formed self-regulation systems, coping strategies, and adaptation patterns constitute the foundational structure of ongoing resilience (Silk et al., 2007; Masten & Barnes, 2018). Furthermore, childhood resilience has significant importance for children's own mental health development. Research shows that even when facing major challenges, some children demonstrate extraordinary resilience, maintaining positive social connections and actively solving problems (Llistosella et al., 2022). In practical terms, this early-formed resilience manifests as better academic performance, healthier interpersonal relationships, and lower risk of anxiety and depression when facing developmental challenges (Silk et al., 2007; Masten, 2013).

Children's mental health has consistently been a focal point for society, with the global prevalence of mental disorders among children and adolescents reaching as high as 15% (World Health Organization, 2024). Traumatic life events in childhood are defined as occurrences that pose serious threats or harm to children and potentially lead

to long-term psychological and emotional consequences. These events may include direct experiences or witnessing incidents involving actual or threatened death, serious injury, or sexual violence (Hovens et al., 2015). Adverse childhood experiences and trauma, particularly those associated with maladaptive family functioning, are highly prevalent and constitute major predictors of childhood and adolescent mental disorders (McLaughlin et al., 2012; Hughes et al., 2017). Notably, childhood adversities account for 29.8% of all mental disorders across countries, and their elimination is projected to reduce the prevalence of mood, anxiety, behavioral, and substance disorders by 22.9-41.6% (Kessler et al., 2010). Furthermore, the co-occurrence of multiple adverse factors exhibits a sub-additive effect, whereby their combined impact is less than the sum of their individual effects, suggesting a pervasive vulnerability (Kessler et al., 2010). However, resilience serves as a key protective factor that may mitigate the negative impacts of childhood trauma. By fostering resilience, children can potentially develop the psychological resources necessary to cope with and recover from traumatic experiences, thereby preventing the development of mental disorders (Masten, 2013).

Resilience has been defined as a proactive, dynamic, and adaptive process constructed during or after exposure to significant stress (Kalisch et al., 2017). It represents an individual outcome in the relationship between traumatic experiences and mental health, with emphasis on children's strengths within the context of risk (Fergus & Zimmerman, 2005; Masten & Barnes, 2018). In contrast, some studies conceptualize resilience as a trait—a stable characteristic inherent to the individual (Luthans et al., 2007). However, this trait approach may inadequately explain variations in resilience

across time and different environments, potentially limiting understanding of how resilience develops and can be enhanced (Kalisch et al., 2017). Therefore, adopting a dynamic, process-oriented definition enables a more comprehensive examination of factors influencing resilience. Within this framework, the residual method has emerged as a valued statistical approach due to its utility in quantifying resilience and measuring its levels (Cahill et al., 2022). Specifically, resilience is quantified as the difference between predicted and actual mental health status after experiencing traumatic life events.

According to Bronfenbrenner's ecological systems theory, individual mental health and well-being are shaped by complex interactions among multiple environmental systems (Bronfenbrenner, 1979). As children, especially during the period from late childhood to early adolescence (approximately 9-11 years old), are in a critical period of cognitive and emotional development, and social skill acquisition, they exhibit particular susceptibility to environmental influences (Batra, 2013; Eschenbeck et al., 2018; Zimmer-Gembeck & Skinner, 2011). Consequently, childhood resilience is influenced by direct and indirect environments in which they function, including peers, family, school, community, and culture (Ungar, 2008; Masten & Barnes, 2018). Through systematic integrative research, Llistosella et al. (2022) proposed the Individual and Environmental Resilience Model (IERM), identifying over 60 protective factors spanning family support, school engagement, positive peer relationships, and individual-level self-regulation and cognitive abilities. However, most studies and existing models focus primarily on associations between individual

environmental factors and childhood resilience, with insufficient attention to the transmission pathways and strength of complex interactions among different environmental factors affecting childhood resilience. Thus, the mechanisms by which environmental factors influence childhood resilience remain incompletely understood, representing a significant research gap.

Therefore, examining the complex interplay between environmental factors and childhood resilience will enhance theoretical understanding of resilience mechanisms and provide more targeted strategies for effectively preventing and intervening in the negative impacts of childhood adversity on mental health, while also providing critical theoretical support for promoting psychological well-being in children. Moreover, systematically identifying protective and risk factors in the environment has substantial practical significance for urban planning and development, contributing to the creation of environments more conducive to childhood resilience. Given these considerations, to address this core issue, the present study aims to investigate the impact of environmental factors on childhood resilience, with particular emphasis on examining both the independent and interactive effects of these factors.

1.1 Research questions and hypotheses

Building upon the identified research gaps and the theoretical framework discussed above, this study employs Bronfenbrenner's ecological systems theory and the Individual and Environmental Resilience Model (IERM) to examine the complex relationship between environmental factors and childhood resilience. Specifically, the present study addresses the following research questions:

Research Question 1: Which environmental factors are significantly associated with resilience among children who have experienced traumatic life events?

Research Question 2: Which environmental factors maintain significant associations with resilience after accounting for the complex interactions between various environmental components within the ecological system?

Based on the theoretical framework and prior empirical evidence, this study proposes the following hypotheses:

Hypothesis 1a: In children who have experienced traumatic life events, resilience will be positively associated with both proximal protective factors and broader environmental resources.

Hypothesis 1b: Risk factors within the ecological environment, including increased family conflict, parental psychopathology, adverse neighborhood conditions, and perceptions of lower neighborhood safety, will be negatively associated with children's resilience levels.

Hypothesis 2a: The interaction between family and neighborhood environmental factors will significantly influence children's resilience, with multiple protective factors demonstrating synergistic effects that exceed the sum of their individual contributions to resilience.

Hypothesis 2b: Protective family environmental factors will moderate the relationship between adverse neighborhood conditions and resilience, such that strong family protective factors will buffer against the negative impact of high-risk neighborhood environments on children's resilience.

2. Methodology

2.1 Study design and data source

This study analyzed baseline data from the publicly available Adolescent Brain Cognitive Development (ABCD) Study, a large multi-site, longitudinal project that recruited 11,878 children aged 9–10 years from 21 sites across the United States between 2016 and 2018 (Garavan et al., 2018). Participants included in the present analysis had complete data on environmental factors, mental health measures, and childhood adversity.

2.2 Outcome: resilience

2.2.1 Mental health

The "Total Problems" score from the Child Behavior Checklist (CBCL), completed by parents or primary caregivers, was used to assess children's mental health status (Achenbach & Rescorla, 2001). This scale generates T-scores across several key dimensions, including Internalizing Problems, Externalizing Problems, and the Total Problems score which was our primary focus.

2.2.2 Childhood trauma experiences

To measure children's exposure to adverse experiences, we employed the Kiddie Schedule for Affective Disorders and Schizophrenia for DSM-5 (KSADS-5) (Hoffman et al., 2019). This comprehensive semi-structured interview captured various traumatic events in children's lives, from physical and sexual abuse to emotional neglect and violence exposure. What makes the KSADS-5 particularly robust is its integration of both child self-reports and caregiver perspectives. We quantified trauma exposure by

tallying responses across 17 specific trauma-related items (questions 754-770), with scores starting at 0 for children reporting no trauma. This cumulative approach allowed us to create a gradient measure where higher scores reflected more extensive trauma exposure.

2.2.3 Resilience

We operationalized resilience through the residual method, which is a statistical approach that quantifies the variance in mental health outcomes unexplained by adversity exposure (Cahill et al., 2022). Our analytical procedure involved constructing a linear regression model wherein mental health symptomatology served as the outcome variable and childhood trauma exposure as the predictor. The resultant residual values from this regression equation constitute our empirical score of resilience. Positive residuals (or less negative values) represent individuals demonstrating better-than-predicted mental health functioning relative to their trauma exposure history, thus indicating greater resilience.

2.3 Environmental factors

This study analyzed a total of 327 environmental variables, which were obtained by excluding 17 variables directly related to trauma experience calculation from an initial set of 344 environmental variables extracted from the ABCD dataset. These 327 variables represented various ecological factors influencing child development, covering 13 domains: Amenities and Services, Community Health Care, Developmental History, Family Values, Laws and Policies, Neighborhood Environment, Neighborhood Safety, Neighborhood Socioeconomic Status, Parental Psychopathology,

Pollution, School Environment, Family Socioeconomic Status, and Urbanization. An exploratory factor analysis (EFA) was then performed to reduce dimensionality and identify 68 key variables that adequately capture the principal dimensions of environmental influence, which were used for all subsequent analyses (Yong & Pearce, 2013).

2.4 Data preprocessing

Data preprocessing was carried out in the R environment (version 4.3.1) using packages such as tidyverse, here, tidymodels, and missForestPredict (Wickham et al., 2019; Müller, 2020; Kuhn, & Wickham, 2020; Stekhoven & Bühlmann, 2012). Our data preprocessing protocol followed a multi-stage refinement approach. Initially, we implemented systematic missing data management by recoding non-standard response codes (specifically 777 and 999) as missing values. To minimize the impact of incomplete records on analytical integrity, we applied an exclusion criterion whereby participants with missing data exceeding 10% were removed from the analytic sample. Furthermore, to address potential violations of statistical independence assumptions, we employed a household-level sampling strategy—when multiple siblings or co-residents were identified within the dataset, a single participant was randomly selected to represent each household unit.

Neuroimaging data underwent rigorous quality control in accordance with established ABCD Study protocols (Hagler et al., 2019). We restricted our analyses to baseline assessments (eventname "baseline_year_1_arm_1") and applied comprehensive inclusion criteria for both T1-weighted and resting-state fMRI data.

These criteria encompassed satisfactory performance on raw quality metrics, FreeSurfer structural imaging quality control, and various automated post-processing parameters. Following the preprocessing approach of another project studying exposome and functional brain relationships, we applied these exclusion criteria to ensure consistency across projects, allowing for more reliable integration of findings. We further excluded participants whose scans revealed clinically significant neuroradiological abnormalities that either compromised reliable interpretation or necessitated clinical intervention. This multi-tiered filtering process yielded an analytical cohort of 6,748 participants.

For validation purposes, we implemented a data partitioning strategy wherein subjects were randomly allocated in a 2:1 ratio to create discovery (n = 4,499) and holdout (n = 2,249) datasets. The discovery dataset served as our primary analytical sample and facilitated the development of a missForest-based imputation framework (Stekhoven & Bühlmann, 2012). This non-parametric approach employs random forest algorithms to iteratively predict missing values based on observed data patterns across variables until convergence criteria are satisfied. To maintain methodological consistency, we subsequently applied the imputation model derived from the discovery dataset to the holdout sample, which functioned as an independent validation cohort for our analytical pipeline.

2.5 Understanding dynamics between environmental factors and the outcome

Our analytical framework comprised several complementary statistical approaches. We began with univariate mixed-effects linear regression analyses to

examine associations between individual environmental factors and resilience (Gelman & Hill, 2007). These models incorporated fixed effects for environmental variables while accounting for site-specific random effects in the hierarchical data structure. Each regression specified resilience scores—operationalized as residuals from mental health-trauma exposure regressions—as the dependent variable, with individual environmental factors serving as predictors alongside demographic covariates (age, gender, and race). To address data clustering by research site, we included a random intercept term (site_id_l) and implemented Bonferroni correction to mitigate inflation of Type I error rates resulting from multiple comparisons (Bland & Altman, 1995).

We employed a cross-validation strategy wherein predictors identified in the discovery cohort underwent secondary evaluation in the holdout dataset (James et al., 2013). Notably, all discovery-derived predictors were retained for subsequent network analyses irrespective of their statistical significance in the holdout dataset to ensure comprehensive environmental factor assessment.

To characterize the complex interdependencies among environmental factors and resilience, we constructed a Gaussian Graphical Model (GGM) network (Hevey, 2018). Given the normal distribution approximation of our resilience scores, GGM provided an appropriate framework for modeling conditional relationships among variables. Considering our substantial sample size (N>1000), we implemented an unregularized model selection approach using the ggmModSelect function (qgraph package, version 1.9.1), which constrains model complexity and prioritizes robust connections while minimizing spurious associations potentially arising from high

statistical power (Williams & Rast, 2020; Isvoranu & Epskamp, 2023). We calculated centrality to identify environmental factors exhibiting the greatest network influence.

The network's stability was evaluated through both case-wise and non-parametric bootstrapping procedures using the bootnet package (Epskamp, Borsboom, & Fried, 2018). These resampling techniques yielded confidence intervals for edge weights and centrality indices, allowing assessment of the network's robustness against sampling variations.

2.6 Data and code availability

The ABCD Study dataset utilized in this research is publicly available through the National Institute of Mental Health (NIMH) Data Archive (https://nda.nih.gov/abcd). The specific dataset used was Release 5.1 (DOI: 10.15154/1523041).

3. Results

3.1 Participant

Numerical values with ± represent the mean and standard deviation. A total of 6748 participants (male: n = 3437, age = 119.18 ± 7.41 months; female: n = 3311, age = 119.18 ± 7.41 months) were included after applying the exclusion criteria. Table 1 shows that age, gender, race, and resilience were similar in the discovery (n = 4498) and holdout (n = 2250) datasets (Table 1, ps > 0.05).

Table 1.

Summary Statistics of the Discovery and Holdout Samples

Characteristic	Overall, *N = 6748*	Discovery, *N = 4498*	Holdout, *N = 2250*	*p*-Value
Age (Mean)	119.18	119.11	119.31	0.300
Age (SD)	7.41	7.40	7.43	
Sex				0.290
Male (N)	3437 (51%)	2270 (50%)	1167 (52%)	
Female (N)	3311(49%)	2228 (50%)	1083 (48%)	
Race				0.529
White (N)	3618 (54%)	2390 (53%)	1228 (52%)	
Black (N)	920 (14%)	618 (14%)	302 (13%)	
Other (N)	2210 (33%)	1490 (33%)	720 (32%)	
Resilience (Mean)	0.00	0.02	-0.05	0.799
Resilience (SD)	10.87	10.92	7.43	

3.2 Generation of resilient scores

Regression analysis revealed a positive association between the number of traumatic life events experienced and CBCL total scores (Fig 1, $r = 0.207$, $p < 0.001$). The distribution of resilience scores approximated a normal distribution, with a mean centered near zero, indicating that most participants exhibited moderate resilience. A small proportion of individuals demonstrated notably high or low resilience scores. The interquartile range for resilience scores was -6.74 to 6.96 (Fig 2).

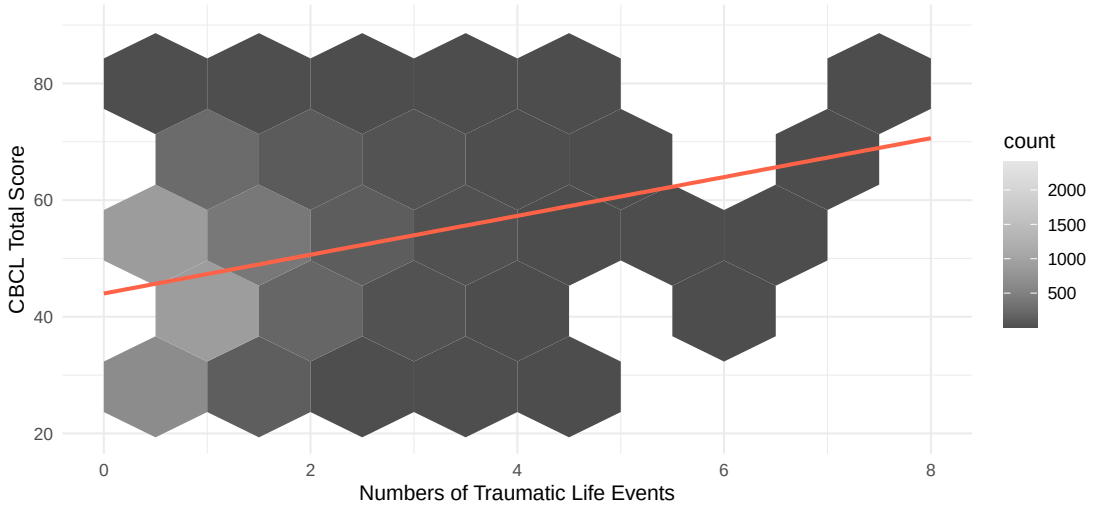

Figure 1: The Correlation of Numbers of Traumatic Life Events and CBCL Total Score

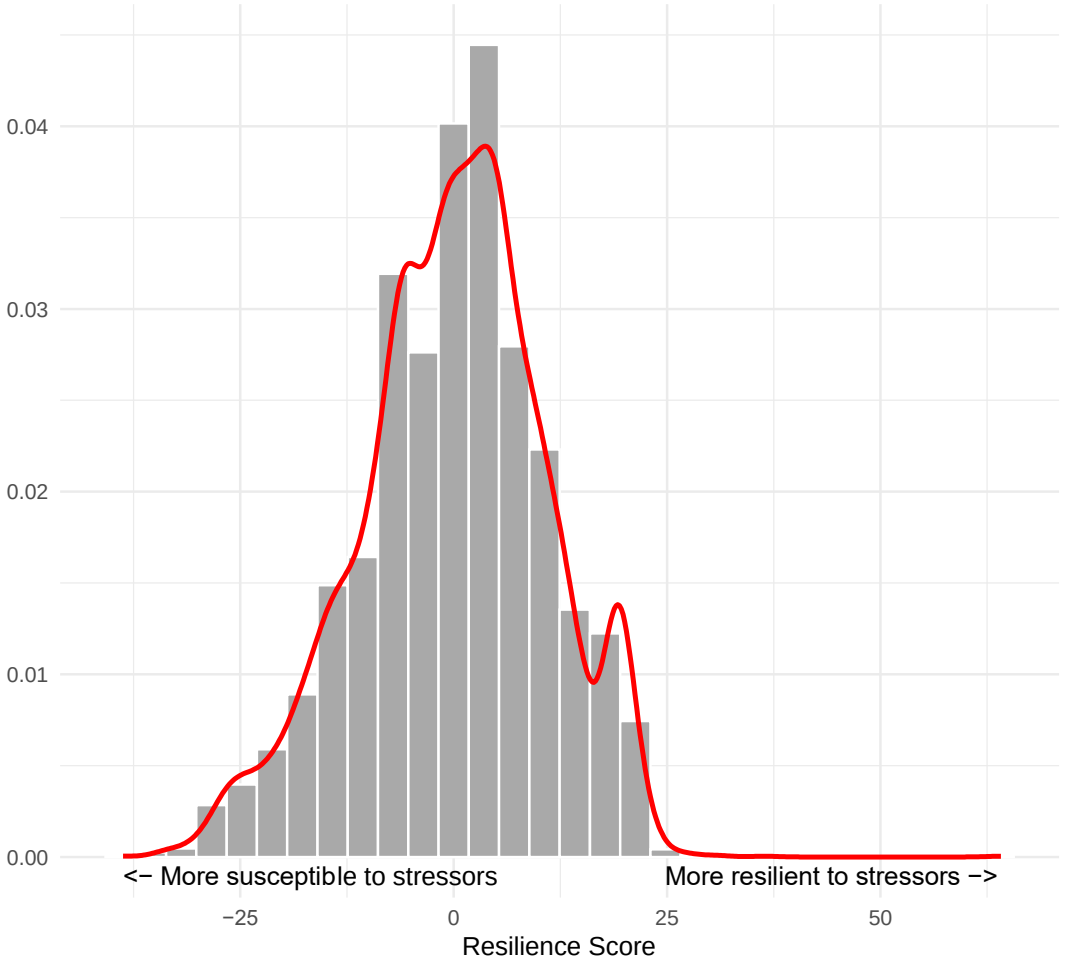

Figure 2: The Distribution of Resilience Scores

3.3 Environmental factors associated with resilience

Exploratory factor analysis identified 68 environmental factors that were subsequently analyzed using univariate mixed-effects linear regression. After applying Bonferroni correction, 22 environmental factors showed significant associations with resilience ($p < 0.05$) in the discovery dataset (Fig. 3, Table S1). Validation analysis in the holdout dataset confirmed significant associations ($p < 0.05$) for 15 of these environmental factors (Fig. 4, Table S2), demonstrating successful replication for a substantial proportion of the initially identified factors. The regression coefficients (estimates) represent the strength and direction of associations between environmental

factors and resilience, with positive values indicating positive associations and negative values indicating negative associations. The factors showing the strongest associations in both datasets were primarily parental characteristics: parental internalizing (discovery: β = -0.500, p < 0.001; holdout: β = -0.505, p < 0.001), parental externalizing (discovery: β = -0.472, p < 0.001; holdout: β = -0.462, p < 0.001), parental mental health history (discovery: β = -0.461, p < 0.001; holdout: β = -0.457, p < 0.001), and parental strength (discovery: β = 0.379, p < 0.001; holdout: β = 0.467, p < 0.001). Other factors significant in both datasets included postnatal adversities (discovery: β = -0.393, p < 0.001; holdout: β = -0.358, p < 0.001), substance use during pregnancy (discovery: β = -0.270, p < 0.001; holdout: β = -0.270, p < 0.001), neighborhood safety (discovery: β = 0.144, p < 0.001; holdout: β = 0.150, p < 0.001), and acceptance and monitoring (discovery: β = 0.165, p < 0.001; holdout: β = 0.150, p < 0.001). Subjective school environment also maintained significance across both datasets (discovery: β = 0.131, p < 0.001; holdout: β = 0.140, p < 0.001).

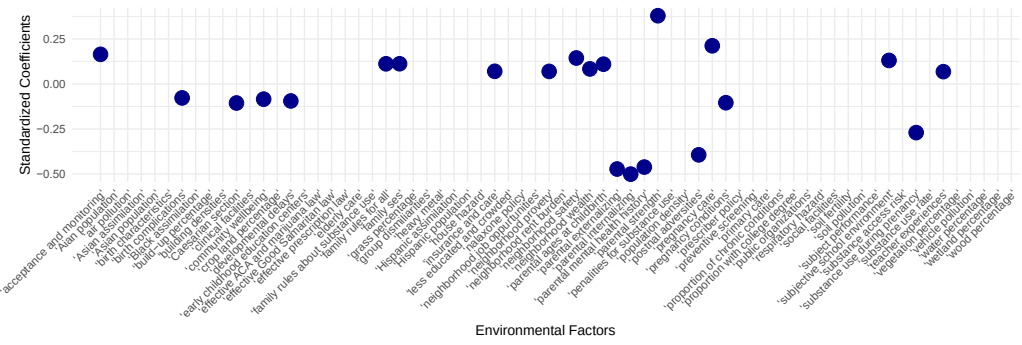

Figure 3: Significant Environmental Factors in the Discovery Dataset

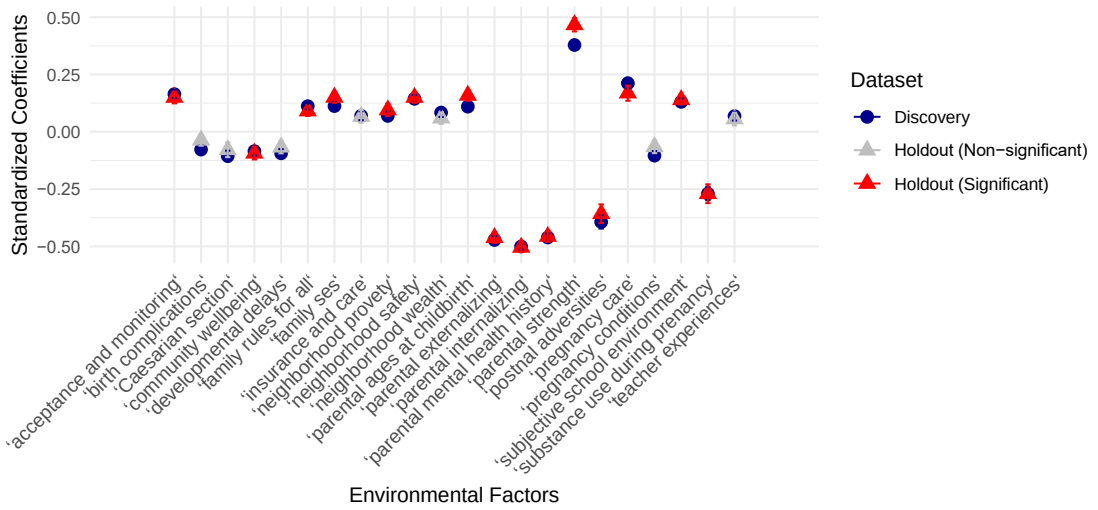

Figure 4: Explore Significant Variables on The Discovery Dataset Versus the Holdout Dataset

3.4 Dynamics between the outcome and factors

The univariate mixed-effects linear regression identified 22 significant factors among the 68 environmental variables. The estimated Gaussian Graphical Model (GGM) in Figure 5 illustrates the network relationships between the 22 factors (yellow nodes) and resilience outcomes (green nodes). Insurance and care access (ENV01) and family socioeconomic status (ENV22) emerged as central nodes in this network (Fig. S1). Table 2 illustrates five factors that showed direct associations with resilience: parental internalizing problems (ENV17), postnatal adversities (ENV10), pregnancy care quality (ENV06), subjective school environment (ENV13), and parental ages at childbirth (ENV04). Bootstrap stability analysis of edge strength indicated that only the connections from parental internalizing problems (ENV17), subjective school environment (ENV13), and parental ages at childbirth (ENV04) to resilience outcomes were statistically stable (Table 2). The strength centrality estimates remained stable across analyses, supporting the reliability of these findings (Fig. S2). The centrality

stability coefficient was 0.75 for both edge weights and expected influence, indicating that up to 75% of the data could be dropped while retaining a correlation of at least 0.7 with the original network estimates in 95% of the samples (Epskamp, Borsboom, & Fried, 2018).

Table 2.

The Nonparametric Bootstrapping Analysis Shows the Stability of Connected Nodes Between Environmental Factors and Outcomes

		Edge strength		
Node 1	**Node 2**	**Sample**	**Bootstrapped mean**	**Bootstrapped 95%CI**
Resilience	Parental Internalizing	-0.210	-0.209	-0.263, -0.157
Resilience	Postnatal Adversities	-0.089	-0.079	-0.128, 0.000
Resilience	Pregnancy Care	-0.073	-0.024	-0.091, 0.000
Resilience	Subjective School Environment	0.109	0.114	0.069, 0.157
Resilience	Parental Ages at Childbirth	0.114	0.094	0.045, 0.149

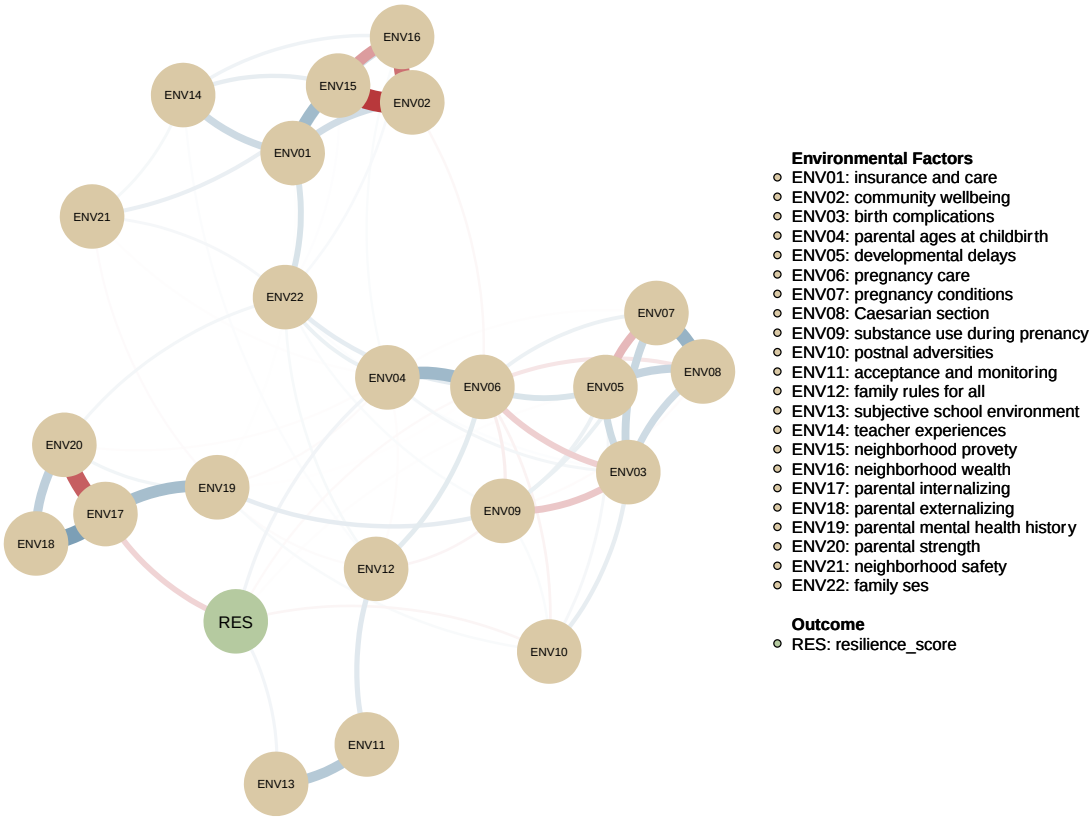

Figure 5: The Interactions between Outcomes (Green Nodes) and Features (Yellow Nodes) Estimated by GGM

4. Discussion and Conclusion

Drawing upon a large sample from the ABCD study, the influence of environmental conditions on resilience to traumatic life events in children was examined. The residual method corroborated a significant correlation between trauma and mental health challenges. Resilience scores were approximately normally distributed, with most children showing moderate resilience and fewer exhibiting either high susceptibility or exceptional resilience.

Univariate mixed-effects linear regression analysis substantiated the hypotheses: protective variables (parental strength, neighborhood safety, acceptance and monitoring, subjective school environment) were positively associated with resilience; risk variables, notably parental internalizing, parental externalizing, and parental mental health history, exerted the most pronounced negative impact, followed by postnatal adversity and substance use during pregnancy. This suggests that the family microsystem, specifically parental mental health, constitutes a crucial determinant in the development of resilience in children.

Network analysis showed that only five of the 22 highly engaged factors were stably and directly related to resilience to trauma, and among these, three (parental internalizing, subjective school environment, and parental ages at childbirth) were robustly validated through a bootstrap analysis. Dense connectivity was observed between environmental factors, with insurance and care and family socioeconomic status functioning as prominent central nodes, integrating numerous factors into a cohesive group. Although a direct moderating effect of family protective factors on

community risks was not observed, the network structure revealed intricate pathways of influence within systems.

4.1 Significant environmental factors in linear regression

4.1.1 Parental mental health characteristics and child resilience

The present research reveals a robust and significant association between parental mental health characteristics and child resilience. Parental Internalizing was significantly associated with resilience in children, showing the strongest inverse correlation. This aligns with the findings of Dubowitz et al. (2016), who reported that reductions in depressive symptoms among caregivers were frequently followed by increased resilience in children. Simultaneously, our study found that parental mental health history was also significantly negatively correlated and moderately affected child resilience. These imply that parental internalizing symptoms may influence child resilience through multiple mechanisms: transmission of genetic predispositions, acquisition of cognitive-affective patterns via social learning, and family environmental reorganization resulting from parental internalizing, such as heightened marital conflict and diminished parent-child interaction quality (Goodman & Gotlib, 2002). For instance, mothers experiencing depression often exhibit negative thought patterns, actions, and feelings, which can hinder their ability to offer stable emotional support and react sensitively to their children's needs (Barnett et al., 2015). These detrimental parenting practices can directly affect a child's ability to form secure attachments and negatively impact their cognitive and emotional growth, ultimately contributing to lower resilience (Toth et al., 2009).

Our analyses revealed a robust negative correlation between parental externalizing and resilience, with this factor demonstrating the second highest influence magnitude following internalizing symptomatology. This finding corresponds with empirical work by Pilowsky et al. (2004) and Iacopetti et al. (2019), which suggests that children exposed to parental externalizing issues tend to have lower self-efficacy and self-esteem, as well as more negative attitudes toward the future. These psychological resources are essential for building resilience, as they influence children's coping mechanisms, stress appraisal, and emotional control. Reduced self-efficacy can limit a child's use of effective coping strategies when facing difficulties, while negative self-perceptions may lead them to view stress as a threat rather than a challenge, and impair their ability to manage emotions effectively (Saltzman & Holahan, 2002; Chesney et al., 2006). Parents having externalizing problems are prone to employing ineffective parenting styles and may expose their children to more adverse life events, thereby impeding the acquisition of their resilience (Pilowsky et al., 2004; Iacopetti et al., 2019).

Notably, parental strength was the only parental characteristic variable that maintained a robust positive correlation with resilience. Parents' positive attributes, strengths, and behaviors appear to furnish children with beneficial resources for coping with adversity. Parents' positive relationship style, active coping strategies, and capacities for emotional regulation, as identified by Morris et al. (2007) and Epstein (2010), not only contribute directly to a supportive environment but are also internalized by children through daily interaction, enhancing their resilience to manage

adversities.

These findings collectively indicate a key tenet: the family microsystem, specifically the mental health status of parents, is a foundational cornerstone for developing child resilience. This implies that interventions centered on families need to simultaneously alleviate parental mental health burdens and foster their strengths to effectively augment the development of children's resilience.

4.1.2 Early life developmental environmental factors

Early developmental environments also exert a powerful impact on child resilience. Postnatal adversity was found to have a moderate negative correlation with child resilience, consistent with the hypothesis advanced by Feldman (2020), who established that adversity experienced early in life that disrupts the mother-infant relationship has the potential to undermine the child's ability to develop primary psychological functions, such as social competence, empathy, and emotional regulation, by affecting the development of the child's nervous system. This concurs with the findings from Rincón-Cortés and Grace's (2021) rat model research, which emphasized the profound influence of early childhood parent-child interaction on neural plasticity.

Substance use during pregnancy likewise evidenced a moderate inverse relationship with resilience, consistent with existing evidence in the field of neurodevelopment. Behnke et al. (2013) indicated that substance exposure during pregnancy affects fetal neurodevelopment and physiological regulation systems, which ultimately has long-lasting negative consequences for cognitive, behavioral, and social function. This early disturbance of neurodevelopmental trajectory potentially limits the

resources available to children later in life in order to contend with adversity.

Conversely, pregnancy care exhibited a lower influence but still significant positive association with resilience in children. For instance, folic acid supplementation may indirectly maintain the normal development of children's cognitive and socio-emotional abilities by stabilizing DNA methylation and reducing the risk of adverse pregnancy outcomes, which is crucial for resilience (Lubinsky, 2018).

Parental age at childbirth presented a novel finding of a significant positive association with resilience, albeit small. Although direct evidence to support such a correlation is limited, Paananen et al. (2013) did find that children born to younger mothers (under 20 years old) had a greater prevalence of mental illness. Research by Camberis et al. (2016) and Veldkamp et al. (2021) offers a possible mediating factor: older parental age is likely to be accompanied by more mature parenting practices, more stable families, and improved socioeconomic resources. However, Waldenström (2016) also cautioned against the potential risks of advanced maternal age (above 35 years), reminding us that the relationship between parental age and child development might be an inverted U-shape, which warrants further examination in future research.

In the preliminary analysis, several other early development indicators (e.g., birth complications, cesarean, pregnancy conditions, and developmental delays) exhibited tentative links with resilience in the discovery sample, but these were not replicated in the holdout sample. This failure to replicate suggests that these variables might affect child resilience through more complex mechanisms or under specific circumstances, and their potential mechanisms merit further detailed examination in

future research.

4.1.3 Family values and parenting environment

The results indicate that parenting environments and family values are vital in the development of child resilience, although the magnitude of their effects is relatively modest. Acceptance and monitoring revealed a large positive correlation with resilience, reflecting the salutary effect of parenting styles that combine emotional support with appropriate monitoring. Research by Butterfield et al. (2021) and Cheraghian et al. (2023) demonstrates that when parents provide emotional nurturing and set appropriate boundaries, children are more likely to develop the bravery and self-protection skills to overcome obstacles. This finding aligns with the view of Llistosella et al. (2022) that family support as one of the protective resources for post-traumatic rehabilitation of the mind, and lends weight to Singh's (2017) argument that an authoritative parental style has a positive effect on child development.

Consistency of family rules for all also had a small positive correlation with resilience. The Thomson (2007) and Nameda et al. (2022) findings suggest that this can be attributed to generating a sense of fairness among family members, but the mechanism behind it requires further exploration. These findings collectively underscore the significance of the stability of a supportive family environment in children acquiring the ability to manage adversity.

4.1.4 School and community environmental factors

At the broader microsystem level, school and community environments also play a role in child resilience, albeit with generally smaller effect sizes. Subjective

school environment correlated positively and steadily with resilience, which aligns with Moreira et al. (2021) evidence that positive peer relationships and a supportive school climate can enhance children's subjective well-being and serve as a protective factor against adversity exposure.

Teacher experiences also showed potential for relationships to resilience in the discovery sample but could not be replicated in the holdout sample. Such inconsistency implies that these variables operate on child resilience through more insidious mechanisms or under specific conditions, suggesting avenues for future research.

Neighborhood safety's positive relationship with child resilience also supports Turner et al.'s (2006) argument that community threats, such as violence, drug abuse, and alcoholism, can potentially undermine children's sense of security, thereby affecting their development of resilience. Notably, it was found that the relationship of economic markers at the local level to resilience was more complex. Family socioeconomic status was indeed positively related to resilience, consistent with the results of Bruno et al. (2023); while neighborhood poverty was also positively related to resilience, which may reflect the ability of children who face adversity at an early stage of their lives to develop unique coping mechanisms, though the specific pathways of this relationship are yet to be examined extensively (Turner et al., 2006). Kim et al. (2019) and Engle and Black (2008) caution that although moderate adversity can be a source of resilience, the negative impact of chronic poverty in the community on children's development should not be underestimated.

The associations between insurance and care and neighborhood wealth with

children's resilience were significant in the discovery dataset but not replicated in the holdout dataset, suggesting these macro-environmental factors operate through complex indirect pathways with potential mediating and moderating mechanisms. For instance, better healthcare services may indirectly enhance children's resilience by facilitating parents' physical and mental health management, thereby influencing parent-child relationships (Levy et al., 2008; Nomaguchi, 2012; Wang & Xie, 2019). Neighborhoods characterized by higher socioeconomic advantage typically provide enhanced educational opportunities and superior social care resources, which indirectly contribute to children's cognitive and social developmental trajectories (Owens & Candipan, 2019). These observed associations highlight the methodological importance of implementing multilevel analytical frameworks in future investigations to characterize the complex interdependencies more accurately between macro-environmental contextual factors and individual-level developmental outcomes.

4.2 Network analysis

4.2.1 Direct environmental factors related to child resilience

Childhood is a critical period for developing cognitive, social skills, and emotional regulation that directly shape children's resilience (Housman, 2017; Llistosella et al., 2022). Network analyses confirm the status of parental internalizing as a key direct influence, indicating that parental internalizing may weaken resilience formation by negatively affecting children's cognitive and emotional competence development (Gladstone et al., 2021). Research has shown the existence of core cognitive vulnerabilities across diagnoses, such as a tendency towards negative

persistent thinking associated with uncertainty, which is closely linked to internalizing symptoms (Poh et al., 2021). These patterns can be passed on to offspring through social learning, influencing children's cognitive and emotional regulation development (Rosenthal & Zimmerman, 2014). At the same time, parental internalizing results in patterns of interaction that can impair the quality of the parent-child relationship and influence children's secure attachment (Guild et al., 2021). These findings suggest that combining treatment for parental internalizing with enhancing the quality of parent-child interactions may be more effective than a single intervention in promoting children's resilience development.

Subjective school environment showed stable direct positive associations in network analyses, albeit with relatively small effect sizes in linear regressions. This suggests that supportive school environments can protect the development of children's key competencies. Schools serve as important microsystems in children's lives, providing social contexts and developmental opportunities beyond the family (Bronfenbrenner, 1979; Neal & Neal, 2013). A longitudinal study has found that close, supportive relationships with teachers enhance children's resilience (Miller-Lewis et al., 2013). Positive peer interactions provide children with a social support network and a field for practicing social skills (Coleman et al., 2017), while a good sense of belonging at school contributes to improved socio-emotional health and reduced isolation (Palikara et al., 2021). Given the wide accessibility of school interventions, this factor represents a focus for public health interventions, especially for children with limited family resources, where the school environment may become a key compensatory

protective factor (Masten, 2018).

Interestingly, network analyses revealed a direct association between Parental ages at childbirth and child resilience, filling an important gap in current research. The established literature has mainly focused on the indirect effects of parental age on child development through socioeconomic conditions (Huurre et al., 2003; Settels, 2022). Our results indicate that there may be a direct mechanism of association between Parental ages at childbirth and child resilience that operates independently of socioeconomic factors. However, biologically, studies have shown that delayed childbearing is associated with an increased risk of neurodevelopmental deficits in children (Bergh et al., 2019). This complex relationship suggests that Parental ages at childbirth may influence child development through multiple pathways. Future research needs to explore the specific mechanisms and incorporate Parental ages at childbirth as an important indicator for assessing the environment in which children develop.

Postnatal adversity and pregnancy care, as early developmental environment factors, had weak edge strengths and confidence intervals containing zero in the network analyses, suggesting that they may indirectly influence child resilience through other nodes. For example, postnatal adversity may influence parental internalizing, which in turn affects the quality of parent-child interactions and the development of children's emotional regulation (Feldman, 2020; Rincón-Cortés & Grace, 2021; Guild et al.). Besides reducing neurodevelopmental risk through supplementation with essential vitamins, pregnancy care may also indirectly support children's resilience through the integration of prenatal mental health services. Monk et al. (2022) and

Wardoyo et al. (2023) note that prenatal mental health screening and interventions can improve parental (and especially mothers') mental health and parenting styles, thereby preserving children's cognitive and socio-emotional growth. This pattern of indirect effects suggests that early developmental environmental interventions need to consider multiple pathways and potential mediating mechanisms, rather than focusing solely on direct effects.

4.2.2 Network structure of parental variable clusters

The edge strength analyses showed that parental mental health-related factors were more important than other environmental factors on children's resilience. Among all parent-related characteristics, only parental internalizing was directly connected to resilience. Parental externalizing, parental mental health history, and parental strength, while significantly associated with resilience in linear regressions, only indirectly influenced resilience through their strong connections with Parental Internalizing within the network. This indicates that Parental Internalizing may be a central pathway through which parental mental health influences children's resilience.

After controlling for other parent-related characteristics, there was a significant positive correlation between parental externalizing and internalizing problems. This suggests that exacerbation of parental externalizing may weaken children's resilience by increasing internalizing problems. This is consistent with existing research, such as animal studies that have found that substance abuse can lead to symptoms such as anxiety, depression, and other similar symptoms, by altering brain structure and functioning, and influencing neurotransmitter systems (Edwards & Koob, 2011).

However, there may be a bidirectional relationship between externalizing and internalizing problems, such as alcohol abuse increasing the risk of negative affect and depression, while depressed individuals may consistently use alcohol to relieve negative affect (Hussong et al., 2011). Given that GGM analyses revealed partial correlations between variables, we hypothesized that parental externalizing and parental internalizing might form mutually reinforcing cycles. Thus, interventions targeting parental externalizing may indirectly reduce the effects of internalizing problems on children's resilience.

Parental mental health history was positively associated with internalizing problems, implying that past mental health conditions may be an important risk factor for current internalizing problems, reflecting the longitudinal nature of mental health problems. One possible explanation is that past mental health problems may involve relatively stable cognitive patterns, such as negative attributional styles and rumination, which tend to persist (Alloy et al., 2006; Hu et al., 2015). Another possible explanation is that prior mental health problems may lead to adaptive changes in the nervous system, such as increased reactivity of the amygdala to stressors, and diminished top-down regulation of the amygdala by the prefrontal cortex, which disrupts the balance of emotion regulation circuits (Laeger et al., 2012; Roseman et al., 2018; Andrewes & Jenkins, 2019). In addition, past mental health problems may impair important social relationships and functional performance, creating more stressful situations and a vicious cycle of self-perpetuation (Hansen et al., 2017). Together, these factors increase susceptibility to internalizing problems and ultimately impact child resilience by

influencing parent-child interactions. This highlights the importance of early identification and intervention for parents with a history of mental health.

Parental strength was the only factor significantly and negatively associated with Parental internalizing, implying that it may act as a key protective resource to indirectly enhance offspring resilience by buffering parental internalizing. From a cognitive and emotional regulation perspective, higher psychological resources enable parents to adopt more adaptive cognitive appraisal frameworks and positive coping strategies, reducing negative avoidance and rumination tendencies (Naragon-Gainey & Watson, 2018; Gladstone et al., 2011). Biologically, greater psychological resources have been associated with more optimal stress response system functioning, such as healthier cortisol secretion patterns, which may be related to fewer internalizing problems (Vargas-Uricoechea et al., 2024). This buffering effect of parental psychological resources on internalizing problems is transmitted to child resilience development through improved parent-child interactions, implying that future interventions should focus on enhancing parental psychological resources.

4.2.3 Macrosystem central nodes: structural support for promoting family functioning

Extending our perspective to the broader macrosystem, network centrality analysis identifies insurance and care and family socioeconomic status as central nodes within the environmental factor network. These factors are not only closely linked to other environmental factors but are also interconnected with family microsystem factors, highlighting the fundamental role of the macrosystem in supporting family

functioning and fostering children's resilient development. This pattern of cross-system connectivity supports Bronfenbrenner's (1979) view of ecosystem theory, in which different system levels interact through specific 'channels.'

Of particular note, the accessibility of mental health services within insurance and care is critical for children's resilience development (Anderson et al., 2015). Existing research suggests that access to adequate mental health services not only improves child mental health but also enhances family functioning by supporting parental mental health (Bai et al., 2009; Acri & Hoagwood, 2015). However, research shows that insurance coverage for mental health services is typically less comprehensive than physical health services, with significant service gaps (Walker et al., 2015; Anderson et al., 2015; Whitney & Peterson, 2019). This inequality in insurance coverage can lead to differences in resilience development between families, particularly affecting socioeconomically disadvantaged groups (Walker et al., 2015). In addition, public stigmatization of mental illness can create additional barriers to seeking services (Corrigan et al., 2014). Therefore, expanding insurance coverage for mental health services and enhancing public mental health education may be highly effective policy intervention points.

Family socioeconomic status is another central node in the developmental environment network, linking multiple family and environmental factors. This validates the Family Stress Model, which suggests that economic stress indirectly undermines parent-child interactions and children's adjustment through parental emotional distress and family conflict (Conger et al., 2010). Correspondingly, high SES families increase

educational resources and developmental opportunities to promote children's competence development through the 'family investment model' (Conger et al., 2010). According to Vukojević et al. in 2017, low SES environments have cumulative risk effects, with multiple risk factors, including barriers to healthcare access, lack of educational resources, and unsafe neighborhood environments, acting in concert to amplify adverse effects on child development. At the biological level, low SES is strongly associated with grey matter abnormalities in key regions of the child's brain, which may affect cognitive function and emotion regulation (Vukojević et al., 2017). This emphasizes the need for macro-level policy interventions to reduce social inequalities and micro-support to enhance family resilience, with particular attention to early intervention in low-income families.

4.3 Strengths

4.3.1 Methodological advantage

This study has significant methodological strengths that enhance the reliability and validity of the findings. We utilized the extensive sample data from the ABCD study (N=6748) while employing a data-driven approach to predictor selection. Using factor analysis, we objectively identified latent constructs across multiple domains while systematically addressing multicollinearity (Yong & Pearce, 2013). Missing data were handled through machine learning-based imputation methods that minimize selection bias (Stekhoven & Bühlmann, 2012). We also implemented a rigorous cross-validation strategy by dividing the data into discovery and holdout datasets, which substantially reduced the risk of false positive findings and overfitting (Wong et al., 2023). The

residual method provides a quantitative estimate of resilience derived from statistical modeling, in contrast to scale-based measures (Cahill et al., 2022). Mixed-effects modeling appropriately accounted for the hierarchical data structure across study sites. Of particular importance, our application of Gaussian Graphical Model (GGM) network analysis offers unique advantages compared to traditional linear regression. This approach allows for the simultaneous consideration of conditional dependencies among environmental factors (Hevey, 2018). By estimating partial correlations and distinguishing between direct and indirect associations, it reveals that only a few factors are directly associated with resilience. In addition, the method identifies key central nodes as integrative hubs. We also augment the reliability of our findings with bootstrap analyses. Together, these methodologically rigorous approaches build a robust analytical framework that provides a more nuanced, multilevel understanding of the mechanisms of resilience development.

4.3.2 Theoretical innovations

This study makes an important theoretical contribution to the understanding of the complex drivers of children's resilience by comprehensively assessing environmental factors across multiple ecosystems, from microsystem parent-child interactions to macro-level socioeconomic factors. The findings strongly support the core assumptions of Bronfenbrenner's ecosystem theory, particularly multilevel system interactions. Network analysis extends beyond traditional linear models, quantifying the complex interplay between systems, revealing that environmental factors influence resilience through complex pathways rather than simple direct associations

(Bronfenbrenner, 1979). Furthermore, our findings closely align with the Individual and Environmental Resilience Model (IERM) proposed by Llistosella et al. (2022) and extend the model's application to children exposed to trauma. In particular, we quantify the strength of the interrelationships between different environmental factors and identify key pathways of influence, deepening our understanding of how environmental factors collectively shape resilience processes and providing an empirical foundation and a novel integrative perspective on resilience theory.

4.3.3 Practical application

Our study found that parental mental health, particularly internalizing problems, has a central and direct impact on children's resilience, providing strong evidence for the importance of the family microsystem. The study highlights the importance of parental mental health support, and practice recommendations include integrating parental mental health screening into children's healthcare services and developing support programs for high-risk parents. Furthermore, the direct positive effect of the perceived school environment on resilience suggests that schools can serve as a key intervention site, particularly for children with limited family resources. The results support the creation of multilevel support systems that integrate family, school, and community resources, underscoring the ecosystemic nature of resilience development. Network analysis identifies insurance coverage, access to care, and family socioeconomic status as central nodes, highlighting key intervention targets at the macro-system level. Policy-level recommendations include improving access to health care, enhancing family economic support, reducing social inequalities, and integrating

resilience promotion into public health frameworks. These recommendations recognize the important role of social structural factors in shaping children's resilience.

4.4 Limitations

Despite the multifaceted strengths of this study, there are several important limitations to consider when interpreting the results.

4.4.1 Study design

The cross-sectional design of this study did not allow for the establishment of causal relationships or developmental trajectories between environmental factors and resilience. The observed associations may reflect bidirectional influences or be attributable to common underlying factors, rather than representing unidirectional effects. In addition, although the sample size was large and diverse, it was limited to children aged 9-10 years, limiting the generalizability to other developmental stages. The operationalization of resilience, although employing a residual approach, had limitations in statistical rigor. Specifically, the combined dataset was used for quantification without separating the holdout dataset.

4.4.2 Variable measurement

While this study used traumatic life events as an indicator of adversity, it did not account for children's perceptions of chronic everyday stress, which is essential for a comprehensive understanding of resilience (Ahrens et al., 2024). Additionally, despite our comprehensive assessment of environmental factors, important unmeasured variables may still be overlooked. While necessary for analytical tractability, the dimensionality reduction methods employed may have obscured nuanced associations

between environmental characteristics and resilience.

4.4.3 Results interpretation

The significant effect of parental age at childbirth on resilience is a novel finding that needs the underlying mechanisms explored in further studies. Notably, some of the extreme values observed in the resilience scores may not be well explained by environmental factors alone, which suggests that genetic predispositions, neurodevelopmental traits, or other biological factors may play an important role, yet these elements have not been examined in this study. The cross-cultural applicability of the findings needs to be approached with care, as there may be differences in the way environmental factors shape children's resilience in different cultural contexts.

4.5 Future direction

Future research should employ longitudinal designs to establish causal relationships and developmental trajectories, incorporating measures of both traumatic events and children's perceptions of chronic everyday stress. Studies should examine the complete resilience process by investigating how environmental factors influence genetic expression and neurobiological functioning that shape resilience outcomes, particularly for explaining extreme resilience values beyond environmental factors alone. Cross-cultural applicability requires further examination, with potential adaptations to Chinese contexts including Hong Kong, where cultural values may uniquely influence resilience development (Greenfield & Cocking, 2014). These efforts could ultimately contribute to more effective, contextually informed interventions to promote positive adaptation in children facing adversity.

4.6 Conclusion

In summary, this study provides important insights into how environmental factors across multiple ecological systems influence children's resilience to traumatic life events, drawing upon data from a large sample in the ABCD study. Our findings reveal that parental mental health characteristics, particularly internalizing problems, exert the most significant direct influence on children's resilience, while subjective school environment and parental ages at childbirth also emerged as stable direct contributors. Network analysis identified complex interrelationships between environmental factors, demonstrating that insurance and care access along with family socioeconomic status function as central nodes integrating numerous environmental influences. The practical implications suggest a multi-level approach to promoting resilience in children through interventions targeting parental mental health, enhancing supportive school environments, and implementing policies addressing healthcare access and socioeconomic inequalities.

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Appendix

Table S1.

Discovery Dataset Environmental Factors Correlation Analysis Results

term	estimate	std.error	statistic	p.value	p_adj
'pregnancy care'	0.2119	0.0234	9.06	0.0e+00	0.0e+00
'substance use during prenancy'	-0.2698	0.0293	-9.21	0.0e+00	0.0e+00
'postnal adversities'	-0.3933	0.0292	-13.48	0.0e+00	0.0e+00
'acceptance and monitoring'	0.1645	0.0179	9.18	0.0e+00	0.0e+00
'subjective school environment'	0.1307	0.0149	8.78	0.0e+00	0.0e+00
'parental internalizing'	-0.5004	0.0137	-36.46	0.0e+00	0.0e+00
'parental externalizing'	-0.4720	0.0163	-28.95	0.0e+00	0.0e+00
'parental mental health history'	-0.4612	0.0173	-26.65	0.0e+00	0.0e+00
'parental strength'	0.3786	0.0206	18.41	0.0e+00	0.0e+00
'neighborhood safety'	0.1441	0.0167	8.62	0.0e+00	0.0e+00
'family rules for all'	0.1119	0.0152	7.36	1.8e-13	1.2e-11
'family ses'	0.1121	0.0171	6.56	5.2e-11	3.5e-09
'parental ages at childbirth'	0.1098	0.0172	6.39	1.6e-10	1.1e-08
'pregnancy conditions'	-0.1040	0.0200	-5.19	2.1e-07	1.5e-05
'developmental delays'	-0.0943	0.0190	-4.96	7.2e-07	4.9e-05
'Caesarian section'	-0.1060	0.0234	-4.53	6.0e-06	4.1e-04
'birth complications'	-0.0774	0.0173	-4.47	7.8e-06	5.3e-04
'neighborhood wealth'	0.0837	0.0188	4.45	8.5e-06	5.8e-04
'community wellbeing'	-0.0845	0.0195	-4.33	1.5e-05	1.0e-03
'neighborhood provety'	0.0696	0.0191	3.64	2.8e-04	1.9e-02
'insurance and care'	0.0702	0.0196	3.58	3.4e-04	2.3e-02
'teacher experiences'	0.0683	0.0195	3.51	4.5e-04	3.1e-02
'Black assimilation'	0.0570	0.0191	2.98	2.8e-03	1.9e-01
'primary care'	0.0565	0.0199	2.85	4.4e-03	3.0e-01
'birth characteristics'	0.0571	0.0201	2.84	4.5e-03	3.1e-01
'proportion with college degree'	0.0620	0.0227	2.73	6.3e-03	4.3e-01
'penalities for substance use'	0.0548	0.0224	2.45	1.4e-02	9.7e-01

'substance access risk'	-0.0340	0.0152	-2.24	2.5e-02	1.0e+00
'social facilities'	0.0357	0.0160	2.23	2.6e-02	1.0e+00
'elderly care'	0.0494	0.0232	2.13	3.4e-02	1.0e+00
'subject performance'	0.0314	0.0174	1.81	7.1e-02	1.0e+00
'house hazard'	-0.0291	0.0164	-1.78	7.6e-02	1.0e+00
'Asian population'	0.0274	0.0159	1.72	8.5e-02	1.0e+00
'early childhood education centers'	0.0330	0.0192	1.72	8.5e-02	1.0e+00
'vehicle pollution'	-0.0467	0.0274	-1.71	8.8e-02	1.0e+00
'less educated and crowded'	-0.0319	0.0189	-1.69	9.2e-02	1.0e+00
'family rules about substance use'	-0.0266	0.0159	-1.68	9.4e-02	1.0e+00
'substance use rate'	0.0352	0.0210	1.67	9.4e-02	1.0e+00
'public organizations'	0.0426	0.0267	1.59	1.1e-01	1.0e+00
'effective Good Samaritan law'	-0.0510	0.0335	-1.52	1.3e-01	1.0e+00
'Asian assimilation'	0.0341	0.0262	1.30	1.9e-01	1.0e+00
'grass percentage'	-0.0225	0.0174	-1.29	2.0e-01	1.0e+00
'Hispanic population'	-0.0219	0.0173	-1.27	2.0e-01	1.0e+00
'build-up percentage'	0.0243	0.0198	1.23	2.2e-01	1.0e+00
'preventive screening'	0.0276	0.0246	1.12	2.6e-01	1.0e+00
'wetland percentage'	0.0210	0.0200	1.05	2.9e-01	1.0e+00
'effective prescription law'	0.0213	0.0216	0.99	3.2e-01	1.0e+00
'building densities'	0.0153	0.0156	0.98	3.3e-01	1.0e+00
'effective ACA and marijuana law'	0.0310	0.0322	0.96	3.4e-01	1.0e+00
'nalaxone policy'	0.0239	0.0301	0.79	4.3e-01	1.0e+00
'Hispanic assimilation'	0.0240	0.0317	0.76	4.5e-01	1.0e+00
'crop land percentage'	-0.0108	0.0165	-0.66	5.1e-01	1.0e+00
'clinical facilities'	-0.0159	0.0244	-0.65	5.1e-01	1.0e+00
'population density'	-0.0105	0.0168	-0.63	5.3e-01	1.0e+00

term	estimate	std.error	statistic	p.value	p_adj
'soil fertility'	0.0193	0.0343	0.56	5.7e-01	1.0e+00
'vegetation percentage'	0.0084	0.0162	0.52	6.1e-01	1.0e+00
'heavy metal'	0.0128	0.0276	0.46	6.4e-01	1.0e+00
'soil pollution'	-0.0087	0.0224	-0.39	7.0e-01	1.0e+00
'neighborhood job oppurtunities'	-0.0063	0.0173	-0.36	7.2e-01	1.0e+00
'neighborhood rent burden'	-0.0066	0.0187	-0.35	7.3e-01	1.0e+00
'air pollution'	0.0109	0.0312	0.35	7.3e-01	1.0e+00
'Aian population'	-0.0061	0.0201	-0.31	7.6e-01	1.0e+00
'prescriber policy'	0.0074	0.0327	0.23	8.2e-01	1.0e+00
'wood percentage'	-0.0046	0.0232	-0.20	8.4e-01	1.0e+00
'proportion of chronic conditions'	-0.0023	0.0178	-0.13	9.0e-01	1.0e+00
'water percentage'	-0.0020	0.0157	-0.13	9.0e-01	1.0e+00
'respiratory hazard'	-0.0029	0.0258	-0.11	9.1e-01	1.0e+00
'group dismiliarities'	0.0017	0.0253	0.07	9.5e-01	1.0e+00

Table S2.

Holdout Dataset Environmental Factors Correlation Analysis Results

term	estimate	std.error	statistic	p.value	p_adj
'postnal adversities'	-0.3579	0.0408	-8.78	0.0e+00	0.0e+00
'parental internalizing'	-0.5045	0.0191	-26.48	0.0e+00	0.0e+00
'parental externalizing'	-0.4624	0.0228	-20.32	0.0e+00	0.0e+00
'parental mental health history'	-0.4570	0.0238	-19.24	0.0e+00	0.0e+00
'parental strength'	0.4669	0.0289	16.14	0.0e+00	0.0e+00
'parental ages at childbirth'	0.1587	0.0235	6.75	1.5e-11	1.0e-09
'subjective school environment'	0.1401	0.0210	6.66	2.7e-11	1.8e-09
'substance use during prenancy'	-0.2703	0.0409	-6.61	3.9e-11	2.7e-09
'neighborhood safety'	0.1498	0.0235	6.38	1.8e-10	1.2e-08
'family ses'	0.1505	0.0239	6.30	3.1e-10	2.1e-08
'acceptance and monitoring'	0.1496	0.0255	5.87	4.4e-09	3.0e-07
'pregnancy care'	0.1685	0.0330	5.11	3.2e-07	2.2e-05
'family rules for all'	0.0903	0.0212	4.26	2.0e-05	1.4e-03
'neighborhood provety'	0.0952	0.0269	3.54	3.9e-04	2.7e-02
'community wellbeing'	-0.0938	0.0274	-3.43	6.1e-04	4.2e-02
'birth characteristics'	0.0822	0.0278	2.96	3.1e-03	2.1e-01
'substance use rate'	0.0733	0.0289	2.54	1.1e-02	7.6e-01
'developmental delays'	-0.0673	0.0268	-2.51	1.2e-02	8.2e-01
'Caesarian section'	-0.0787	0.0322	-2.44	1.5e-02	1.0e+00
'insurance and care'	0.0666	0.0274	2.43	1.5e-02	1.0e+00
'neighborhood wealth'	0.0596	0.0256	2.33	2.0e-02	1.0e+00
'pregnancy conditions'	-0.0652	0.0282	-2.31	2.1e-02	1.0e+00
'public organizations'	0.0786	0.0342	2.30	2.2e-02	1.0e+00
'subject performance'	0.0564	0.0247	2.29	2.2e-02	1.0e+00
'teacher experiences'	0.0560	0.0278	2.02	4.4e-02	1.0e+00
'family rules about substance use'	-0.0421	0.0224	-1.88	6.0e-02	1.0e+00

term	estimate	std.error	statistic	p.value	p_adj
'vehicle pollution'	-0.0569	0.0359	-1.58	1.1e-01	1.0e+00
'Black assimilation'	0.0448	0.0284	1.58	1.1e-01	1.0e+00
'nalaxone policy'	0.0564	0.0367	1.54	1.2e-01	1.0e+00
'birth complications'	-0.0368	0.0243	-1.52	1.3e-01	1.0e+00
'Aian population'	-0.0401	0.0275	-1.46	1.5e-01	1.0e+00
'elderly care'	0.0439	0.0307	1.43	1.5e-01	1.0e+00
'proportion with college degree'	0.0450	0.0321	1.40	1.6e-01	1.0e+00
'Asian assimilation'	0.0448	0.0320	1.40	1.6e-01	1.0e+00
'respiratory hazard'	0.0457	0.0345	1.32	1.9e-01	1.0e+00
'Hispanic population'	-0.0320	0.0243	-1.32	1.9e-01	1.0e+00
'effective ACA and marijuana law'	0.0502	0.0384	1.31	1.9e-01	1.0e+00
'primary care'	0.0341	0.0269	1.26	2.1e-01	1.0e+00
'less educated and crowded'	-0.0328	0.0262	-1.25	2.1e-01	1.0e+00
'early childhood education centers'	0.0334	0.0271	1.23	2.2e-01	1.0e+00
'penalities for substance use'	-0.0349	0.0319	-1.09	2.7e-01	1.0e+00
'soil pollution'	0.0305	0.0300	1.02	3.1e-01	1.0e+00
'Hispanic assimilation'	0.0404	0.0398	1.02	3.1e-01	1.0e+00
'water percentage'	0.0213	0.0220	0.97	3.3e-01	1.0e+00
'substance access risk'	-0.0188	0.0215	-0.88	3.8e-01	1.0e+00
'building densities'	0.0188	0.0235	0.80	4.3e-01	1.0e+00
'clinical facilities'	0.0251	0.0326	0.77	4.4e-01	1.0e+00
'preventive screening'	0.0261	0.0341	0.77	4.4e-01	1.0e+00
'heavy metal'	0.0244	0.0360	0.68	5.0e-01	1.0e+00
'group dismiliarities'	0.0218	0.0337	0.65	5.2e-01	1.0e+00
'proportion of chronic conditions'	0.0141	0.0252	0.56	5.8e-01	1.0e+00
'social facilities'	0.0119	0.0228	0.52	6.0e-01	1.0e+00
'air pollution'	0.0200	0.0388	0.52	6.1e-01	1.0e+00

term	estimate	std.error	statistic	p.value	p_adj
'build-up percentage'	0.0100	0.0270	0.37	7.1e-01	1.0e+00
'effective prescription law'	0.0105	0.0294	0.36	7.2e-01	1.0e+00
'soil fertility'	0.0126	0.0413	0.31	7.6e-01	1.0e+00
'effective Good Samaritan law'	-0.0116	0.0416	-0.28	7.8e-01	1.0e+00
'population density'	-0.0058	0.0252	-0.23	8.2e-01	1.0e+00
'neighborhood rent burden'	-0.0056	0.0263	-0.21	8.3e-01	1.0e+00
'grass percentage'	-0.0049	0.0241	-0.20	8.4e-01	1.0e+00
'crop land percentage'	0.0038	0.0227	0.17	8.7e-01	1.0e+00
'vegetation percentage'	-0.0034	0.0229	-0.15	8.8e-01	1.0e+00
'house hazard'	-0.0030	0.0231	-0.13	9.0e-01	1.0e+00
'wood percentage'	-0.0039	0.0313	-0.12	9.0e-01	1.0e+00
'prescriber policy'	-0.0041	0.0411	-0.10	9.2e-01	1.0e+00
'Asian population'	-0.0004	0.0213	-0.02	9.9e-01	1.0e+00
'neighborhood job oppurtunities'	-0.0002	0.0233	-0.01	9.9e-01	1.0e+00

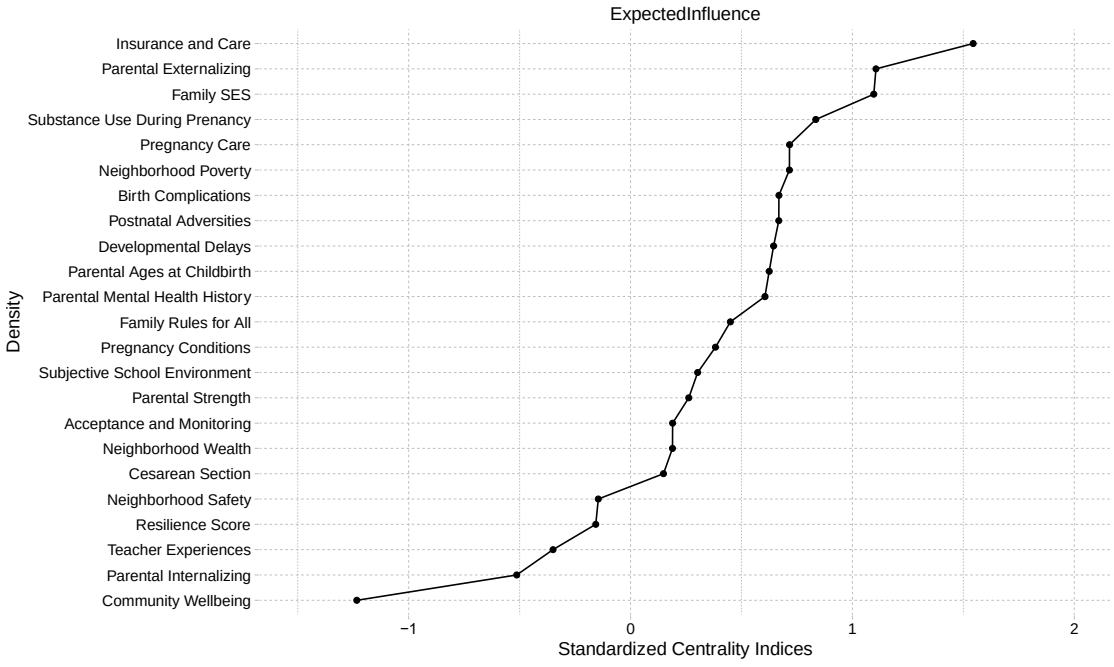

Figure S1: Expected Influence Centrality

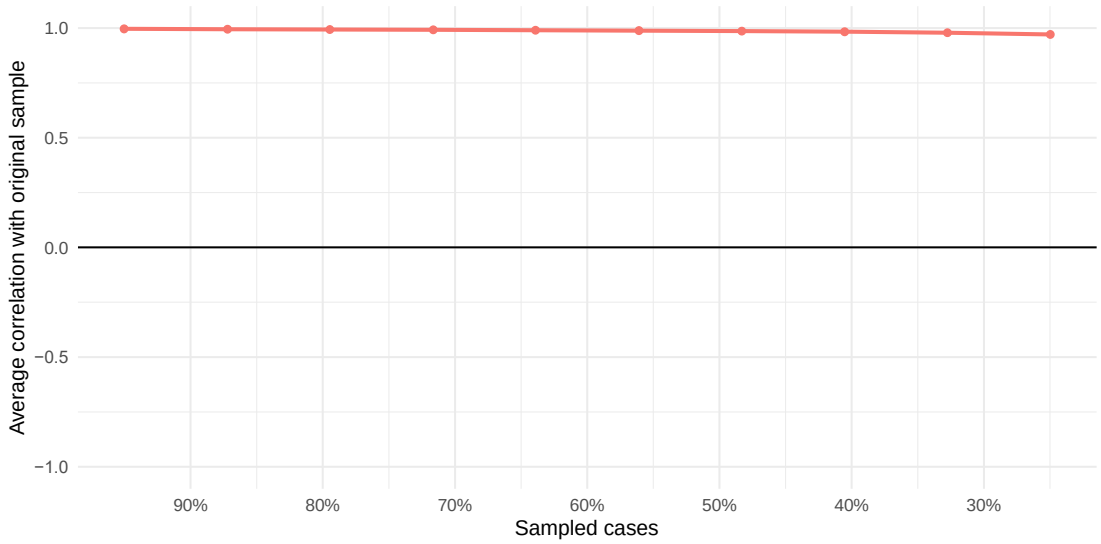

Figure S2: Correlation Stability Coefficients

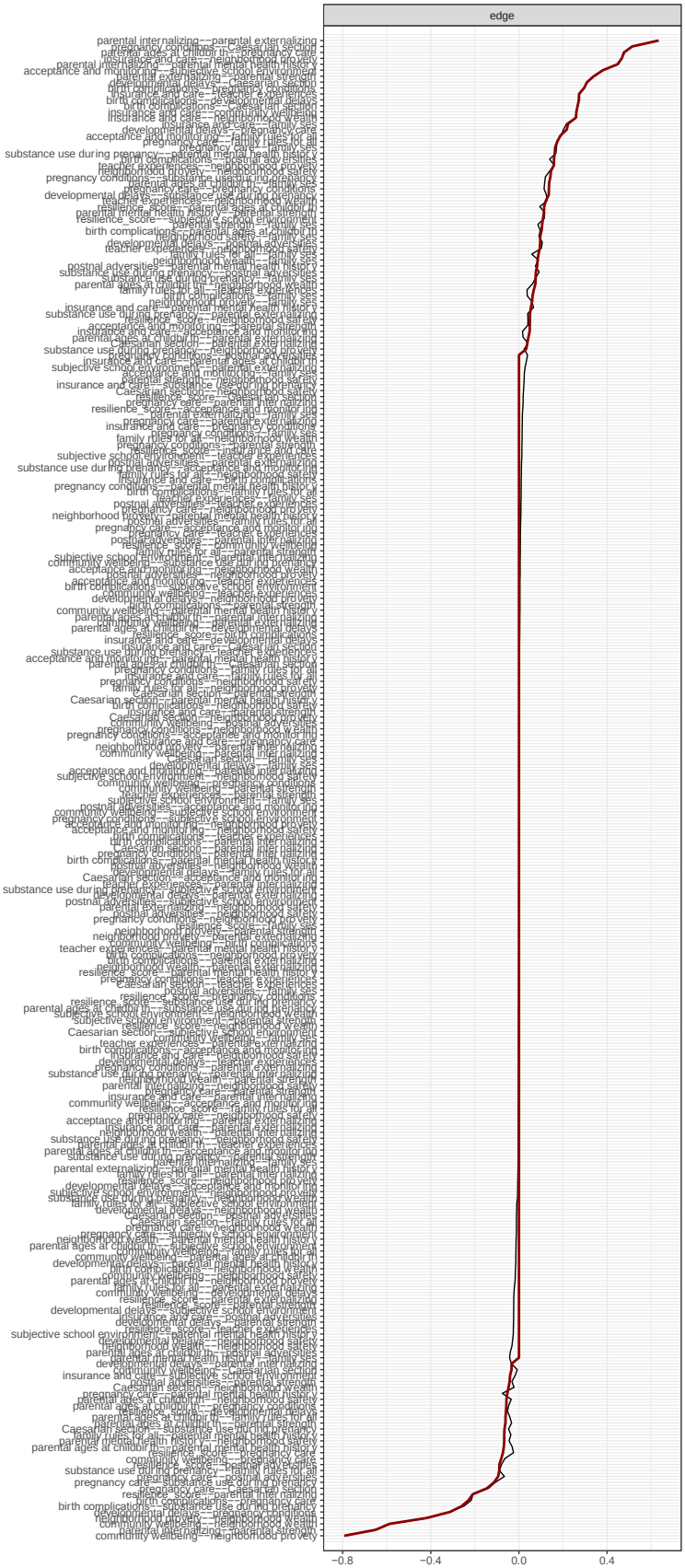

Figure S3: Edge Weight Distribution