Journal of Affective Disorders 349 (2024) 262–271

Contents lists available at ScienceDirect

Journal of Affective Disorders

journal homepage: www.elsevier.com/locate/jad

Research paper

A network analysis of psychopathology in young Black children: Implications for predicting outcomes in adolescence

Mahnoor Hyat [a,*,1], Jonas G. Miller [b,**,1], Ian H. Gotlib [c]

[a] Department of Psychology, University of Washington, 119A Guthrie Hall, Seattle, WA 98195, United States of America
[b] Department of Psychological Sciences, University of Connecticut, 406 Babbidge Road, Unit 1020, Storrs, CT 06269, United States of America
[c] Department of Psychology, Stanford University, 450 Serra Mall, Stanford, CA 94305, United States of America

ARTICLE INFO

Keywords:
Network analysis
Symptomatology
Competencies
Black children and adolescents

ABSTRACT

Objective: Network analysis may identify specific symptoms involved in the maintenance and development of psychopathology. This approach, however, has not been applied to the study of young Black children, a population facing unique challenges and developmental risks. It is also unclear whether network analysis identifies early symptoms in Black children that are linked to their longer-term difficulties and strengths in adolescence.
Methods: We conducted a network analysis of emotional and behavioral difficulties in 1238 Black (non-Hispanic) children from the age-3 assessment in the Future of Families and Child Wellbeing Study (47 % female). We also explored whether early childhood symptoms predict subsequent caregiver-reported internalizing and externalizing problems, and youth-reported social competencies and extracurricular and community involvement, at the age-15 assessment.
Results: We identified specific symptoms of externalizing and emotional reactivity as central in the network. Symptoms of emotional reactivity were also involved in comorbidity, bridging different communities of symptoms. Using elastic net models, we identified specific central and bridge symptoms, but also peripheral network symptoms, that contributed uniquely to the prediction of internalizing and externalizing problems in adolescence. Early childhood symptoms were less predictive of positive outcomes in adolescence.
Conclusions: This study identified central and bridge symptoms in young Black children, an underrepresented population in network analysis research. Some of these central and bridge symptoms, but also peripheral network symptoms, may be useful targets in early interventions to prevent long-term difficulties. Conversely, network approaches to understanding early psychopathology may have less utility for predicting Black children's subsequent strengths in adolescence.

1. Introduction

Network analysis has been used to visualize the structure of relations among symptoms in a range of disorders and populations (e.g., Mullarkey et al., 2019; Rouquette et al., 2018; Russell et al., 2017). In addition, this approach holds promise for identifying specific symptoms that are implicated in the development and maintenance of psychopathology (McNally, 2016). Intervening to reduce the severity of such symptoms may decrease the strength of other symptoms. Despite the growing interest in network analysis and increasing recognition of its clinical potential, this approach has not been applied to the study of young African American, or Black, children. To extend network analysis to this population, we drew on a subset of participants from the Future of Families and Child Wellbeing Study (FFCWS), a population-based cohort that was oversampled for non-marital births. We analyzed the network structure of emotional and behavioral difficulties in preschool-age Black children in this sample and examined whether network analysis can identify early symptoms that forecast risk for both the subsequent development of psychopathology and attenuated psychosocial strengths or competencies in adolescence.

* Correspondence to: M. Hyat, Department of Psychology, University of Washington, Seattle, WA, United States of America.
** Correspondence to: J. Miller, Department of Psychological Sciences, University of Connecticut, Weston A. Bousfield Psychology Building, Storrs CT 06269, United States of America.
E-mail addresses: mhyat30@uw.edu (M. Hyat), jonas.miller@uconn.edu (J.G. Miller).
[1] These authors share first authorship. Their authorship order is alphabetical.

https://doi.org/10.1016/j.jad.2024.01.071
Received 18 July 2023; Received in revised form 27 December 2023; Accepted 4 January 2024
Available online 9 January 2024

Network analysis conceptualizes mental health difficulties as arising from relations among symptoms (Borsboom, 2017). From this perspective, psychopathology is a complex organization of symptoms that can be represented by a set of nodes (i.e., individual symptoms) and their interconnections, or edges (i.e., relations between symptoms). Activation of symptoms that are *central* within the network (i.e., highly connected with other symptoms) may lead to spreading activation to other symptoms across the network (Borsboom et al., 2011). Conversely, activation of more peripheral symptoms that share fewer connections is less likely to activate other symptoms. Network analysis also conceptualizes comorbidity as the outcome of relations among symptoms of multiple disorders; these connecting pathways are termed *bridge* symptoms (Cramer et al., 2010). Measures of centrality and bridge symptoms offer clinically useful insights; identifying central and bridge symptoms may facilitate the early identification both of vulnerable children and of targets for intervention (Mullarkey et al., 2019; Rouquette et al., 2018).

Despite its increasing use and significant promise (Bansal et al., 2020; Martel et al., 2016; Rouquette et al., 2018), network analysis has not yet been used to elucidate the structure of emotional and behavioral problems in Black preschool-age children, nor have researchers examined whether central and bridge symptoms predict future psychosocial outcomes in this population. This is a significant gap in the literature as it is unclear whether findings from network analysis studies generalize to Black children in the United States, who face unique challenges, including being disproportionately affected by socioeconomic disadvantage (Hodgkinson et al., 2017) and being at increased risk for experiencing bias and discrimination (Gilliam et al., 2016). These conditions and experiences can have profound implications for both well-being and the development of socioemotional and cognitive skills (Coker et al., 2009; Merz et al., 2019; Priest et al., 2013; Reiss, 2013). It is important to recognize, however, that the majority of Black youth exhibit competencies in domains that have been implicated in mental health (Gaylord-Harden et al., 2018), such as social skills and extracurricular and community involvement (Caplan et al., 1992; Fredricks and Eccles, 2010). Considering within-group variability may inform early identification and targeted treatment efforts for Black children who are at risk for developing psychopathology and/or fewer psychosocial strengths.

The current study examined the network structure of emotional and behavioral problems in preschool-age Black (non-Hispanic) children from predominantly low-income backgrounds. We conducted network analysis to identify which symptoms are most central for activating other symptoms within the network, and which are the strongest bridge symptoms and pathways that connect different communities of symptoms. In addition, we used elastic net regression to test whether central and bridge symptoms in early childhood predict the subsequent development of both psychopathology and psychosocial strengths in adolescence.

2. Methods

2.1. Participants

The Future of Families and Child Wellbeing Study (FFCWS) is a longitudinal birth cohort study with a sample of 4898 children born in large US cities between 1998 and 2000. Nonmarital births were oversampled to facilitate the inclusion of low-income families. Both parents were interviewed in the hospital shortly after birth, which marked the start of data collection for the core study. Follow-up interviews were conducted at multiple waves. Detailed methodology is available in Reichman et al. (2001) and at https://fragilefamilies.princeton.edu/documentation. Our network analysis focused on symptoms, reported by primary caregivers of Black (non-Hispanic) children, at the age-3 assessment. We conducted elastic net regression for Black children for whom data were also available for internalizing and externalizing problems and positive developmental outcomes at the age-15 assessment. All FFCWS participants (or their parents) provided informed consent and all procedures were approved by the affiliated human subjects review board.

We used both parents' self-reported race and ethnicity to determine whether a child was non-Hispanic Black. We did not include mixed race/ethnicity children in our analysis due to the small sample sizes of those groups. Our final sample was composed of 1238 Black children (i.e., both parents reported being non-Hispanic Black; 47.2 % female) who had complete Child Behavior Checklist data at the age-3 assessment (see below). We used the mean value of mother and father incomes to estimate family income; we considered only one parent's income if the other parent's income was not reported. The mean annual household income in our sample was $28,498 (SD = $26,722).

2.2. Emotional and behavioral difficulties at preschool-age

At the age-3 assessment, primary caregivers completed the Child Behavior Checklist (CBCL) for ages 1.5 to 5 (Achenbach and Rescorla, 2000). The CBCL is a widely used measure that allows researchers and clinicians to assess emotional and behavioral problems in children. Primary caregivers provided responses to each CBCL item on a scale from 0 to 2, with 0 indicating "Not True," 1 indicating "Somewhat or Sometimes True," and 2 indicating "Very True or Often True." We focused on 39 CBCL items that comprise the Emotional Reactivity (4 items), Aggressive (19 items), Withdrawn (8 items), and Anxious/Depressed (8 items) subscales. In Table 1 we present the assigned labels and relevant communities/subscales for each of these 39 CBCL items. We did not analyze the 6 items from the Attention Deficit/Hyperactivity Problems subscale in FFCWS both because some of these items overlapped with items in the Aggressive subscale, and because this is a DSM-oriented scale, whereas the other subscales are syndrome scales.

2.3. Psychosocial outcomes in adolescence

To assess negative and positive psychosocial outcomes at the age-15 assessment, we analyzed caregivers' reports of their adolescents' internalizing and externalizing problems, and the adolescents' self-reports of their social skills and extracurricular/community involvement.

Primary caregivers used the CBCL to report on their adolescents' internalizing and externalizing problems. Internalizing problems were computed as the average of responses to items on the Anxious/Depressed (6 items) and Withdrawn (2 items) subscales. Externalizing problems were computed as the average score of responses to items on the Aggressive (11 items) and Delinquent Behaviors (9 items) subscales. In FFCWS, caregivers rated their adolescents' behavior from 1 (Not true) to 3 (Often true). To be consistent with the age-3 scoring, we recoded these ratings to range from 0 to 2 prior to computing mean internalizing and externalizing scores. There were 1089 Black children with CBCL data at both the age-3 and age-15 assessments.

Youths' self-reported social competencies were assessed using items from modified versions of the Social Skills Rating System (SSRS; Gresham and Elliott, 1990) and the Adaptive Social Behavior Inventory (ASBI; Hogan et al., 1992). We summed responses to 9 SSRS items (e.g., "I make friends easily," "I start conversations rather than waiting for others to talk first") and 3 ASBI items (e.g., "I understand others' feelings like when they are happy, sad, or mad," "I try to comfort others when they are upset"). In FFCWS, adolescents were asked to report how true they think each statement is for them on a scale from 1 to 3, with 1 indicating "not true," 2 indicating "sometimes true," and 3 indicating "often true." As recommended by the FFCWS, these items were recoded to range from 0 to 2 prior to creating sum scores. There were 1056 Black children with both CBCL data at the age-3 assessment and social competencies data at the age-15 assessment.

Adolescents self-reported their extracurricular and community involvement since the beginning of the school year or in the previous school year. We computed the average of participants' responses to six

Table 1
CBCL items with labels and communities.

Community (color)	Label	CBCL Item
Aggressive (Blue)	A_Wait	Can't stand waiting; wants everything now
	A_Belon	Destroys things belonging to his/her family or other children
	A_Figh	Gets in many fights
	A_Atta	Physically attacks people
	A_Defi	Defiant
	A_Dema	Demands must be met immediately
	A_Frus	Easily frustrated
	A_Hits	Hits others
	A_Angr	Angry moods
	A_Puni	Punishment doesn't change his/her behavior
	A_Self	Selfish or won't share
	A_Unco	Uncooperative
	A_Hurts	Hurts animals or people without meaning to
	A_Atten	Wants a lot of attention
	A_Obed	Disobedient
	A_Scre	Screams a lot
	A_Guil	Doesn't seem to feel guilty after misbehaving
	A_Stub	Stubborn, sullen, or irritable
	A_Temp	Temper tantrums or hot temper
Anxious/Depressed (Yellow)	AN_Feel	Feelings are easily hurt
	AN_Sepa	Gets too upset when separated from parents
	AN_Unha	Looks unhappy without good reason
	AN_Emba	Self-conscious or easily embarrassed
	AN_Clin	Clings to adults or too dependent
	AN_Nerv	Nervous, highstrung, or tense
	AN_Fear	Too fearful or anxious
	AN_Sad	Unhappy, sad, or depressed
Withdrawn (Green)	W_Answ	Doesn't answer when people talk to him// her
	W_Acti	Refuses to play active games
	W_Affe	Seems unresponsive to affection
	W_Show	Shows little affection towards people
	W_Inter	Shows little interest in things around him/ her
	W_With	Withdrawn, doesn't get involved with others
	W_Youn	Acts too young for age
	W_Look	Avoids looking others in eye
Emotional Reactivity (Orange)	EM_Rout	Disturbed by any change in routine
	EM_Whin	Whining
	EM_Mood	Sudden changes in mood or feelings
	EM_Sulk	Sulks a lot

items that were based on measures from the National Longitudinal Study of Adolescents Health Wave 3 (Add Health), and the Panel Study of Income Dynamics Child Development Supplement. Frequency of involvement was rated on a scale from 0 ("Never") to 4 ("several times a week"). There were 1057 Black children with both CBCL data at the age-3 assessment and extracurricular and community involvement data at the age-15 assessment.

2.4. Statistical analysis

All analyses were conducted in R version 4.1.3 (R Core Team, 2022). Our first aim focuses on the network structure at the age-3 assessment, including examining how different symptoms cluster together in Black children, determining which symptoms were connected most strongly to other symptoms (i.e., most central), and elucidating which symptoms served as bridges between different clusters (Boorsboom and Cramer, 2013). Gaussian Graphical Models, which are based on polychoric correlations, were used to estimate the networks for the CBCL individual items; this estimation was conducted using the *qgraph* R package (Epskamp et al., 2012). To ensure inclusion of the most robust empirical relations in the network, we used the least absolute shrinkage and selection operator (LASSO) in the *graphicalLASSO* (glasso) package. This method is appropriate for networks based on ordinal variables and produces a sparse network by removing edges that are likely spurious. The model was then visualized using a network analysis plot. The layout of the plot was determined using the Fruchterman-Reingold (F-R) algorithm, which enhances comprehension by placing strongly connected nodes in the center of the network and moving weakly connected nodes to the perimeter. Nodes are represented by circles and edges are represented by their connecting lines. The darkness and thickness of edges indicate the magnitude of the association between two nodes, whereas the color of edges indicates whether the association is positive or negative.

Node strength (the sum of weighted number and strength of connections of a node) was estimated as the main measure of symptom centrality. Other centrality indices that were calculated were betweenness (importance of a node in the average path between other node pairs) and closeness (node's relations to other nodes through examination of indirect connections). We used the R package *bootnet* to determine the stability of edge weights and the stability of strength centrality, using 1000 nonparametric subset bootstraps. In addition, we calculated bridge strength (the sum of absolute values for paths connecting a node to symptoms that are part of other communities), which was used to identify symptoms that bridge different clusters of emotional and behavioral difficulties.

Our second aim was to evaluate whether early childhood difficulties, particularly those identified as central or bridge symptoms in our network analysis, predicted psychosocial outcomes in adolescence. We conducted elastic net regression using the *glmnet* package (Friedman et al., 2010). We tested four elastic net models that used the 39 CBCL items at the age-3 assessment as predictors of internalizing problems, externalizing problems, social competencies, and extracurricular and community involvement at the age-15 assessment. The elastic net approach is useful for selecting predictors that are highly correlated provided that they minimize error (Zou and Hastie, 2005). Model complexity is penalized using a lambda value to shrink the coefficients of correlated predictors towards each other. We used a full elastic net penalty ($\alpha = 0.50$). We used leave-one-out cross-validation to identify the lambda values for each model that minimized mean squared error, yielding sparse models with non-zero coefficients for only the most important predictors of each outcome. To complement the elastic net coefficients, we conducted follow-up zero-order correlations between predictors at the age-3 assessment selected by elastic net models and psychosocial outcomes at the age-15 assessment.

3. Results

3.1. Emotional and behavioral symptoms network in early childhood

The network of symptoms is presented in Fig. 1. Visual inspection suggests a dense network with many connections among symptoms, but with subscale items tending to cluster together, particularly items from the aggressive and withdrawal subscales. The network parameter estimates were stable (edge stability coefficient = 0.59; strength centrality stability coefficient = 0.67). Fig. 2 presents the node centrality indices (strength, betweenness, closeness) for each symptom. Most of the highly central symptoms were from the aggressive and emotional reactivity subscales, whereas symptoms that were part of the anxious/depressed and withdrawn subscales were more peripheral in the network. Based on strength centrality, the top eight central symptoms (i.e., those with the highest peaks in Fig. 3) were temper tantrums or hot temper, angry moods, sudden changes in mood or feelings, can't stand waiting; wants everything now, demands must be met immediately, uncooperative, sulks a lot, and whining. Similar findings were obtained for the betweenness and closeness metrics of centrality (see Fig. 2).

We conducted a bridge analysis to identify symptoms that were integral in establishing connections between communities of symptoms. For this analysis, items from the emotional reactivity, withdrawn,

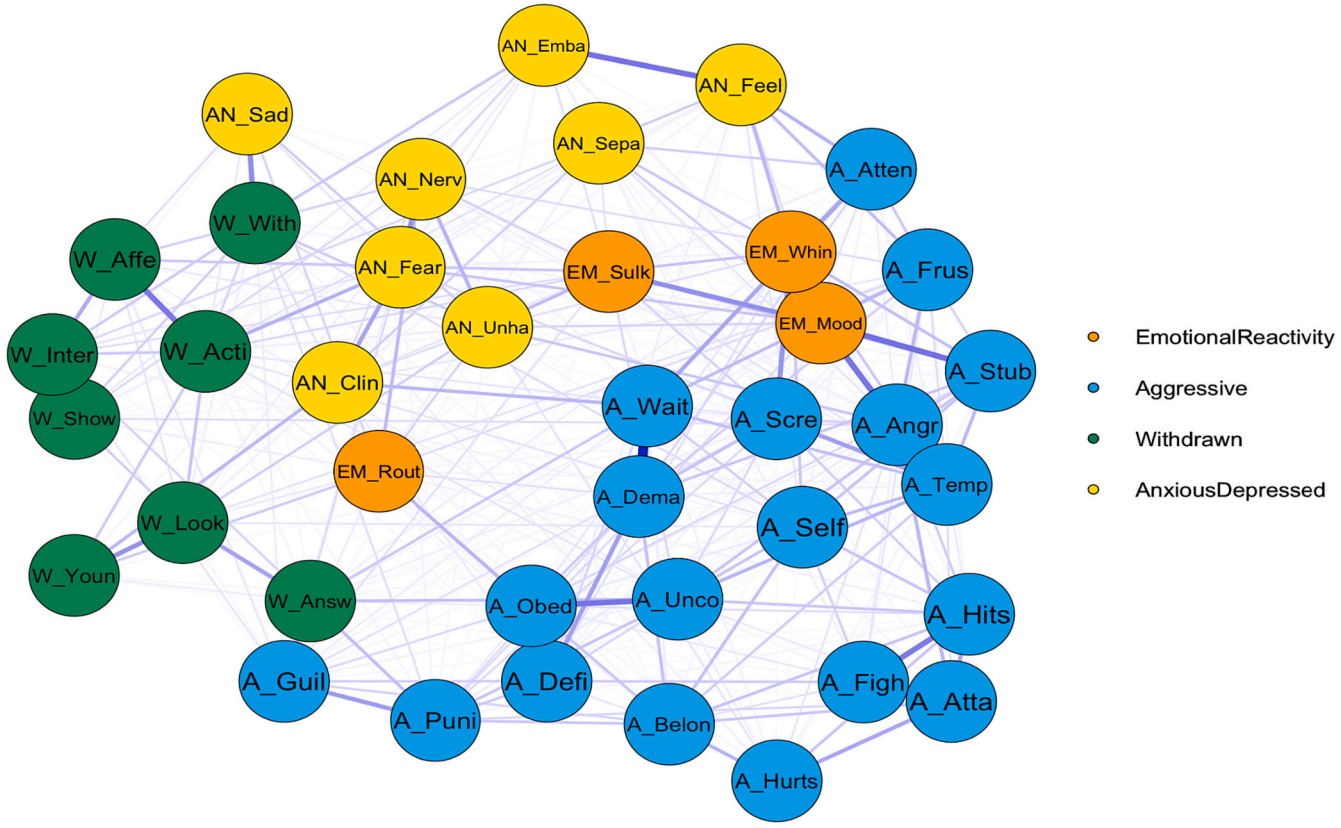

Fig. 1. Network of Symptoms for Black Children at Age 3
Note. The blue lines indicate that all edge weights are positive. Stronger regularized partial correlations are represented by darker and thicker edges. Node colors indicate community. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

anxious/depressed, and aggressive subscales were conceptualized as separate communities. Fig. 3 presents the bridge strength of all the nodes and helps identify the key bridge symptoms for this network. The strongest four bridge symptoms were all from the emotional reactivity community: sudden changes in mood or feelings; whining; sulks a lot; and is disturbed by changes in routine. The other highly ranked bridge symptoms were part of the anxious/depressed (e.g., looks unhappy without good reason, too fearful or anxious) and withdrawn communities (e.g, withdrawn; doesn't get involved with others, doesn't answer when people talk to him/her). We computed a partial correlation matrix to find the strongest inter-symptom associations involving top bridge symptoms. The top bridge symptom – sudden changes in moods or feelings – had the strongest connections with the stubborn, sullen, or irritable ($r = 0.20$) and angry moods ($r = 0.19$) symptoms from the aggressive community. These connections may be particularly strong bridge pathways between different communities of symptoms.

3.2. Predicting psychosocial outcomes in adolescence

3.2.1. Internalizing problems

Table 2 presents the results of the elastic net models using CBCL symptoms in early childhood as predictors of internalizing and externalizing problems in adolescence. The elastic net model identified 15 CBCL symptoms that helped to minimize error in predicting future internalizing problems. All of these symptoms were positively and significantly associated with internalizing problems. Two of the childhood symptoms that contributed uniquely to predicting internalizing problems in adolescence were also identified as highly central in the network analysis: "Child has temper tantrums or hot temper" from the Aggressive subscale and "Child has sudden changes in mood or feelings" from the Emotional Reactivity subscale were the first and third ranked symptoms, respectively, based on strength centrality. It is noteworthy that the "sudden changes in mood" item was also the top-ranked symptom in terms of bridge strength. In addition, the item "child is disturbed by any change in routine" from the Emotional Reactivity subscale emerged as both a unique predictor of future internalizing problems in the elastic net model and a top bridge symptom in the network analysis (ranked 4th). Most of the unique predictors of internalizing were middle- or bottom-ranked symptoms in terms of centrality and bridge strength. Collectively, the childhood symptoms selected by the elastic net model accounted for 9 % of the variance in internalizing problems in adolescence.

3.2.2. Externalizing problems

The elastic net model predicting externalizing problems in adolescence selected 13 CBCL items from the age-3 assessment, all of which were positively and significantly associated with externalizing problems. The central and bridge symptoms that were identified as significant predictors of internalizing problems were also selected as predictors of externalizing problems (temper tantrums, changes in mood, and disturbed by change in routine). Angry mood was identified as an additional predictor of externalizing problems and was highly central in the network analysis (ranked second in terms of strength centrality). Many of the other predictors of externalizing problems were the same items that were selected as predictors in the internalizing problems model. Collectively, childhood symptoms selected by the elastic net model accounted for 13 % of the variance in externalizing problems in adolescence.

3.2.3. Positive social outcomes

Table 3 presents the results of the elastic net models using CBCL symptoms in childhood as predictors of social competencies and

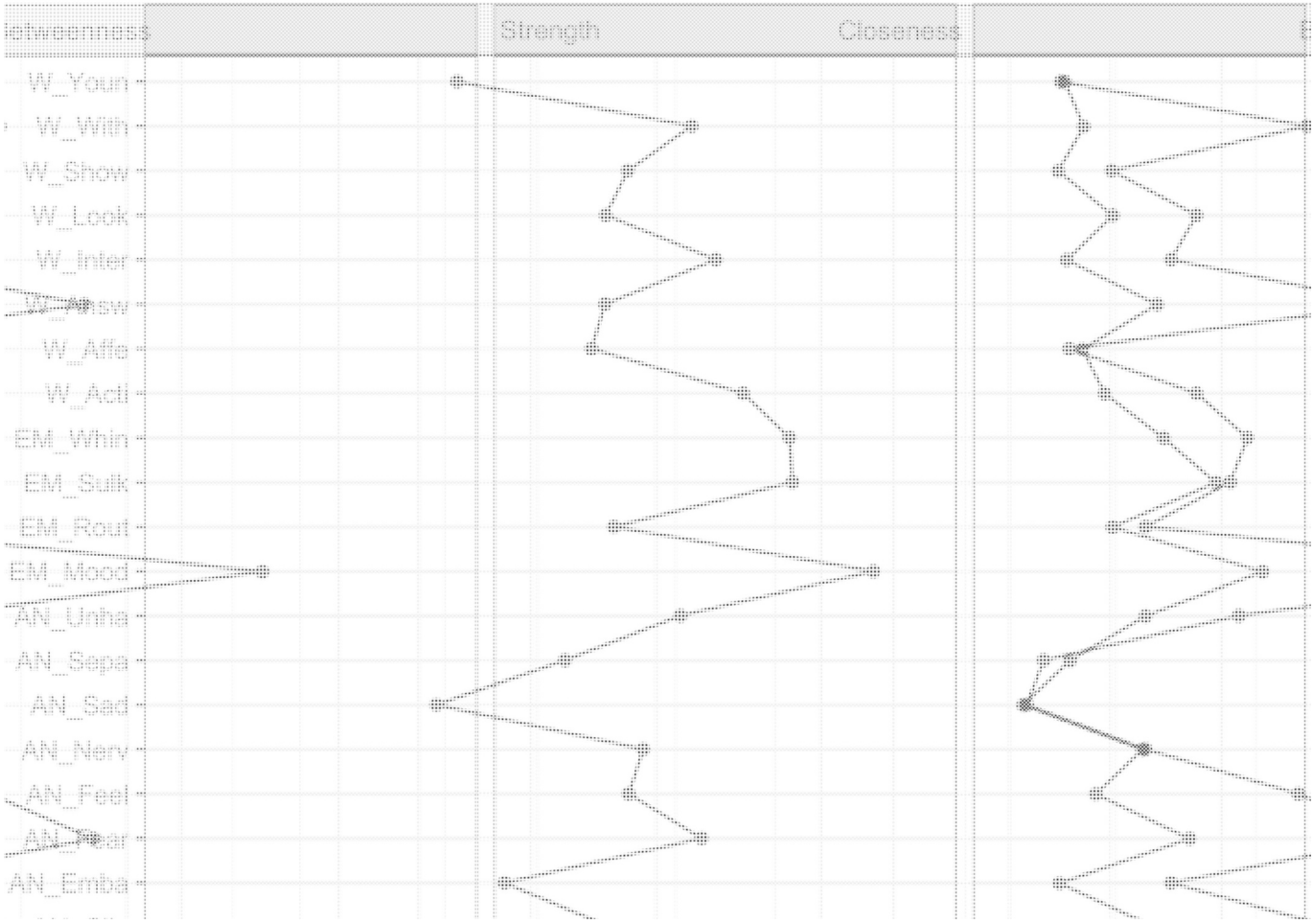

Fig. 2. Centrality Indices.

extracurricular and community involvement in adolescence. The elastic net model predicting social competencies selected 12 symptoms as unique predictors. However, four of these symptoms were not significantly correlated with social competencies; we do not interpret these symptoms as meaningful predictors. Of the remaining eight predictors, the most central symptom that was selected by elastic net regression was 'can't stand waiting, wants everything now' from the Aggressive subscale (ranked fourth in strength centrality). The "whining behaviors" symptom, which is part of the emotional reactivity subscale and was selected as a predictor of social competencies, was ranked second in bridge strength in the network analysis. Collectively, childhood symptoms selected by the elastic net model accounted for 3 % of the variance in social competences adolescence.

Finally, the elastic net model predicting extracurricular and community involvement in adolescence selected 4 symptoms as predictors. As was the case with the elastic net model predicting externalizing problems, the highly central symptom of angry moods (ranked second in terms of strength centrality) from the aggressive subscale was selected as a predictor of less extracurricular and community involvement. Two other predictors that were selected from the aggressive subscale were screaming (ranked ninth in strength centrality) and physically attacking people (ranked 20th in strength centrality). Being unhappy, sad, or depressed (ranked last in strength centrality) from the anxious/depressed subscale was also selected as a predictor of extracurricular and community involvement, although the direction of this association was positive. The childhood symptoms selected by the elastic net model accounted for 2 % of the variance in extracurricular and community involvement in adolescence.

3.3. Sensitivity analyses

Regarding the network analysis, it is noteworthy that the number of nodes is unbalanced across communities. For example, the aggressive subscale includes twice as many items as the withdrawn and anxious/depressed subscales. To test whether the relatively high number of aggressive nodes artificially inflated their strength centrality, we conducted a network analysis that included the top eight aggressive symptoms in terms of strength centrality instead of the full subscale (18 items). This network yielded similar results as our original network, with most of the top central symptoms remaining the same (see Supplement).

It is possible that the elastic net models distributed predictive importance among symptoms that were more central in the network. This could have led the model to select some highly central symptoms over others. To test this possibility, we repeated our predictive models using a stronger ridge regularization penalty, which would be expected to include more correlated features as important predictors. These results are presented in the Supplement. Briefly, these models yielded results similar to those that we obtained in our original elastic net model. Thus, item centrality does not appear to undermine the predictive utility of symptoms.

4. Discussion

This study is the first to use network analysis to elucidate the structure of relations among emotional and behavioral difficulties in preschool-age Black children from predominantly low-income families,

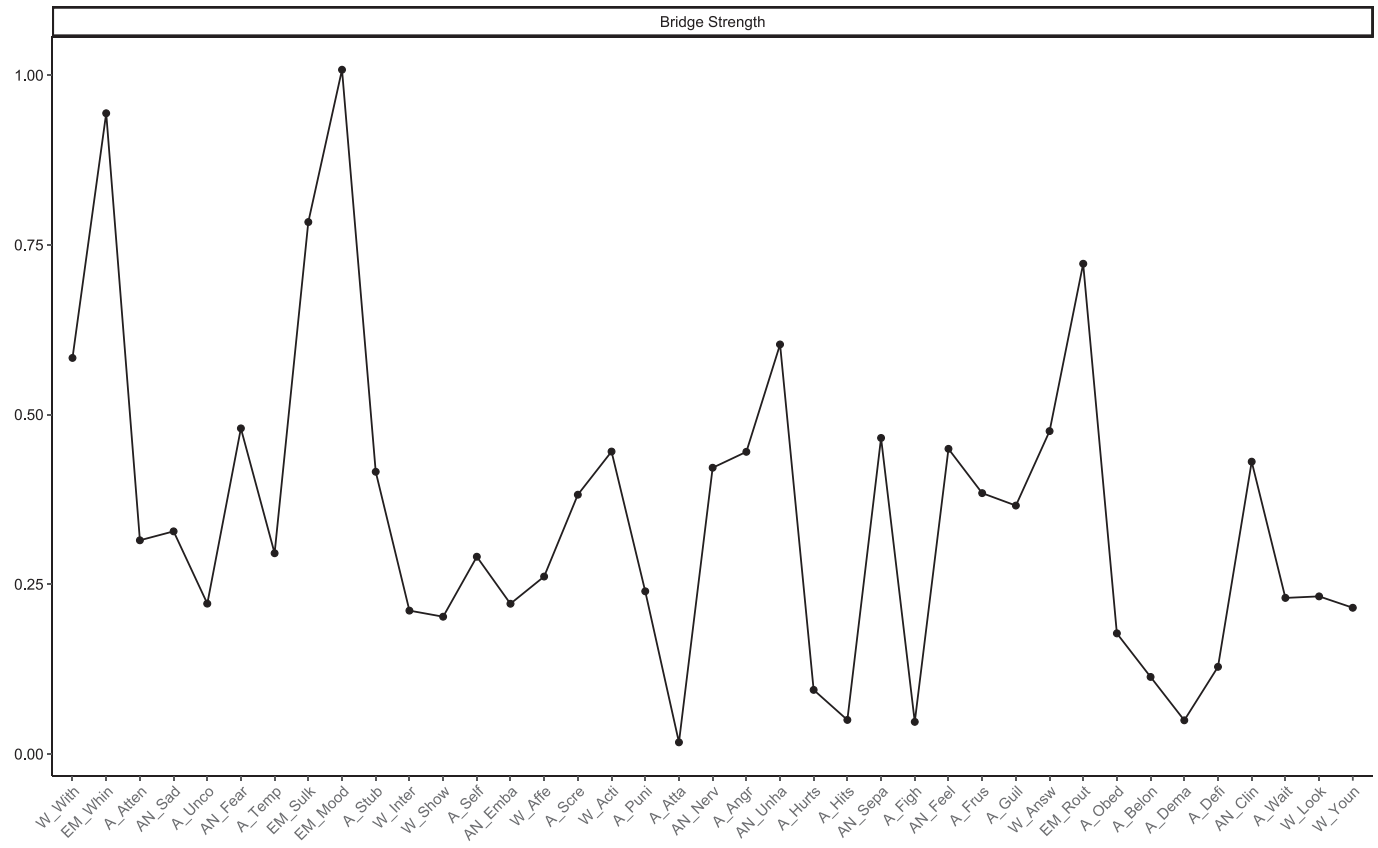

Fig. 3. Bridge Strength.

and to explore the role of early central and bridge symptoms in predicting psychosocial problems and competencies in adolescence. Our analyses identified specific externalizing and emotional reactivity symptoms that are central to a psychopathology network in early childhood, and that may be particularly important for bridging different kinds of emotional and behavioral difficulties. Consistent with the perspective that central and bridge symptoms are involved in the maintenance and development of psychopathology (Rouquette et al., 2018; Smith et al., 2019), we observed that some of the central and bridge symptoms were also selected in elastic net models as predictors of internalizing and externalizing problems in adolescence. Importantly, however, peripheral symptoms in the network also contributed uniquely to the prediction of future problems. Further, symptoms in early childhood explained relatively little variance in participants' psychosocial strengths in adolescence, assessed by social competencies and extracurricular and community involvement. Taken together, our findings highlight specific symptoms in young Black children that may contribute to other difficulties and comorbidities in early childhood and that may be involved in processes leading to difficulties in mental health in adolescence. Targeted assessment, intervention, and prevention efforts may benefit by focusing on the emotional and behavioral difficulties identified in our network and elastic net analyses.

Most network analyses in developmental psychopathology have focused on school-age children and adolescents (Kim et al., 2021; Mullarkey et al., 2019; Rouquette et al., 2018; Russell et al., 2017); in contrast, the current study provides novel insights concerning the structure of emotional and behavioral difficulties in preschool-age Black children. We found that proneness to anger, temper tantrums, sudden changes in mood, and needing demands met immediately were among the most central symptoms in the network. Thus, struggling with anger, irritability, and impatience appear to be significant difficulties that activate other symptoms. From a network perspective, reducing these high-centrality symptoms should have the benefit of initiating reductions in other emotional and behavioral difficulties (McNally, 2016; Mullarkey et al., 2019; Russell et al., 2017).

We found that the top bridge symptoms in the network were emotional reactivity difficulties, including sudden changes in mood or feelings, being disturbed by changes in routine, and proneness to whining and sulking. These bridge symptoms may constitute pathways between internalizing and externalizing problems in young Black children. Our findings build on research suggesting that children's problems with emotion reactivity and dysregulation are associated with risk for comorbidities (Dvir et al., 2014) and may serve as a transdiagnostic mechanism underlying the development of general psychopathology (Weissman et al., 2019). In addition, we found that sudden changes in mood and feelings, the top-ranked bridge symptom, had the strongest relations with the central symptoms of proneness to anger and being stubborn, sullen, or irritable. Bidirectional influences between these symptoms could be particularly important for the emergence of comorbid difficulties in early childhood and beyond. Indeed, we found that proneness to sudden changes in mood and feelings was an important prospective predictor of internalizing and externalizing problems in adolescence. For Black children from high-risk family backgrounds, assessments that capture information about sudden changes in mood/feelings could support efforts to prevent the development of psychopathology and comorbidities in childhood and adolescence. Our findings are consistent with prior findings that bridge symptoms predict future anxiety disorders (Rouquette et al., 2018) and, further, extend this work by examining the predictive value of bridge (and highly central) symptoms in preschool-age Black children.

It is worth noting that we found considerable overlap in the preschool-age symptoms that were associated with internalizing and externalizing problems in adolescence. Researchers have documented that internalizing and externalizing problems in adolescents are

Table 2
Elastic net regression results predicting internalizing and externalizing problems at age 15.

Predicting internalizing problems								
Variable (Node name)	Strength centrality ranking	Closeness centrality ranking	Betweenness centrality ranking	Bridge Ranking	Elastic net estimate	Pearson's *r*	95%CI	*p*-Value
A_Temp	1	3	8	21	0.02	0.17	0.11, 0.23	<0.001
EM_Mood	3	2	3	1	0.01	0.14	0.08, 0.20	<0.001
A_Obed	10	12	10	32	0.04	0.16	0.10, 0.22	<0.001
A_Stub	11	6	28	15	0.002	0.14	0.08, 0.20	<0.001
W_Acti	12	27	19	11	0.03	0.12	0.06, 0.18	<0.001
A_Belon	13	22	20	34	0.10	0.19	0.13, 0.25	<0.001
A_Hits	14	26	32	36	0.01	0.15	0.09, 0.20	<0.001
A_Frus	15	11	29	16	0.02	0.15	0.09, 0.21	<0.001
A_Atta	20	23	33	39	0.06	0.16	0.10, 0.22	<0.001
A_Defi	21	17	21	33	0.03	0.16	0.10, 0.21	<0.001
AN_Nerv	25	19	26	14	0.13	0.17	0.11, 0.23	<0.001
A_Figh	28	29	35	38	0.10	0.16	0.11, 0.22	<0.001
EM_Rout	29	25	25	4	0.08	0.17	0.11, 0.22	<0.001
AN_Clin	30	16	9	13	0.08	0.16	0.10, 0.22	<0.001
W_Youn	38	35	34	29	0.08	0.12	0.06, 0.18	<0.001

Predicting externalizing problems								
Variable (Node name)	Strength centrality ranking	Closeness centrality ranking	Betweenness centrality ranking	Bridge Ranking	Elastic net estimate	Pearson's *r*	95%CI	p-Value
A_Temp	1	3	8	21	0.07	0.23	0.17, 0.29	<0.001
A_Angr	2	1	1	12	0.03	0.21	0.15, 0.26	<0.001
EM_Mood	3	2	3	1	0.01	0.17	0.11, 0.23	<0.001
A_Obed	10	12	10	32	0.11	0.23	0.18, 0.29	<0.001
A_Belon	13	22	20	34	0.15	0.26	0.20, 0.31	<0.001
A_Hits	14	26	32	36	0.07	0.23	0.17, 0.28	<0.001
A_Self	18	10	27	22	0.01	0.18	0.18, 0.23	<0.001
A_Atta	20	23	33	39	0.04	0.20	0.15, 0.26	<0.001
A_Defi	21	17	21	33	0.03	0.20	0.14, 0.26	<0.001
A_Figh	28	29	35	38	0.24	0.26	0.21, 0.32	<0.001
EM_Rout	29	25	25	4	0.01	0.15	0.09, 0.21	<0.001
A_Atten	34	20	17	20	0.03	0.15	0.09, 0.21	<0.001
W_Youn	38	35	34	29	0.08	0.12	0.06, 0.18	<0.001

moderately correlated, suggesting that these symptoms frequently co-occur (Buthmann et al., 2022; Liu et al., 2017) and that comorbidities may be driven by a more general psychopathology factor (Caspi et al., 2014; Laceulle et al., 2015). From this perspective, it is perhaps unsurprising that adolescent internalizing and externalizing problems in adolescence are predicted by similar preschool-age symptoms. The present findings provide further support for the perspective that central and bridge symptoms (but also some peripheral symptoms) are involved in the development of psychopathology in adolescence (McNally, 2016), which is often characterized by high comorbidity.

In addition to studying risk for psychopathology, it is important to consider the development of strengths and competencies that promote well-being (Coll et al., 1996; Gaylord-Harden et al., 2018). We found that symptoms explained less variance in psychosocial strengths than

Table 3
Elastic net regression results predicting social competencies and extracurricular and community involvement at age 15.

Predicting social competencies								
Variable (Node name)	Strength centrality ranking	Closeness centrality ranking	Betweenness centrality ranking	Bridge Ranking	Elastic net estimate	Pearson's *r*	95%CI	p-Value
A_Wait	4	4	2	26	−0.02	−0.06	−0.002, −0.12	0.041
EM_Sulk	7	7	16	3	0.04	−0.01	−0.07, 0.05	0.806
EM_Whin	8	14	14	2	−0.04	−0.07	−0.01, −0.13	0.026
W_Acti	12	27	19	11	−0.12	−0.09	−0.03, −0.15	0.002
A_Frus	15	11	29	16	−0.05	−0.08	−0.01, −0.14	0.010
A_Atta	20	23	11	39	−0.07	−0.07	−0.01, −0.13	0.022
A_Defi	21	17	21	33	0.05	0.01	−0.05, 0.07	0.788
A_Puni	23	21	22	24	−0.02	−0.06	−0.001, −0.12	0.046
AN_Nerv	25	19	26	14	−0.07	−0.08	−0.02, −0.14	0.009
AN_Feel	26	28	13	10	0.01	−0.001	−0.06, 0.06	0.956
W_Answ	32	15	7	8	−0.04	−0.07	−0.01, −0.13	0.020
A_Atten	34	20	17	20	0.05	0.02	−0.04, 0.08	0.521

Predicting extracurricular and community involvement								
Variable (Node name)	Strength centrality ranking	Closeness centrality ranking	Betweenness centrality ranking	Bridge Ranking	Elastic net estimate	Pearson's *r*	95%CI	p-value
A_Angr	2	1	1	12	−0.02	−0.09	−0.03, −0.15	0.005
A_Scre	9	13	30	17	−0.07	−0.11	−0.05, −0.17	<0.001
A_Atta	20	20	11	39	−0.06	−0.09	−0.03, −0.15	0.003
AN_Sad	39	39	37	19	0.09	0.07	0.01, 0.13	0.026

they did in indicators of psychopathology in adolescence. It is possible that in Black children, early emotional and behavioral difficulties do not portend future development in positive domains. We should note, however, that the stronger predictive utility of early symptoms for future problems may be due, at least in part, to the fact that the same measures and reporters were used at the age-3 and the age-15 assessments; indeed, 16 CBCL items were repeated across the two assessments. Thus, it is important that future work replicate and extend our findings to other measures of psychosocial problems and strengths.

Although we identified specific central and bridge symptoms as longitudinal predictors of psychosocial outcomes, peripheral symptoms from the social withdrawal and anxious/depressed communities of symptoms also appeared to be important predictors. Specifically, acting too young for one's age (ranked 38th in strength centrality) significantly predicted subsequent internalizing and externalizing problems. Clinging to adults or being too dependent (ranked 30th in strength centrality) and being nervous, high-strung, or tense (ranked 25th in strength centrality) predicted subsequent internalizing, but not externalizing, problems. The fact that more peripheral symptoms were identified as predictors of future psychosocial outcomes may be related to the density of the network, which was characterized by many connections among symptoms. It is possible that central and bridge symptoms have less unique predictive utility in dense networks that have many paths to spreading activation of symptoms. Thus, the density of the symptom network may reflect the vulnerability of this population to the development of emotional and behavioral difficulties (Kalisch et al., 2019); however, as we noted above, our findings also raise the possibility that early childhood symptoms are less predictive of future competencies than they are of future difficulties. Black children may be largely resilient to the effects of early difficulties on positive youth development.

Our findings raise the question of why symptoms such as anger appear to be influential in the development and maintenance of psychopathology in Black children. One explanation is informed by research suggesting that adults who regularly interact with children, such as teachers, often have racial bias in how they perceive and respond to Black children's negative emotions, especially anger (Halberstadt et al., 2022; Thomas et al., 2009). Black parents often encourage their children to suppress anger-related emotions and behaviors to protect them against such bias and discrimination (Dunbar et al., 2017). From this perspective, the expression of some emotions and behaviors in Black children may have unique adverse social consequences, increasing risk for psychopathology across childhood and adolescence (Simons et al., 2002; Smith-Bynum et al., 2014). Future research that assesses transactional processes of discrimination and Black children's emotions and behaviors should test this possibility more directly. One implication of our findings is that clinical interventions for young Black children may benefit from targeting emotions and behaviors that are also commonly the focus of emotion and racial socialization in Black families.

We should note five limitations of the current study. First, the sample size of 1238 Black preschool-age children may be small for estimating a network of 39 variables, although it is worth noting that our sample and network size is comparable to prior studies (Rouquette et al., 2018), and our network estimates appeared to be stable based on bootstrapping procedures. As a related point, we did not explore potential moderators in our analyses, such as child sex and family income. Future research with larger samples is needed to compare network and predictive features across different groups of children. Second, we limited our network analysis to the age-3 assessment in FFCWS. Although the CBCL was administered at subsequent waves, the versions of the measure and items administered were not consistent across assessments, preventing us from investigating changes in network structure and features over time. Longitudinal examinations of networks will also be important for

understanding the directions of effects among symptoms over time (McNally, 2021). Third, we conducted our primary analyses with children whose parents both reported being non-Hispanic Black. It is also worth noting that the FFCWS study oversampled for children born out of wedlock, contributing to high levels of socioeconomic disadvantage within the sample. Thus, our findings may not generalize to Black children growing up in other racial/ethnic, family, and socioeconomic contexts. Individual differences in contextual factors, such as parent and family characteristics, play a role in the development of symptoms of psychopathology (Giannouli, 2018; Harold and Sellers, 2018). Integrating these contextual factors into symptom networks is a promising approach for understanding which "non-symptom" factors are most central to the development and maintenance of psychopathology (Zhang et al., 2023). Fourth, we used caregiver reports on the CBCL to assess psychological symptoms in both childhood and adolescence, and youth reports on positive outcomes in adolescence. As we noted above, overlap in the measures, reporters, and constructs may have led childhood symptoms to be stronger predictors of difficulties than of strengths in adolescence. Finally, the FFCWS sample included children born between 1998 and 2000; it is unclear whether the network and elastic net models will replicate using data from more recent cohorts.

Despite these limitations, the current study advances our understanding of the network structure of symptoms in young Black children. Specific externalizing and emotional reactivity symptoms appear to be central to emotional and behavioral difficulties; further, emotional reactivity symptoms may play a particularly important role in early comorbidity. Although some central and bridge symptoms during the preschool years predicted future internalizing and externalizing problems in adolescence, many peripheral symptoms also contributed to these predictions. The dense nature of the network structure may explain the wide selection of central, bridge, and peripheral symptoms as predictors of future psychopathology; young Black children growing up in at-risk contexts may have several paths to spreading activation among symptoms reflecting emotional and behavioral difficulties. Consequently, the set of early childhood predictors of adolescent psychopathology may extend beyond those symptoms that are highly central or involved in bridging different communities of symptoms. Conversely, network approaches to understanding early psychopathology may be less useful for predicting the development of positive psychosocial outcomes in Black adolescents. Our study serves as a call for investigators to conduct within-group network analyses of psychopathology and psychosocial strengths in Black and other racial/ethnic minority children.

CRediT authorship contribution statement

Mahnoor Hyat: Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft. **Jonas G. Miller:** Conceptualization, Formal analysis, Methodology, Supervision, Visualization, Writing – original draft. **Ian H. Gotlib:** Conceptualization, Funding acquisition, Writing – review & editing.

Declaration of competing interest

None.

Acknowledgments

Ms. Hyat received mentorship and guidance on this project through the Honors Thesis program in the Department of Psychology at Stanford University.

Funding

The Future of Families and Child Wellbeing Study was supported by the Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD) through grants R01HD36916, R01HD39135, and R01HD40421, as well as a consortium of private foundations. The data analysis and preparation of this manuscript was supported by the National Institute of Mental Health (IHG, R37MH101495).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jad.2024.01.071.

References

Achenbach, T.M., Rescorla, L.A., 2000. Manual for the ASEBA preschool forms & profiles: an integrated system of multi-informant assessment. In: Child Behavior Checklist for Ages 1 1/2-5. Burlington: University of Vermont.

Bansal, P.S., Goh, P.K., Lee, C.A., Martel, M.M., 2020. Conceptualizing callous-unemotional traits in preschool through confirmatory factor and network analysis. J. Abnorm. Child Psychol. 48 (4), 539–550. https://doi.org/10.1007/s10802-019-00611-9.

Boorsboom, D., Cramer, A.O.J., 2013. Network analysis: an integrative approach to the structure of psychopathology. Annu. Rev. Clin. Psychol. 9, 91–121. https://doi.org/10.1146/annurev-clinpsy-0502120185608.

Borsboom, D., 2017. A network theory of mental disorders. World Psychiatry 16 (1), 5–13. https://doi.org/10.1002/wps.20375.

Borsboom, D., Cramer, A.O.J., Schmittmann, V.D., Epskamp, S., Waldorp, L.J., 2011. The small world of psychopathology. PLoS One 6 (11), e27407. https://doi.org/10.1371/journal.pone.0027407.

Buthmann, J., Miller, J.G., Chahal, R., Berens, A., Gotlib, I.H., 2022. Negative caregiving and stress reactivity moderate the relation between early life stress and externalizing in adolescence. Dev. Psychobiol. 64 (7), e22327 https://doi.org/10.1002/dev.22327.

Caplan, M., Weissberg, R.P., Grober, J.S., Sivo, P.J., Grady, K., Jacoby, C., 1992. Social competence promotion with inner-city and suburban young adolescents: effects on social adjustment and alcohol use. J. Consult. Clin. Psychol. 60, 56–63. https://doi.org/10.1037/0022-006X.60.1.56.

Caspi, A., Houts, R.M., Belsky, D.W., Goldman-Mellor, S.J., Harrington, H., Israel, S., Moffitt, T.E., 2014. The p factor: one general psychopathology factor in the structure of psychiatric disorders? Clin. Psychol. Sci. 2 (2), 119–137. https://doi.org/10.1177/2167702613497473.

Coker, T.R., Elliott, M.N., Kanouse, D.E., Grunbaum, J.A., Schwebel, D.C., Gilliland, M.J., Schuster, M.A., 2009. Perceived racial/ethnic discrimination among fifth-grade students and its association with mental health. Am. J. Public Health 99 (5), 878–884. https://doi.org/10.2105/AJPH.2008.144329.

Coll, C.G., Crnic, K., Lamberty, G., Wasik, B.H., Jenkins, R., García, H.V., McAdoo, H.P., 1996. An integrative model for the study of developmental competencies in minority children. Child Dev. 67 (5), 1891–1914. https://doi.org/10.1111/j.1467-8624.1996.tb01834.x.

Cramer, A.O.J., Waldorp, L.J., van der Maas, H.L.J., Borsboom, D., 2010. Comorbidity: a network perspective. Behav. Brain Sci. 33 (2–3), 137–150. https://doi.org/10.1017/S0140525X09991567.

Dunbar, A.S., Leerkes, E.M., Coard, S.I., Supple, A.J., Calkins, S., 2017. An integrative conceptual model of parental racial/ethnic and emotion socialization and links to children's social-emotional development among African American families. Child Dev. Perspect. 11 (1), 16–22. https://doi.org/10.1111/cdep.12218.

Dvir, Y., Ford, J.D., Hill, M., Frazier, J.A., 2014. Childhood maltreatment, emotional dysregulation, and psychiatric comorbidities. Harv. Rev. Psychiatry 22 (3), 149–161. https://doi.org/10.1097/HRP.0000000000000014.

Epskamp, S., Cramer, A., Waldorp, L., Schmittmann, V.D., Borsboom, D., 2012. Qgraph: network visualizations of relationships in psychometric data. J. Stat. Softw. 48 (1), 1–18. https://doi.org/10.18637/jss.v048.i04.

Fredricks, J.A., Eccles, J.S., 2010. Breadth of extracurricular participation and adolescent adjustment among African-American and European-American youth. J. Res. Adolesc. 20 (2), 307–333. https://doi.org/10.1111/j.1532-7795.2009.00627.x.

Friedman, J., Hastie, T., Tibshirani, R., 2010. Regularization paths for generalized linear models via coordinate descent. J. Stat. Softw. 33 (1), 1–22.

Gaylord-Harden, N.K., Barbarin, O., Tolan, P.H., Murry, V.M., 2018. Understanding development of African American boys and young men: moving from risks to positive youth development. Am. Psychol. 73 (6), 753–767. https://doi.org/10.1037/amp0000300.

Giannouli, V., 2018. On the importance of focusing on family and parent factors in multilevel analyses regarding psychopathology of adolescents with an intellectual disability who present to general hospital services. Austral. Psychiatry 26 (3), 325–326. https://doi.org/10.1177/1039856217749055.

Gilliam, W.S., Maupin, A.N., Reyes, C.R., Accavitti, M., Shic, F., 2016. Do Early Educators' Implicit Biases Regarding Sex and Race Relate to Behavior Expectations and Recommendations of Preschool Expulsions and Suspensions?. Yale Child Study Center, Yale University, New Haven, CT.

Gresham, F.M., Elliott, S.N., 1990. Social skills rating system: Manual. American Guidance Service.

Halberstadt, A.G., Cooke, A.N., Garner, P.W., Hughes, S.A., Oertwig, D., Neupert, S.D., 2022. Racialized emotion recognition accuracy and anger bias of children's faces.

Emotion (Washington, D.C.) 22 (3), 403–417. https://doi.org/10.1037/emo0000756.
Harold, G.T., Sellers, R., 2018. Annual research review: interparental conflict and youth psychopathology: an evidence review and practice focused update. J. Child Psychol. Psychiatry 59 (4), 374–402. https://doi.org/10.1111/jcpp.12893.
Hodgkinson, S., Godoy, L., Beers, L.S., Lewin, A., 2017. Improving mental health access for low-income children and families in the primary care setting. Pediatrics 139 (1), e20151175. https://doi.org/10.1542/peds.2015-1175.
Hogan, A.E., Scott, K.G., Bauer, C.R., 1992. The Adaptive Social Behavior Inventory (Asbi): a new assessment of social competence in high-risk three-year-olds. J. Psychoeduc. Assess. 10 (3), 230–239. https://doi.org/10.1177/073428299201000303.
Kalisch, R., Cramer, A.O.J., Binder, H., Fritz, J., Leertouwer, Ij., Lunansky, G., van Harmelen, A.-L., 2019. Deconstructing and reconstructing resilience: a dynamic network approach. Perspect. Psychol. Sci. 14 (5), 765–777. https://doi.org/10.1177/1745691619855637.
Kim, D., Kwon, H.-J., Ha, M., Lim, M.H., Kim, K.M., 2021. Network analysis for the symptom of depression with Children's Depression Inventory in a large sample of school-aged children. J. Affect. Disord. 281, 256–263. https://doi.org/10.1016/j.jad.2020.12.002.
Laceulle, O.M., Vollebergh, W.A.M., Ormel, J., 2015. The structure of psychopathology in adolescence: replication of a general psychopathology factor in the TRAILS study. Clin. Psychol. Sci. 3 (6), 850–860. https://doi.org/10.1177/2167702614560750.
Liu, J., Mustanski, B., Dick, D., Bolland, J., Kertes, D.A., 2017. Risk and protective factors for comorbid internalizing and externalizing problems among economically disadvantaged African American youth. Dev. Psychopathol. 29 (3), 1043–1056. https://doi.org/10.1017/S0954579416001012.
Martel, M.M., Levinson, C.A., Langer, J.K., Nigg, J.T., 2016. A network analysis of developmental change in ADHD symptom structure from preschool to adulthood. Clin. Psychol. Sci. 4 (6), 988–1001. https://doi.org/10.1177/2167702615618664.
McNally, R.J., 2016. Can network analysis transform psychopathology? Behav. Res. Ther. 86, 95–104. https://doi.org/10.1016/j.brat.2016.06.006.
McNally, R.J., 2021. Network analysis of psychopathology: controversies and challenges. Annu. Rev. Clin. Psychol. 17, 31–53. https://doi.org/10.1146/annurev-clinpsy-081219-092850.
Merz, E.C., Wiltshire, C.A., Noble, K.G., 2019. Socioeconomic inequality and the developing brain: spotlight on language and executive function. Child Dev. Perspect. 13 (1), 15–20. https://doi.org/10.1111/cdep.12305.
Mullarkey, M.C., Marchetti, I., Beevers, C.G., 2019. Using network analysis to identify central symptoms of adolescent depression. J. Clin. Child Adolesc. Psychol. 48 (4), 656–668. https://doi.org/10.1080/15374416.2018.1437735.
Priest, N., Paradies, Y., Trenerry, B., Truong, M., Karlsen, S., Kelly, Y., 2013. A systematic review of studies examining the relationship between reported racism and health and wellbeing for children and young people. Soc. Sci. Med. 1982 (95), 115–127. https://doi.org/10.1016/j.socscimed.2012.11.031.
R Core Team, 2022. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.
Reichman, N.E., Teitler, J.O., Garfinkel, I., McLanahan, S.S., 2001. Fragile Families: sample and design. Child Youth Serv. Rev. 23 (4–5), 303–326. https://doi.org/10.1016/S0190-7409(01)00141-4.
Reiss, F., 2013. Socioeconomic inequalities and mental health problems in children and adolescents: a systematic review. Soc. Sci. Med. 90, 24–31. https://doi.org/10.1016/j.socscimed.2013.04.026.
Rouquette, A., Pingault, J.-B., Fried, E.I., Orri, M., Falissard, B., Kossakowski, J.J., Borsboom, D., 2018. Emotional and behavioral symptom network structure in elementary school girls and association with anxiety disorders and depression in adolescence and early adulthood: a network analysis. JAMA Psychiatry 75 (11), 1173–1181. https://doi.org/10.1001/jamapsychiatry.2018.2119.
Russell, J.D., Neill, E.L., Carrión, V.G., Weems, C.F., 2017. The network structure of posttraumatic stress symptoms in children and adolescents exposed to disasters. J. Am. Acad. Child Adolesc. Psychiatry 56 (8), 669–677.e5. https://doi.org/10.1016/j.jaac.2017.05.021.
Simons, R.L., Murry, V., McLoyd, V., Lin, K.-H., Cutrona, C., Conger, R.D., 2002. Discrimination, crime, ethnic identity, and parenting as correlates of depressive symptoms among African American children: a multilevel analysis. Dev. Psychopathol. 14 (2), 371–393. https://doi.org/10.1017/s0954579402002109.
Smith, K.E., Mason, T.B., Crosby, R.D., Cao, L., Leonard, R.C., Wetterneck, C.T., Moessner, M., 2019. A comparative network analysis of eating disorder psychopathology and co-occurring depression and anxiety symptoms before and after treatment. Psychol. Med. 49 (2), 314–324. https://doi.org/10.1017/S0033291718000867.
Smith-Bynum, M.A., Lambert, S.F., English, D., Ialongo, N.S., 2014. Associations between trajectories of perceived racial discrimination and psychological symptoms among African American adolescents. Dev. Psychopathol. 26 (4pt1), 1049–1065. https://doi.org/10.1017/S0954579414000571.
Thomas, D.E., Coard, S.I., Stevenson, H.C., Bentley, K., Zamel, P., 2009. Racial and emotional factors predicting teachers' perceptions of classroom behavioral maladjustment for urban African American male youth. Psychol. Sch. 46 (2), 184–196. https://doi.org/10.1002/pits.20362.
Weissman, D.G., Bitran, D., Miller, A.B., Schaefer, J.D., Sheridan, M.A., McLaughlin, K. A., 2019. Difficulties with emotion regulation as a transdiagnostic mechanism linking child maltreatment with the emergence of psychopathology. Dev. Psychopathol. 31 (3), 899–915. https://doi.org/10.1017/S0954579419000348.
Zhang, W., Tang, Y., Wu, Q., Zhou, N., Lin, X., 2023. Oppositional defiant disorder symptoms and multi-level family factors in Chinese migrant children: a network perspective. Res. Child Adoles. Psychopathol. 51 (8), 1143–1161. https://doi.org/10.1007/s10802-023-01074-9.
Zou, H., Hastie, T., 2005. Regularization and variable selection via the elastic net. J. R. Stat. Soc. Ser. B Stat Methodol. 67 (2), 301–320. https://doi.org/10.1111/j.1467-9868.2005.00503.x.