The influence of Functional Impairment in a Network of Child and Adolescent Psychopathology Domains

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Jala Rizeq[1], Christie L. Burton[2], Paul D. Arnold[2,3], Jennifer Crosbie[2,4]

1 School of Health and Wellbeing, University of Glasgow, Glasgow, Scotland

2 Hospital for Sick Children, Toronto, Canada

3 The Mathison Centre for Mental Health Research and Education, Hotchkiss Brain Institute, Calgary, Canada

4 University of Toronto, Toronto, Canada

Corresponding author

Dr. Jennifer Crosbie, The Hospital for Sick Children (SickKids), 555 University Ave, Psychiatry Research, 4th Floor, Black Wing, Toronto, ON, M5G 1X8. Email: jennifer.crosbie@sickkids.ca

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Abstract

In this study, we examined the unique associations between functional impairment and different psychopathology domains across childhood and adolescence. We examined whether functional impairment's associations with psychopathological domains can offer important insights to understanding direct and indirect pathways for the co-occurrence among mental health difficulties across childhood and adolescence. From the population-based study Spit for Science, we included 5163 participants between the ages of 6 and 18.97 years (Mean age = 9.98, SD = 2.89) with parent/self-rated quantitative measures of psychopathology. We used network estimation to examine the unique associations among ratings of functional impairment, inattention, hyperactivity, autism, obsessions and compulsions, depression, anxiety, and irritability, while accounting for age effects. Bootstrapped difference tests of edges (partial correlations between two domains in a network) and node (domains/ variable within a network) influence on network connectivity were conducted. In addition to domain specific associations, functional impairment-irritability and functional impairment-depression ratings were two of the strongest connections in the network. Overall, functional impairment and depression ratings had some of the highest centrality indices, in terms of their strength and number of direct and indirect connections. Age effects varied in the network with the positive age-depressive ratings connection being the strongest. This study demonstrates the importance of examining associations among psychopathology domains together with functional impairment to delineate important direct and indirect pathways for co-occurrence. We offer data driven hypotheses for impairment-related pathways and suggest important targets for intervention that can be examined in clinical research to mitigate comorbidities.

Childhood and adolescence are critical stages for the development of psychopathology (Ford et al., 2003; Kessler et al., 2005), whereby having a mental health disorder in either period increases the risk for having a disorder later in life (Copeland et al., 2013; Costello et al., 2003). Comorbid psychopathology is also common across the lifespan (Costello et al., 2014; Kessler et al., 2005). Comorbid mental health difficulties are associated with negative health outcomes (e.g., Gibb et al., 2010; Nock et al., 2010), poor quality life and impairment in daily functioning (Hofmeijer-Sevink et al., 2012; Storch et al., 2010), and thus is of concern to both clinicians and researchers (Van Loo & Romeijn, 2015).

Common reported comorbidities in childhood and adolescence include those between attention-deficit/hyperactivity disorder (ADHD) and conduct, learning, and developmental disorders, and autism spectrum disorder (ASD) (Jensen & Steinhausen, 2015), anxiety and depression disorders (Cummings et al., 2014; Garber & Weersing, 2010), obsessive-compulsive disorder (OCD) with anxiety and depressive disorders (Peris et al., 2017) and ASD with anxiety disorders, ADHD, and OCD (Gjevik et al., 2011). Most research examining rates of comorbidity examines co-occurrence of disorders or associations between two domains at a time, which does not account for the possibility that the co-occurrence or association between certain domains is better explained by a third confounding comorbid domain.

Network approach to psychopathology has afforded researchers an innovative way to conceptualize and empirically study the maintenance and development of psychopathology and comorbidity, as well as how mental health disorders develop and are maintained (Robinaugh et al., 2020). Psychopathology is viewed as a network of interactive components, with the hypothesis that the interactions among the components lead to the development and maintenance of disorders or psychopathology (Borsboom, 2017; Borsboom & Cramer, 2013; Fried et al.,

2017; McNally, 2016). The idea being that when a symptom or domain of psychopathology develops it will lead to the onset of other symptoms or domains with which it has strong associations. An important aspect of the network theory to psychopathology is the centrality hypothesis – central domains have network-wide effects with the potential to activate several other domains and are more influential than peripheral domains (Cramer et al., 2010). At a symptom level, it is theorised that a highly central symptom is notable in the onset and remission of disorders (Cramer et al., 2010). That is, when a central symptom emerges, it may lead to the activation of other connected symptoms, even those that cross multiple disorders because of their existing connections, and thus increases the risk of comorbidity (van Loo & Romeijin, 2015). Clinically, this may manifest with a young person who presents with generalized worry and/or avoidance of social and academic settings, which may then stimulate a host of other symptoms that cross diagnostic categories such as loneliness and sadness.

Most clinicians and researchers examine psychopathology at the construct level (i.e., disorders or syndrome/problem domains). Network modelling is flexible and can be extrapolated to examine the associations among psychopathological domains at various levels of measurement (Anker et al., 2017). This is particularly important when researchers are interested in examining associations among various psychopathology domains and including all symptoms might complicate interpretation. Indeed, studies with children and adolescents have examined the unique associations among psychopathological domains at the disorder level (McElroy et al., 2018) or problem/symptom domain total scale level (Barcaccia et al., 2020; Cao et al., 2020; Groen et al., 2019). These studies varied in the psychopathological domains assessed and none of them included functional impairment within their networks of psychopathology, despite the significance of this clinical marker in diagnostic decision making, service utilization, and

treatment planning. Psychopathology has been consistently linked to functional impairment – the degree to which the individuals' ability to meet developmental expectations within their home, school, and social settings is impaired (Bird & Gould, 1995). Functional impairment is a key element to clinical referrals (Becker et al., 2011) and is considered within mental health assessment and intervention (American Psychiatric Association, 2013; Sasser et al., 2017). There is evidence that functional impairment worsens in adolescence as compared to childhood (Cleverley et al., 2020), at a time when certain types of psychopathology and rates of comorbidity increase (Cummings et al., 2014; Peris et al., 2017; Gjevik et al., 2011). Functional impairment is viewed as an important clinical marker for psychopathology, however, its role as a risk factor is not as clear. In the multiple pathway model, one disorder can be linked to the other via functional impairment, whereby depression-related impairment can lead to anxiety and vice versa (Cummings et al., 2014). Therefore, to properly understand how psychopathology emerges and the connections between various domains of psychopathology, it is vital that we examine this co-occurrence in conjunction with functional impairment.

Understanding the associations among psychopathology domains alongside functional impairment and across development is important given differences in onset and prevalence of various psychopathology domains in childhood and adolescence (Costello et al., 2011; Merikangas et al., 2010), which may impact how they associate with age (Cummings et al., 2014; Gjevik et al., 2011). Therefore, in the current study we estimated a network model in a large sample of children and adolescents (6–18 years) taking into account the effect of age in the network to delineate the unique associations between functional impairment and common psychopathological domains – inattention, hyperactivity, depression, anxiety, autism, obsessions and compulsions, and irritability – that present with frequent comorbidities across childhood and

adolescence (e.g., Evans et al., 2017; Garber & Weersing, 2010; Gjevik et al., 2011; Humphreys et al., 2019; Jensen & Steinhausen, 2015; Peris et al., 2017). We include domains that have not been previously examined in child and adolescent psychopathology networks, particularly ratings of functional impairment, autism, and irritability. Irritability has been associated with both internalizing and externalizing psychopathology (Evans et al., 2017; Humphreys et al., 2019), is included as part of the criteria for several mental health disorders in the 5th Edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013) and has also been associated with functional impairment (e.g., Dougherty et al., 2015; Galera et al., 2021). We maintain an exploratory approach to examining those associations. Nonetheless, we expect that because functional impairment is meant to be implicated with most mental health disorders that it may present with strong unique associations with psychopathological domains and high centrality within the networks. To fully appreciate diagnostic comorbidity across development, we need to consider psychopathology alongside functional impairment and transdiagnostic factors such as irritability, which is what the network approach allows us to fully investigate.

Method

Participants and Procedure

Data for this study were collected as part of Spit for Science, a population-based sample of children/adolescents recruited at an urban science museum (see Crosbie et al., 2013). Data on 5163 participants between the ages of 6 and 18.97 years (Mean age = 9.98, SD = 2.89) who participated in 2019 and 2020 were available. Of the total sample, 48.54% identified their sex at birth as male, 48.40% as female, 0.15% as other or prefer not to respond, and 2.91% did not

disclose. Based on grandparents' ancestry, 39.55% identified being of European descent, 17.16% identified being of mixed descent, 15.01% and 8.91% identified being of East Asian and South Asian descent, respectively, 8.39 indicated unknown descent, 5.37% identified being of either Arab, Black African, Indigenous, Latin, Pacific Islander, or West Asian descent, and 5.62% had either completely or partially missing information. Two thousand four hundred and sixty-six participants had at least one sibling in the sample[1]. Of the total sample, those who identified as having psychiatric disorders included: 5.19% any anxiety disorder, 7.42% ADHD, 2.52% ASD, 0.14% Bipolar, 1.78% Depression, 0.66% Intellectual Disability, 0.58% OCD, 0.76% oppositional defiant disorder, 0.02% Schizophrenia, and 0.64% Tics.

For participants younger than 13 years, data were provided through parent report. Participants 13 years and older had the option to provide self-report data (n = 585), otherwise data were provided through parent-report. Questionnaires were completed using REDcap electronic data capture tools (Harris et al., 2019). Part of the survey was optional, and thus only a proportion of the full sample completed select questionnaires asking about mood and anxiety symptoms (response rates are shown in Table 1). Parents/youth received a small amount in gift cards for completing questionnaires and each child/youth received a small prize. All procedures for this study were approved at all institutional research ethics boards (Hospital for Sick Children Research Ethics Board #1000062807) and all participants provided informed consent.

Measures

[1] We ran sensitivity analysis using a sample without siblings, where we only retained data from the eldest sibling to ensure the largest age range possible and developmental representation. The sample included 3857 participants between the ages of 6 and 18.97 years (Mean age = 10.40, SD = 2.99). The overall structure of the network and centrality results were also very similar to results reported with the full sample (see Table S2 and Figure S1 supplementary material).

Inattention and hyperactivity/impulsivity. Nine-item subscales of the Strengths and Weaknesses of ADHD symptoms and Normal-behaviors (SWAN; Swanson et al., 2012; Burton et al., 2019) were used to assess difficulties with inattention (9 items; α = .93) and hyperactivity/impulsivity (9 items; α = .94). Items were rated on a 7-point likert scale (-3 = Far below; +3 = Far above). For each domain, a total subscale score was computed by summing the ratings the respective domain items with higher scores indicative of higher difficulties.

Obsessive-compulsive. The 28-item Toronto Obsessive–Compulsive Scale (TOCS; Park et al., 2016) was used to assess obsessions and compulsions. Items were rated on a 7-point likert scale (-3 = Far less than others;+ 3 = Far more than others). A total scale score was computed by summing ratings across all items, with higher scores indicating more difficulties (α = 0.97).

Autism. Twenty-eight items from the children's version of the Autism Quotient (AQ-Child; Auyeung et al., 2008) were used to assess autism symptoms. Items were rated on a 4-point likert scale (0 = Definitely Agree; 3 = Definitely Disagree). A total score was computed by summing ratings across all items with higher scores indicative of more difficulties (α = 0.84).

Irritability. Thirteen items from The Irritability and Dysregulation of Emotion Scale (TIDES; Dissanayake et al., 2022) were used to assess irritability. Items were rated on a 7-point likert scale (-3 = Far less than others;+ 3 = Far more than others). We used the total scale score by summing ratings across all items to assess global irritability that encompasses proneness to anger, externalized or internalized negative emotional reactivity, and reactive aggression (higher scores indicate higher irritability; α = 0.95).

Functional impairment. The 13-item Columbia Impairment Scale (CIS; Bird et al., 1993) was used to assess functional impairment in the past six months within the following domains: interpersonal relations, job or school, leisure time, and psychopathology. Items were rated on a

5-point likert scale (0 = no problem to 4 = very bad). A total scale score was computed by summing item-level ratings with higher ratings indicative of higher impairment (α = 0.91).

Generalized anxiety and depression. Two total subscale scores from the Revised Children's Anxiety and Depression Scale (RCADS-25; Ebesutani et al., 2012, 2017) were used to measure overall difficulties with anxiety (15 items; α = 0.84) and depression (10 items; α = 0.85). Items were rated on a 4-point likert scale (1 = never; 4 = always). The total subscale scores were computed by summing item-level ratings across the respective domains, with higher scores indicative of higher difficulties.

Data Analysis

Data were analysed in R Studio version 1.3.1093 (RStudio Team, 2020). Descriptive statistics were generated and bivariate associations were estimated for all variables.

The qgraph package was used to estimate and visualize a regularized partial correlation network with continuous data using "cor_auto" (Epskamp & Fried, 2018; Epskamp et al., 2012). Total scale or subscale raw scores were used in the network to represent the various domains. Hyperparameter was set to 0.5 to prioritize network parsimony and minimize spurious edges. All available data were used in estimating the network and full information maximum likelihood was used to handle missing data. Nodes in our network represent the total scale/ subscale scores for inattention, hyperactivity/impulsivity, obsessions and compulsions, autism, depression, anxiety, irritability, and functional impairment in addition to age in years. Edges represent partial correlations between variables controlling for the effect of all other variables within the network and can have a value between -1 and 1. Thicker edges represent stronger associations. Before examining the network results, stability analyses of the estimated network structure were conducted using the bootnet package (Epskamp et al., 2018). These analyses inform us of the

robustness of the network – accuracy and stability – and whether it meets the accepted threshold for interpretation. We estimated the 95% confidence intervals around the edge weights and generated case-dropping bootstrap plots showing stability of the strength centrality index (Epskamp et al., 2018). The correlation stability (CS) coefficient was also estimated to assess the accuracy of the three centrality indices. The CS-coefficient represents the "proportion of data that can be dropped to retain with 95% certainty a correlation of at least 0.7 with the original centrality coefficients," with values above 0.50 indicative of high robustness and the lowest threshold of 0.25 suggested (p.12, Epskamp & Fried, 2018).

The importance of each node to the overall network structure and connectivity was assessed using three centrality indices: 1) strength - represents how much a node is directly connected to all other nodes in the network and is the sum of weighted connections with other nodes; 2) closeness – the degree to which a node is indirectly connected with other nodes in the network and is the average distance from a node of interest to all other nodes in the network; and 3) betweenness – is the count of the number of times a node is in the shortest paths between two other nodes in the network (Epskamp et al., 2018). Bootstrapped difference tests use confidence intervals (alpha 0.05) to assess differences in edge weights and node centrality scores within the network (Epskamp et al., 2018). A significant difference is indicated when zero is not included within the confidence interval.

Results

Table 1 presents the descriptive statistics for all variables used in the study and Table 2 presents the bivariate correlations among all variables used in the network. All variables were significantly associated except for the association between age and ratings of inattention and irritability (*ps* > .05).

Network stability. Before interpreting the network structure and results, the stability of the estimated network was explored. The stability analyses indicated that the network was accurately estimated. We observed narrow width of confidence intervals around the edge weights (See Figures S2 and S3 in the supplementary material showing plots for the bootstrapped 95% confidence interval around edges and the stability of centrality indices when dropping cases at random). The CS-coefficients for the strength, betweenness, and closeness centrality indices were 0.75, indicating excellent stability, increasing our confidence in the accuracy of the network (0.25; Epskamp et al., 2018; Epskamp & Fried, 2018).

Network results. The network structure is presented in Figure 1[2] (The edge weights are also presented in Table S1 in Supplementary material). Figure 2 shows the bootstrapped edge-weight (i.e., partial correlation) difference tests. As can be seen in Figs. 1 and 2, the inattention-hyperactivity and anxiety-depression positive edges had the strongest two weights in both groups, significantly stronger than all weaker edges. The functional impairment-irritability and depression-age edges were also positive and were the third and fourth strongest pairs of edge weights, significantly stronger from weaker edges except from the depression-functional impairment edge. The four negative edge weights included obsessive–compulsive-functional impairment, inattention-anxiety, irritability-age, and hyperactivity-age. These four edge weights did not significantly differ from each other.

Figure 3 presents the bootstrapped difference tests ($\alpha = 0.05$) that compare the node strength, betweenness, and closeness indices of the nine variables in the network. As can be seen,

We estimated the network in girls and boys separately and tested its invariance. The results indicated that the networks were invariant (Network invariance test M = 0.14, p = .11) in girls and boys and thus have kept the analysis and our reporting at the level of the full sample. Further, we estimated separate networks for youth and parent report for the subsample of participants 13 years or older. The network invariance results indicated that the networks were invariant (Network invariance test M = 0.24, p = .55), and thus we keep the analysis and reporting at the level of the full sample.

depression ratings had the strongest strength centrality, significantly stronger than all other nodes in the network. This was followed by ratings of functional impairment, hyperactivity, inattention, and anxiety, which did not significantly differ from each other in terms of their strength centrality. From the psychopathology domains, autism ratings had the weakest strength centrality, significantly weaker than other domains. Functional impairment had the highest closeness centrality score, stronger than all other domains. Irritability and depression ratings followed in terms of closeness centrality scores and both were significantly stronger than all weaker domains. Inattention, hyperactivity, and autism ratings and age had the four lowest closeness centrality scores and did not significantly differ from each other. Finally, in terms of betweenness centrality scores, functional impairment and depression ratings had two of the highest scores and did not significantly differ from each other. Functional impairment had significantly higher betweenness score than all other domains and so did depression ratings except for a non-significant difference with the irritability ratings' betweenness score. Age and ratings of autism, inattention, and obsessions and compulsions all had values of zero, indicating they were not in any of the shortest paths between any two nodes in the network.

Discussion

In this study we examined the interplay among eight domains relevant to child and adolescent psychopathology while controlling for the effect of age using a network approach. We delineate important dynamics among those domains across childhood and adolescence and offer directions for future research. We primarily discuss the following: 1) differences in connections among domains in the network; 2) centrality of functional impairment alongside certain domains of psychopathology within the network; 3) age effects observed within the network. Implications for clinical work and further research are also highlighted.

Unsurprisingly, the two strongest edges were domain and measure specific and included depression-anxiety and inattention-hyperactivity, extending findings with 18.5-year-old adolescents (Groen et al., 2019) to a sample of both children and adolescents (6–18 years), supporting the co-occurrence of difficulties across these pairs of domains irrespective of the effects of other variables in the network. The strong connection between ratings of anxiety and depression and hyperactivity and inattention can be seen as evidence for a shared diathesis pathway characterizing these types of co-occurrence. Functional impairment-irritability had the third strongest connection in the network. Despite irritability's documented association with various psychopathological domains (Evans et al., 2017; Humphreys et al., 2019; Vidal-Ribas et al., 2016), its association with functional impairment ratings was significantly stronger than its association with all other psychopathology domains. Previous research has shown irritability's independent effect on functional impairment above and beyond psychopathology (Dougherty et al., 2015; Galera et al., 2021). Together these findings could be taken as evidence for irritability's transdiagnostic nature – its importance across psychopathological domains may be due to its association with functional impairment. Indeed, irritability had one of the highest closeness centrality scores, indicating that it was one of the variables most indirectly connected with other variables in the network. These results support the need to address irritability within mental health treatment, especially considering its association with functioning observed in children and adolescents who present to clinics (e.g., Evans et al., 2020; Kircanski et al., 2018; Stringaris et al., 2018).

In terms of centrality, functional impairment had one of the highest strength (degree of direct associations), closeness (degree of indirect associations), and betweenness (total count of the number of times it falls within the shortest paths between two other nodes) centrality scores. One

interpretation of the centrality of functional impairment is the impact that psychopathology domains have on functional impairment reflected by the strength of its direct associations in the network. Alternatively, the burden associated with functional impairment on children, adolescents, and families could also further exacerbate or activate mental health difficulties across various psychopathological domains and increase risk of co-occurrence of difficulties. The latter is reflected in functional impairment's betweenness score, having the highest total count of the number of times it falls within the shortest paths between other variables in the network (total of 28 paths). For example, some possible impairment-related pathways can be viewed in our network particularly in the indirect pathways between autism ratings and irritability, inattention, and depression ratings. Although autism ratings had one of the lowest centrality scores, its association with functional impairment is consistent with autism traits or symptoms' effect on quality of life within social, academic, physical, and school settings (e.g., de Vries & Geurts, 2015). Previous research has reported that higher depressive symptoms in children and adolescents with ASD were associated with poorer global functioning (Mazzone et al., 2013). The impairment-related pathways implicated with ratings of autism mentioned above are further evidence for the need for prospective designs that can identify whether these associations are mutually reinforcing or if there's a directionality, such as having autism difficulties that are functionally impairing may increase risk for developing depressive symptoms. Such hypothesis driven investigations can elucidate important directions for prevention and inform work that currently suggests functional impairment as an important target for intervention (Ford et al., 2017).

Equally central to network connectivity was the depression ratings score with the highest strength and second highest betweenness and closeness scores. This finding extends research

with children and adolescents showing depression's central role within networks of internalizing and externalizing psychopathology, with some noting that depressive symptoms could be considered nonspecific (Cao et al., 2020; Funkhouser et al., 2021; Imperiale et al., 2021). Including age in the network has revealed important findings with opportunities to generate hypotheses for future examination, with a notable association with depression ratings. The depression-functional impairment and depression-age edge weights were some of the strongest in the network with age-depression-functional impairment indirect pathway emerging, especially when functional impairment did not have an edge weight with age. This is an important finding from the network as it suggests that when the effects of other variables are taken into account, functional impairment is not characteristic of a developmental stage or a particular age but may co-occur as a result of other difficulties that emerge or worsen with age, such as depressive symptoms in adolescence. These results closely follow from research showing that depression symptoms are uniquely associated with impairment in childhood and adolescence (see Nagar et al., 2010) above and beyond the effect of general psychopathology factor (Aitken et al., 2020) and that rates of depressive symptoms and disorders increase with age (Cohen et al., 2018; Kessler et al., 2012; Ormel et al., 2015).

In contrast to depression ratings, the anxiety ratings were not connected to age which may speak to anxiety's early age of onset (Kessler et al., 2005). It could also be that the total anxiety score used in our network masks developmental associations whereby certain types of anxiety have an earlier age of onset (e.g., Ormel et al., 2015). Research that focuses on a narrower subset of psychopathological domains within their networks can shed light on these specific developmental considerations (e.g., Klaufus et al., 2022). Further, the lack of edge weight with inattention symptoms and the negative edge weight with hyperactivity symptoms are consistent

with longitudinal evidence for the stability and persistence of difficulties with inattention from childhood through adolescence and a reduction in hyperactivity with age (Holbrook et al., 2016; Vergunst et al., 2019). This may in part explain the weak edge weight connecting hyperactivity symptoms and functional impairment, whereby the hyperactivity-inattention-functional impairment and hyperactivity-irritability-functional impairment alternate pathways were apparent, suggesting that hyperactivity may be connected to functional impairment through the presence of co-occurring difficulties with inattention or irritability. This finding may also reflect the higher rates of the inattentive and combined subtypes of ADHD in older participants in addition to functional social and academic impairments being associated more strongly with inattention than hyperactivity (Elia et al., 2008; Graetz et al., 2001).

Overall, the strengths of this study lie in its large sample size, spanning a broad age range, inclusion of multiple psychopathology domains and functional impairment, and its multivariate analytic approach. Nonetheless, there are some important limitations to consider. This study is limited by the cross-sectional data, which preclude us from making any inference about causality or direction of associations. Future research can follow up on our findings with longitudinal data to elucidate the direction of the indirect pathways highlighted in the network. Further, the networks estimated using eight domains relevant to psychopathology across childhood and adolescence, however, there are additional domains that are relevant and that would be important to capture in future work; this has implications for node centrality, whereby a node might be central in one network and peripheral in another depending on the nodes/domains included. In addition, our sample was recruited from the community which can impact on the generalizability of our results, especially to clinic-seeking children and adolescents, although the evidence is mixed when it comes to psychopathology network structure across severity levels of

psychopathology (Groen et al., 2019; Imperiale et al., 2021). It is notable that studying these associations in community samples can help us identify the interplay at early stages of psychopathology, advancing discovery of preventative and early intervention targets.

conclusion, this study provided novel and important findings regarding the associations among various domains of psychopathology across childhood and adolescence while accounting for age. The study highlights the central role of functional impairment with insights for its potential role in linking psychopathology domains. The impairment-related pathways highlighted in our network offer valuable future directions for clinical research to identify when functional impairment is a marker/consequence of psychopathology, a risk marker for future psychopathology, or both, which will inform both psychological assessment and intervention with children and adolescents. Further, the heterogeneity in the associations between age and domains of psychopathology offer important clinical and etiological insights that can guide both clinical practice and research focused on the prevention of comorbidity across development, particularly in the case of depressive symptoms that appear to be most strongly linked with age with a clear role in overall network connectivity.

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Disclosure statement

The authors report there are no competing interests to declare.

Data availability

Individual participant data that underlie the results reported in this Article (after de-identification) can be made available for researchers who provide a methodologically sound proposal. Of note, the execution of such a proposal will require Research Ethics approval.

Requests can be directed to the corresponding author. To gain access, those requesting access to the data will need to sign a data access agreement.

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Table 1

Descriptive statistics of the variables examined in the study

Variables	n	mean	SD	Range (min, max)
Inattention	4901	-4.65	9.41	-27, -27
Hyperactivity	4905	-4.44	9.54	-27, 27
Obsessive-compulsive	4835	-16.33	28.74	-84, 78
Autism	4741	31.74	10.11	0, 80
Depression	1409	3.53	3.78	0, 30
Anxiety	1407	6.02	5.07	0, 45
Irritability	4078	-4.08	14.54	-39, 39
Functional Impairment	3567	7.29	7.31	0, 45

Note. The eight variables represent total scale scores of eight problem domains

Table 2

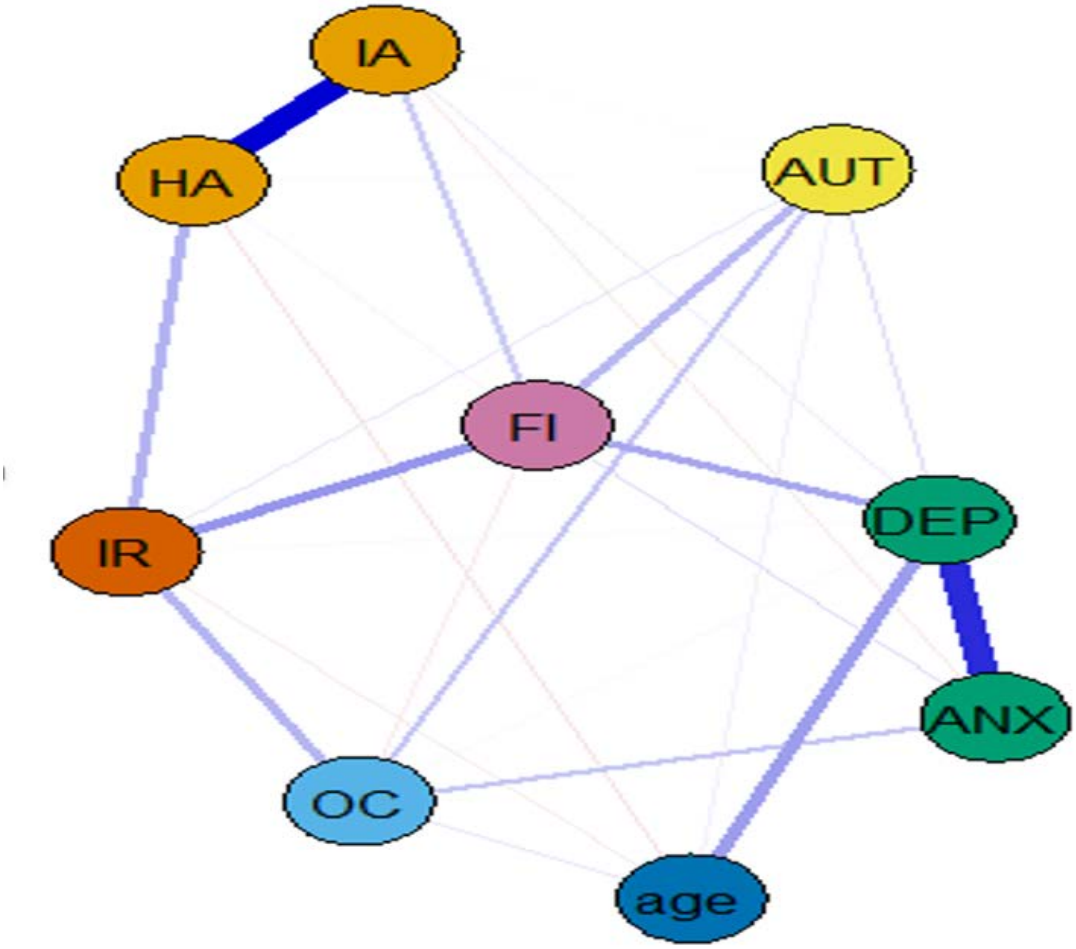
Bivariate correlations

	1	2	3	4	5	6	7	8	9
1. Inattention	1								
2. Hyperactivity	0.78	1							
3. Obsessive-compulsive	0.10	0.14	1						
4. Anxiety	0.12	0.12	0.31	1					
5. Depression	0.24	0.2	0.27	0.72	1				
6. Autism	0.20	0.20	0.29	0.28	0.34	1			
7. Functional impairment	0.40	0.38	0.21	0.43	0.52	0.4	1		
8. Irritability	0.38	0.45	0.32	0.25	0.31	0.3	0.5	1	
9. Age	*-0.01*	-0.07	0.17	0.24	0.37	0.16	0.15	*0.02*	1

Note. All correlations were significant at alpha = 0.05, except for the italicized values in the table.

Figure 1

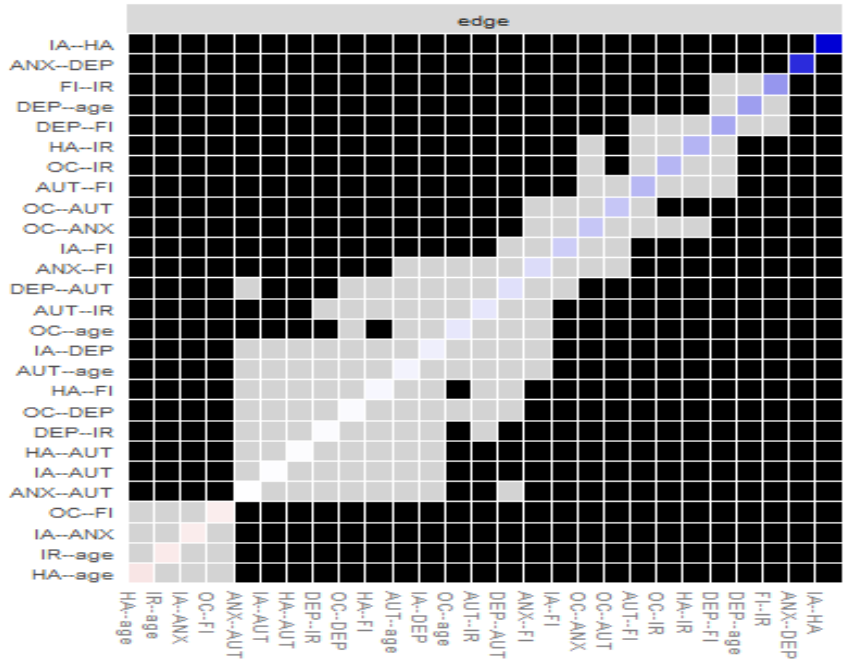
Regularized partial correlation network



Note. IA = inattention symptoms; HA = hyperactivity symptoms; IR = irritability symptoms; AUT = autism spectrum disorder symptoms; DEP = depression symptoms; ANX = anxiety symptoms; OC = obsessive-compulsive disorder symptoms; FI = functional impairment difficulties. Blue edges represent positive associations and red edges represent negative associations. The colors of the nodes represent the different measures used for the separate domains.

Figure 2

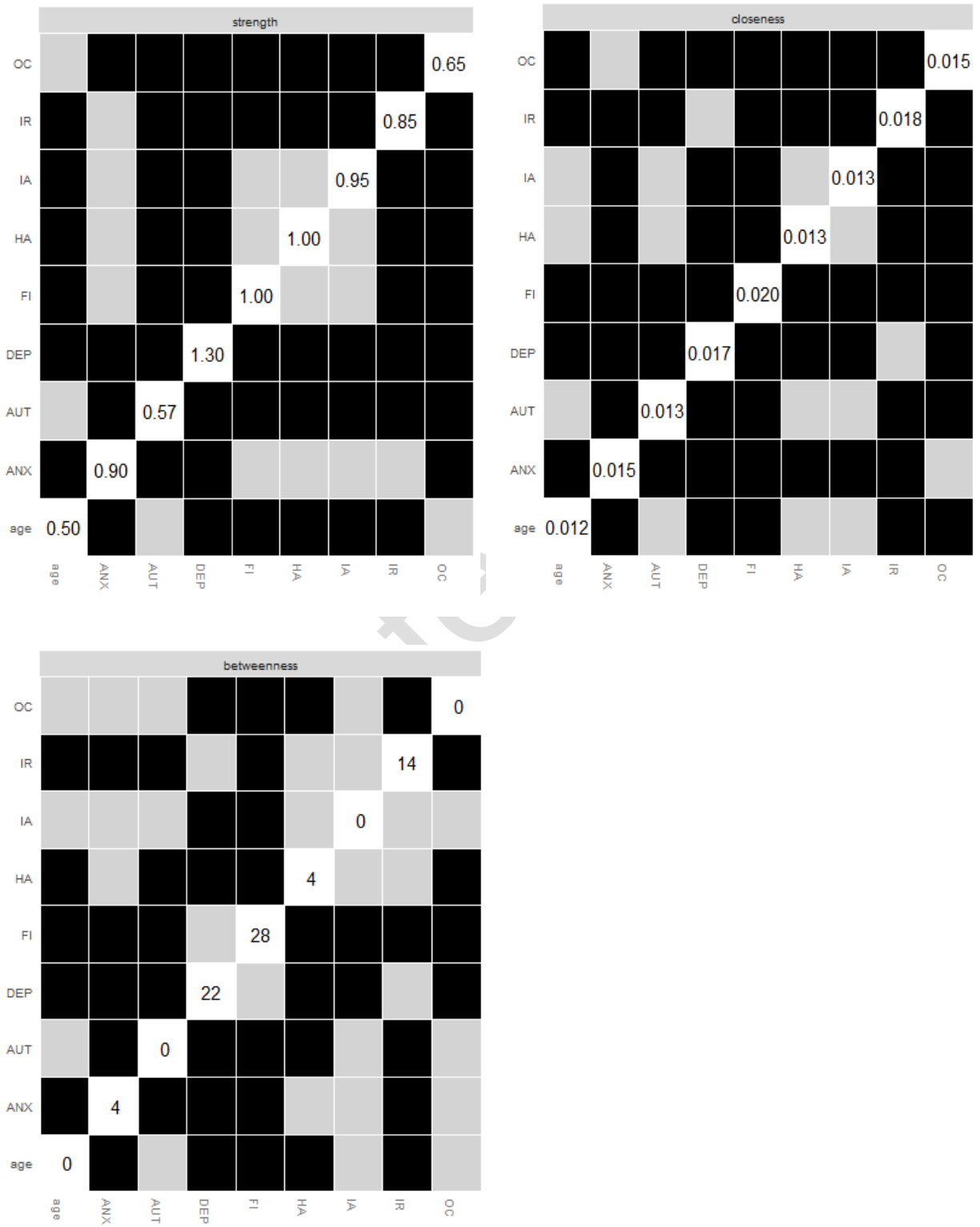
Bootstrapped difference tests for the edge weights



Note. IA = inattention symptoms; HA = hyperactivity symptoms; IR = irritability symptoms; AUT = autism spectrum disorder symptoms; DEP = depression symptoms; ANX = anxiety symptoms; OC = obsessive-compulsive disorder symptoms; FI = functional impairment difficulties. Blue edges represent positive associations and red edges represent negative associations. *Gray boxes* indicate edges that do not differ significantly from one another and *black boxes* represent edges that do differ significantly from one another. *Colored boxes* in the edge-weight plot correspond to the color of the edge (see Figure 1).

Figure 3

Bootstrapped difference tests for the centrality indices



Note. IA = inattention symptoms; HA = hyperactivity symptoms; IR = irritability symptoms; AUT = autism spectrum disorder symptoms; DEP = depression symptoms; ANX = anxiety symptoms; OC = obsessive-compulsive disorder symptoms; FI = functional impairment difficulties. Blue edges represent positive associations and red edges represent negative associations. *Gray boxes* indicate node centrality scores that do not differ significantly from one another and *black boxes* represent node centrality scores that do differ significantly from one another. *White boxes* in the centrality plots show the value of node centrality raw score (higher scores indicate stronger centrality).

Supplementary material

Table S1. Network structure
Table S2. Network structure with data without siblings (sensitivity analysis)
Figure S1. Centrality indices with data without siblings (sensitivity analysis)
Figure S2. Bootstrapped 95% confidence interval around edges plot
Figure S3. The correlation between the original centrality index and the centrality index after dropping a percentage of subjects at random

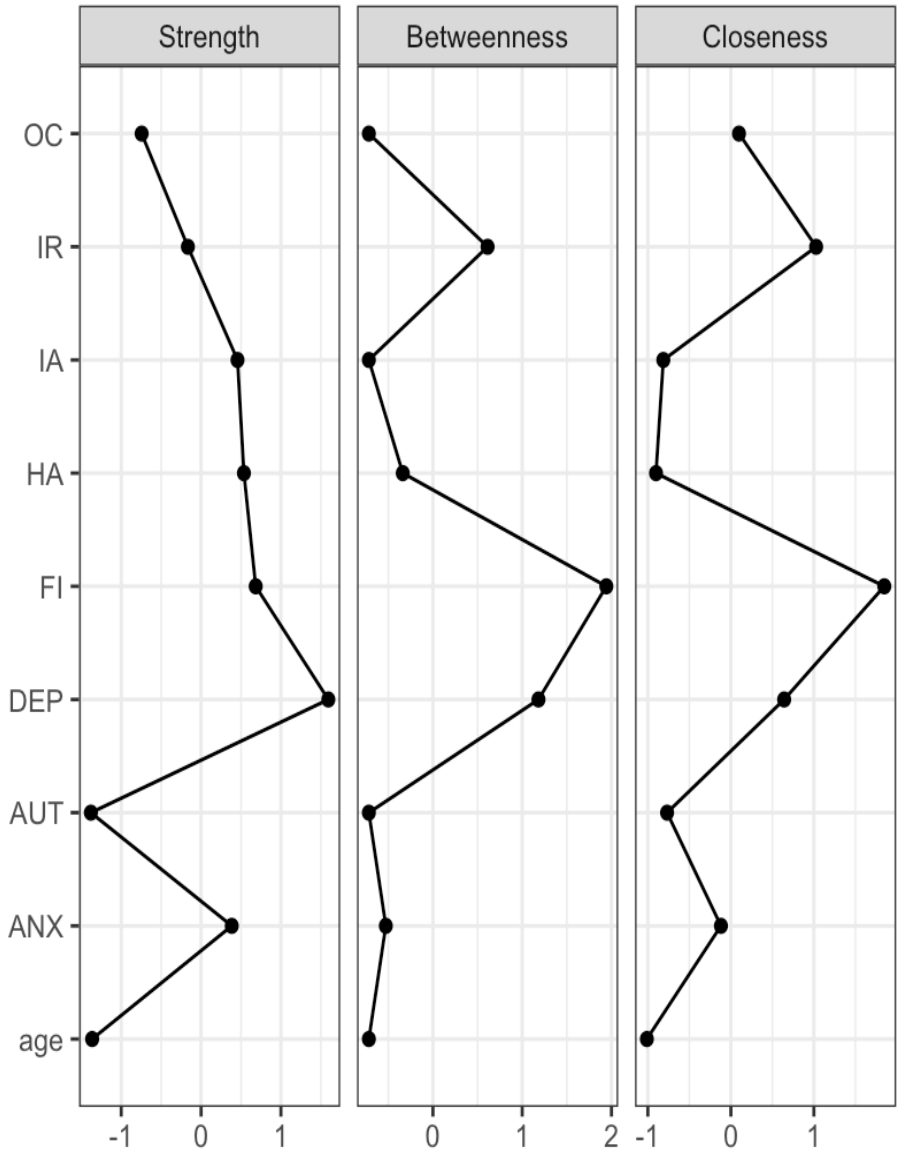
Table S1. Network structure

	1	2	3	4	5	6	7	8	9
1. Inattention	0								
2. Hyperactivity	0.71	0.00							
3. obsessions and compulsions	0.00	0.00	0.00						
4. Anxiety	-0.05	0.00	0.16	0.00					
5. Depression	0.04	0.00	0.01	0.59	0.00				
6. Autism	0.01	0.01	0.16	0.00	0.09	0.00			
7. Functional impairment	0.14	0.02	-0.05	0.10	0.24	0.20	0.00		
8. Irritability	0.00	0.21	0.20	0.00	0.01	0.07	0.29	0.00	
9. Age	0.00	-0.07	0.07	0.00	0.27	0.03	0.00	-0.06	0.00

Table S1. Network structure with data without siblings (sensitivity analysis)

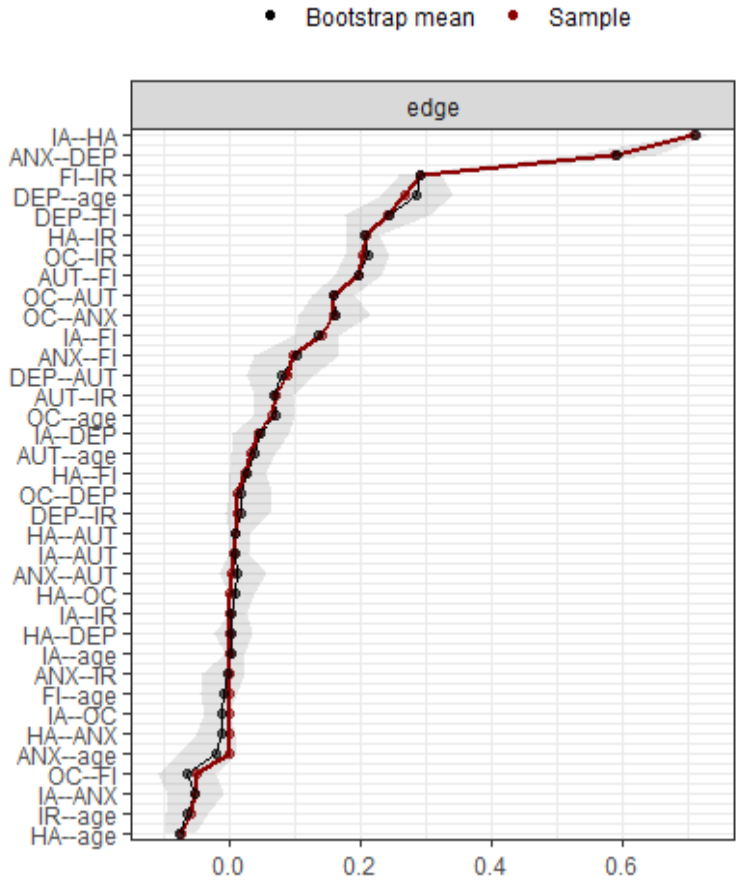
	1	2	3	4	5	6	7	8	9
1. Inattention	.00								
2. Hyperactivity	.71	.00							
3. obsessions and compulsions	-.03	.02	.00						
4. Anxiety	-.07	-.00	.15	.00					
5. Depression	.06	.00	.01	.62	.00				
6. Autism	.01	.01	.18	.00	.07	.00			
7. Functional impairment	.14	.02	-.06	.12	.21	.20	.00		
8. Irritability	.00	.20	.21	.00	.02	.08	.30	.00	
9. Age	.00	-.07	.09	-.04	.30	.04	-.01	-.06	.00

Figure S1. Centrality indices (z-scores shown on the x-axis) with data without siblings (sensitivity analysis)



Note. IA = inattention symptoms; HA = hyperactivity symptoms; IR = irritability symptoms; AUT = autism spectrum disorder symptoms; DEP = depression symptoms; ANX = anxiety symptoms; OC = obsessive-compulsive disorder symptoms; FI = functional impairment difficulties.

Figure S2. Bootstrapped 95% confidence interval around edges plot



Note. IA = inattention symptoms; HA = hyperactivity symptoms; IR = irritability symptoms; AUT = autism spectrum disorder symptoms; DEP = depression symptoms; ANX = anxiety symptoms; OC = obsessive-compulsive disorder symptoms; FI = functional impairment difficulties.

Figure S3. The correlation between the original centrality index and the centrality index after dropping a percentage of subjects at random for the 6-8 age group