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Peer functioning difficulties may exacerbate symptoms of attention-deficit/hyperactivity disorder and irritability over time: a temporal network analysis

Nellia Bellaert,[1,2] Kristina Morreale,[2,3] and Wan-Ling Tseng[2]

[1]Cognitive Psychology and Neuropsychology Department, University of Mons, Mons, Belgium; [2]Yale Child Study Center, Yale School of Medicine, New Haven, CT, USA; [3]University of New Haven, New Haven, CT, USA

Background: Children with attention-deficit/hyperactivity disorder (ADHD) have been consistently found to experience impairments in peer functioning. Irritability is highly prevalent in children with ADHD and may worsen social impairments given the frequent temper outbursts and low frustration tolerance characterizing irritability. However, it is still unclear how ADHD and irritability symptoms interact with peer functioning difficulties over time. Assessing these temporal dynamics using a novel longitudinal approach (i.e., temporal network analysis) may reveal precise targets for intervention. **Methods:** This study investigates the dynamic associations between ADHD symptoms, irritability, and peer functioning in a community sample of 739 children (ages 8–11 years, M_{age} = 10.06 [*SD* = 0.59], 47.77% females) assessed at three timepoints, 6 months apart, in a school-based study. Parents reported their child's ADHD symptoms using the Swanson, Nolan, and Pelham Rating Scale (SNAP-IV), and irritability symptoms using the Child Behavior Checklist (CBCL) irritability items. Children's peer functioning (i.e., peer acceptance, peer rejection, number of friendships, and victimization) was measured via peer nomination. To estimate the longitudinal associations between the variables, we built a graphical vector autoregression model for panel data. **Results:** The longitudinal network highlighted that poor peer functioning contributed to increases in symptoms over time. Specifically, (1) physical victimization predicted increases in inattention, hyperactivity, and irritability; (2) peer rejection predicted increases in inattention, which in turn predicted increases in irritability; (3) peer acceptance predicted decreases in inattention and irritability; and (4) higher numbers of mutual friendships increased inattention. **Conclusions:** These results suggest that a negative social environment involving physical bullying and rejection may aggravate ADHD and irritability symptoms. Conversely, positive social interactions, such as being liked by peers, may improve inattention and irritability symptoms. Fostering social–emotional skills and positive social interactions and environments in children with ADHD and irritability may be a promising target for future interventions to reduce symptoms. **Keywords:** Irritability; ADHD; peer functioning; peer victimization; temporal network.

Introduction

Children with ADHD have been consistently found to experience impairments in peer functioning (Ros & Graziano, 2018). Specifically, children with ADHD tend to experience more peer rejection (Grygiel, Humenny, Rębisz, Bajcar, & Świtaj, 2018; Lee et al., 2018), physical and relational victimization (Becker, Mehari, Langberg, & Evans, 2017; Efron, Wijaya, Hazell, & Sciberras, 2021; Wiener & Mak, 2009), and have less reciprocated friendships (Hoza, 2007; Lee, Mikami, & Owens, 2021) and poorer quality of close friendships (Normand, Miller, & Mikami, 2021) compared to children without ADHD. Symptoms of ADHD comprise two dimensions: inattention (e.g., difficulty sustaining attention, distractibility) and hyperactivity–impulsivity (e.g., fidgeting, excessive talking; American Psychiatric Association, 2013), which have differential associations with peer functioning. Inattention predicts lower peer acceptance, fewer number of reciprocated friendships (Becker, Langberg, Evans, Girio-Herrera, & Vaughn, 2015; Scholtens, Diamantopoulou, Tillman, & Rydell, 2012; Tseng, Kawabata, Gau, & Crick, 2014), and bullying perpetration and victimization (Murray, Zych, Ribeaud, & Eisner, 2021), whereas hyperactivity–impulsivity may increase risk for physical and relational aggression (Tseng et al., 2012).

Irritability, defined as an elevated proneness to anger relative to peers, is highly prevalent in children with ADHD (Eyre et al., 2017); it is estimated that 30–50% of youths with ADHD also show symptoms of irritability or irritability-related emotion dysregulation (Brotman, Kircanski, Stringaris, Pine, & Leibenluft, 2017; Shaw, Stringaris, Nigg, & Leibenluft, 2016; Stringaris, Vidal-Ribas, Brotman, & Leibenluft, 2018). Irritability may further exacerbate peer functioning deficits given the frequent temper outbursts and low frustration tolerance characterizing irritability (Brotman et al., 2017). Indeed, a small body of the literature has examined associations between irritability and peer functioning, in community samples and in disruptive mood dysregulation disorder (DMDD) or oppositional defiant disorder (ODD), both of which are characterized by irritability. While DSM-5 criteria for DMDD include severe chronic irritability (most days in ≥1 year) and

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recurrent temper outbursts (≥3 per week), ODD diagnosis requires the presence of either irritable mood, argumentative/defiant behaviors, or vindictiveness for at least 6 months (American Psychiatric Association, 2013). Cross-sectionally, higher irritability was associated with worse peer functioning (Elvin et al., 2021; Lin, Tseng, & Gau, 2021), including greater peer rejection (Evans, Pederson, Fite, Blossom, & Cooley, 2016; Waschbusch, Baweja, Babinski, Mayes, & Waxmonsky, 2020), physical and relational victimization (Chen et al., 2022; Evans et al., 2016; Tseng, Kawabata, & Gau, 2011), and peer disruptive behaviors (e.g., fights, hits, is bossy; Waschbusch et al., 2020). Youths with DMDD displayed more physical and verbal aggressive behaviors than youths with depression (Benarous et al., 2020). Longitudinally, early irritability increases the risk for later peer difficulties. For example, irritability at age 3 was associated with worse peer functioning in adolescence (Sorcher et al., 2022); persistent and rising irritability trajectories between 6 and 12 years old predicted greater peer victimization at age 13 (Forte et al., 2021), and DMDD at age 6 predicted more frequent peer victimization, relational aggression toward peers, and peer exclusion at age 9 (Dougherty et al., 2016).

Although ADHD and irritability are highly co-occurring and consistently associated with peer functioning impairments, the interplay between these clinical dimensions and peer functioning has rarely been examined. These interactions are particularly relevant given evidence that children who meet the criteria for both ADHD and ODD displayed worse peer relationships (including peer rejection and bullying) than children who meet the criteria for either ADHD or ODD alone (Eskander, 2020; Tseng et al., 2011). Evans et al. (2020) examined the longitudinal effects of ADHD and ODD dimensions on peer functioning and found that irritability was concurrently associated with peer rejection and victimization, whereas inattention and hyperactivity–impulsivity robustly predicted subsequent peer rejection and victimization. This suggests that irritability may be linked to more acute peer problems, whereas only ADHD symptoms may increase the risk for chronic peer difficulties, highlighting that ADHD symptoms and irritability may have differential effects on peer functioning depending on the timescales. However, Evans et al. (2020) used a US-based predominantly White sample, and it is therefore unknown whether these results can be generalized to non-Western populations. The current study critically expands Evans et al.'s study by examining the temporal associations between ADHD symptoms, irritability, and peer functioning in a non-Western sample from Taiwan using a network approach with peer functioning assessed via peer nomination. Previous research (Tseng et al., 2012, 2014) on the same Taiwanese sample used in the current study has found that inattention predicted later impairment in peer functioning, which subsequently contributed to increased inattention and hyperactivity. The current study expands upon this past research in three aspects. First, we examined the role of irritability on the interplay between ADHD and peer functioning, given the high comorbidity between irritability and ADHD symptoms (Shaw et al., 2016) and the well-documented social difficulties experienced by children with severe irritability (e.g., Brotman et al., 2017; Elvin et al., 2021; Lin et al., 2021). Second, since peer victimization was identified as a possible pathway leading to suicidality in adolescents with ADHD (Chen, Ho, Hsiao, Lu, & Yen, 2020; Liu, Hsiao, Chou, & Yen, 2021 – although these studies were cross-sectional) and as an environmental mechanism explaining the risk for suicidality in children experiencing persistent and increasing irritability (Forte et al., 2021), we also considered the effect of peer victimization to improve the public health significance of our study. Third, the current study used an innovative method to model how variables predict each other over time – temporal network analysis (Epskamp, 2020), which has the advantage of disentangling within- and between-person effects to provide a more accurate assessment of the relationship between the study variables, in contrast with the cross-lagged panel model used in past studies (Tseng et al., 2012, 2014), which confounds these two types of effect.

Temporal network analysis is a novel and promising approach that has advantages over other more commonly used longitudinal modeling techniques (e.g., cross-lagged panel models [CLPM], regression models). First, the graphical vector autoregression (GVAR) model built in temporal network analysis allows for the estimation of a directed network that accounts for within-person variation across time (Epskamp, 2020), while CLPM does not disentangle the within- and between-person effects, which may lead to incorrect conclusions about the causal relationships between variables. Although random intercept CLPM – an extension of CLPM – can disentangle time-invariant, trait-like between-person effects from within-person effects, it requires larger samples and greater power especially with more complex models with greater numbers of variables (Mulder, 2023). Second, temporal network analysis assesses the centrality of each variable in the model, which allows for identification of the most central (or influential) nodes in the network. As highly central nodes influence the most variables in the network, they may represent useful targets for interventions (Rodebaugh et al., 2018).

Taking an innovative approach, this study used temporal network analysis with three-wave longitudinal data from a non-Western sample to examine the dynamic interplay among children's peer functioning and symptoms of ADHD and irritability by

assessing the network structure of these variables, both cross-sectionally and longitudinally.

Method

Participants and procedure

The sample included 739 children (47.77% females) from northern Taiwan (ages 8–11 years, M_{age} = 10.06 years, SD = 0.59). Participants were assessed at three timepoints, 6 months apart. Subsets of the current dataset have been published previously, and details about recruitment and sample characteristics have been described elsewhere (Tseng et al., 2012, 2014). Data on irritability and peer victimization have not been published. A summary of the sociodemographic characteristics of the sample is presented in Table 1. Children were recruited from 27 classrooms from four public elementary schools in Taipei City and Taipei County, Taiwan. In total, 471 students (63.73%) and 514 students (69.55%) remained in Time 2 and Time 3, respectively. Children who remained in the study did not differ from those who dropped out at Time 3 in hyperactivity, inattention, irritability symptoms, peer variables, and all the demographic variables (p values ranging from .16 to .99), except for age (see Result S1 and Table S1 for details). Parental consent and child assent were obtained, and the research was approved by the Institutional Review Board at the last author's university at the time of the study.

Table 1 Sociodemographic characteristics of the sample (N = 739)

Sociodemographic variable	M (SD), n, or %
Age	10.06 (0.59)
Gender	
Male	386
Female	353
Grade	
Fourth grade	239
Fifth grade	500
Parental marital status	
Married	73.34%
Separated/divorced	6.90%
Widowed	0.68%
Never married	0.95%
Other	0.68%
No answer	17.45%
Mother's age	40.05 (4.89)
Father's age	43.22 (5.45)
Maternal education	
Junior high and below	12.45%
Senior high school and vocational	34.24%
College and above	35.72%
No answer	17.59%
Paternal education	
Junior high and below	14.75%
Senior high school and vocational	30.72%
College and above	37.75%
No answer	16.78%
Monthly household income (in New Taiwan Dollar)	
25,000 and below	7.17%
25,000–50,000	23.68%
50,000–75,000	20.70%
75,000–100,000	15.02%
100,000 and above	13.40%
No answer	20.03%

Measures

At all timepoints, children's ADHD and irritability symptoms were assessed using parent reports. Children's peer functioning (i.e., peer acceptance, peer rejection, number of friendships, and relational and physical victimization) was assessed via peer nomination.

ADHD symptoms. Parents reported their child's ADHD symptoms using the Chinese version of the Swanson, Nolan, and Pelham, version IV scale (SNAP-IV). The SNAP-IV is a 26-item questionnaire rated on a 4-point Likert scale from 0 (not at all true) to 3 (very much true; Gau et al., 2008; Swanson et al., 2001). Only the inattention (nine items) and hyperactivity–impulsivity (nine items) subscales, which map onto the DSM-IV diagnostic criteria for ADHD (Gau et al., 2008; Swanson et al., 2001), were used in this study. The norms and psychometric properties of the parent reports on the Chinese SNAP-IV have been established in Taiwan (Gau et al., 2008). For the present sample, the subscales showed good internal consistency across three timepoints (αs = .89–.91 for inattention and .89–.90 for hyperactivity–impulsivity). Mean scores of inattention and hyperactivity–impulsivity subscales were used as continuous measures of symptoms in the analysis.

Irritability. Children's irritability was assessed using three items from the parent-rated Chinese Child Behavior Checklist (CBCL; Achenbach, 2011). These items were 'stubborn, sullen or irritable', 'temper tantrums or hot temper', and 'sudden changes in mood or feelings' rated on a 3-point Likert scale from 0 (not true) to 3 (very/often true). These CBCL irritability items (Tseng et al., 2017; Wiggins, Mitchell, Stringaris, & Leibenluft, 2014) are well-validated and widely used in studies conducted before specific instruments were developed for irritability, such as the affective reactivity index (ARI; Stringaris et al., 2012), for school-aged children (which was developed after data collection had completed). The CBCL irritability items are correlated with ARI (rs = .26–.64) (Tseng, 2020; Tseng et al., 2017) and capture an adequate to good amount of irritability information relative to ARI (Dougherty et al., 2016). In addition, the CBCL irritability items show good internal consistency (Tseng et al., 2017; Wiggins et al., 2014), a single factor structure (Wiggins et al., 2014), and excellent test–retest reliability (Tseng et al., 2017). Mean scores of these items were used as a continuous measure of irritability. Cronbach αs for this sample were 0.80–0.83 across three timepoints.

Peer functioning. A peer nomination instrument (Crick & Bigbee, 1998; Crick & Grotpeter, 1995) was administered to measure five peer functioning variables – peer acceptance (one item), peer rejection (one item), number of reciprocated friendships (one item), relational victimization (three items), and physical victimization (three items). For *peer acceptance*, children were asked to nominate peers that they 'like to hang out with the most'. For *peer rejection*, children were asked to nominate peers that they 'like to hang out with the least'. For *number of reciprocated friendships*, children were asked to nominate best friends from their class; reciprocated friendships were identified as pairs of children who chose each other as a best friend. For *relational victimization*, children were asked to nominate peers that 'get ignored when someone is mad at them', 'get excluded or left out of things when someone is mad at them', and 'that other kids tell rumors about behind their backs'. For *physical victimization*, children were asked to nominate peers who get 'hit', 'beat up', and 'pushed and shoved' a lot by other classmates. Children were provided with a class roster and asked to nominate up to five classmates who best fit the descriptions provided for each item. The number of

nominations children received from classmates for each item was standardized within each classroom. The average of these standardized scores for each variable was used in the analyses. Across timepoints, relational and physical victimization subscales showed good internal consistency ranging from .84 to .87 and .91 to .96, respectively.

Data analysis

Descriptive analyses. Means and standard deviations of the study variables were computed, and bivariate, zero-order correlations between them were examined.

Cross-sectional network analysis. We estimated the structure of three networks, one for each of the three timepoints, using Gaussian graphical model (GGM; Epskamp, Waldorp, Mõttus, & Borsboom, 2018), to investigate the cross-sectional associations between the symptoms and peer functioning variables. The associations, or edges, represent partial correlation coefficients between two observed variables (i.e., nodes) after controlling for all other variables in the model. For all networks, we applied a nonparanormal transformation (Liu, Lafferty, & Wasserman, n.d.) using the *huge* package (version 1.3.5; Zhao, Liu, Roeder, Lafferty, & Wasserman, 2012) to account for the non-normality of the data. Graphical least absolute shrinkage and selection operator (LASSO) regularization was implemented to limit spurious edges (Friedman, Hastie, & Tibshirani, 2008) using the *ggmModSelect* function from the *bootnet* package (version 1.5) with a rank-order transformation (Spearman correlations) and pairwise deletion to account for missing data. We computed edge strengths and node centrality indices of the network structures (i.e., node strength, closeness, and betweenness). Node strength indicates direct connectivity and is the sum of absolute edge weights connected to each node, while closeness and betweenness describe indirect connectivity. Closeness quantifies how well a node is indirectly connected to every other node in the network, and betweenness quantifies how often a node lies on the shortest path connecting two other nodes (Epskamp, Borsboom, & Fried, 2018). We assessed the robustness of these parameters using bootstrapping methods (Epskamp, Borsboom, et al., 2018). The accuracy of edge weights was estimated by drawing nonparametric 95% bootstrapped confidence intervals (CIs) with 2,500 iterations around them. To assess the stability of centrality indices, a correlation-stability coefficient (CSC) was computed using case-dropping bootstrap comparing the bootstrapped and the original sample, CSC(cor = .7) indicates the percentage of the sample that can be dropped to maintain, with a 95% confidence interval, a correlation of a least .7 between the original sample's centrality indices and the bootstrapped sample's centrality indices. A CSC value between .25 and .5 indicates an adequate stability of the centrality indices, and a value >.5 indicates a strong stability (Epskamp, Borsboom, et al., 2018). Network estimation and visualization were performed using the *bootnet* (version 1.5), *psychonetrics* (version 0.10), and *qgraph* (version 1.9.2) R packages, and all networks were described according to the most recent guidelines (Burger et al., 2022). For better visualization, we used the colorblind theme in *qgraph* (Epskamp, Cramer, Waldorp, Schmittmann, & Borsboom, 2012) and fixed the average layout between the three network plots using the *averageLayout* function. Blue and red edges between nodes indicated positive and negative partial correlations (accounting for all other nodes in the network), respectively, and thicker edges reflected stronger associations.

Longitudinal network analysis. To examine the longitudinal relations between the study variables, a panel GVAR model was built using the *panelvgar()* function from the *psychonetrics* package (version 0.10; Epskamp, 2020). The panel GVAR encodes temporal dependencies as partial correlations between the deviations from the person-wise mean in one variable at a certain timepoint and the deviations from the person-wise mean in the next timepoint while controlling for all the variables at the previous timepoint. This creates a matrix of regression coefficients that can be used to plot a directed lag-1 network (i.e., the temporal or longitudinal network), which represents the generalized temporal within-subject effects between variables (Epskamp, 2020). The panel GVAR also estimates two additional networks through two Gaussian graphical models (GGMs) – a *contemporaneous network* that allows for a within-person interpretation of the relationships between variables at the same timepoint after accounting for temporal effects, and a *between-person network*, which describes the associations between the stationary means of all subjects. These contemporaneous and between-person networks were not of primary interest for the present study but are reported in the Supporting Information. Because GVAR models assume stationary variables (i.e., variables with characteristics, such as means or variances, that are stable over time), we accounted for linear trends in the data (Epskamp, van Borkulo, et al., 2018). ADHD symptoms and number of friendships were identified as having a significant trend and were therefore detrended prior to estimating networks. To account for missing data, the GVAR model was fitted using full information maximum likelihood (FIML) estimation. We searched for the optimal model (i.e., pruned model) by minimizing Bayesian information criterion (BIC) and thresholding at $\alpha = .05$. To assess model fit, we used the confirmatory fit index (CFI) and the Tucker-Lewis index (TLI) and the root mean squared error of approximation (RMSEA), with values >.95 (CFI and TLI) and <.05 (RMSEA) as indicating good fit (Hooper, Coughlan, & Mullen, 2007). We assessed the robustness of the results by evaluating how often each edge was included in the 1,000 bootstrapped models. Models were plotted using the R package *qgraph* (version 1.9.2; Epskamp et al., 2012). R code is available at https://osf.io/w9f58/?view_only=5ab521be19df4ce88f561b577d94dbb2.

Supplementary analysis. First, we examined the gender differences in the study variables and compared the network structure of the cross-sectional networks at Time 1, Time 2, and Time 3 in males and females (see Figure S1) using Network Comparison Test (van Borkulo et al., 2022). The results of these analyses can be found in Result S2. Briefly, results suggest that the patterns of associations between males and females were mostly similar across timepoints, with slight evidence showing that the magnitude of some edges at Time 2 was stronger in females than males. Second, we specified the number of children who meet the clinical cut-off for ADHD symptomatology on the SNAP-IV and compared the correlations between symptoms and peer functioning variables in these children with the children who did not meet the cut-off for ADHD symptomatology. Details can be found in Result S3 and Figure S2.

Results

Descriptive results

Means, *SD*s, and bivariate correlations of the study variables across three timepoints are presented in Table 2. Both within and across timepoints, inattention was negatively correlated with peer acceptance and number of friendships, and positively correlated with peer rejection and relational (except within Time

Table 2 Mean (*M*), standard deviation (*SD*), and zero-order correlations of the study variables.

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1. Ina_1	0.88	0.55																							
2. Hyp_1	0.55	0.50	.59**																						
3. Irr_1	0.28	0.44	.33**	.39**																					
4. Acc_1	0.09	0.99	−.24**	−.17**	−.06																				
5. Rej_1	0.03	0.99	.27**	.29**	.16**	−.49**																			
6. Fri_1	2.40	1.25	−.11*	−.05	−.06	.62**	−.26**																		
7. Rvict_1	0.02	0.88	.26**	.22**	.12**	−.44**	.81**	−.31**																	
8. Pvict_1	0.04	0.93	.21**	.19**	.11*	−.13**	.44**	−.06	.52**																
9. Ina_2	0.81	0.54	.66**	.37**	.21**	−.25**	.28**	−.07	.27**	.12															
10. Hyp_2	0.48	0.48	.45**	.64**	.29**	−.10	.30**	.00	.26**	.16**	.63**														
11. Irr_2	0.24	0.39	.28**	.29**	.45**	−.12*	.23**	−.12	.24**	.15*	.28**	.37**													
12. Acc_2	0.04	0.98	−.29**	−.13*	−.05	.72**	−.51**	.45**	−.42**	−.13*	−.32**	−.17**	−.17**												
13. Rej_2	0.00	0.97	.26**	.23**	.18**	−.42**	.82**	−.22**	.78**	.40**	.28**	.33**	.27**	−.51**											
14. Fri_2	1.92	1.50	−.19**	−.10	.02	.58**	−.42**	.46**	−.37**	−.10	−.19**	−.11	−.08	.70**	−.42**										
15. Rvict_2	0.00	0.85	.25**	.18**	.14**	−.38**	.74**	−.23**	.83**	.49**	.24**	.26**	.24**	−.40**	.83**	−.34**									
16. Pvict_2	−0.00	0.92	.16**	.15**	.07	−.11*	.35**	.01	.40**	.76**	.09	.16**	.06	−.13*	.41**	−.06	.52**								
17. Ina_3	0.80	0.57	.61**	.36**	.24**	−.30**	.30**	−.13*	.27**	.31**	.68**	.45**	.25**	−.35**	.35**	−.22**	.35**	.27**							
18. Hyp_3	0.45	0.46	.41**	.52**	.24**	−.18**	.29**	−.09	.25**	.22**	.42**	.59**	.27**	−.29**	.34**	−.20**	.28**	.20**	.66**						
19. Irr_3	0.27	0.43	.30**	.22**	.45**	−.15**	.19**	−.18**	.17**	.09	.34**	.30**	.57**	−.19**	.29**	−.14*	.24**	.05	.38**	.36**					
20. Acc_3	0.04	1.00	−.17*	−.05	−.10	.67**	−.49**	.43**	−.44**	−.16*	−.23**	−.09	−.08	.77**	−.48**	.63**	−.35**	−.15*	−.27**	−.22*	−.12				
21. Rej_3	−0.01	0.98	.23**	.10	.15	−.44**	.85**	−.22**	.77**	.33**	.26**	.20*	.20*	−.47**	.83**	−.40**	.78**	.28**	.24**	.23*	.17	−.52**			
22. Fri_3	2.20	1.54	−.18*	−.04	−.08	.51**	−.42**	.30**	−.38**	−.21**	−.19*	−.05	−.04	.54**	−.40**	.52**	−.32**	−.19**	−.22*	−.21*	−.01	.72**	−.45**		
23. Rvict_3	0.01	0.87	.20*	.02	.15	−.34**	.74**	−.18*	.77**	.34**	.20*	.11	.24**	−.33**	.77**	−.31**	.84**	.33**	.17	.12	.18	−.39**	.86**	−.39**	
24. Pvict_3	0.01	0.97	.27**	.09	.12	.02	.14	−.01	.18*	.56**	.17*	.14	.12	−.04	.12	−.00	.19**	.75**	.28**	.16	.03	−.08	.19**	−.09	.20**

Acc, peer acceptance; Fri, number of friendships; Hyp, hyperactivity; Ina, inattention; Irr, irritability; PVict, physical victimization; Rej, peer rejection; RVict, relational victimization.
$^*p < .05$; $^{**}p < .01$.

3) and physical victimization (except within Time 2). Within timepoints, hyperactivity was negatively linked to peer acceptance and positively linked to peer rejection and victimization (except at Time 3). Longitudinally, Time 1 hyperactivity was linked to all Time 2 peer variables except for number of friendships; Time 2 hyperactivity was positively linked to Time 3 peer rejection. At Time 1 and 2, irritability was cross-sectionally negatively linked to peer acceptance and positively linked to peer rejection and relational and physical victimization. Across timepoints, Time 1 irritability was linked to all Time 2 peer variables except for peer acceptance and number of friendships, and Time 2 irritability was positively correlated with Time 3 peer rejection and relational victimization.

Cross-sectional networks

Network visualization. Figure 1 illustrates the cross-sectional networks at three timepoints. Edge weights ranged from −.03 (Time 2 Inattention to Time 2 Acceptance) to .88 (Time 3 Friendships to Time 3 Acceptance). In all networks, symptoms and peer functioning variables clustered within constructs, and only a few bridge edges connected these two clusters together. Specifically, at Time 1, positive correlations were found between inattention and physical victimization (estimate = .08), and between hyperactivity–impulsivity and peer rejection (.06). At Time 2, inattention was positively linked to peer rejection (.07) and negatively linked to peer acceptance (−.03); hyperactivity–impulsivity was positively linked to physical victimization (.04); and irritability was positively linked to peer acceptance (.07). At Time 3, no bridge edges were found between symptoms and peer functioning variables.

Accuracy and stability checks. As shown in Figure S3, CIs around the edge weights were narrow for all three networks, indicating good edge accuracy. The CSC indicated that node strength showed high stability at all three timepoints (*CSC*(cor = .7) = .75 at Time 1, .52 at Time 2, and .52 at Time 3. Closeness was moderately stable at Time 2 (*CSC*(cor = .7) = .28) but not at Time 1 (*CSC*(cor = .7) = .21) and Time 3 (*CSC*(cor = .7) = .00). Betweenness was not stable at all three timepoints (all *CSC*(cor = .7) = .00).

Centrality indices. Node strength, betweenness, and closeness are shown in Figure 2. The three most central nodes (i.e., the nodes with the highest strength standardized coefficient) at each timepoint were: peer rejection, physical and relational victimization at Time 1; relational victimization, peer acceptance, and hyperactivity at Time 2; and peer rejection, peer acceptance, and hyperactivity at Time 3. Because the closeness and betweenness indices were not stable, they were not interpreted.

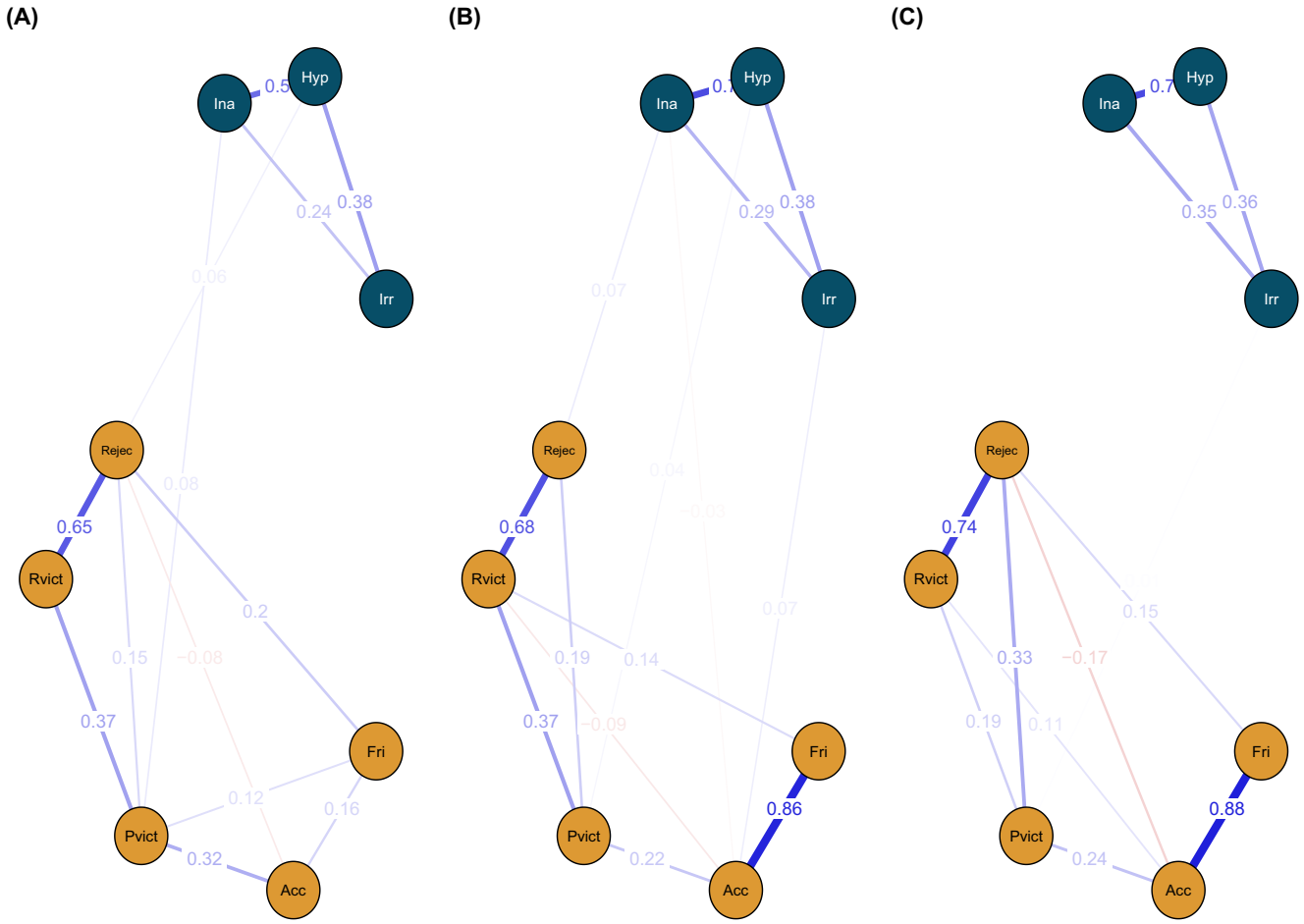

Figure 1 Cross-sectional networks of partial direct correlations between symptoms and peer functioning at Time 1 (A), Time 2 (B), and Time 3 (C). Acc, peer acceptance; Fri, number of friendships; Hyp, hyperactivity; Ina, inattention; Irr, irritability; PVict, physical victimization; Rej, peer rejection; RVict, relational victimization

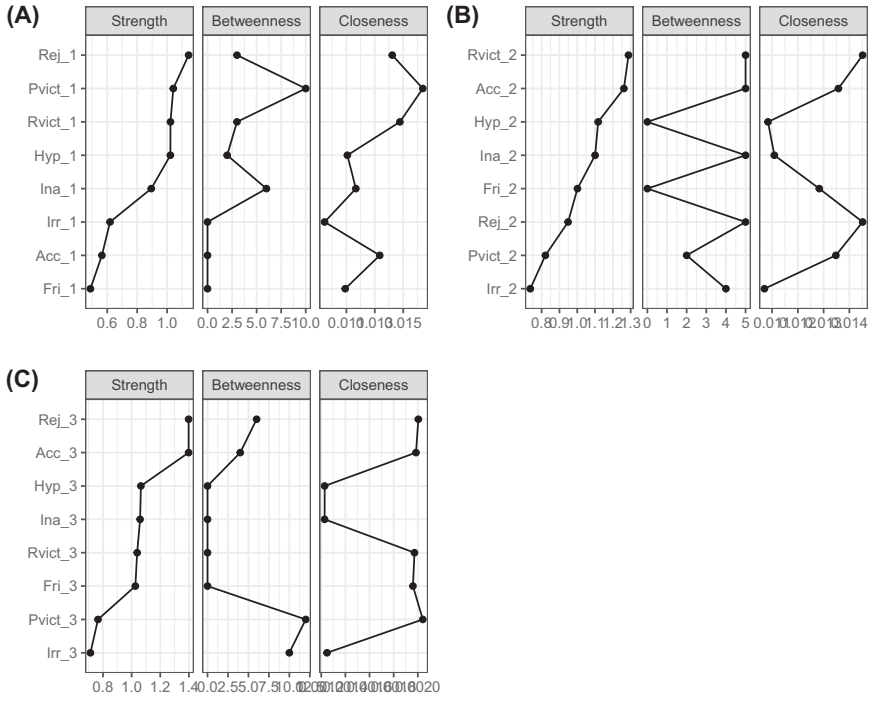

Figure 2 Centrality indices of the cross-sectional networks at Time 1 (A), Time 2 (B), and Time 3 (C). Standardized coefficients of strength, betweenness, and closeness of the nodes are presented. For readability, nodes were ordered by strength. Acc, peer acceptance; Fri, number of friendships; Hyp, hyperactivity; Ina, inattention; Irr, irritability; PVict, physical victimization; Rej, peer rejection; RVict = relational victimization

Longitudinal network

The saturated GVAR network (CFI = 0.98, TLI = 0.97, RMSEA = 0.030, BIC = 16,851.94), in which all possible edges were estimated, showed a better fit than the pruned model (CFI = 0.84, TLI = 0.84, RMSEA = 0.070, BIC = 17,147.42). The bootstrapping results (Table S2) showed that most estimated edges were not included in the bootstrapped models. Therefore, to facilitate interpretability and visualization of the saturated network, we exclusively plotted edges that were replicated at least 500 times (i.e., 50%, above chance) in the 1,000 bootstrapped models, that is, the more 'stable' edges. We focused on interpreting edges between symptoms and peer functioning. This trimmed longitudinal network (Figure 3) showed that physical victimization predicted increases in inattention, hyperactivity, and irritability; peer rejection predicted increases in inattention, which in turn predicted more irritability and inattention; peer acceptance predicted decreases in inattention and irritability; and a higher number of mutual friendships increased inattention and hyperactivity but decreased irritability over time. The saturated network with all the estimated edges is plotted in Figure S4 and the matrix of all possible edges is presented in Table S3. The contemporaneous within-time and the between-person networks can be found in the Supporting Information (Figure S5).

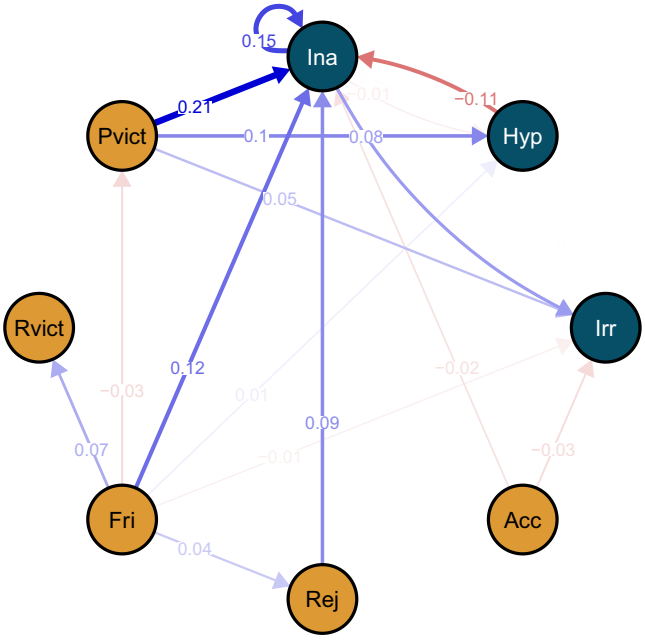

Figure 3 Longitudinal network of attention-deficit/hyperactivity disorder (ADHD) symptoms, irritability, and peer functioning. This is a directed network of regression coefficients depicting lagged associations between variables from one time point to the next. Only edges that were included at least 500 times in the 1,000 bootstrapped models are displayed. Acc, peer acceptance; Fri, number of friendships; Hyp, hyperactivity; Ina, inattention; Irr, irritability; PVict, physical victimization; Rej, peer rejection; RVict, relational victimization

Discussion

This study examined cross-sectional and longitudinal associations between inattention, hyperactivity–impulsivity, and irritability symptoms and children's peer functioning using a novel longitudinal approach (i.e., temporal network analysis) and an objective measure of peer functioning (i.e., peer nomination) in a large, non-Western sample. Overall, our results revealed that poor peer functioning contributed to increases in ADHD and irritability symptoms over time. Specifically, the temporal network showed that physical victimization predicted higher levels of future inattention, hyperactivity, and irritability symptoms, and that peer rejection predicted increases in later inattention, which in turn predicted more irritability and inattention. The network also showed that a higher number of mutual friendships increased ADHD symptoms but decreased irritability, and that peer acceptance decreased inattention and irritability symptoms over time. These findings suggest that future interventions targeting decreasing peer victimization and rejection and improving peer acceptance, at least at the peer group level, may be promising in reducing ADHD and irritability symptoms.

The present study showed that physical victimization and peer rejection predicted increases in later ADHD and irritability symptoms. ADHD symptoms were also cross-sectionally linked with peer rejection and physical victimization at Time 1 and Time 2, which is consistent with previous research demonstrating that higher symptoms of ADHD are cross-sectionally associated with peer victimization (Fite, Evans, Cooley, & Rubens, 2014; McQuade, Breslend, & Groff, 2018) and rejection (Grygiel et al., 2018; Lee et al., 2018; McDonald & Gibson, 2017). Previous longitudinal studies have similarly demonstrated that negative peer interactions worsen ADHD or irritability symptoms. For example, peer victimization at age 8 worsened irritability symptoms at age 10 (Barker & Salekin, 2012), and peer rejection at age 4 predicted heightened ADHD symptoms at age 6 (Stenseng, Belsky, Skalicka, & Wichstrøm, 2016). Our study extends these findings by demonstrating that peer victimization and rejection can also have a detrimental effect on children's ADHD and irritability symptoms within a 6-month timeframe. These findings align with the view that psychosocial adversity may aggravate the expression of ADHD symptomatology (Thapar, Cooper, Jefferies, & Stergiakouli, 2012), and expand this observation to irritability – a highly co-occurring symptom of ADHD (Brotman et al., 2017; Shaw et al., 2016; Stringaris et al., 2018). Our study extends the work of Evans et al. (2020) by showing that not only irritability was *concurrently* associated with peer rejection and victimization, but these negative social experiences also had *longitudinal* effects on irritability.

Specifically, physical victimization directly predicted higher irritability, and peer rejection indirectly predicted higher irritability through increases in inattention. This suggests that future research on factors contributing to the persistence and aggravation of irritability symptoms should pay particular attention to negative peer interactions and the mediating effect of inattention symptoms.

Among all the peer variables impacting children's symptoms in our network, physical victimization seems to be a significant and direct contributor to worsening of all symptoms. Physical victimization, or bullying, is a major public health concern as it has been identified as a leading risk factor for mental disorders (e.g., depression, anxiety) worldwide (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018; Smokowski & Kopasz, 2005; Yang et al., 2021). In Taiwan, where the current sample was from, bullying has a lifetime prevalence of 13.5% and has been found to increase the risk for later psychopathology and suicidality (J.-I. Lee et al., 2022). These epidemiologic studies, along with our current findings, suggest that implementation of effective antibullying strategies (e.g., school safety facilities, adult patrols; Chen & Chen, 2018) may be a promising way to decrease children's ADHD and irritability symptoms.

Our longitudinal network also showed that a higher number of mutual friendships reduced irritability, and that peer acceptance decreased inattention and irritability symptoms. Peer acceptance and mutual friendships have been found to buffer the negative consequences of ADHD, such as poor academic performance (Dvorsky, Langberg, Evans, & Becker, 2018; Khalis, Mikami, & Hudec, 2018). Our findings suggest that these positive social interactions could also improve ADHD and irritability symptoms themselves, which may be a mechanism through which academic performance is preserved. Promoting positive peer interactions/relationships has been shown to improve social functioning in youths with ADHD (Cordier, Vilaysack, Doma, Wilkes-Gillan, & Speyer, 2018). Recent evidence suggests that Parental Friendship Coaching (Mikami & Normand, 2022), an intervention that teaches the parent how to develop their child's friendship and emotional skills, may help children with ADHD learn and engage in better friendship behaviors (e.g., validation and caring, altruistic behaviors) and may also improve friendship quality in children with a comorbid ODD (Mikami et al., 2020; Smit, Mikami, & Normand, 2022). Whether the interventions targeting peer functioning could in turn reduce ADHD and co-occurring irritability symptoms has yet to be tested and warrants future research. In contrast, we found no evidence that ADHD or irritability symptoms increase the risk for lower peer acceptance and fewer number of reciprocated friendships as reported in previous studies (Becker et al., 2015; Scholtens et al., 2012). Of note, most prior research used cross-sectional study designs (Becker et al., 2015; Scholtens et al., 2012) or cross-lagged panel models (Tseng et al., 2014). The former precludes inferences of directionality, while the latter confounds within- and between-person effects, potentially obscuring meaningful temporal within-person effects.

The finding that a higher number of friendships predicted more ADHD symptoms is unexpected. One possible explanation is that, despite the higher number of reciprocated friendships, these friendships may be of low quality. Indeed, extensive literature demonstrates that children with ADHD tend to have friendships with poor quality (Hoza, 2007; Lee et al., 2021; Marton, Wiener, Rogers, & Moore, 2015; Normand et al., 2021). Specifically, youths with ADHD experience more deterioration of friendship quality over time, including more conflict, less satisfaction (Normand et al., 2013), less social support (Rokeach & Wiener, 2020), and are prone to forming friendships with children who display more behavioral problems (Marton et al., 2015). Following a social skill training, a minority of children with ADHD-inattentive type exhibited worse social behaviors, suggesting that they may have imitated the negative behaviors displayed by children with ADHD-combined type (Antshel & Remer, 2003). It is therefore plausible that these dysfunctional friendships have a detrimental effect on later ADHD symptoms. Future research should evaluate quality of friendships and examine characteristics of friends in children with ADHD symptoms and test whether and how these friendship variables affect symptom worsening over time. It is also possible that our findings are not consistent with previous studies because these studies have mostly focused on Western-based samples. It is known that culture influences the way children evaluate and interpret their peers' behaviors and use this information to shape their social interactions and peer relationships (e.g., Chen et al., 2018). For example, it has been found that children displaying more shyness/inhibition and less aggression may be perceived as more popular and more accepted by their peers in Chinese culture, whereas the opposite behaviors (i.e., less shyness, more aggression) may receive more social support from peers in Western cultures (Chen, 2012; Chen, Wang, & Cao, 2011). Whether and how these peer relationships established on different cultural norms may later impact ADHD and irritability symptoms is unclear and warrants further research.

In our short-term longitudinal study, irritability and ADHD symptoms seemed to be a 'consequence', rather than a 'cause', of developmental changes in peer functioning impairments. Past studies have commonly found effects in the opposite direction (more symptoms predicting poorer peer functioning, e.g., Elvin et al., 2021; Lin et al., 2021; Tseng

et al., 2014). In our study, we did not find evidence that symptoms predicted poor peer functioning. It is possible that the effects of ADHD and irritability symptoms on peer functioning are more acute and short-lived, and that a timeframe of 6 months between assessments may not capture these potentially short-term effects. These effects may be better probed using ecological momentary assessment or experience sampling methodology, which provides more ecologically valid and repeated measures of symptoms, experiences, and behaviors in children's everyday lives and natural environments that are less contaminated by recall bias (Russell & Gajos, 2020). Conversely, the negative effects of symptoms on peer functioning may be largely chronic, consistent with prior research showing that ADHD and irritability symptoms predicted worse peer functioning several years later (Dougherty et al., 2016; Evans et al., 2020; Forte et al., 2021; Sorcher et al., 2022).

A few other limitations are worth noting beyond what is discussed above (e.g., friendship quality, ecological momentary assessment). First, ADHD symptoms and irritability were measured exclusively via parent reports. Future research should consider a multi-informant approach when measuring symptoms in this age range, given previous work showing informant discrepancies in ADHD (Kennerley et al., 2018; Yeguez & Sibley, 2016) and irritability (Mallidi et al., 2022; Zik et al., 2022). Second, although our study used a longitudinal design and temporal network analysis, our findings are correlational in nature as the temporal edges in the network represent partial correlations between lagged and nonlagged variables after controlling for all other variables from the previous timepoint. Therefore, future research with experimental designs or clinical trials are necessary to clarify the causal associations among ADHD symptoms, irritability, and peer functioning over time. Third, our sample is a nonclinical community sample, and therefore, results may not generalize to children with clinical irritability (e.g., DMDD, ODD) or ADHD. In our study, we found that physical victimization and peer rejection more strongly predicted inattention, as compared to hyperactivity and irritability. A recent study comparing community-based and clinical samples has shown differential associations between ADHD symptoms and later peer functioning (Ahmad et al., 2021). Specifically, in a community-based sample, inattention (but not hyperactivity) predicted later peer problems, whereas in a clinical sample, hyperactivity (but not inattention) predicted subsequent peer problems, although these differences may also be attributed to cultural and demographic factors (Ahmad et al., 2021). It is possible that in children with clinically diagnosed ADHD, peer impairments and hyperactivity/irritability may be more strongly associated, potentially because cases with more severe hyperactive and irritability symptoms and greater functional impairments (including peer problems) are more commonly referred to the clinic (Evans, Corteselli, Edelman, Scott, & Weisz, 2023; Gau et al., 2010). Thus, the replication of our research is needed using clinical samples of youths with ADHD and comorbid irritability.

Taken together, our study revealed that negative social experiences that involve physical bullying and rejection by peers may aggravate the ADHD and irritability symptomatology. Conversely, this study also revealed that positive social interactions, such as being liked by peers, may improve inattention and irritability symptoms. The present study indicates that developing antibullying programs, promoting social–emotional skills, and fostering positive social environments in children with ADHD and irritability may be promising targets of interventions to reduce symptoms.

Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article:

Table S1. Comparisons of sociodemographics and study variables between children who remained in the study and children who dropped out.

Table S2. The number of times each parameter was included in the 1,000 bootstrapped models.

Table S3. Matrix of saturated partial direct correlations between the study variables.

Figure S1. Cross-sectional networks of partial direct correlations between symptoms and peer functioning at Time 1 (a), Time 2 (b), and Time 3 (c) in males and females.

Figure S2. Correlation matrices in the nonclinical subsample on the left (n = 682) and in the 'clinical' subsample on the right (n = 57).

Figure S3. Accuracy estimations of all edge weights at Time 1 (a), Time 2 (b), and Time 3 (c) using the nonparametric bootstrapping method.

Figure S4. Saturated network with all the estimated edges displayed. Edges range from −0.001 (inattention to irritability) to 0.49 (relational victimization to relational victimization).

Figure S5. Contemporaneous within-person (a) and between-person (b) networks.

Result S1. Comparisons between children who remained throughout the three timepoints versus those who dropped out of the study at Time 3.

Result S2. Gender differences in the study variables.

Result S3. Comparing correlations between symptoms and peer functioning in children who meet the clinical cut-off for ADHD symptomatology with those who did not.

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Data availability statement

The data are available from the corresponding authors upon reasonable request.

Correspondence

Nellia Bellaert, Yale Child Study Center, Yale School of Medicine, 230 S Frontage Road, New Haven, CT 06519, USA; Email: nellia.bellaert@umons.ac.be

Key points

- ADHD and irritability symptoms are highly co-occurring and associated with impairments in peer functioning. However, the temporal, dynamic interplay between these clinical dimensions and peer functioning remains elusive.
- Using an innovative temporal network approach with three-wave longitudinal data, this study examined how ADHD and irritability symptoms influence peer functioning, and vice versa, over time.
- Our temporal network showed that physical victimization and peer rejection directly or indirectly predicted increases in ADHD and irritability symptoms and that peer acceptance directly predicted decreases in inattention and irritability symptoms. Moreover, a higher number of mutual friendships increased inattention and hyperactivity but decreased irritability over time.
- Preventing bullying and promoting positive peer interactions may be effective in reducing ADHD and irritability symptoms.

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