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The Network Structure of Psychopathology in a Community Sample of Preadolescents

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Psychopathology is often classified according to diagnostic categories or scale scores. These ignore potentially important information about associations between specific symptoms and, consequently, lead to heterogeneous constructs that may mask relevant individual differences. Network analyses focus on these specific symptom associations, providing the opportunity to explore the complex structure of psychopathology in more detail. We examined the empirical network structure of 95 emotional and behavioral problems of the Youth Self-Report (YSR) to explore how well this structure reflected the predefined YSR domains. The study was conducted in a large community sample (N = 2,175) of preadolescents (mean age = 11.1, SD = 0.6 years), and the network structure was determined by means of the recently developed network analysis technique, eLasso. Although problems within the same domain, in general, showed more and stronger connections than problems belonging to different domains, some problems showed substantially more or stronger associations than others; consequently, problems cannot be considered interchangeable indicators of their domain. Furthermore, no sharp boundaries were found between the domains as specific symptom pairs of different domains showed strong connections. Taken together, our findings indicate that network models provide a promising addition to the more traditional way of distinguishing diagnoses or scale scores.

General Scientific Summary
This study shows the detailed patterns in which a broad range of emotional and behavioral problems tend to co-occur. This structure is rather complex and suggests that conventional ways of classifying psychopathology lead to loss of information.

Keywords: network theory, network model, emotional and behavioral problems, Youth Self-Report, preadolescents

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Psychiatric and psychological research is often based on diagnoses or scale scores, which are established by summing sets of symptoms. This strategy has proven to be highly valuable for clinicians, because it informs them about the problem domains that need attention. However, it also results in loss of information, because differences in the meaning of individual symptoms are ignored. Consider, for example, symptoms such as "depressed mood," "concentration problems," "fatigue," and "suicidal ideation," which are all criteria of a *Diagnostic and Statistical Manual of Mental Disorders* (DSM)-based major depressive disorder (American Psychiatric Association, 2013), and illustrate that patients with the same diagnosis can experience substantially different symptoms. An analysis of 3,703 outpatients with major depressive disorder consequently revealed as many as 1,030 unique symptom profiles (Fried & Nesse, 2015b).

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Recent research, mainly on depression, stresses the importance of an approach focusing on individual symptoms (Fried & Nesse, 2015a). Symptoms are, for example, differentially affected by chronic stress (Fried, Nesse, Guille, & Sen, 2015) and other well-known risk factors (Fried, Nesse, Zivin, Guille, & Sen, 2014). In addition, symptoms differ in their impact on psychosocial functioning (Fried & Nesse, 2014), their patterns of comorbidity with other diagnoses (Lux & Kendler, 2010), and their response to antidepressants (Hieronymus, Emilsson, Nilsson, & Eriksson, 2015). These findings have motivated us, together with other researchers, to propose *symptomics*, a research program that focuses on individual symptoms rather than diagnoses or scale scores (Fried, Boschloo, et al., 2015).

The network approach is a conceptualization of psychopathology that specifically focuses on individual symptoms and the associations between them (for a schematic representation of a network, see Figure 1). As a consequence, it may provide insights into the patterns in which symptoms co-occur. In a recent study, we presented the empirical network structure of 120 psychiatric symptoms of 12 *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., *DSM–IV)* diagnoses in the adult general population (Boschloo et al., 2015). Although symptoms generally showed more and stronger connections with symptoms of the same diagnosis than with symptoms of other diagnoses, the structure was rather complex; that is, symptoms were only associated with specific symptoms of the same diagnosis and with specific symptoms of other diagnoses. Such a network, thus, provides detailed information about the complex structure of psychopathology.

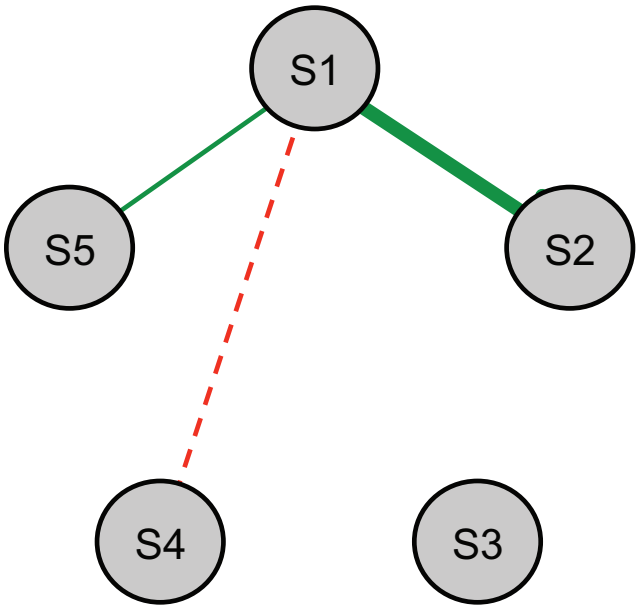

Figure 1. Schematic representation of a network structure. Symptoms S1 to S5 are represented as nodes and associations between them as edges. The green (solid black) edges between S1 and S2 as well as S1 and S5 indicate positive associations, whereas the red (dashed black) edge between S1 and S4 represents a negative association. The thickness of edges represents the strength of associations, so S1 is more strongly associated to S2 than to S4 or S5. S3 is not connected to any of the other symptoms, indicating that it is not associated with the other symptoms. See the online article for the color version of this figure.

The present study used data from a large community sample of Dutch preadolescents (N = 2,175) on 95 emotional and behavioral problems as assessed with the Youth Self-Report (YSR; Achenbach, 1991; Achenbach & Rescorla, 2001). Previous principal component analyses have revealed several broad- and narrow-band domains (Achenbach, 1991; Achenbach & Rescorla, 2001) and, consequently, the instrument is commonly used to determine various scale scores by summing specific sets of items. This study estimated the network structure of the 95 individual emotional and behavioral problems and we expected that the network-based associations corresponded to the scale structure of the YSR. However, we also expected that the network structure provided more precise information about the complex associations among emotional and behavioral problems.

Method

Participants

The TRacking Adolescents' Individual Lives Survey (TRAILS) is an ongoing, prospective cohort study of Dutch (pre)adolescents (age at baseline = 10–12 years) with bi- or triennial follow-up assessments. The key objective of the study is to chart and explain the development of mental health from preadolescence into adulthood, both at the level of psychopathology and the levels of underlying vulnerability and environmental risk factors. The present study involved data from the baseline assessment, which ran from March 2001 to July 2002. A detailed description of the sampling procedures and methods are provided by de Winter et al. (2005) and Huisman et al. (2008).

The target sample involved preadolescents living in five municipalities in the North of the Netherlands, including both urban and rural areas. The sampling procedure consisted of two stages. First, the municipalities were requested to provide information from the community registers (i.e., name, date of birth, gender, and address) of all inhabitants that were born between October 1, 1989, and September 30, 1990 (first two municipalities), or between October 1, 1990, and September 30, 1991 (last three municipalities). Subsequently, all primary schools, including schools for special education, received a letter accompanied by detailed information about the goals, design and practical procedures of the study. A total of 135 schools (encompassing 3,483 children) were identified and approached, of which 122 (encompassing 3,145 children) agreed to participate in the study. School participation was a prerequisite for children and their parents to be approached.

Second, parents (or guardians) were informed about the study goals, measures, selection procedure, and confidentiality through information brochures (one for themselves and one for their children). Approximately 1 week later, an interviewer contacted them by telephone to give additional information, answer questions, and ask whether they and their son or daughter were willing to participate in the study. Of the 3,145 approached children, 210 (6.7%) were excluded because they were unable to participate, incapable of doing so because of severe mental or physical handicaps, or if no Dutch-speaking parent or parent surrogate was available (Turkish and Moroccan parents who were unable to speak Dutch were interviewed in their own language). After intensive recruitment efforts (including telephone calls, reminder letters, and home visits), a total of 2,230 children (76.0% of the 2,935 eligible children)

were included in the study. For the present analyses, we selected the 2,175 children (97.5% of the baseline sample) who had complete data on emotional and behavioral problems.

Assessment of Emotional and Behavioral Problems

Emotional and behavioral problems in the past six months were assessed with the YSR 2001 version (Achenbach & Rescorla, 2001), which was filled out at school, in groups, under the supervision of one or more trained TRAILS assistants. The questionnaire comprises 105 items on a wide range of problems. Previous principal component analyses have identified two broad-band domains, and these items are commonly summed in order to determine two scale scores: internalizing problems (31 items), comprising the narrow-band domains withdrawn/depressed, anxious/depressed, and somatic complaints, and externalizing behaviors (32 items), comprising the narrow-band domains of aggressive behavior and rule-breaking behavior. In addition, three other domains are distinguished: attention problems (9 items), thought problems (12 items), and social problems (11 items). The 95 items from these five domains were included in our analyses (see Table S1, available online as supplemental material, for an overview of the items). Excluded items were nine items that did not load on any of these domains and one open-ended item for describing additional somatic complaints. Response categories of all selected items are 0 = *not true*, 1 = *somewhat or sometimes true*, and 2 = *very true or often true*. The assumptions of linearity and normality were not satisfied in our data and, therefore, all 95 polytomous items were recoded into either present (combining response categories 1 and 2) or absent (response category 0) and analyzed with a network estimation technique for dichotomous data.

Statistical Analyses

Network estimation: As the network structure of emotional and behavioral problems is unknown, we used network estimation technique eLasso (van Borkulo et al., 2014) to extract this information from the data. eLasso has been developed for the analysis of binary data and is based on the Ising model, which models variables that can have two states (i.e., either present or absent) (Ising, 1925; Kindermann & Schnell, 1980). To identify relevant associations between the 95 YSR items, l1-reguralized logistic regression was used (Tibshirani, 1996). This works as follows. First, logistic regression analyses were performed to determine associations between all items and, then, an l1-penalty was imposed on the regression coefficients to acquire an optimal balance between sparsity and goodness of fit of the network. l1-regularization results in multiple models with varying levels of sparsity. To find the best fitting model, goodness of fit is assessed with the extended Bayesian information criterion (Chen & Chen, 2008). Assuming that the data are brought about by sparse pairwise associations between problems, this procedure will converge to the true network (Foygle & Drton, 2014). An advantage of this technique it that is avoids the multiple testing problem that would arise in traditional significance testing (i.e., a network structure of 95 items would result in 95*94/2 = 4,465 significance tests). eLasso is described in more detail in van Borkulo et al. (2014) and is freely available in R package IsingFit (https://cran.r-project.org/web/packages/IsingFit/IsingFit.pdf).

Network visualization: To visualize the network structure of the 95 YSR items, R package qgraph (https://cran.r-project.org/web/packages/qgraph/qgraph.pdf; Epskamp, Cramer, Waldorp, Schmittmann, & Borsboom, 2012) was used. The individual YSR items are represented as nodes and associations between them as edges. Green (solid black) edges represent positive associations and red (dashed black) edges represent negative associations. The thickness of edges indicates the strength of associations (*b*s, as derived from the logistic regression) and only associations with b > 0.05 are shown. The layout of the graph is based on the Fruchterman-Reingold algorithm, which iteratively computes the optimal layout so that YSR items with stronger or more connections are placed closer to each other (Fruchterman & Reingold, 1991).

Inspection of the network: Based on the network estimation and visualization, the network structure of emotional and behavioral problems was carefully inspected. We mainly focused on the connection strengths between all individual YSR items and distinguished absent or weak ($b \leq 0.05$; odds ratio ≤1.05), moderate ($b > 0.05$ and ≤0.40: odds ratio >1.05 and ≤1.49) and strong ($b > 0.40$; odds ratio >1.49) connections. We explicitly focused on associations of items within the same domain, as well as associations of items between different domains.

Sensitivity analyses: Finally, two sets of sensitivity analyses were performed. First, we explored whether floor and ceiling effects could have affected the network estimation by examining the relation between the prevalence of items (as derived from simple descriptives) and number of connections (as derived from the network). The scatter plot was inspected and, in addition, Pearson's correlation coefficient was calculated.

As *eLasso* requires dichotomous data, the 95 polytomous YSR items were recoded into either present or absent. This strategy naturally results in loss of information but alternative estimation techniques (e.g., based on partial correlations) are based on assumptions of linearity and normality that are not satisfied in our data. As a sensitivity analysis, the network structure of the original, polytomous YSR items was estimated using partial correlations. Similar to the eLasso for binary data, an *l*1-penalty was imposed on the associations (Tibshirani, 1996) and the best fitting network was chosen through model selection with the EBIC (Chen & Chen, 2008). This procedure is implemented in R package qgraph (Epskamp et al., 2012).

Results

Sample Descriptives

In our sample of 2,175 preadolescents, 50.9% were female and the mean age was 11.11 ($SD = 0.55$) years. Supplementary Figure S1 shows the prevalence rates of all 95 emotional and behavioral problems, which ranged from 1.1% for "I use drugs for nonmedical purposes" (externalizing item 32) to 63.4% for "Headaches" (internalizing item 26).

General Network Structure of Emotional and Behavioral Problems

The network structure of emotional and behavioral problems is presented in Figure 2, which is based on the estimated connection strengths between all 95 individual problems (i.e., 95*94/2 =

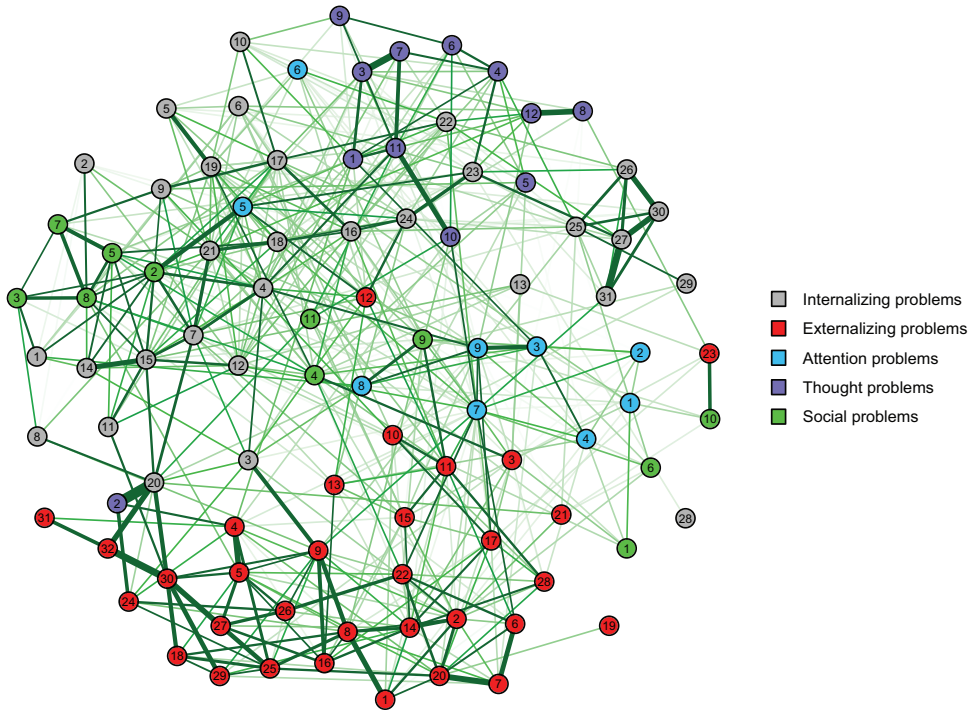

Figure 2. Network structure of emotional and behavioral problems. Emotional and behavioral problems are represented as nodes and associations between them as edges. Node colors refer to specific problem domains and numbers refer to individual problems (see Supplementary Table S1). Green (solid black/gray) edges represent positive associations and negative associations, which are not found in the current network, would have been shown as red (dashed black/gray) edges. The thickness of edges indicates the strength of associations and only associations with $b > 0.05$ are shown. See the online article for the color version of this figure.

4,465 potential connections; see Supplementary Table S2). Figure 3 shows the number of moderate ($b > 0.05$ and ≤ 0.40) and strong ($b > 0.40$) connections among problems within the same domain, as well as connections with problems belonging to each of the four other domains; in addition, percentages of connections are presented in Supplementary Figure S2. An overview of the connections within the same domain as well as connections between different domains is provided in Table 1.

Of the 4,465 potential connections, 429 (9.6%) were moderate and 94 (2.1%) were strong. The remaining 3,942 (88.3%) problem pairs were not or only weakly associated, and no negative associations were found. In general, the network structure roughly corresponded with the scale structure of the YSR (Figure 2). That is, more connections were found within than between domains (Table 1). The within-domain percentages of connections ranged from 21.8% for social problems to 44.5% for attention problems, while the percentage of connections between problems of different domains ranged from 3.4% for internalizing and externalizing problems as well as externalizing and thought problems to 20.2% for attention and social problems.

Specific Associations Between Individual Emotional and Behavioral Problems

In addition to the general patterns, we found that individual problems differed substantially in their within- and between-domain connections:

- Internalizing problems: The number of connections within the domain of internalizing problems ranged from one for "Problems with eyes" (item 28) to 14 for "I am too fearful or anxious" (item 17). Of the 31 internalizing problems, 27 were connected to at least one problem of another domain. "I am secretive or keep things to myself" (item 4) had the most (ten) connections with other domains.
- Externalizing problems: The number of connections within the domain of externalizing problems ranged from one for "I do not feel guilty after doing something I shouldn't" (item 19) and "I hang around with kids who get in trouble" (item 21) to 17 for "I tease others a lot" (item 14). Of the 32 externalizing problems, 24 were connected to at least one problem of another domain. "My moods or feelings change suddenly" (item 12) had the most (12) connections with other domains.
- Attention problems: The number of connections within the domain of attention problems ranged from zero for "I feel confused or in a fog" (item 5) to six "I have trouble concentrating or paying attention" (item 3). All nine attention problems were connected to at least one problem of another domain. "I act without stopping to think" (item 7) had the most (24) connections with other domains.
- Thought problems: The number of connections within the domain of thought problems ranged from zero for "I deliberately try to hurt myself'" (item 2) to eight for "I cannot

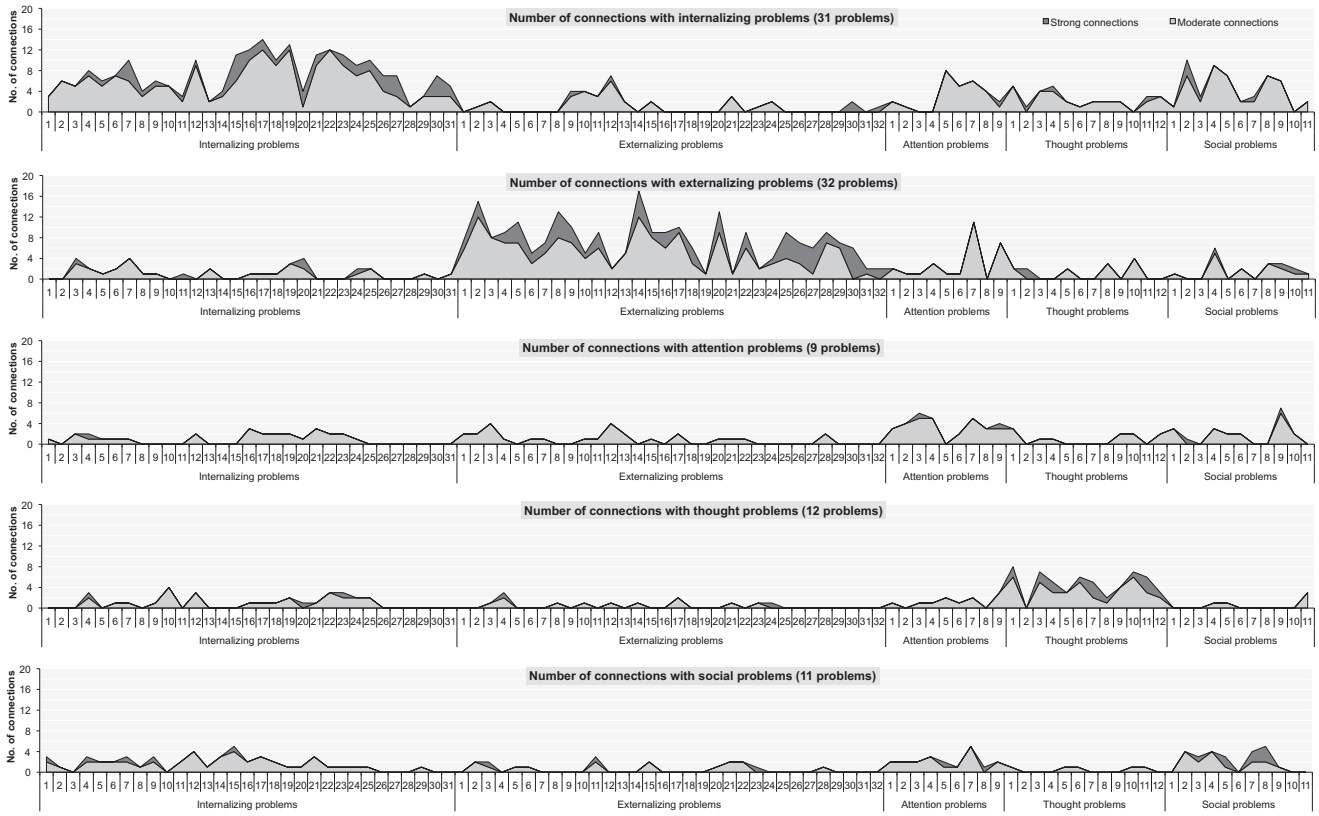

Figure 3. Number of connections from all individual emotional and behavioral problems to problems of each of the problem domains. Connections are categorized into moderate ($b > 0.05$ and ≤ 0.40) and strong ($b > 0.40$) connections. Numbers refer to individual emotional and behavioral problems (see Supplementary Table S1).

get my mind off certain things" (item 1). All 12 thought problems were connected to at least one problem of another domain. "I cannot get my mind off certain things" (item 1) had the most (11) connections with other domains.

- Social problems: The number of connections within the domain of social problems ranged from zero for four items (items 1, 6, 10, and 11) to five for "I am not liked by other kids" (item 8). All 11 social problems were connected to at least one problem of another domain. "I am jealous of others" (item 4) had the most (19) connections with other domains.

Sensitivity Analyses

Supplementary Figure S3 shows that the prevalence of problems was weakly related to the number of moderate or strong connections in the network ($r = .26$, $p = .01$). The correlation disappeared ($r = .02$, $p = .87$) after exclusion of the items that were rare in our sample (prevalence of <15%). These findings suggest that, in general, the prevalence of problems was not related to the number of connections but floor effects may have occurred for the problems that are relatively rare.

Supplementary Figure S4 shows the network structure of emotional and behavioral problems based on the original, polytomous YSR items with three response categories. The structure is similar to the network structure of emotional and behavioral problems based on the dichotomized YSR items (Figure 2).

Discussion

To our knowledge, this is the first study that examined the empirical network structure of emotional and behavioral problems as assessed with the YSR. As expected, the network structure roughly corresponded with the scale structure that was previously identified through principal component analyses (e.g., Achenbach, 1991; Achenbach & Rescorla, 2001); that is, problems within the same domain showed more and stronger connections than problems of different domains. This implies that the strategy of establishing these particular scale scores is justifiable. However, the network structure also incorporated important additional information about the complex associations between emotional and behavioral problems and illustrated the unique role of each of these problems.

The within-domain percentages of connections ranged from 21.8 to 44.5%, which is substantially lower than the 64.7% to 100% that were previously found for symptoms within DSM diagnoses (Boschloo et al., 2015). In contrast, the percentages of connections between domains were higher in the present study (i.e., 3.4%–20.2%) than the percentages of connections between DSM diagnoses in our previous study (i.e., 1.1%–6.9%; Boschloo

Table 1
Overview of the Number and Percentages of Connections Within and Between Problem Domains

Variable	*N* (%)				
	Internalizing problems (31 problems)	Externalizing Problems (32 problems)	Attention problems (9 problems)	Thought problems (12 problems)	Social problems (11 problems)
Internalizing problems					
Connection strength[a]:					
Absent/weak	352 (75.7)				
Moderate	90 (19.4)				
Strong	23 (4.9)				
No. of potential connections	465 (100)				
Externalizing problems					
Connection strength[a]:					
Absent/weak	958 (96.6)	378 (76.2)			
Moderate	29 (2.9)	81 (16.3)			
Strong	5 (.5)	37 (7.5)			
No. of potential connections	992 (100)	496 (100)			
Attention problems					
Connection strength[a]:					
Absent/weak	251 (90.0)	261 (90.6)	20 (55.6)		
Moderate	27 (9.7)	27 (9.4)	15 (41.7)		
Strong	1 (.4)	0 (.0)	1 (2.8)		
No. of potential connections	279 (100)	288 (100)	36 (100)		
Thought problems					
Connection strength[a]:					
Absent/weak	342 (91.9)	371 (96.6)	97 (89.8)	38 (57.6)	
Moderate	27 (7.3)	11 (2.9)	11 (10.2)	20 (30.3)	
Strong	3 (.8)	2 (.5)	0 (.0)	8 (12.1)	
No. of potential connections	372 (100)	384 (100)	108 (100)	66 (100)	
Social problems					
Connection strength[a]:					
Absent/weak	291 (85.3)	334 (94.9)	79 (79.8)	127 (96.2)	43 (78.2)
Moderate	45 (13.2)	15 (4.3)	18 (18.2)	5 (3.8)	8 (14.5)
Strong	5 (1.5)	3 (.9)	2 (2.0)	0 (.0)	4 (7.3)
No. of potential connections	341 (100)	352 (100)	99 (100)	132 (100)	55 (100)

[a] Absent/weak: $b \leq .05$; moderate: $b > .05$ and $b \leq .40$; strong: $b > .40$.

et al., 2015). The segregated structure of the network in our previous study may be a reflection of the structure of the DSM. A diagnosis of, for example, posttraumatic stress disorder is based on the core symptom of "exposure to a traumatic event" (criterion A1), as well as related symptoms such as "recollections of the event" (criterion B1), "disturbing dreams of the event" (criterion B2), and "acting or feeling as if the event were recurring" (criterion B3). It is, therefore, not surprising that DSM symptoms tend to show relatively many connections within the same diagnosis and relatively few connections with other diagnoses. These findings also illustrate the importance of applying network analysis techniques to problems that are not assessed according to a diagnostic system such as the DSM (i.e., as in our current study).

Although emotional and behavioral problems generally showed several connections within their domain, it is important to note that individual problems differed substantially in both the number and strength of their within-domain connections. In addition, different domains were connected via specific problem pairs, suggesting that emotional and behavioral problems cannot be defined according to the sharp boundaries that are presumed by the scale structure of the YSR. These findings imply that potentially important information is lost when items are summed in order to establish scale scores. This was also supported by our recent finding that the role of symptoms in the network had prognostic value (Boschloo et al., in press); that is, subthreshold depressive symptoms that had many and/or strong connections in the network more strongly predicted the onset of full-blown depression than symptoms that had few and/or weak connections in the network. We therefore believe that both research and clinical practice could benefit from an approach that specifically focuses on individual problems and their unique role in the network.

Previous principal component analyses have also demonstrated that individual YSR items have a unique role as they differ substantially in their within-domain loadings as well as cross-loadings (Achenbach, 1991; Achenbach & Rescorla, 2001). The network approach provides important additional information about the specific associations between symptoms, which can help both researchers and clinicians to formulate hypotheses on the etiological mechanisms underlying the onset and course of psychopathology. Several epidemiological studies have, for example, found that sleep disturbances predict the onset of depression (e.g., Baglioni et al., 2011), but much is still unclear about the exact mechanisms underlying this association. Our empirical network structure of emotional and behavioral problems showed that "sleep disturbances" (thought item 12) was not directly connected to any of the depression-related problems (e.g., "I am unhappy, sad, or depressed," internalizing item 7), but was connected via worry ("I worry a lot," internalizing item 21). This may imply that sleep disturbances do not directly cause depression-like symptoms, but can lead to depression via the mediating role of excessive worry.

It is, however, important to note that our network structure was based on a cross-sectional assessment of emotional and behavioral problems and conclusions regarding the temporal relationships between problems are, therefore, precluded. To examine the dynamics of problems over time, it would be valuable to use data from the experience sampling method (ESM) including multiple assessments with short time intervals. Groundbreaking research revealed that psychiatric symptoms or emotional states are directly and indirectly related over time and, consequently, form complex dynamical networks (e.g., de Wild-Hartmann et al., 2013; van de Leemput et al., 2014; Wigman et al., 2013, 2015; Bringmann et al., 2015).

A strength of our study is that emotional and behavioral problems were assessed with the reliable and valuable YSR (e.g., Achenbach, 1991; Achenbach & Rescorla, 2001). An important advantage of this instrument is that it is not based on classification systems such as the DSM. In addition, we included a large community sample of preadolescents (N = 2,175). As preadolescence is a critical period for the development of emotional and behavioral problems (e.g., Angold, Costello, & Worthman, 1998; Weems & Costa, 2005; Costello, Sung, Worthman, & Angold, 2007), it can provide valuable insights into the nature of these problems. However, it is also possible that some participants have not yet developed a psychiatric disorder at such a young age (10–12 years), but will develop one in the future. The high within-diagnosis connections and the low between-diagnoses connections in the DSM network of our previous publication (Boschloo et al., 2015) would, therefore, not only reflect the structure of the DSM but could also be the result of the higher age of that sample (mean age = 49.1 years). It would, therefore, be highly valuable if future studies could examine whether the network structure of emotional and behavioral problems changes over time.

It would also be interesting to determine the network structure of emotional and behavioral problems in other samples, such as clinical samples of patients with specific diagnoses. Because a problem is more likely to induce other problems in a strongly connected network than in a weakly connected network, one would expect that persons with a strongly connected network have more problems than persons with a weakly connected network. This was supported by a study of Wigman et al. (2015) who showed that patients with psychosis or depression had a more strongly connected network of mental states than healthy controls. According to the network theory, one would also expect that patients with a strongly connected network are more likely to have a poor prognosis than patients with a weakly connected network. A recent study of our group indeed found that depressed patients who had a chronic disorder during follow-up had a more strongly connected symptom network than depressed patients who remitted during follow-up (van Borkulo et al., 2015). We therefore want to encourage other researchers to not only consider the network structure of emotional and behavioral problems in other samples but also to examine its clinical implications.

In conclusion, the empirical network structure of emotional and behavioral problems supported the scale structure of the YSR. Establishing scale scores is, therefore, justifiable and can inform clinicians about the problem domains that need attention. However, it is important to realize that potentially important information about the unique role of individual problems is lost. By using network analysis techniques, it is possible to reveal complex associations of each of the problems with other problems within as well as outside their domain. This provides insights into the complex nature of emotional and behavioral problems and may help clinicians to formulate specific hypotheses on the mechanisms underlying prognosis and shape their treatment strategies.

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