A Cross-sectional and Longitudinal Network Analysis Approach to Understanding Connections among Social Anxiety Components in Youth

Miers, A. C.[1*], Weeda, W. D.[1], , Blöte, A. W.[1], Cramer , A. O. J.[3], Borsboom, D.[2], & Westenberg, P. M.[1]

[1] Institute of Psychology, Faculty of Social and Behavioral Sciences, Leiden University

[2] Department of Psychology, Faculty of Social and Behavioral Sciences, University of Amsterdam

[3] Department of Methodology and Statistics, Social and Behavioral Sciences, Tilburg University

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Some of the results that appear in this paper were presented at the International Society for Affective Disorders conference, London, July 2017. We presented the social anxiety networks at T1, T2, and T3, as well as the node strength centrality at T1.

Correspondence concerning this article should be addressed to Anne C. Miers, Faculty of Social and Behavioral Sciences, Institute of Psychology, Unit Developmental and Educational Psychology, Pieter de la Court building, P.O. Box 9555, 2300 RB, Leiden, the Netherlands. E-mail: acmiers@fsw.leidenuniv.nl

Abstract

As proposed in a prominent developmental model, social anxiety has different manifestations: social fear, shy temperament, anxious cognitions, and avoidance of social situations. Drawing from this model, we used the network approach to psychopathology to gain a detailed understanding of specific social anxiety components and their associations. The current paper investigated (a) how social anxiety components are interconnected within a network, and (b) the consistency of the network over time, in a community sample of children and adolescents. Data from 3 waves of a longitudinal study were used. At time 1 (T1) the total sample comprised 331 participants (M_{age} = 13.34 years); at time 3 (T3) there were 236 participants (M_{age} = 17.48 years). Social anxiety components were assessed with self-report questionnaires. Networks of 15 nodes (i.e., components) were estimated. Network analysis of T1 components revealed four communities: *cognitive*, *social-emotional*, *avoidance of performance*, and *avoidance of interaction* situations. There were no direct connections between the *cognitive* and *behavioral* communities; *social-emotional* nodes appeared to act as bridge components between the two communities. A similar pattern of component associations and communities was found in the T2 and T3 networks, and the longitudinal network incorporating node change trajectories. Networks were estimated on group-level observational data and conclusions about cause-effect relationships are therefore tentative. Although the sample size decreased across the three waves, the reliability of parameter estimates were minimally affected. Findings attest to the potential value of applying the network approach to investigate the pattern of associations among social anxiety components in youth.

Keywords: avoidance; negative cognitions; network analysis; social anxiety components; social performance.

General Scientific Summary

This study suggests that social anxiety in adolescence has four important and interrelated components: negative thoughts, nervousness in social situations and shyness, avoidance of social interactions, and avoidance of performance situations. Negative thoughts appeared to be linked to avoidance behavior through the feelings of nervousness and shyness. Increases or decreases in negative thoughts about social situations may go along with increases or decreases in shyness and nervousness across the adolescent period.

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Social anxiety is conceptualized as existing on a continuum (Rapee & Spence, 2004; Spence & Rapee, 2016). Experiencing some anxiety in social situations, such as giving a speech or going to a party, is a normal reaction, low on the continuum, and adaptive. A little further up on the continuum is shyness, mild social fears, and avoidance. Towards the upper end is more intense social fear that may interfere with a person's daily functioning for example through avoidance (Rapee & Spence, 2004; Spence & Rapee, 2016). Social anxiety disorder (SAD) is most likely to lie at the upper end of the continuum. SAD is defined as a marked and persistent fear of social situations in which humiliation or embarrassment may occur and is described not only by social anxiety severity, but also by the degree of interference in the individual's life (American Psychiatric Association, 2013). SAD typically onsets in early- to mid-adolescence (Knappe, Sasagawa, & Creswell, 2015; Lawrence et al., 2015). It is one of the most prevalent disorders in youth affecting between 3% and 9% of adolescents (Ranta, La Greca, Garcia-Lopez, & Marttunen, 2015) and strong, but undiagnosed, social fears appear in 22.3% of males and 32.3% of female youth (Wittchen, Stein, & Kessler, 1999).

In order to understand the construct of social anxiety and its clinical outcome from a developmental perspective Rapee and Spence (2004) proposed an etiological model of SAD, which has recently been updated (Spence & Rapee, 2016). In this theoretical model, social anxiety manifestation in youth consists not only of social fear or anxiety severity, but also an individual's shy or inhibited temperament, anxious cognitions concerning evaluation by others, and behavioral avoidance of social situations (Spence & Rapee, 2016). Hence, the model points to different components of social anxiety psychopathology that, through processes of interaction, can influence an individual's point along the social anxiety continuum. Therefore, in order to gain a detailed and fine-grained understanding of social anxiety and its development, researchers should investigate these different components in youth populations. The recently emerged network theory of psychopathology (Borsboom, 2017; Borsboom & Cramer, 2013), through its focus on symptoms, or specific components of psychopathology, has the potential to do just this. In this context, the current paper features a network analysis of the components of social anxiety in a large, longitudinal community sample of children and adolescents[1].

In network theory, a mental disorder is conceptualized as a network of components that influence each other (Borsboom, 2017; Borsboom & Cramer, 2013). Network theory challenges existing approaches to psychopathology because, in this theory, components do not *reflect* an underlying and unobserved latent cause, but actually *constitute* the disorder (Borsboom, 2017; McNally, 2016). The theory is accompanied by widely applicable methodology that is designed to estimate the structure of such psychopathology on the basis of empirical data (Epskamp, Cramer, Waldorp, Schmittmann, & Borsboom, 2012; van Borkulo et al., 2014). The methodology allows for analysis of different properties of network components. For example, one could investigate the potential presence of clusters (sometimes termed modules or communities) of components that tend to be closely related to each other, but not to other components. These properties can be related to, for example, diagnostic group membership, or other variables such as gender and age. Advantages of network analysis include providing a description of the complete pattern of relevant relations between the

[1] In line with network theory of mental disorders (Borsboom, 2017) a network consists of components (e.g., thoughts, feelings, symptoms) and interactions between these components. The components included in many network studies are symptoms that directly assess diagnostic criteria and therefore these studies use the term *symptoms*. In this paper we choose the term *components* because it is more in line with the theoretical model describing the different manifestations of social anxiety (Spence & Rapee, 2016).

components, without using sum scores or a pre-defined factor structure. It allows a representation of these relationships as well as objective estimates of centrality and clustering; as such, network analysis may help to identify components that play particularly important roles in the network and which may open up new possibilities for the treatment of psychopathology (Borsboom & Cramer, 2013).

A recent network study characterized the patterns of connections among fear and avoidance of different interpersonal and social evaluative situations in adults with and without SAD (Heeren & McNally, 2018). The networks consisted of 24 items from the Liebowitz Social Anxiety Scale (Liebowitz, 1987) that measure fear and avoidance of different social situations such as speaking up at a meeting, going to a party, and looking at people you don't know very well in the eyes. Whilst there was a *quantitative* difference between the networks of individuals with and without SAD in terms of overall strength connectivity (i.e., how strongly the symptoms are interconnected), the networks were *qualitatively* similar. That is, the fear and avoidance items clustered in a single community in both the clinical and nonclinical networks. These findings suggest that network analysis of psychopathology related components in nonclinical samples can inform knowledge of network structure in clinical samples.

Nevertheless, findings regarding a network of social anxiety components in adult samples are not necessarily directly transferable to youth populations. In developmental psychopathology models (Ollendick & Hirshfeld-Becker, 2002; Spence & Rapee, 2016), a proposed diathesis for SAD is the temperamental factor shyness (or behavioural inhibition to the unfamiliar; Ollendick & Hirshfeld-Becker, 2002). Supporting this premise, studies have shown that shy temperament in young children is associated with social anxiety psychopathology later in childhood and adolescence (Biederman et al., 2001; Hirshfeld-Becker et al., 2007; Prior, Smart, Sanson, & Oberklaid, 2000). Shyness may develop into social anxiety through its interaction with several environmental and psychological processes, including fear and avoidance of social situations, and anxious cognitions concerning evaluation by others (Ollendick & Hirshfeld-Becker, 2002). Therefore, when investigating a social anxiety network in youth it seems necessary to include shyness as one of the components. Another difference between youth and adult populations in terms of social anxiety network components is behavioral avoidance. Research shows that an increased avoidance developmental pathway behavior slowly emerges in adolescence, reaching a peak level around 16-17 years (Miers, Blöte, Heyne, & Westenberg, 2014). This finding might suggest that associations between avoidance and the other social anxiety components are weaker in youth as compared to adult populations.

In sum, informed by prominent theoretical models and empirical research regarding the development of social anxiety psychopathology (Ollendick & Hirshfeld-Becker, 2002; Spence & Rapee, 2016), we sought to characterize how components of social anxiety are connected within a network in a large, longitudinal sample of children and adolescents. We chose to examine components that reflect four manifestations from the social anxiety continuum: fear of social situations, shyness, anxious cognitions concerning evaluation by others, and avoidance of social situations (Spence & Rapee, 2016). In relation to avoidance we chose to focus on two types of social situation: public performance in one's own classroom (e.g., answering a question in class) and social interaction (e.g., joining in a conversation) situations (Heeren & McNally, 2018). These situations are feared and avoided most by socially anxious children and adolescents (Blöte, Miers, Heyne, & Westenberg, 2015; Rao et al., 2007) and particularly the classroom performance situations are very relevant at this developmental stage. The current investigation therefore goes beyond previous social anxiety network research (Heeren & McNally, 2018) by including two additional social anxiety components that are essential to understanding the social anxiety construct in youth populations: fear of negative evaluation and shyness (Spence & Rapee, 2016; Wong & Rapee, 2016). Furthermore, utilizing our longitudinal, 3-wave data set we, for the first time, investigate questions related to the consistency of a social anxiety component network structure over time, and the importance of particular components within the network.

We posed the following two research questions (a) how are social anxiety components (related to fear or anxiety about social situations, shyness, anxious cognitions, and behavioral avoidance) interconnected within a network and do they cluster in communities of coherent component connections? and (b) does the social anxiety component network show consistency in the pattern of component-component connections over time? We investigated the latter question in two ways. First, by observing patterns of component interconnections at each of the three study waves separately; second, by exploring the connections between components within a longitudinal network that incorporates individual component change over time.

Due to the scarcity of studies investigating social anxiety psychopathology from a network analysis perspective and the fact that current state-of-the-art network methods are not confirmatory, we do not propose specific hypotheses for our research questions. Nevertheless, drawing from the etiological model of social anxiety psychopathology (Spence & Rapee, 2016), and in the context of the study's nonclinical sample of children and adolescents, we may tentatively suggest the following (a) the different components would be positively connected with each other and components would cluster in three communities, with anxious cognitions and behavioral avoidance components as separate communities; in terms of social fear severity and shyness, these may cluster together as shyness is sometimes described as a manifestation of social anxiety (Rapee & Spence, 2004), and (b) that, in terms of the number of communities and their content, the network structure would be similar over time; we did not have specific expectations regarding the consistency of the *pattern* of interconnections over time.

Methods

Participants and Procedure

The present study uses data from participants in the Social Anxiety and Normal Development study (SAND; Miers, Blöte, de Rooij, Bokhorst, & Westenberg, 2013; Westenberg et al., 2009). A complete description of the procedure employed in the SAND study can be found in Miers et al. (2013). At the start of the SAND study children and adolescents were recruited from one secondary school and two primary schools in Leiden, a middle-sized city in the Netherlands. Adolescents who were treated for mental health problems or had other medical conditions were excluded. This longitudinal study, with a cohort-sequential design, had four assessment waves. Waves one to three were conducted over three consecutive years and wave four took place between one and three years after wave three. Data from the first, third, and fourth waves are used in the current study (the Multidimensional Anxiety Scale for Children (MASC) was not administered at wave two), hereafter referred to as T1, T2, and T3 respectively. Informed parental consent and participant assent was obtained in writing at each study wave. The SAND study was approved by the Leiden University Medical Ethical Committee (P05.118). At T1 and T2 the participants attended the university for a pre- and lab-session, the latter involving the Leiden Public Speaking Task (Leiden-PST; Westenberg et al., 2009). T3 was also administered at the university, and participants attended only one session during which they completed a battery of questionnaires and tasks. At all waves the MASC was administered in a paper-and-pencil format and the avoidance of social situations measure (AvoSS; Miers et al., 2014) was administered on a desktop computer.

At T1 the total sample comprised 331 participants (170 boys and 161 girls) aged between 9 and 17 years, with a M_{age} of 13.34 years (*SD* = 2.25). Eighty-two (81.6%) percent of participants lived with their biological parents, 5.7% with biological mother only, and 5.1% with biological mother and stepfather. Ninety-two (91.5%) percent of participants were born in the Netherlands and 49.0% of biological mothers had completed tertiary education. At T2 there were 127 boys and 121 girls, M_{age} = 15.25 years (*SD* = 2.23); and at T3, respectively, 121 boys and 115 girls, M_{age} = 17.48 years (*SD* = 2.72).

Measures

Multidimensional Anxiety Scale for Children (MASC; March, Parker, Sullivan, Stallings, & Conners, 1997). To assess fear of social situations, anxious cognitions, and shyness, items from the social anxiety subscale from the MASC were used. The MASC was developed to help researchers distinguish between normal and pathological anxiety, and is grounded in trait anxiety theory (Marks, 1987) through its inclusion of items that address emotional, cognitive, physical, and behavioral symptom domains. It is recommended as a screening measure for anxiety disorders (Silverman & Ollendick, 2005) and is suitable for youth aged between 8 and 19 years. Participants indicate the extent to which they have experienced the descriptive item (e.g., "I worry about other people laughing at me") in the past two weeks on a four-point Likert scale (0 = *never true for me* and 3 = *often true for me*). The social anxiety scale consists of 9 items (see Table 1). These items and their corresponding network abbreviations are: "I worry about other people laughing at me" (*LGH)*; "I'm afraid that other kids will make fun of me" (*FUN*); "I'm afraid other people will think I'm stupid" (*SPD*); "I worry about what other people think of me" (*THK*); "I worry about doing something stupid or embarrassing" (*EMB*); "I worry about getting called on in class" (*CLS*); "I get nervous if I have to perform in public" (*NER*); "I have trouble asking other kids to play with me" (*PLA*); and "I feel shy" (*SHY*). Internal consistency of the 9 items is acceptable at all waves: T1 α = .89, T2 α = .89, and T3 α = .88.

Avoidance of Social Situations (AvoSS; Miers et al., 2014). To assess behavioral avoidance the AvoSS questionnaire (Miers et al., 2014) was employed. This questionnaire is based on the social phobia module from the Anxiety Disorders Interview Schedule for Children, specifically the section that asks about interference in several social situations. Written permission was obtained from the first author to adjust the format to a questionnaire (W. Silverman, personal communication, April 19, 2005). The questionnaire begins with a standardized written instruction explaining that there are different ways to avoid situations (e.g., when a teacher asks a question in class you look downwards in the hope that you don't have to answer the question). A situation is then presented, for example, "giving a speech in your class" and the participant is asked to answer the question "Do you try to avoid this situation?" on a nine-point Likert scale (0 = *never*, 4 = *sometimes*, 8 = *always*). The questionnaire includes 20 different social situations and showed high internal consistency across all 20 situations (Miers et al., 2014).

For the purposes of the current study we selected six situations (Table 1) that have theoretical relevance from the perspective of the SAD developmental model (Spence & Rapee, 2016) and have been shown to discriminate between high and low socially anxious adolescents (Blöte et al., 2015)[2]. Three of the six situations reflect avoidance of public performance situations in the classroom, namely (network abbreviation in brackets): answering questions in class (*AQU*); giving a speech (*ASP*); and writing on the board (*ABO*). The other three situations reflect avoidance of social interaction situations, namely: starting or

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[2] Our choice of 6 social situations to assess avoidance was also motivated by the requirement of a sufficient observation-to-parameter ratio to perform the network analyses.

joining in a conversation (*ACO*); speaking to an adult (*AAD*); and talking to persons you don't know well (*AUN*). Internal consistency of these 6 items combined was acceptable at all three study waves: T1 α = .71, T2 α = .74, and T3 α = .77.

[Table 1 here]

Data Analysis

Networks were estimated with the 9 MASC and 6 AvoSS items as the *nodes* of the network[3]. Relationships between these nodes (called *edges*) were the partial correlations between the nodes. In order to prevent false positives (i.e., an estimated non-zero edge that is in fact not present), we used regularization by means of a g10raphical LASSO (GLASSO) approach (Friedman, Hastie, & Tibshirani, 2008; Friedman, Hastie, & Tibshirani, 2014). LASSO adds a penalty parameter to the estimation process that results in small edge weights being shrunk to zero. As such, regularization with LASSO yields a parsimonious, conservative representation of the relationships between nodes, corrected for the relationships with all other nodes. The optimal value of the penalty parameter, providing a trade-off between the amount of bias and variability in the estimates, was estimated using the Extended BIC (EBIC; Foygel & Drton, 2010). The partial correlations were calculated with Pearson correlations for the continuous variables (all AvoSS nodes) and polychoric correlations for the ordinal variables (all MASC nodes) using the bootnet package (Epskamp, Borsboom, & Fried, 2017). As network analysis does not handle missing data networks were estimated with available complete data at each wave and therefore the *n* per network varies.

The optimal model (with the lowest EBIC value) was visualized using the Fruchterman-Reingold algorithm (Fruchterman & Reingold, 1991), clustering nodes with

[3] In this and the Results section we use the term *nodes* to refer to the 15 social anxiety components included in the social anxiety network.

high interrelations together. All networks were visualized using a fixed node placement (i.e., the average node position over the three waves based on the Fruchterman-Reingold algorithm) thereby easing comparison of the networks. Figures of networks where node placement is estimated for each wave separately are provided in supplementary materials Figure S1. All analyses were performed using the bootnet and qgraph packages (Epskamp et al., 2017; Epskamp et al., 2012) in R (R Core Team, 2016).

To estimate which nodes tend to cluster together we performed community detection analyses using the Louvain algorithm (Rubinov & Sporns, 2011). The Louvain algorithm, first developed by Blondel, Guillaume, Lambiotte, and Lefebvre (2008), is based on modularity, which is defined as the density of edges of a community versus the density of edges outside this community. The algorithm very broadly works by moving each node to different communities to optimize modularity. An advantage of the Louvain approach is that it does not require any thresholding of the estimated networks. It has been shown to have good performance (Gates, Henry, Steinley, & Fair, 2016). To highlight the stability of the community detection procedure we used a non-parametric bootstrap (1000 iterations), and indicated at each bootstrap iteration if the same nodes fall within the same community. To compare the network structure and global strength invariance at T1 and T3 we conducted a network comparison test (van Borkulo et al., 2017) for dependent samples.

In order to investigate consistency of the network using the longitudinal data we related change trajectories on the nodes to each other as suggested by von Klipstein, Borsboom, and Arntz (2018). For each participant, we estimated the (linear) slope of the scores for each node across T1, T2, and T3 using Ordinary Least Squares (OLS) regression. These slope scores thus represent each node’s change over time for each individual. The slope scores were subsequently used as variables to estimate a network, where we used the same settings as the cross-sectional networks (GLASSO with EBIC model selection). This allows us to assess to what extent the network structure of change trajectories resembles the network structure of individual differences.

In addition to the aforementioned analyses we explored the role of the nodes in the resulting networks by looking at strength centrality. The simplest centrality coefficient is *strength centrality*. Strength centrality of a node equals the sum of its the edge strengths that connect that node to other nodes in the network. In a psychometric context, strength centrality is proportional to the extent to which a given indicator uniquely explains variance in neighboring indicators, to which it is connected in the network (Haslbeck & Waldorp, 2018). Strength centrality has the additional advantage that it bears clear relations to well-understood psychometric metrics; for example in a completely connected network of multivariate normal indicators, differences in strength centrality mirror differences in factor loadings (Marsman et al., 2018). Finally, if there are in fact differences in strength centrality, these are relatively easy to estimate robustly (Epskamp et al., 2017). Thus, strength centrality is a clear and psychometrically meaningful metric that describes differences between the positions of indicators in a network structure.

The stability of the centrality measures was investigated by using the correlation stability coefficient (Epskamp et al., 2017) with which centrality measures are re-calculated for subsamples in which an increasing random percentage of cases are dropped. The correlation stability coefficient is defined as the amount of cases that can be dropped while still maintaining a high (> 0.7) correlation with the original centrality estimate (Epskamp et al., 2017). A stability value between .25 and .5 indicates that the centrality estimates have an acceptable stability while a value higher than .5 indicates that centrality estimates are very stable (Epskamp et al., 2017). In the context of current discussion about the relevance of centrality indices derived from cross-sectional networks (Rodebaugh et al., 2018), we also explored whether component centrality within each cross-sectional network was related to component centrality within the longitudinal network that incorporated individual component change across the three time points.

Results

Network of T1 Social Anxiety Components

The network of 15 social anxiety nodes is presented in Figure 1a. All connections were positive. The community detection algorithm yielded four communities in which all 15 nodes clustered; no node was isolated. The first community that includes the nodes depicted in black (*LGH, THK, FUN, EMB,* and *SPD*) reflects core anxious cognitions characteristic of social anxiety: fear of negative evaluation. This community of *cognitive* components showed connections ranging from 0.12 between *FUN* and *EMB* to 0.3 between *FUN* and *LGH*. A second community, depicted in dark gray (*PLA*, *NER*, and *SHY*), includes nodes that depict *social-emotional* components: feelings of nervousness or apprehension for social situations and shyness. The third community (depicted in light gray) is represented by the avoidance nodes relating to classroom situations (*ASP*, *AQU*, and *ABO*) and the node *CLS* (worry about getting called on in class) from the MASC. This community could be said to reflect *avoidance and worry* specific to *performance* situations in the classroom. That *CLS* fell in this community seems quite reasonable given the content overlap with the avoidance nodes specific to performance situations in the classroom. The fourth community (depicted in white) included *avoidance* components reflecting *social interaction* situations (*ACO*, *AUN*, *AAD*). Only one node (*AAD*) from this community was connected to one avoidance node (*ABO*) from the *performance* community (0.12).

There were no direct connections between the *cognitive* and *avoidance* nodes; nodes from each community were associated with *social-emotional* components, but the *cognitive* and *avoidance* communities were not associated with each other. For example, there was a pathway from worrying about doing something stupid or embarrassing (*EMB*), through feeling shy (*SHY*), to becoming nervous about when performing in public (*NER*) which was connected to avoidance of giving a speech in class, or vice-versa. Both *CLS* and *PLA* were also placed in between the *cognitive* and *avoidance* nodes.

[Figure 1 here]

To examine the consistency of the communities and the nodes falling in each community we calculated bootstrapped community stability analyses, presented in Figure S3a[4]. The values are a stability proportion, indicating how often a particular node falls in a community with another node. The higher the stability proportion, the greater the indication that two nodes form a community. Each of the five items from the *cognitive* community showed high stability proportions (0.86 – 1.00) with the other four *cognitive* nodes. Similarly, high stability proportions were found for the 3 nodes in each of the *avoidance* communities. *CLS* had a relatively high (0.47 and 0.44) stability proportion with *NER* and *SHY*, yet the proportions with the *avoidance of social performance* nodes were somewhat higher (all at 0.59). The node *CLS* was placed in a community with the latter nodes. These analyses also showed that *NER* and *SHY* had a strong connection, with a stability proportion of 0.94, and lower proportions with the other nodes. The item *PLA* showed the least clear results, with stability proportions moderate in strength with nodes from different communities; in increasing order, the *avoidance of social interactions* community, the *cognitive* community and the *social-emotional* community. Taken together with the position of the items *SHY*, *NER*, *CLS* and *PLA* in between the *cognitive* and *avoidance* communities and their lower

[4] Figure S3 also includes the full and partial correlation matrices at T1, T2, and T3. Figure S2 visualizes the confidence intervals around every edge in the T1, T2, and T3 networks.

community stability, we may suggest that these are bridge components, connecting different communities (Borsboom & Cramer, 2013).[5]

Networks of T2 and T3 Social Anxiety Components

In terms of the consistency of the social anxiety network over time, the networks at T2 and T3 showed a very similar pattern and communities of nodes as the T1 network (Figure 1b and 1c). It can be seen that the same 4 communities are still evident at T3 indicating consistency of the social anxiety component network over time. Another similarity is that *PLA, CLS* and *NER* remained bridge nodes. The stability proportions from the bootstrap community analyses indicate that these nodes do not clearly align to a particular community (Figure S3a). In the T3 network the *avoidance* nodes concerning *social interaction* situations (*AUN*, *AAD*, and *ACO*) were very weakly connected (< .10, Figure 1c) to the nodes reflecting *avoidance of social performance* situations, and were more isolated from other nodes.

The Network Comparison Test showed that differences between network structures and global strengths at T1 and T3 were nonsignificant; respectively, $M = 0.19$, $p = 0.623$, and $S = 0.18$, $p = 0.457$ (global strength at T1 = 6.28; at T3 = 6.46). These results are in line with the observed consistency of the network structure, as well as its global strength, over time.

Change Trajectory Network

The network using the change trajectories of social anxiety components is shown in Figure 1d. It appeared that changes in the *cognitive* and *avoidance of performance*

[5] We conducted exploratory network analyses in boys and girls separately at T1. In boys, three communities were observed and four in girls. The components *SHY*, *PLA*, *NER*, and *CLS*, appeared to act as bridge symptoms between the cognitive community and both avoidance communities in the male and female subsamples. Hence, we do not report on these analyses.

components were associated with each other over time. Within the original T1 *cognitive* community the node *EMB* was associated only with *THK*. *EMB* also showed cross-community associations with components from the T1 *social-emotional* community, particularly with *SHY* and *NER.* Thus, changes in worrying about doing something stupid or embarrassing over time were positively correlated with changes in feeling shy and nervous when performing in public. Changes in *CLS* were not associated with changes in components from the T1 *social-emotional* community but with avoidance of answering questions in class (*AQU*). Changes in *SHY* over time were also weakly associated with changes in avoidance of two classroom situations: writing on the board and answering a question (*ABO* and *AQU*). The *avoidance of interaction situations* community showed no cross-community connections. Changes in avoidance of different interaction situations therefore did not appear to be associated with changes in other social anxiety components over time.

Three communities were detected and these largely overlap with the communities from the cross-sectional networks (mainly T1 and T3). The nodes from the T1 *social-emotional* community did not form their own community but fell within one of the other three communities. Two nodes (*SHY*, *NER*) were placed in the *cognitive* community, the node *PLA* fell within the *avoidance of social interaction situations* community and the node *CLS* fell within the *avoidance of performance situations* community.

In addition, we correlated the edge weights from the cross-sectional and the longitudinal slopes network. The correlations between the edge weights from the longitudinal slopes network and cross-sectional networks were: T1 = 0.80, T2 = 0.73, and T3 = 0.72 (all p's < .001). These correlations indicate overlap in the edge weights suggesting that the strongest edges in the cross-sectional networks are also the strongest in the trajectory network of changes over time.

Strength centrality results at T1, T2, and T3, are presented in Figure S2d. Correlation stability for strength centrality was, respectively, 0.52 , 0.36, and 0.44 at T1, T2, and T3. We correlated the centrality scores from the longitudinal slopes network with the centrality measures at T1, T2, and T3. Correlations were T1 = 0.71 (p = .003), T2 = 0.55 (p = .035), and T3 = 0.60 (p = .018).

Discussion

The current study represents the first network analysis of social anxiety components in youth, using a longitudinal design. In line with the etiological model of social anxiety (Spence & Rapee, 2016) the findings reveal a clustering of components into *cognitive*, *social-emotional*, and behavioral *avoidance* communities. An interesting finding was that the social-emotional components appeared to bridge the connections between the cognitive and avoidance components. The overall pattern of component position and grouping within the network was quite consistent across time. These findings are discussed in the following paragraphs in relation to the study's two research questions regarding respectively, component connections and network consistency.

The first research question asked, how are social anxiety components interconnected within a network and do they cluster in communities of coherent component connections? We found four communities, with a separation of anxious cognitions from behavioral avoidance, the latter further separated by social situation type (performance or interaction). The fourth community, social-emotional, consisted of the components assessing fear about social situations and shyness. Positive component connections were particularly strong *within* the cognitive and the two avoidance communities, and weaker *between* communities. The connections within the social-emotional community were weaker, except for the association between the items *I feel shy* and *I get nervous if I have to perform in public.* There was an apparent separation between the cognitive and avoidance communities. These communities were connected only *through* the social-emotional components, which, assuming bidirectionality of components within the network, would suggest that these act as bridge components. The community stability analyses supported this; the social-emotional components did not clearly align to a particular community, as shown by the low stability proportion estimates with other components.

The four communities are, for the most part, in line with the theoretical model of social anxiety psychopathology described by Spence and Rapee (2016), but there are also subtle differences. Specifically, the avoidance items did not cluster in one community, and the position of the social-emotional components in between the cognitive and avoidance communities, without direct connections between the latter two, hints at a different role of the social-emotional components as compared to the cognitive and avoidance components. This role may be interpreted from a developmental (Spence & Rapee, 2016) or maintenance (Leigh & Clark, 2018) perspective of social anxiety. In a developmental interpretation, the social-emotional components could be inferred as manifestations of a shy or inhibited temperament. Given the position of these components in the middle of the network, their development may lead to both negative cognitions and avoidance behavior. In such an interpretation, shyness or inhibited temperament may act as a starting point for the development of social anxiety symptoms. Nevertheless, due to the fact that in our sample age and time are intertwined and our findings cannot (only) be attributed to age-related development, we provide an alternative interpretation from the perspective of the maintenance of social anxiety psychopathology (Leigh & Clark, 2018). Youth with high social anxiety are concerned about negative judgment from others and worry they will act in a way that is embarrassing; this may enhance their anxiety feelings of being shy, nervous, and hesitant in different social situations, and these emotions may in turn reinforce their avoidance of social situations, both interpersonal and performance in nature.

The observed clustering of components may also be said to be in line with trait anxiety theory whereby the components formed communities reflecting the three dimensions of trait anxiety: cognitive, emotional, and behavioral (Marks, 1987; Mõttus & Allerhand, 2017). That is, items about the fear of negative evaluation from others formed a community, items about a person's feelings in social situations were captured in a second community, and items about wanting to behaviorally avoid social situations, both performance and interaction related, formed the remaining two communities. Moreover, the network analysis approach yielded novel and detailed results about how the social anxiety component communities are interrelated.

Second, turning to the question of whether the pattern of component-component connections is similar over time our analysis of the network structure over a period of approximately four years, and the non-significant network comparison test results, provide support for its consistency. That is, the T3 network of social anxiety components revealed that the community structure was invariant and remained intact: the cognitive and avoidance components were connected through the social-emotional bridge components. Nevertheless, there were some differences in the organization of components within communities at T2 as compared to T1. This may be attributed to sample variation across time points. The differences mainly concerned the components from the social-emotional community; these were exactly the components with the most variable community stability values and hence are most sensitive to alterations in community allocation.

Compared to the T1 network, connections in the T3 network between the avoidance of interaction situations and the social performance situations weakened, hinting at a separation of these two types of social situation. This separation could be explained by changes in the learning environment of youth in our sample: at T3 fewer participants attended high school than at T1. At a high school learning environment it is likely that the classroom and interaction situations involve the same people whom these youth would like to avoid, yielding a connection between these situation types. However, once youth leave high school, it is likely that the overlap in terms of the composition of these situations lessens, and the connection between them weakens. In addition, a potential separation of performance from interaction situations over time, each with a similar pattern of connections with the social-emotional and cognitive components, would seem to support the *performance only type* specifier of DSM 5 for youth (Bögels et al., 2010). The weaker connections between avoidance of social interaction situations and the other social anxiety components at T3 might imply that avoidance of such situations is less likely to maintain, or be maintained by, social fears and anxious cognitions in a group of older adolescents. Furthermore, future research should examine whether a similar separation of avoidance of performance and interaction social situations is found in youth diagnosed with SAD.

We make the following observations in relation to our analysis of a longitudinal network that incorporated individual component change across the three time points and strength centrality derived from this network. The longitudinal network showing associations between slopes over time may be said to be similar to the T1 cross-sectional network in that the social-emotional components are positioned in between the cognitive and avoidance communities. Moreover, a similar set of communities was found as detected in the cross-sectional networks. However, in the slopes network, the avoidance of interaction situations community is completely separate from the other communities. This is in line with the aforementioned observation of a potential separation between T1 and T3 of the avoidance communities. Indeed, these findings seem to suggest that increases or decreases in levels of avoidance for interaction situations during the adolescent period do not coincide with increases or decreases of social anxiety components such as negative cognitions and avoidance of performance situations. Avoidance of interaction situations appears removed from the social anxiety construct, at least in our community sample of adolescents.

Of course, it is important not to over interpret either network structures or centrality metrics based on them: as is always the case in statistics, correlational analyses can suggest but not prove causal hypotheses (e.g., that interventions on central nodes will be more efficient). The same holds for dynamical interpretations in terms of flow (see Bringmann et al., 2018), which can never be justified on the basis of statistical models alone; even to generate such hypotheses, one needs a substantive theory that specifies the functional form and time scale at which the different components in a network interact (e.g., see Robinaugh et al., 2019 for a fully explicated network theory of this kind). Thus, while network analyses and centrality coefficients can generate important dynamical and causal hypotheses, like all causal hypotheses these should be tested in dedicated studies, that are ideally experimentally controlled.

Limitations

The present study has limitations. First, the associations (edges) among T1 social anxiety components were estimated with cross-sectional observational data and therefore at the *group* level. This means that we (a) cannot draw conclusions about the *direction* of activation through the component network, nor can we (b) readily extrapolate our findings to what actually happens in individuals. In relation to (a) a connection between social anxiety components (e.g., *EMB* and *SHY*) might indicate an actual causal relationship at the group level, that fear of negative evaluation leads to shyness, but the relationship could also exist due to an unmeasured confounder (then the edge is spurious). With regard to (b) the connections observed at a group level do not necessarily imply that *individuals* are characterized by the same pattern of connections. In relation to the community detection analyses we must provide a note of caution. In our group-level network analyses, we cannot determine whether the components formed clusters because they measure the same underlying construct (e.g., fear of negative evaluation) or because there are actual component-component causal relationships that give rise to these connections. In order to confirm the latter, intensive time-series or experimental data tapping social anxiety components would be required. Second, the pattern of associations among social anxiety components illustrated in the current study cannot be generalized to children younger than 9 years, nor to a more diverse sample in terms of education level and ethnicity. Third, although the SAND sample included participants with social anxiety scores in the clinical range (at T1 21.7% of participants scored above the MASC clinical cut-off of 13.5; Wood, Piacentini, Bergman, McCracken, & Barrios, 2002), replication of the network in a sample of youth with a diagnosis of social anxiety disorder is required. Given that a previous study in adults with and without SAD showed a similar clustering of items (Heeren & McNally, 2018), we might expect that a social anxiety network in youth diagnosed with SAD would show a similar community structure as in a community sample, with stronger connections within and between communities. Fourth, whilst we used a fairly large sample at T1, the sample size decreased across the three waves, possibly affecting the reliability of parameter estimates. This means that the T2 and T3 networks should be interpreted with caution. Fifth, a challenge to the network approach is to demonstrate network reproducibility. A network analysis of the same 15 social anxiety components in a *different* sample of youth should be conducted to demonstrate replicability (Fried & Cramer, 2017).

The limitations notwithstanding, the present study is the first to conduct a detailed investigation of the associations among social anxiety components in youth, over time, using network analysis. Notable findings gained from the network analysis approach were (a) the position of the social-emotional community in between the communities reflecting anxious cognitions and social avoidance, at all three assessment waves and in the trajectory network, (b) the increasing differentiation between avoidance of performance and interaction situations and the latter's decreasing connection to other social anxiety components over time, and (c) there is converging evidence, from both the cross-sectional T1-T3 networks and the change trajectory network, for the social anxiety component network structure here presented. The present study's findings attest to the potential value of applying the network approach to investigate the pattern of associations among social anxiety components in youth.

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Table 1. MASC and AvoSS items and their node abbreviations.

#	Item	Node abbreviation	T1 *M*(SD)	T2 *M*(SD)	T3 *M*(SD)
	MASC				
1	I worry about other people laughing at me	LGH	1.15 (0.93)	0.99 (0.83)	1.02 (0.83)
2	I'm afraid that other kids will make fun of me	FUN	0.88 (0.84)	0.73 (0.74)	0.66 (0.78)
3	I'm afraid other people will think I'm stupid	SPD	0.75 (0.82)	0.70 (0.81)	0.78 (0.92)
4	I worry about what other people think of me	THK	1.21 (0.96)	1.09 (0.89)	1.24 (0.97)
5	I worry about doing something stupid or embarrassing	EMB	1.18 (0.93)	1.10 (0.92)	1.07 (0.96)
6	I worry about getting called on in class	CLS	0.85 (0.90)	0.58 (0.81)	0.68 (0.87)
7	I get nervous if I have to perform in public	NER	1.35 (0.95)	1.22 (0.93)	1.30 (0.93)
8	I have trouble asking other kids to play with me	PLA	0.58 (0.77)	0.51 (0.77)	0.44 (0.75)
9	I feel shy	SHY	1.05 (0.87)	1.02 (0.89)	0.93 (0.89)
	AvoSS				
10	Do you try to avoid: Answering questions in class	AQU	1.90 (1.80)	2.15 (1.89)	2.04 (2.03)
11	Do you try to avoid: Giving a speech in class	ASP	1.72 (2.18)	2.22 (2.44)	2.05 (2.33)
12	Do you try to avoid: Writing on the board	ABO	1.20 (1.85)	1.53 (2.18)	1.54 (2.11)
13	Do you try to avoid: Starting or joining in a conversation	ACO	0.99 (1.29)	0.77 (1.32)	0.76 (1.41)
14	Do you try to avoid: Speaking to an adult	AAD	1.27 (1.60)	1.10 (1.53)	0.97 (1.49)
15	Do you try to avoid: Talking to persons you don't know well	AUN	2.14 (1.93)	1.81 (1.93)	1.48 (1.66)

Note. MASC = Multidimensional Anxiety Scale for Children; AvoSS = Avoidance of Social Situations. Due to missing data on some of the variables (≤ 2% of available data per wave) the *n*'s per wave range between: at T1, 328-331; at T2, 243-247; and at T3, 235-236.

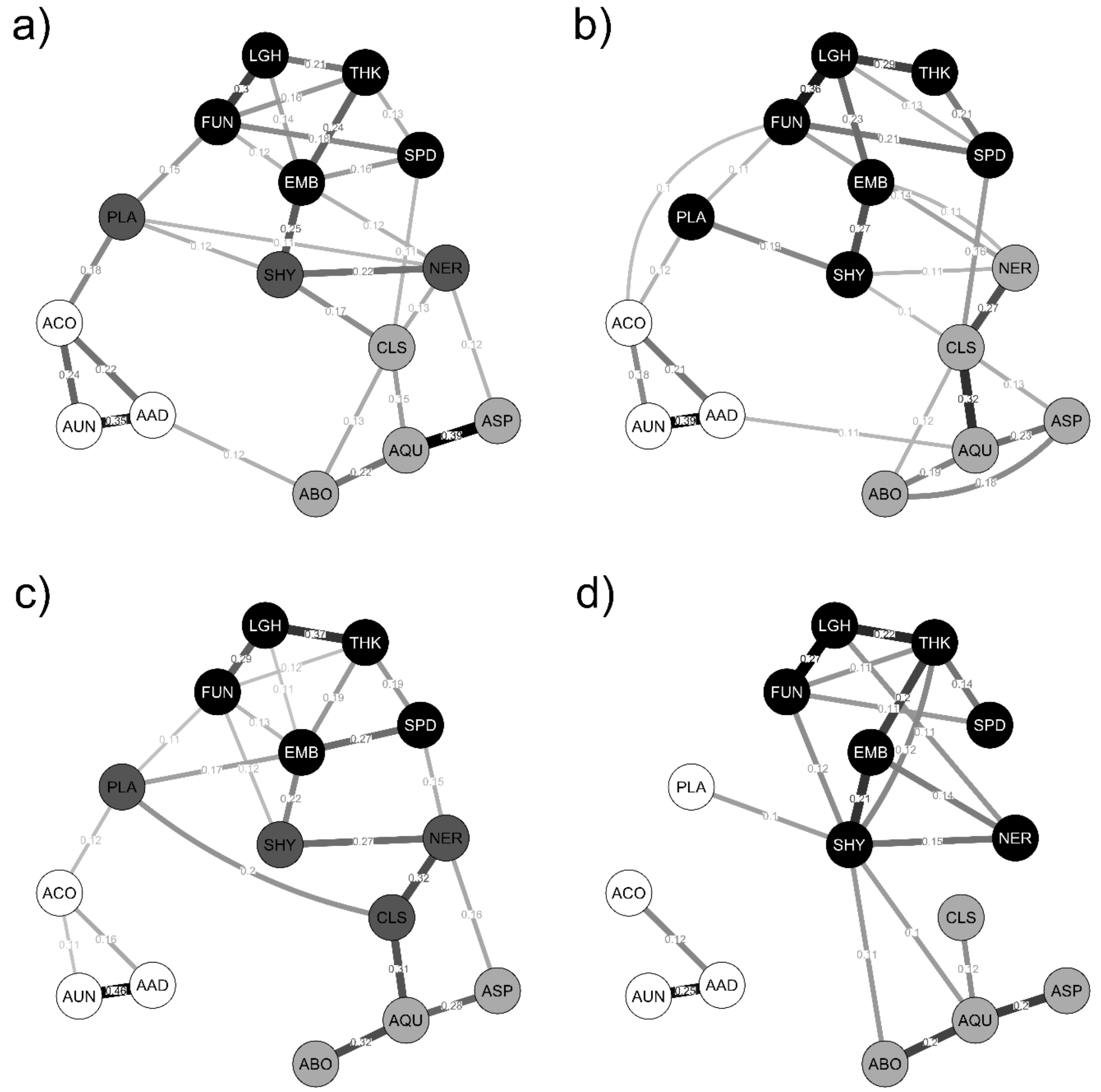

Figure 1a - 1d

Networks of 15 social anxiety components with community detection at T1(Figure 1a; *n* = 324), at T2 (Figure 1b; *n* = 242), at T3 (Figure 1c. *n* = 234), and T1-T3 Slopes network (Figure 1d; *n* = 226). Communities are depicted in grayscale: black, cognitive; dark gray, social-emotional; white, avoidance interaction situations; light gray, avoidance performance situations. Node abbreviations: *LGH* = I worry about other people laughing at me; *FUN* = I'm afraid that other kids will make fun of me; *SPD* = I'm afraid other people will think I'm stupid; *THK* = I worry about what other people think of me; *EMB* = I worry about doing something stupid or embarrassing; *CLS* = I worry about getting called on in class; *NER* = I get nervous if I have to perform in public; *PLA* = I have trouble asking other kids to play with me; *SHY* = I feel shy; *AQU* = avoid answering questions in class; *ASP* = avoid giving a speech; *ABO* = avoid writing on the board; *ACO* = avoid starting or joining in a conversation; *AAD* = avoid speaking to an adult; *AUN* = avoid talking to persons you don't know well.

Supplementary Materials

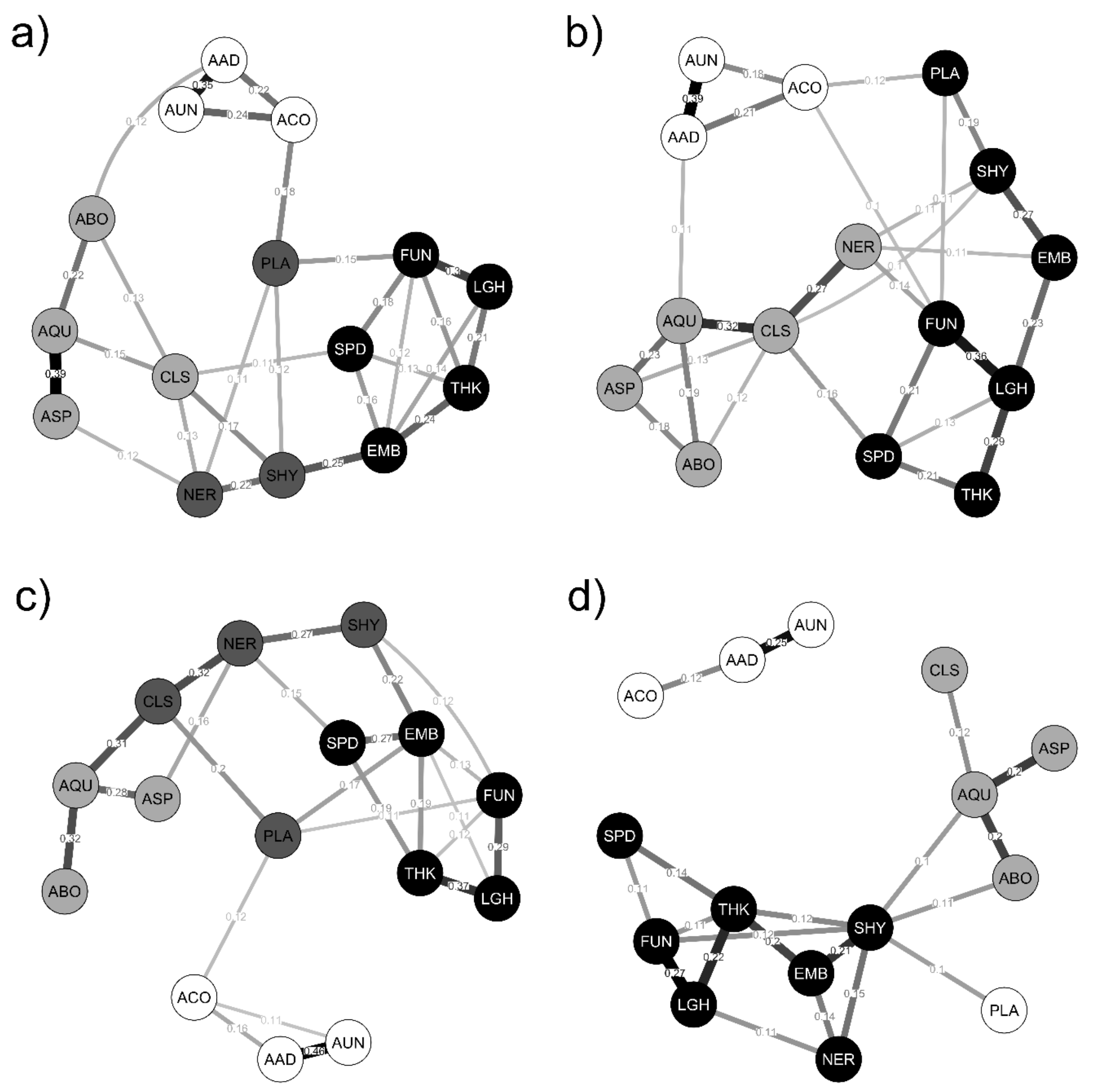

Figure S1a – S1d

Networks of 15 social anxiety components without fixed node placement at T1 (Figure S1a; *n* = 324), at T2 (Figure S1b; *n* = 242), at T3 (Figure S1c. *n* = 234), and T1-T3 Slopes network (Figure S1d; *n* = 226). Communities are depicted in grayscale: black, cognitive; dark gray, social-emotional; white, avoidance interaction situations; light gray, avoidance performance situations. Node abbreviations: *LGH* = I worry about other people laughing at me; *FUN* = I'm afraid that other kids will make fun of me; *SPD* = I'm afraid other people will think I'm stupid; *THK* = I worry about what other people think of me; *EMB* = I worry about doing something stupid or embarrassing; *CLS* = I worry about getting called on in class; *NER* = I get nervous if I have to perform in public; *PLA* = I have trouble asking other kids to play with me; *SHY* = I feel shy; *AQU* = avoid answering questions in class; *ASP* = avoid giving a speech; *ABO* = avoid writing on the board; *ACO* = avoid starting or joining in a conversation; *AAD* = avoid speaking to an adult; *AUN* = avoid talking to persons you don't know well.

Supplementary material S1e

To rule out network estimation issues due to differences in range between the AvoSS and MASC items we also estimated all networks whereby the range of the AvoSS items was restricted to 0 to 3. Results showed a correlation between centrality measures of the original network and the restricted-range network to be 0.87 ($p < .001$) for T1, 0.89 ($p < .001$) for T2, and be 0.87 ($p < .001$) for T3. With respect to community detection, the overall pattern was consistent with the original analyses and the only slight difference was that the 'social-emotional items' CLS/PLA/SHY/NER have a tendency to form a community somewhat more often with the avoidance items in the 'restricted range' networks than in the original networks. For further clarification readers may contact the first author, dr. A. Miers.

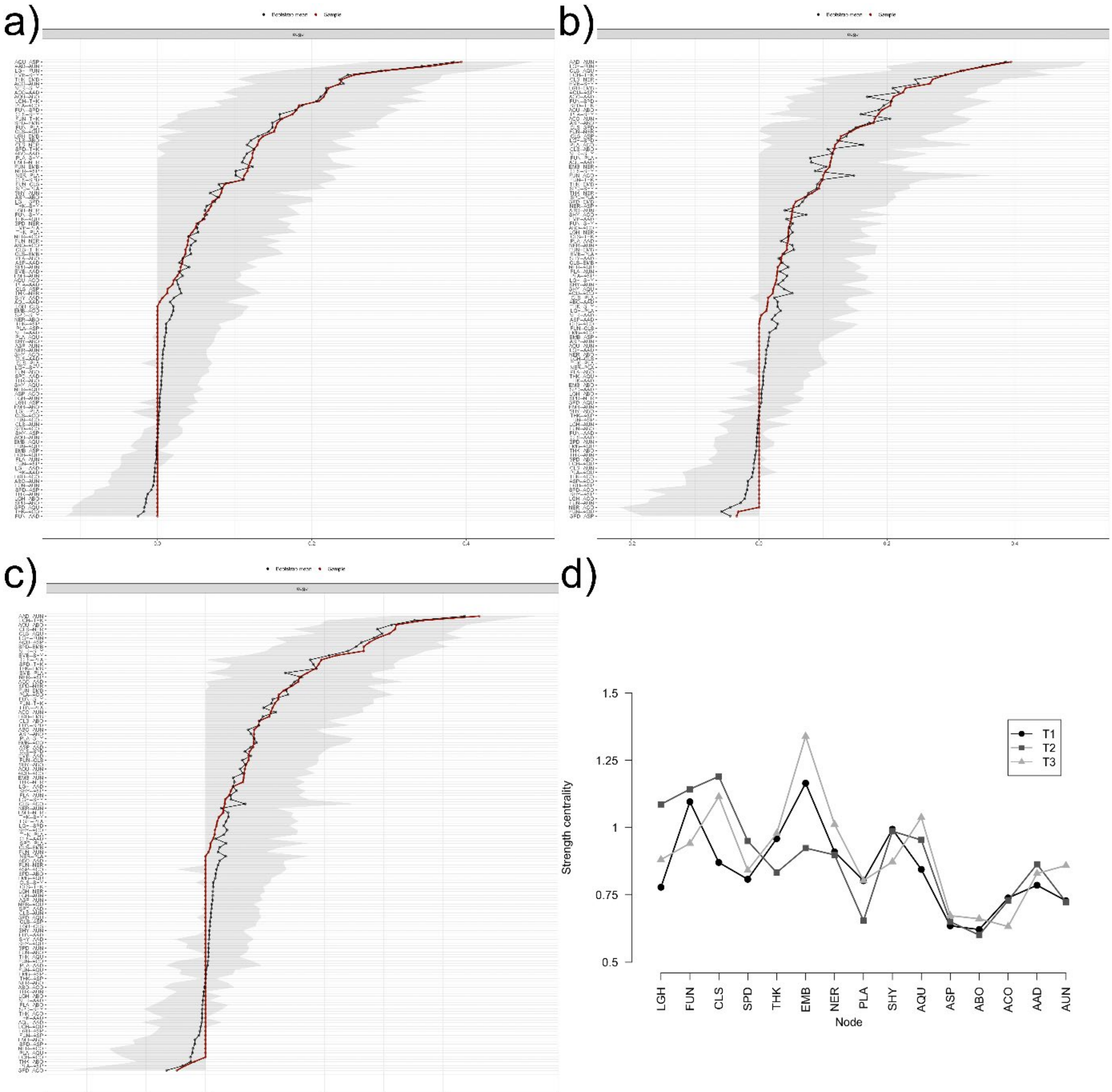

Figure S2a – S2d

Confidence intervals for every edge in networks at T1 (Figure S2a), T2 (Figure S2b), and T3 (Figure S2c). Red line depicts edge weights from sample mean and black line from bootstrap mean. Figure S2d depicts node strength centrality estimates at T1, T2, and T3. Node abbreviations: *LGH* = I worry about other people laughing at me; *FUN* = I'm afraid that other kids will make fun of me; *SPD* = I'm afraid other people will think I'm stupid; *THK* = I worry about what other people think of me; *EMB* = I worry about doing something stupid or embarrassing; *CLS* = I worry about getting called on in class; *NER* = I get nervous if I have to perform in public; *PLA* = I have trouble asking other kids to play with me; *SHY* = I feel shy; *AQU* = avoid answering questions in class; *ASP* = avoid giving a speech; *ABO* = avoid writing on the board; *ACO* = avoid starting or joining in a conversation; *AAD* = avoid speaking to an adult; *AUN* = avoid talking to persons you don't know well.