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An integrative network approach to social anxiety disorder: The complex dynamic interplay among attentional bias for threat, attentional control, and symptoms

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ABSTRACT

Cognitive models posit that social anxiety disorder (SAD) is associated with and maintained by biased attention allocation vis-à-vis social threat. However, over the last decade, there has been intense debate regarding whether AB in SAD results from preferential engagement with or difficulty in disengaging from social threat. Further, recent evidence suggests that AB may merely result from top-down attentional impairments vis-à-vis non-emotional material. Consequently, uncertainty still abounds regarding both the relative importance and the mutual interactions of these different processes and SAD symptoms. Inspired by novel network approaches to psychopathology that conceptualize symptoms as complex dynamic systems of mutually interacting variables, we computed weighted directed networks to investigate potential causal relations among laboratory measures of attentional components and symptoms of social anxiety disorder. Global and local connectivity of network structures revealed that the three most central variables were the orienting component of attention as well as both avoidance and fear of social situations. Neither preferential attention engagement with threat nor difficulty disengaging from threat exhibited high relative importance as predictors of symptoms in the network. Together, these findings suggest the value of extending the network approach beyond self-reported clinical symptoms to incorporate process-level measures from laboratory tasks to gain new insight into the mechanisms of SAD.

1. Introduction

Social anxiety disorder (SAD) is a common syndrome with a lifetime prevalence of more than 12% (e.g., Kessler et al., 2005). SAD is characterized by intense fear and avoidance of social situations causing considerable distress and impaired daily functioning. It has an early age of onset and tends to follow a chronic and debilitating course if untreated (e.g., Hayward et al., 2008). Moreover, SAD usually precedes the onset of other common comorbid anxiety, mood, and substance abuse disorders (e.g., Lampe, Slade, Issakidis, & Andrews, 2003; Randall, Thomas, & Thevos, 2001).

Although the personal and economic costs of SAD as well as its comorbidity with other disorders are well documented, uncertainty remains regarding factors responsible for the etiology and chronicity of this disorder. As highlighted by Hirsch and Clark (2004), a curious feature of SAD is that it persists even when sufferers perform naturalistic exposure to at least some feared social situations on a regular basis in their daily life. One possibility is that people with chronic SAD process information in ways that maintain their anxiety. Laboratory studies involving probe detection and probe discriminations tasks indicate that people with SAD respond faster to probes replacing social-threat stimuli, such as faces expressing anger or contemptuous disgust, or to words, such as *humiliation*, than to probes replacing neutral cues, thereby exhibiting an attentional bias (AB) for social threat that is absent in nonanxious individuals (for a meta-analysis, see Bantin, Stevens, Gerlash, & Hermann, 2016). Moreover, as argued by cognitive theorists, AB may causally contribute to increased anxiety proneness, and thereby figure prominently in the maintenance, and perhaps the etiology, of SAD (e.g., Heimberg, Brozovich, & Rapee, 2010; Rapee & Heimberg, 1997; for a review, see Wong & Rapee, 2016). Accordingly, AB may interfere with the ability to process external cues that disconfirm the negative beliefs about socially

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challenging situations held by people with SAD. Failure to disconfirm these beliefs may impede anxiety reduction, which, in turn motivates avoidance of social situations and worsens anxiety or least prevents it from extinguishing (e.g., Heimberg et al., 2010; Wong & Rapee, 2016). Therefore, reducing AB may yield clinical benefits (for a meta-analysis, see Heeren, Mogoaşe, Philippot, & McNally, 2015). Likewise, transiently fostering AB promotes anxiety proneness among nonanxious controls (e.g., Heeren, Peschard, & Philippot, 2012; MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002). Taken together, such findings are suggestive of a causal relation between AB and SAD.

To date, several explanations have been proposed to account for the maintenance of AB in anxiety disorders (e.g., Cisler & Koster, 2010; Eysenck & Derakshan, 2011; Heeren, De Raedt, Koster, & Philippot, 2013; Peers, Simons, & Lawrence, 2013). One of the most common explanations focuses on general attention control (AC), that is, the ability to voluntarily regulate the allocation of attentional resources. According to this account, AB may result from impaired AC. For example, Derryberry and Reed (2002) found that AB exhibited by individuals with elevated trait anxiety was moderated by AC. Individuals with lower AC exhibited stronger AB for threat in comparison to those with higher AC. Since this initial study, several replications of this effect have been reported across numerous paradigms and anxiety disorders (e.g., Bardeen & Orcutt, 2011; Reinholdt-Dunne, Mogg, & Bradley, 2009; Taylor, Cross, & Amir, 2016). However, despite increasing research linking AB and SAD symptoms, there are several limitations to these studies.

First, many studies on SAD failed to find a correlation between AB and severity of symptoms (e.g., Gotlib et al., 2004; Ononaiye, Turpin, & Reidy, 2007; Taylor et al., 2016). Likewise, although meta-analyses indicated a significant difference on AB between SAD and nonanxious participants, the effect size is small (for a meta-analysis, see Bantin et al., 2016). Moreover, modifying AB had only a very small effect – albeit significant – on reducing SAD symptoms (for a meta-analysis, see Heeren, Mogoaşe, Philippot et al., 2015). Likewise, the anxiolytic benefit resulting from AB reduction may be more complicated than initially thought as recent studies suggest that control procedures lacking a contingency between emotional cues and probes reduced anxiety just as much as AB modification procedures where probes reliably followed nonthreat cues (e.g., Carleton et al., 2015; Heeren, Coussement, & McNally, 2016; McNally, Enock, Tsai, & Tousian, 2013; Yao, Yu, Qian, & Li, 2015). Taken together, these findings seemingly challenge the claim that AB figures prominently in the maintenance of SAD (e.g., Clark & Wells, 1995; Rapee & Heimberg, 1997).

Second, there have been attempts to disentangle subcomponents of AB through the use of variants of the probe discrimination and detection tasks as well as through eye-tracking procedures to determine whether AB in SAD reflects facilitated attentional engagement with social-threat cues (e.g., Grafton & MacLeod, 2016; Klumpp & Amir, 2010) or impaired attentional disengagement from them (e.g., Amir, Elias, Klumpp, & Przeworksi, 2003; Buckner, Maner, & Schmidt, 2010; Schofield, Johnson, Inhoff, & Coles, 2012; Taylor et al., 2016). Some studies suggest that people with SAD, relative to nonanxious participants, exhibit increased attentional engagement with social-threat cues and impaired disengagement with them (for a meta-analysis, see Bantin et al., 2016). Yet it remains unclear how these biases interact with AC and with symptoms such as fear and avoidance. Moreover, researchers have usually tested only simple, unidirectional relationships among these variables. This is unfortunate as many of these may have reciprocal influences among them in SAD. For instance, facilitated attentional engagement with social-threat cues may influence fear of social situations, and fear of these situations may motivate avoidance that exacerbates fear. Hence, feedback loops among symptoms may foster maintenance of the disorder.

Third, prominent models of attentional systems postulate that AC is a multifaceted construct (e.g., Petersen & Posner, 2012; Posner & Rothbart, 2007), including at least three components: alerting (maintenance of alertness), orienting (selective engagement and disengagement with certain stimuli rather than others), and an executive component (top-down control of attention exemplified by maintenance of attention on certain stimuli and resisting distraction by other stimuli). However, most studies in the field of AB research have treated AC as a unitary construct. This is unfortunate as SAD is associated, in some studies, with the orienting component (e.g., Heeren, Maurage, & Philippot, 2015; Moriya & Tanno, 2009a, 2009b) whereas, in others, with the executive one (e.g., Judah, Grant, Mills, & Lechner, 2013; Sutterby & Bedwell, 2012). To date, no study has explored the relations between AB and all three components of attention in SAD.

To clarify the dynamics among AB components, the three components of AC, and the core symptoms of SAD, such as fear and avoidance of social situations and reactivity to social-evaluative challenge, we applied network analytic methods pioneered in the psychopathology field by Borsboom and his colleagues (e.g., Borsboom & Cramer, 2013; Cramer, Waldorp, van der Maas, & Borsboom, 2010) and increasingly used by others (e.g., Costantini et al., 2015; Hoorelbeke, Marchetti, De Schryver, & Koster, 2016; McNally et al., 2015; Robinaugh, Leblanc, Vuletich, & McNally, 2014). According to this approach, mental disorders are complex dynamic systems of interacting elements or "symptoms" in traditional psychiatric parlance (Borsboom & Cramer, 2013; Cramer et al., 2010). Based on graph theory (i.e., the branch of mathematics concerned with the study of networks), a network consists of nodes and edges that connect them. Such a network approach can be used to describe many kinds of phenomena, including social relations, biological structures, and information networks (Barabási, 2012).

Although several psychological studies have already explored the associations among the aforementioned processes of interest, network approaches can be employed to disentangle complex dynamic systems of such mutually interacting psychological processes (e.g., Hoorelbeke et al., 2016; Robinaugh et al., 2014). Particularly, as compared to mere correlational approaches, computational tools from graph theory can be used to examine the extent to which nodes are central to the network, based the amount and direction of (potentially) causal influence that flows from one node to other ones (Borgatti, 2005; Costantini et al., 2015). Moreover, aside from the local connectivity among nodes, one additional relevant feature of graph theory is the notion of modularity-based community detection, defined as the identification of subsets of nodes where there is a higher density of edges within these communities ("clusters") than between them (Boccaletti, Latora, Moreno, Chavez, & Hwang, 2006; Fortunato, 2010). Such communities can function as relatively independent modules of a network, playing distinctive roles just as organ systems do in the human body (Fortunato, 2010). Community detection algorithms can uncover major sub-networks that correspond to specialized functional modules (Boccaletti et al., 2006; Fortunato, 2010).

In the present study, we computed weighted and directed networks to investigate the dynamic interplay among laboratory measures of AB, attentional components, emotional reactivity to social-evaluative challenge, and core symptoms of SAD (i.e., fear and avoidance of social situations). Of primary interest was the elucidation of local connectivity between variables, and especially their centrality and the predictive relations among them. Aside from local connectivity, we also examined global connectivity by using modularity-based community detection methods. In this way, we tested whether these variables cohere as a single causal system of mutually interacting elements or constitute distinct functionally specialized communities of interacting elements.

Table 1
Demographic and clinical measures for individuals with social anxiety disorder.

	Mean (*SD*)
Demographic measures	
Age	25.90 (9.17)
Educational level (in years)	16.26 (2.62)
Clinical measures	
BDI-II	13.49 (7.81)
STAI-T	45.90 (8.73)
LSAS	75.20 (13.74)

Note: Education level was assessed according to the numbers of years of education completed after starting primary school. BDI-II = Beck Depression Inventory; STAIT-T = Spielberger State-Trait Anxiety Inventory-Trait; LSAS = Liebowitz Social Anxiety Scale.

2. Method

2.1. Participants

The sample consisted of 61 individuals (49 females) with a primary DSM-IV-TR diagnosis of SAD (American Psychiatric Association, 2000) who participated in a cognitive bias modification training study (Heeren, Mogoaşe, McNally, Schmitz, & Philippot, 2015). To be eligible, individuals had to meet (a) DSM-IV-TR diagnosis criteria for SAD, (b) have no current substance abuse or dependence, (c) no current heart, respiratory, neurological problems, or use of psychotropic medications, (d) no current psychological or psychiatric treatment, and (e) normal or corrected-to-normal vision. Regarding the diagnostic criteria for SAD, participants were first screened via the self-report version of the Liebowitz Social Anxiety Scale (LSAS; Liebowitz, 1987). To be eligible, participants had to score above 56 on the LSAS (i.e., the cut-off score for probable diagnosis of SAD in the French version of the scale; Bouvard & Cottraux, 2010). Participants were then assessed by a clinical psychologist who used the screening version of the Mini-International Neuropsychiatric Interview (MINI; Sheehan et al., 1998) at the Université Catholique de Louvain (UCL, Belgium). They also completed the Spielberger Trait Anxiety Inventory (STAI-T; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) and the Beck Depression Inventory (BDI-II; Beck, Steer, & Brown, 1996). The STAI-T is a 20-item self-report questionnaire assessing anxiety proneness. The BDI-II is a 21-item self-report measure of symptoms of depression. We used the validated French versions of these scales (MINI, Lecrubier, Weiller, Bonora, Amorin, & Lépine, 1998; LSAS, Heeren, Maurage et al., 2012; BDI-II, Beck et al., 1996; STAI-T, Bruchon-Schweitzer & Paulhan, 1993). Each participant was tested individually in a quiet room and all sessions occurred in the same laboratory. Participants received financial compensation (15 Euros) for their participation in the training study. This study was approved by the Ethical Committee of the Université Catholique de Louvain (UCL, Belgium) and conducted according to the Declaration of Helsinki. Participants' characteristics appear in Table 1.

2.2. Materials and measures

2.2.1. Measures of SAD severity

The LSAS is a 24-item scale that measures fear and avoidance experienced in a range of social and performance situations over the last two weeks prior to completion (e.g., returning goods to a store, talking with people you do not know very well, working while being observed). Participants rate each of the 24 social situations on a 4-point Likert-type scale, once for the intensity of fear (0, *None*; 1, *Mild*; 2 *Moderate*; 3 *Severe*) and once for frequency of avoidance of the situation (0, *Never*; 1, *Occasionally*; 2 *Often*; 3 *Usually*). Fear and avoidance ratings, as well as the global scale score, possess good psychometric properties, and the French adaptation of the scale has demonstrated good structural, convergent, and discriminant validity (Heeren, Maurage et al., 2012). The internal reliability of LSAS was high in the present sample, with a Cronbach's alpha of 0.90 for the global scale score (0.89 for the fear scale score and 0.91 for the avoidance scale score). Accordingly, because of our interest in distinguishing the relative importance of fear and avoidance symptoms, we computed separate scores for fear and avoidance ratings.

2.2.2. Measure of AB

2.2.2.1. Stimuli. To assess AB, we used eight French social threat words (stupid, humiliation, embarrassed, shame, mockery, foolish, idiot, rejection) and eight neutral words (book, radiator, spoon, tree, computer, procession, piano, towel), matched on frequency of usage in French (New, Pallier, Ferrand, & Matos, 2001) and similar to those in previous research (e.g., Heeren, Peschard, & Philippot, 2012). The threat and neutral words did not differ in length, $t(14) = 0.44$, $p > 0.66$, $d = 0.23$. We used words, rather than faces, to be consistent with previous studies using this paradigm in SAD (e.g., Amir et al., 2003; Amir, Weber, Beard, Bomyea, & Taylor, 2008).

2.2.2.2. Procedure. Participants completed a modified version of the spatial cueing task (e.g., Amir et al., 2008; Julian, Beard, Schmidt, Powers, & Smits, 2012). Words appeared in lowercase white letters (5–8 mm in height) against a black background in the center of the screen. On each trial, the word appeared in a rectangle to the left or right of the central fixation cross, thereby directing attention to the left or right. After 600 ms, the cue word disappeared, and an asterisk (the probe) appeared in one of the two locations.

The probe remained on the screen until the participant responded, and the computer recorded this response latency for each trial. The inter-trial interval, from target offset to the next fixation cross, was 1650 ms. On some trials, the cue word was valid (i.e., the probe appeared in the same location as the cue word), whereas on others the cue word was invalid (i.e., the probe appeared in the location opposite to the cue word).

Participants were exposed to 192 experimental trials, two thirds of which were validly cued ($128 = 8$ words $\times$ 2 word types $\times$ 2 word positions $\times$ 4 repetitions), one sixth were invalidly cued ($32 = 8$ words $\times$ 2 word types $\times$ 2 word positions), and one sixth were uncued ($32 = 8$ words $\times$ 2 word types $\times$ 2 word positions; e.g., Stormark, Nordby, & Hugdahl, 1995). Trials were presented in a different random order for each participant. The task was programmed and presented via E-Prime 2 Professional® (Psychology Software Tools, Pittsburgh, PA, USA).

2.2.3. Attentional network task (ANT)

The ANT was administered to determine the efficiency of three independent attentional networks: alerting, orienting, and executive control (Fan, McCandliss, Sommer, Raz, & Posner, 2002). Participants had to determine as quickly and as accurately as possible the direction of a central arrow (the target) located in the middle of a horizontal line projected either at the top or at the bottom of the screen. They responded by pressing the corresponding button (left or right) on the keyboard. Each target was preceded by either no cue, a center cue (an asterisk replacing the fixation cross), a double cue (two asterisks, one appearing above and one below the fixation cross), or a spatial cue (an asterisk appearing above or below the fixation cross and indicating the location of the upcoming target). Moreover, flankers appeared horizontally on each side of the target. There were three possible flanker types: either two arrows pointing in the same direction as the target (congruent condition), two arrows pointing in the opposite direction of the target (incongruent condition), or two dashes (neutral condition). Each trial had the following structure: (1) a central fixation cross (random duration between 400 and 1600 ms); (2) a cue (100 ms); (3) a central fixation cross (400 ms); (4) a target and its flankers, appearing above or below the fixation cross (the target remained on the screen until the participant responded or for 1700 ms if no response occurred); (5) a central fixation cross [lasting for 3500 ms minus the sum of the first fixation period's duration and the reaction time (RT)]. RT (in ms) and accuracy (percentage of correct responses) were recorded for each trial.

The ANT task comprised 288 trials, divided in three blocks of 96 trials each (with a short break between blocks). There were 48 possible trials, based on the combination of four cues (no cue, center cue, double cue, spatial cue), three flankers (congruent, incongruent, neutral), two directions of the target arrow (left, right) and two localizations (upper or lower part of the screen). Trials were presented in a random order and each possible trial was presented twice within a block. The task was programmed and presented via E-Prime 2 Professional® (Psychology Software Tools, Pittsburgh, PA, USA).

2.2.4. Impromptu speech challenge

We administered a speech task to assess anticipatory speech-anxiety and behavioral measures of reactivity to social-evaluative challenge. Each participant began the task sitting in a chair in front of a computer screen. A set of instructions then appeared on the screen and informed participants that they would have to make a 2-min speech concerning controversial topics widely discussed in the Belgian media, and that their performance would be video recorded. They were given 2 min to prepare and a sheet of paper to write down their notes; however, they were told that they would not be allowed to use these notes during the speech. After participants had prepared their speech, they were asked to stand in front of a video camera. Just before the speech, the experimenter asked participants to rate, using *Subjective Units of Discomfort Scale* (SUDS; Wolpe, 1958), their level of anticipatory anxiety from 0 (*not anxious*) to 100 (*extremely anxious*). The participant then delivered the speech while being video recorded. Two clinical psychologists, blind to the hypothesis of the study, used the *Behavioural Assessment of Speech Anxiety* (BASA; Mulac & Sherman, 1974) method to rate the speech of the participant. The BASA includes 18 molecular categories (e.g., having a clear voice, searching for the words), and the mean score of these categories has excellent concurrent validity with experts' ratings of speech anxiety (Mulac & Sherman, 1974). Interrater reliability of the total score was high (intraclass correlation coefficient = 0.74). Accordingly, we averaged the scores of the two raters. The same two raters assessed all the speeches.

2.3. General procedure

For the analyses reported here, we used the data from the baseline assessment of the cognitive bias modification training study (see Heeren, Mogoaşe, McNally et al., 2015 for the full protocol). Participants first completed demographic and screening questionnaires. We then administered the modified spatial cueing task, which provided an index of AB, the ANT, and the speech task. Debriefing and reimbursement occurred at the end of the training study.

3. Preparation of the data and data analytic plan

3.1. Data reduction

3.1.1. Spatial cueing task

Following Ratcliff's (1993) recommendations, we addressed outliers and errors in the RT tasks of each participant as follows. First, trials with incorrect responses were excluded (0.77% of trials). Second, RTs lower than 200 ms or greater than 2000 ms were removed from analyses (0.27% of trials). Third, RTs of more than 1.96 *SD* below or above each participant's mean for each experimental condition were excluded as outliers (0.80% of trials). Faster probe detection on validly cued trials when the cue is threatening compared to neutral suggests facilitated attention to threatening cues. Alternatively, slower probe detection during invalidly cued trials when the cue is threatening compared to neutral suggests difficulty disengaging from threatening cues. Consequently, following previous work (e.g., Cisler, Bacon, & Williams, 2009), facilitated attentional engagement with threat is computed by subtracting the mean latency of validly cued trials when the cue is threatening from those when the cue is neutral. In contrast, difficulty disengaging from threat is computed by subtracting the mean latency of invalidly cued trials when the cue is threatening from those where the cue is neutral. Positive scores indicate facilitated attentional engagement with and difficulty disengaging from threat, respectively.

3.1.2. ANT

We excluded data from trials with incorrect responses (0.80% of trials), RTs lower than 200 ms or greater than 2000 ms (0.41%), and RTs exceeding 1.96 *SD* below or above each participant's mean for each experimental condition (0.26%). Following Fan et al. (2002), we computed the *alerting* effect by subtracting the mean (i.e., RT or accuracy score) for double cue trials from the mean for no cue trials (No cue – Double cue); the *orienting* effect by subtracting the mean for spatial cue trials from the mean result for center cue trials (Center cue – Spatial cue); and the *executive conflict* effect by subtracting the mean for congruent trials (summed across cue types) from the mean for incongruent trials (Incongruent – Congruent). For both alerting and orienting effects, greater subtraction scores for RT (and lower for accuracy) indicate greater efficiency. In contrast, greater subtraction scores for RT (and lower for accuracy) on executive conflict indicated increased difficulty with executive control of attention (Fan et al., 2002).

3.1.3. Normality and outlier assessment

Before performing the analyses, we examined the distribution of the nine dependent variables. Kolmogorov-Smirnov tests revealed that normality was achieved for each variable (all $ps > 0.05$). Moreover, none of the individual observations related to these variables was more than 1.96 *SD* below or above the mean for these variables.

3.2. Data analytic plan

3.2.1. Network visualization

We used the R package *qgraph* (Epskamp, Cramer, Waldorp, Schmittmann, & Borsboom, 2012) to compute networks. Each network was displayed in accordance to Fruchterman and Reingold's (1991) algorithm, which positions nodes with stronger connections near the center of the network, and those with weaker connections near the periphery of the network. We first computed an association network in which edges represents the zero-order correlations between pairs of variables (nodes; Borsboom & Cramer, 2013). Green lines represent positive correlations, whereas red lines represent negative correlations. The thicker an edge, the larger is the correlation between two nodes. Association networks whose edges depict zero-order correlations between pairs of nodes provide an initial approximation of the structure of a network and display patterns in the data that might otherwise be difficult to detect. However, they are suboptimal as the association between two variables may be spurious rather than direct (e.g., Borsboom & Cramer, 2013). For instance, spurious associations may arise as the consequences of their shared connections to a third variable, rather than representing a direct influence between the two variables (e.g., Maurage, Heeren, & Pesenti, 2013). Accordingly, we also computed a concentration network (Cox & Wermuth, 1993), where edges depict the partial correlations between each pair of nodes after we controlled statistically for all other variables in the network. However, although both association and concentration networks are weighted, neither is directed. Consequently, they are limited in their ability to illuminate the causal dynamics of the network.

To index predictive directionality and to move us closer to elucidating the causal dynamics of the network, we computed a relative importance network (McNally et al., 2015; Robinaugh et al., 2014). Relative importance denotes the proportionate contribution that each predictor makes to R^2, considering both its direct effect (i.e., its correlation with the criterion) and its effect when combined with the other model variables in the regression equation (Grömping, 2006; Johnson & LeBreton, 2004). The relative importance metric ranges from 0 and 1, and quantifies the amount of explained variance attributable to each predictor after one controls for multicollinearity (Johnson & LeBreton, 2004). Using the R package *relaimpo* (Grömping, 2006), we computed the *lmg* relative importance metric. The resultant relative importance network is both weighted and directed with arrows signifying the direction of prediction, not causality.

3.2.2. Centrality analysis

To quantify the importance of each node in the relative importance network, we computed centrality indices (Costantini et al., 2015; Freeman, 1978/1979). The *betweenness* centrality of a node equals the number of times that it lies on the shortest path length between any two other nodes. *Closeness* centrality indicates the average distance of a node from all other nodes in the network, computed as the inverse of the weighted sum of shortest path lengths of a given node from all the other nodes in the network. Node *strength* is the sum of the weights of the edges attached to that node. Because the relative importance network is a weighted directed network, in-strength can be separated from out-strength. *In-strength* equals the sum of the directed edge weights incident on a node that originates from other nodes in the network. It quantifies the extent to which a certain node is influenced by the other nodes of the network. In contrast, *out-strength* equals the sum of the directed edge weights emanating from a specific node and connecting to other nodes. It quantifies the extent to which a certain node influences other nodes in the network. Each index was calculated with the R package *qgraph* (Epskamp et al., 2012). For each index, higher values reflect greater centrality in the network. We created centrality plots that depict these values.

3.2.3. Community detection

To examine whether the nodes cohere as a single causal system of mutually interacting elements, we implemented modularity-based community detection algorithms (for a review, see Fortunato, 2010). Among the most often implemented algorithms suitable for relatively small graphs is the spin glass algorithm (Reichardt & Bornholdt, 2006). This algorithm tests for communities – clusters of nodes – in the network whereby the number and weighted strength of edges within a cluster exceed the number and weighted strength of edges between nodes in another cluster. To implement the algorithm, we used the *spinglass.community* function ($\gamma = 0.5$, start temperature = 1, stop temperature = 0.01, cooling factor = 0.99, spins = 9) of the R package *igraph* (Csárdi & Nepusz, 2006). We applied this algorithm over the relative importance network.

4. Results

4.1. Network visualization

The association network depicts the zero-order correlations between pairs of nodes (Fig. 1). Several features are immediately apparent. Fear of social situations and avoidance of social situations are strongly correlated ($r = 0.47$), and both of these nodes are strongly linked to difficulty disengaging attention from threat cues. Anticipatory speech-anxiety is linked to selectively engaging with threat cues. Finally, orienting is linked to fear of social situations, behavioral manifestations of anxiety while speaking, and difficulty disengaging from threat cues.

The concentration network depicts partial correlations between pairs of nodes (Fig. 2). By controlling for the influence of all other nodes, this analysis removes spurious associations from the graph, leaving only direct associations between pairs of nodes. The concentration network takes us one step closer to elucidating causal connections between nodes. Important links between pairs of nodes detected in the association network remained in the concentration network, thereby confirming that their association is not spurious. For example, strong edges remained between fear and avoidance; fear and orienting; alerting and behavioral expression of anxiety while speaking; preferential engagement with threat and difficulty disengaging from threat; SUDS and behavioral manifestation of anxiety while speaking; and SUDS and preferential engagement with threat.

The relative importance network is directed as well as weighted, depicting the relative importance of a node as predictive of another one, controlling for the influence of all other nodes (Fig. 3). The orienting aspect of attention was strongly predictive ($lmg = 0.73$) of fear of social situations which, in turn, was predictive of avoidance of these situations ($lmg = 0.62$). Avoidance was strongly predictive of the alerting aspect of attention ($lmg = 0.35$), preferential engagement with threat cues ($lmg = 0.44$) and difficulty disengaging fr om them ($lmg = 0.40$). Difficulty disengaging from threat was strongly predictive of anticipatory speech-anxiety ($lmg = 0.36$).

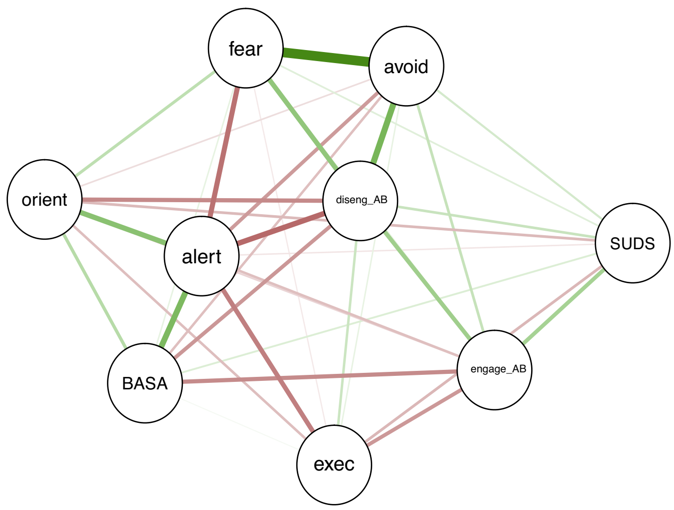

Fig. 1. Association network.
Note: Each node represents a variable of interest, and each edge represents the zero-order correlation between two variables. The thickness of an edge reflects the magnitude of the association (the thickest edge representing a value of 0.47). Green lines represent positive correlations, whereas red lines represent negative correlations.
alert = Alert score of the Attention Network Task; avoid = Avoidance ratings of the Liebowitz Social Anxiety Scale; BASA = Behavioural Assessment of Speech Anxiety; diseng_AB = difficulty disengaging attention from social threat; engag_AB = preferential attentional engagement with social threat; exec = Executive score of the Attention Network Task; fear = Fear ratings of the Liebowitz Social Anxiety Scale; orient = Orienting score of the Attention Network Task; SUDS = Subjective Units of Discomfort Scale. The color version of this figure is available in the online version.

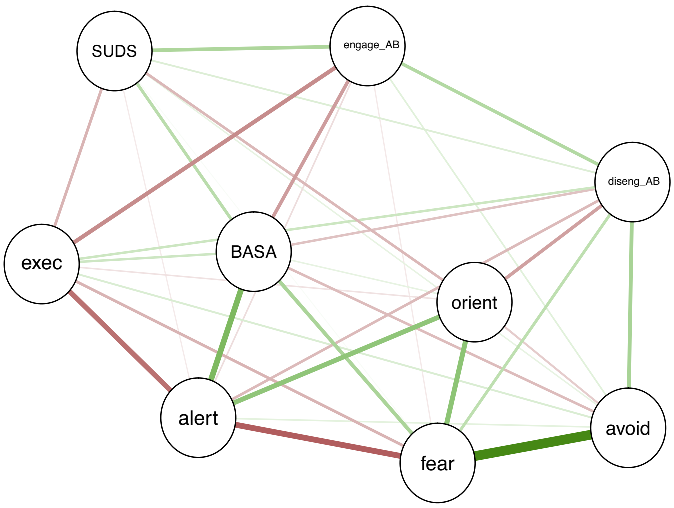

Fig. 2. Concentration network.
Note: Each node represents a variable of interest, and each edge represents the partial correlation between two variables after controlling for all other variables in the network. The thickness of an edge reflects the magnitude of the association (the thickest edge representing a value of 0.45). Green lines represent positive correlations, whereas red lines represent negative correlations.
alert = Alert score of the Attention Network Task; avoid = Avoidance ratings of the Liebowitz Social Anxiety Scale; BASA = Behavioural Assessment of Speech Anxiety; diseng_AB = difficulty disengaging attention from social threat; engage_AB = preferential attentional engagement with social threat; exec = Executive score of the Attention Network Task; fear = Fear ratings of the Liebowitz Social Anxiety Scale; Orient = Orienting score of the Attention Network Task; SUDS = Subjective Units of Discomfort Scale. The color version of this figure is available in the online version.

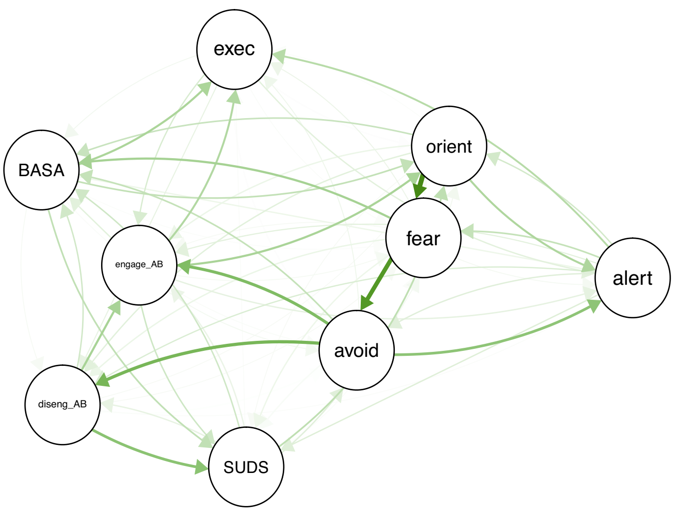

Fig. 3. Relative importance network.
Note: Each edge represents the relative importance of a variable as predictor of another variables, and thickness signifies its magnitude (the thickest edge representing a value of 0.73). Arrows indicate the direction of prediction.
alert = Alert score of the Attention Network Task; avoid = Avoidance ratings of the Liebowitz Social Anxiety Scale; BASA = Behavioural Assessment of Speech Anxiety; diseng_AB = difficulty disengaging attention from social threat; engage_AB = preferential attentional engagement with social threat; exec = Executive score of the Attention Network Task; fear = Fear ratings of the Liebowitz Social Anxiety Scale; Orient = Orienting score of the Attention Network Task; SUDS = Subjective Units of Discomfort Scale. The color version of this figure is available in the online version.

4.2. Centrality analysis

Centrality analysis of the relative importance network confirmed the aforementioned observations (Fig. 4). Preferential attentional engagement with threat, the orienting component of attention, and both avoidance and fear of social situations showed the highest levels of betweenness and closeness centrality. Furthermore, preferential attentional engagement with threat, fear of social situations, and behavioral anxiety during speech yielded the higher in-strength values, indicating that these nodes are those the most influenced by all the other nodes of the network. In contrast, both fear and avoidance of social situations as well as the orienting component of attention showed the highest out-strength values, implying that these nodes are those exerting the strongest predictive influence within the entire network.

4.3. Modularity-based community detection

The spin glass algorithm detected four functionally distinct communities of nodes in the relative importance network. One community comprised avoidance of social situations, the alerting component of attention, behavioral manifestations of anxiety while speaking, and both preferential engagement with and difficulty disengaging from social threat. A second community comprised the orienting component of attention and fear of social situations. Finally, both SUDS and the executive component of attention formed their own distinct community.

5. Discussion

This is the first study to apply network analysis to investigate the complex structure among laboratory measures of AB, the three components of general attention, anticipatory speech-anxiety, behavioral reactivity to social-evaluative challenge, and core symptoms of SAD (i.e., fear and avoidance of social situations). First, we computed association and concentration networks to estimate the topological structure among the variables. Then, we computed weighted and directed networks to take us one step closer to the causal dynamic interplay among these variables. Of primary interest was the local connectivity between variables, and especially their centrality and predictive relations among them. Finally, we also examined global connectivity by using modularity-based community detection methods.

Both the association and concentration networks revealed that the nodes denoting the orienting component of attention and the avoidance of social situation act as highly central hubs within the entire network. By unveiling the directionality and the predictive values of these connections, the relative importance network indicated that people with elevated ability to orient attention vis-à-vis non-emotional material (i.e., the ability to voluntary select information from sensory input by engaging or disengaging attention to one stimulus among others) may be prone to experience fear of social situations, which, in turn, may promote the avoidance of these situations. Further, a general state of alertness as well as both preferential attentional engagement with and difficulty disengaging from social threat might arise from avoidance of social situations.

Nodes centrality analyses identified the orienting aspect of attention as well as both fear and avoidance of social situations as nodes exerting the strongest influence as predictors within the entire network. Surprisingly, neither preferential attention engagement nor disengagement from threat exhibited high relative importance as predictors of other nodes. Yet preferential engagement with threat exhibited high relative importance as a predicted variable. Additionally, these highly central nodes settled into two functionally distinct communities of nodes, one including attentional orienting and fear of social situations, the others featuring avoidance of social situations with general alertness, preferential engagement with and difficulty disengaging from threat, as well

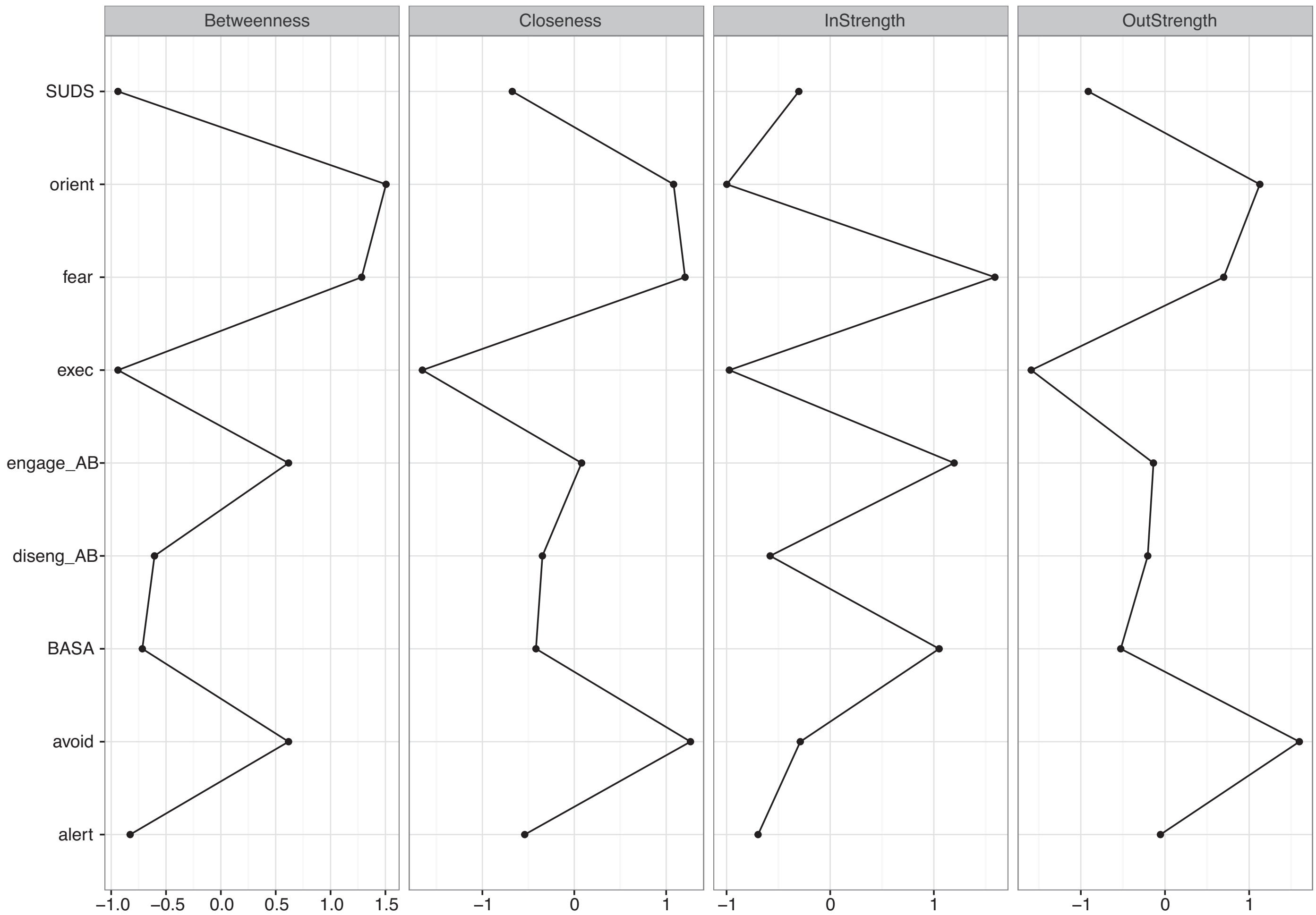

Fig. 4. Centrality plots for the relative importance network depicting the betweenness, closeness, in-strength, and out-strength of each node.
Note: Betweenness centrality of a node equals the number of times that it lies on the shortest path length between any two other nodes. *Closeness* centrality indicates the average distance of a node from all other nodes in the network, computed as the inverse of the weighted sum of shortest path lengths of a given node from all the other nodes in the network. *In-strength* equals the sum of the directed edge weights incident on a node that originate from other nodes in the network. *Out-strength* equals the sum of the directed edge weights emanating from a specific node and connecting to other nodes. It quantifies the extent to which a certain node influences other nodes in the network. For each index, higher values reflect greater centrality in the network.
alert = Alert score of the Attention Network Task; avoid = Avoidance ratings of the Liebowitz Social Anxiety Scale; BASA = Behavioural Assessment of Speech Anxiety; diseng_AB = difficulty disengaging attention from social threat; engage_AB = preferential attentional engagement with social threat; exec = Executive score of the Attention Network Task; fear = Fear ratings of the Liebowitz Social Anxiety Scale; Orient = Orienting score of the Attention Network Task; SUDS = Subjective Units of Discomfort Scale.

as behavioral manifestations of anxiety during speech gravitating around.

Remarkably, fear and avoidance have been considered as core mechanisms of the maintenance of anxiety disorders since the early days of experimental psychopathology (e.g., Mowrer, 1960). Drawing on this work, several prominent theorists of SAD emphasize that avoidance of feared social situations thwarts opportunities for inhibitory learning by blocking access to information that is incompatible with fear-related expectations, in turn preventing the disconfirmation of threat-related beliefs and the reduction of anxiety (Aderka, McLean, Huppert, Davidson, & Foa, 2013; Clark, 2005; Hofmann, 2004, 2007; Moscovitch, 2009). In this way, avoidance of social situations and use of safety behaviors in social situations from which the person cannot overtly avoid, may directly exacerbate a general state of alertness and reinforce threat-related beliefs, in turn, maintaining fear of social situations (Aderka et al., 2013; Kim, 2005; McManus, Sacadura, & Clark, 2008; Morgan & Raffle, 1999; Taylor & Alden, 2010). In line with this view, it is not surprising that avoidance exhibits the highest level of influence over the entire network in the present study. Furthermore, although we did not assess threat-related beliefs, our observation that avoidance predicts general alertness, which, in turn, intensifies fear of social situations by means of a feedback loop, is clearly in line with these models of SAD.

Interestingly, the central prominence and influence of the orienting ability of attention also illuminates an unexpected variable vis-à-vis the dynamics of SAD. Yet, on the other hand, developmental psychologists have argued that individual differences in the orienting aspect of attention might interact with a child's initial temperamental bias toward behavioral inhibition – a disposition predictive of subsequent SAD (e.g., Reeb-Sutherland et al., 2009; Schwartz, Snidman, & Kagan, 1999). Typically, behaviorally inhibited children are slow-to-warm-up, shy, and reticent in novel or unfamiliar situations, especially social ones (Coplan, Girardi, Findlay, & Frohlick, 2007; Kagan, Reznick, & Snidman, 1988; Kagan & Snidman, 2004). The precursors to this behavioral profile are evident in elevated levels of attentional orienting response to novel sensory stimuli in the first months of life (Fox, Henderson, Rubin, Calkins, & Schmidt, 2001; Kagan et al., 1988; Marshall, Reeb, & Fox, 2009). Likewise, differences in the orienting aspect of attention are associated with social anxiety among adults (Heeren, Maurage et al., 2015; Moriya & Tanno, 2009a, 2009b). Such differences in the orienting response may negatively bias a child's attention to novel social stimuli such that they respond as if the cues are threatening, prompting behavioral withdrawal (Fox, Hane, & Pine, 2007; Kagan et al., 1988). This withdrawal limits the interactions with the environment and further predisposes the child to detect and attend to threat, leading to the development of SAD (Fox et al., 2007; Schwartz et al., 1999). Indeed, the relative importance network suggests that individuals with higher levels of orienting are prone to experience such fear and withdraw from social-evaluative situations, but not vice versa. Beyond the scope of SAD, this set of findings also lends some support to mounting evidence for fear of the unknown as an important core transdiagnostic process involved in both the development and the maintenance of psychopathology (for a review, see Carleton, 2016). Yet, our findings cannot directly speak to the etiology of SAD per se. Rather, they should be considered in terms of predictability within a dynamic system of mutually interacting variables that maintain SAD.

From a theoretical point of view, because neither preferential engagement with and difficulty disengaging from social threat act as strong predictors in the entire network, our results seemingly challenge the claim that AB figures prominently in the maintenance of SAD by promoting avoidance and worsening fear of social situations (Heimberg et al., 2010; Wong & Rapee, 2016). Preferential engagement with threat, but not difficulty disengaging from threat, exhibited a high relative importance as a predicted variable. Likewise, a close inspection of the modularity-based communities also reveals that preferential attentional engagement with threat may act as a bridge between the two functionally important communities of nodes, perhaps participating in a self-reinforcing feedback loop via the impoverishment of the orienting aspect of attention. This finding is in line with the observation that individuals with SAD are best characterized by preferential attentional engagement with threat rather than impaired disengagement from threat (e.g., Grafton & MacLeod, 2016). Yet, difficulty disengaging from threat was strongly predictive of anticipatory speech-anxiety and facilitated attentional engagement with threat. These findings suggest that both preferential engagement with and difficulty disengaging from threat are encapsulated within the network and may play functionally distinct roles in the maintenance of SAD.

Our findings may have several therapeutic implications. By turning off a central node that has many outgoing weighted edges, clinicians may foster beneficial cascade of downstream benefits, deactivating other nodes as its effects propagate throughout the entire network (McNally et al., 2015). Because avoidance of social situations is the node exerting the strongest influence, our findings point to it as a key target whose deactivation should produce such therapeutic effects. Moreover, fear of social situations also appears as a key target. That should not come as a surprise; there are indeed plenty of studies supporting the notion that the successful treatment of SAD involves the identification of idiosyncratic overt and subtle avoidance behaviors and encouragement of the individual to drop these strategies prior to engaging in exposure to reduce fear of social situations (Kim, 2005; Morgan & Raffle, 1999). Aside from avoidance, the present findings also reveal orienting of attention as a promising target of intervention whose alteration may also produce beneficial propagation throughout the network by relieving fear of social situations. Programs have already been developed to improve attention vis-à-vis non-emotional material in SAD (e.g., Wells, White, & Carter, 1997). Moreover, programs directly promoting the orienting component of attention have already been proposed for other disorders (e.g., Cerasa et al., 2013). Likewise, mindfulness training improves one's ability to orient attention (Jha, Krompinger, & Baime, 2007). In addition, as targeting nodes having high centrality may be more likely to propagate through the network when re-activated after treatment, the network approach may help to identify new harbingers of relapse. In this way, both fear and avoidance of social situations as well as the orienting function of attention may constitute prodromal signals of relapse deserving careful audit during follow-up sessions. Similarly, future studies should also explore how intervention affects central nodes and how it may foster therapeutically beneficial downstream effects throughout the network.

In follow-up research, several issues require further examination. First, an important limitation is the cross-sectional nature of the data. Although the computational techniques implemented here provide an indication of the directions of these associations, this does not allow drawing strong inference vis-à-vis their cause-effect relationships.

Second, our data were collected at one point in time. As such, one cannot exclude that the network dynamics remains stable over time. Likewise, the network trajectory over time may vary across individuals. This point is especially important given that there is mounting evidence that emotional measurements such as those used in the present study (e.g., emotional reactivity to an impromptu speech challenge, AB for threat) are guided by both situational (state anxiety, environmental factors, threat-value of the situation) and stable (e.g., trait anxiety, allelic variations) responses to the current situation (e.g., Allen & Potkay, 1981; Heeren, Philippot, & Koster, 2015; Srivastava et al., 2009). To best capture the within-person temporal dynamics of individual networks, one would need to apply graphical vector autoregressive modeling approaches on intensive time-series data from individual participants (e.g., Wichers, Groot, Psychosystems, & EWS Group, 2016; Wild et al., 2010). Moreover, as noted by Borsboom and Cramer (2013), techniques from the study of sudden transitions in ecosystems (e.g., Hirota, Holmgren, Van Nes, & Scheffer, 2011) may also help identify when a person is on the brink of tipping into a disordered state or returning to a mentally healthy one.

Third, we examined whether our sample exhibited an AB for threat, as indexed by scores significantly greater than 0, signifying the absence of facilitated attentional engagement with and difficulty disengaging from threat, respectively. However, neither the former, $t(60) = 0.90$, $p = 0.37$, nor the latter, $t(60) = 0.65$, $p = 0.52$, significantly differed from 0. Yet, because most of the previous studies reporting the presence of AB among individuals with SAD relied on group comparison (e.g., Bantin et al., 2016), it remains difficult to interpret these data without a nonanxious comparison group.

Fourth, we used a spatial cueing task to index preferential engagement with and difficulty in disengaging from threat. Yet, although we instructed participants to fixate their attention to a predetermined spatial location during presentation of stimuli, we could not ensure that participants did so. Moreover, this task may produce a suboptimal assessment of the attentional processes it claims to assess (e.g., Clarke, MacLeod, & Guastella, 2013). Recently developed experimental paradigms enabling verification of participants' initial attentional allocation and subsequent attentional shift may accomplish this aim (e.g., Clarke et al., 2013; Grafton & MacLeod, 2016).

Fifth, like most extant procedures for assessing AB (e.g., Waechter, Nelson, Wright, Hyatt, & Oakman, 2014), the spatial cueing tasks exhibit poor psychometric properties (e.g., Enock, Hofmann, & McNally, 2014; Waechter & Stolz, 2015). Likewise, MacLeod et al. (2010) have raised similar concerns vis-à-vis the ANT. On the other hand, McNally et al. (2013) reported satisfactory Spearman-Brown corrected split-half reliabilities for the executive conflict index ($r_s = 0.76–0.80$). In future studies, it would thus be useful to replicate our procedure by using different measurement tools. Finally, uncertainty still abounds regarding the optimal way to determine the *minimum* sample size requested for network computation. As such, one cannot exclude the possibility that some edges would have been thicker with a larger sample size. Next steps would thus be to apply computer-intensive simulation methods for exploring empirical performances of the network stability under different constraints, such as the sample size, the number of nodes, or the experimental design.

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