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Abstract

Objective: In recent years, the network analysis (NA) methodology has been applied to identify the central features of the psychopathology of anorexia nervosa (AN) and specific connections to previously recognized vulnerabilities. However, an NA investigating both multidimensional perfectionism and interoceptive sensibility in connection to eating symptomatology is currently missing.

Method: A total of 260 individuals (139 patients with AN, 121 healthy control individuals) completed the Frost Multidimensional Perfectionism Scale, the Multidimensional Assessment of Interoceptive Awareness, and the Eating Disorders Inventory-2. Using state-of-the-art techniques, we estimated a main network with data from all participants and then compared the two separated networks. We checked the variables for empirical overlap through goldbricker, combined as suggested, and implemented the empirical measure of the bridge nodes.

Results: Ineffectiveness and need for control over self and body (resulting from combining Asceticism and Drive for Thinness) were the most central nodes, whereas perfectionistic evaluative concerns (resulting from combining Doubts about Actions and Concern over Mistakes) and mistrust in body sensations were the bridge nodes. No significant differences between the patient and control networks emerged.

Conclusions: Perfectionistic evaluative concerns and mistrust in body sensations could be key components in the relationships among perfectionism, interoceptive sensibility, and eating symptomatology.

Keywords: eating disorders, interoceptive awareness, ineffectiveness, drive for thinness, eating psychopathology

Highlights

- Perfectionism and interoceptive alterations are highly relevant features of Anorexia Nervosa (AN)
- Network Analysis allows to identify central symptoms as well as elements bridging different psychological constructs
- Ineffectiveness and need for control over self and body were the most central nodes. Perfectionistic evaluative concerns and mistrust in body sensations were the bridge nodes and could represent relevant intervention points in AN

1. Introduction

Network analyses (NAs) have recently been applied to investigate the connections between the core features of anorexia nervosa (AN) and vulnerability factors (Levinson, Vanzhula, et al., 2018). NA is a statistical tool to investigate the cooccurrence of symptoms or affective states, rooted in the network theory of mental disorders, which conceives syndromes as emerging from symptom interactions (Robinaugh et al., 2020). NAs on eating disorders (EDs) have reported shape and weight overvaluation (DuBois et al., 2017; Forrest et al., 2019; Wang et al., 2018), fear of weight gain (Christian et al., 2019; Forrest et al., 2018; Levinson et al., 2017; Vanzhula et al., 2019), ineffectiveness, and interoceptive awareness (Cascino et al., 2019; Monteleone et al., 2019; Olatunji et al., 2018; Solmi et al., 2018) as having the highest centrality (i.e., supposedly more relevant for psychopathology; Robinaugh et al., 2020). Networks comprising not only symptoms but also personality traits have been advocated for (Fried & Cramer, 2017) and studied (e.g., Levinson, Brosof, et al., 2018; Monteleone et al., 2019; Vervaet et al., 2020).

Traditionally, the need for control and difficulties in recognizing bodily sensations have conceptualized AN pathogenesis (Bruch, 1962) with increasing support found for this view over the past decades (Kaye et al., 2009). Empirical research (including NAs) has confirmed the relevance of *perfectionism* (Dahlenburg et al., 2019; Fairburn et al., 2003; Gárriz et al., 2020), a personality trait expressing "the tendency to set high standards and employ overly critical self-evaluations" (Frost & Marten, 1990, p. 559), and *altered interoception*, namely, the perception of the internal state of the body (Khalsa et al., 2018) in the vulnerability to AN.

1.1 Perfectionism

The main conceptualizations of perfectionism (Frost et al., 1990; Hewitt & Flett, 1991) recognize it as a construct with several dimensions and a two-factor solution (Limburg et al., 2017). Dimensions pertaining to "maladaptive" evaluative concerns (Frost et al., 1990) show a stronger association with clinical conditions such as depression, anxiety, obsessive–compulsive disorder

(OCD), and EDs (Limburg et al., 2017) than do "adaptive" perfectionistic strivings. However, both are associated with the psychopathology of AN and bulimia nervosa (BN) (Dahlenburg et al., 2019; Limburg et al., 2017), with unclear implications for treatment. Shafran et al. (2002; 2010) have considered only what they define as "clinical" perfectionism as relevant for the maintenance of EDs. In this regard, NA identifying specific and unique connections between constructs could help clarify the relationship between perfectionism dimensions and eating symptomatology.

Currently, three NAs have introduced a multidimensional investigation of perfectionism, using the Frost Multidimensional Perfectionism Scale (FMPS; Frost et al., 1990). In one study with a mixed clinical and nonclinical sample, only seven items of the FMPS were used, with few results on perfectionism and focusing on the comorbidity between social anxiety disorder and EDs (Levinson, Brosof, et al., 2018). A second NA, with a large ED sample utilizing all FMPS subscales, found Personal Standards as highly central among vulnerability and resilience traits in connection to eating symptomatology (Vervaet et al., 2020). The most central node in the entire network was a *maladaptive schemata measure,* referring to "excessive focus on inhibiting emotions and feelings in order to avoid mistakes" (Vervaet et al., 2020, p. 8). More recently, Vanzhula and collaborators (2021) have applied NA to a large mixed sample of students and patients with EDs, introducing the FMPS in a network investigating the comorbidity between OCD and EDs, finding the highest centrality for elements of perfectionism and items from the FMPS subscale Doubts about Actions, as bridging OCD and EDs.

1.2 Interoception

The perception of the internal state of the body (Khalsa et al., 2018), *interoception,* has been increasingly investigated in AN, shifting from interoceptive awareness (Garner et al., 1983) to the distinction between interoceptive accuracy or sensitivity, namely, the correct detection of internal sensations and sensibility, that is, the self-perceived disposition to attend to bodily sensations (Khalsa et al., 2018). In line with earlier data (Fassino et al., 2004), a more recent meta-analysis

found significantly-lower interoceptive sensibility in patients with AN and BN compared with healthy control individuals (HCs) and patients with binge-eating disorder (Jenkinson et al., 2018).

Moreover, recent studies on patients with ED have shown interoceptive awareness and ineffectiveness, as measured by the Eating Disorders Inventory–2 (EDI-2), as the most central subscales (Olatunji et al., 2018; Solmi et al., 2018; Vervaet et al., 2020). In an NA exploring anxiety in BN, body sensations bridged eating symptoms and anxiety and depressive symptoms (Levinson et al., 2017); in another study with mixed clinical patients, interoceptive deficits strongly connected ED symptoms and suicidality (Smith et al., 2020). Similarly, interoceptive awareness has emerged as the node of connection between childhood maltreatment experiences and eating psychopathology in an NA in patients with AN (Monteleone et al., 2019). Only one NA, specifically investigating interoception in patients with EDs, has been recently published and found that mistrust in body sensations is a bridge to eating symptomatology (Brown et al., 2020).

1.3 Present study: the rationale

Taken together, the aforementioned studies have clarified the relevance of both perfectionism and interoception as separate constructs in AN. Notwithstanding, few investigations of the potential connections between such constructs and symptoms of AN exist despite some literature-based considerations. First, it has been proposed that patients' need for control could affect their intolerance of uncertainty (Abbate-Daga et al., 2015), with the latter possibly involved with interoception. Second, recent literature has provided preliminary evidence on the relationship between perfectionism and AN grounded in interoceptive alterations (Duffy et al., 2019). In fact, both starvation ("starvation to avoid actual sensing of visceral sensations"; Paulus et al., 2019, p. 111) and cognitive control (i.e., perfectionism) could provide patients with a brief respite from uncertain or aversive bodily sensations (Boswell et al., 2019; Duffy et al., 2019) thus, contributing to AN pathogenesis (Barca & Pezzulo, 2020). In other words, feeling uncertain about eating-related

interoceptive signals could alter patients' ability to accurately perceive and manage bodily sensations (Boswell et al., 2019; Duffy et al., 2019; Merwin et al., 2010).

Consequently, to avoid such aversive interoceptive stimuli, patients with AN could activate their well-known cognitive strategies (Kaye et al., 2009) to regulate uncertain—thus aversive—interoceptive signals. Therefore, perfectionism, a hallmark of AN (Dahlenburg et al., 2019), could be a "safe" cognitive strategy to shift the focus from internal values to external and more controllable ones (Duffy et al., 2019). Similarly, prompted by earlier studies on marked interoceptive difficulties in perfectionistic patients with AN (Fassino et al., 2004), a path analysis study has found a significant indirect pathway linking high perfectionism to AN cognitions and behaviors through interoceptive dysfunction (Duffy et al., 2019).

1.3 Present study: methodology and aims

Given these premises, we adopted the NA methodology to clarify the relationships among perfectionism, interoceptive sensibility, and eating psychopathology in AN. First, to provide a detailed investigation, we performed a fine-grained multidimensional measurement of both perfectionism and interoceptive awareness, thus, complementing previous results. Second, we guided our investigation using the network theory that conceptualizes syndromes as the product of symptom interactions; NA provides a model for these interactions by estimating them from data. Third, we adhered to the principle by which an adequate network model must contain all relevant constructs but not several elements referred to the same symptom; if the latter is the case, an overlap rather than an association would be reported (Fried & Cramer, 2017). As a result, the evaluation of content overlap before the inclusion of variables in the network represents another expansion of the earlier literature (Vanzhula et al., 2021; Vervaet et al., 2020) provided by our work.
Fourth, in keeping with previous explorative studies (Levinson, Brosof, et al., 2018; Levinson & Williams, 2020; Olatunji et al., 2019; Vanzhula et al., 2021), we included HCs in our analysis because, although reporting lower scores on clinical measures, their data still can be informative.

Finally, while modeling this network, we were mostly interested in the nodes serving as bridges among three communities: a) multidimensional perfectionism, b) interoceptive sensibility, and c) the eating psychopathology of AN.

Therefore, the overarching aim of this exploratory study was to investigate the interactions among perfectionism, interoceptive sensibility, and eating psychopathology in AN. Our goals were to ascertain the most central nodes and clarify the bridge nodes. We expected to find ineffectiveness as central to the network, in keeping with previous studies with EDI, with concern over mistakes as having a higher bridge value than have other perfectionism nodes and mistrust in body sensations reporting the highest bridge centrality.

2. Method

2.1 Participants

We consecutively recruited 146 patients seeking treatment at [affiliation], and 140 HCs. Patients were both hospitalized and partially-hospitalized inpatients with AN, whereas HCs comprised university students, medical residents and individuals from the general population all coming from the same catchment area as the patients.

In order to maximise the representativeness of the sample, the following inclusion criteria were adopted for patients: a) age between 16 and 55 years; (b) formal diagnosis of AN according to DSM-5 criteria as assessed by an experienced psychiatrist per clinical interview (First et al., 2016); c) being fully or partially hospitalized at [affiliation]. Moreover, for HCs, inclusion criteria were: a) age between 16 and 55 years; b) absence of a lifetime diagnosis of ED; c) being not on medications. Similarly, in order to avoid bias, exclusion criteria for both patients and HCs were: a) psychotic-spectrum disorders, bipolar disorders, or substance-use dependence, b) organic illnesses (e.g., epilepsy or diabetes), c) failing to provide a valid written informed consent or returning incomplete assessments.

Out of the 146 candidates, three patients refused study participation, and four returned incomplete assessments; similarly, 19 HCs returned incomplete questionnaires. Therefore, the final sample was 260 individuals: 139 inpatients and partially hospitalized patients with AN (99 AN restricting, 40 AN binge−purging subtype) and 121 HCs. Three patients were in partial remission at the time of the assessment (Body Mass Index; BMI > 19, still fulfilling the other AN criteria) and showing clinical-level scores at psychometric questionnaires so they were retained in the study sample.

2.2 Procedure

For patients, an experienced psychiatrist assessed patients' diagnosis and study eligibility upon admission using the Structured Clinical Interview from the *DSM−5* (First et al., 2016).

Subsequently, height and weight were measured, and BMI was calculated. Patients were then administered the questionnaires which were completed within the first week of the treatment.

HCs were recruited from the community via flyers and word of mouth. Once they accepted to participate in the study, they also underwent an assessment with a psychiatrist (or a psychiatric trainee at [affiliation]) who conducted a clinical interview aimed at assessing the fulfilment of the aforementioned inclusion and exclusion criteria. Individual's height and weight were measured to calculate BMI and then participants were administered the questionnaires. HCs were enrolled on a voluntary basis and did not receive monetary compensation for their participation since this practice is not allowed in our country; rather, they received the researchers' feedback on the scoring of their assessments.

This study was approved by the local Ethical Committee, and all participants (or parents in case of patient's age < 18 years old) provided written informed consent.

2.3 Measures

All participants completed the following measures; We reversed the scores for the Multidimensional Assessment of Interoceptive Awareness (MAIA) (as also done by Brown et al., 2020) to be congruent with the EDI-2 and the FMPS so that, in all subscales, higher scores signified higher symptomatology.

The FMPS, Italian version (Lombardo, 2008) which evaluates perfectionism with sound psychometric properties, comprises 35 items organized into 6 subscales: Concern over Mistakes, Personal Standards, Parental Expectations, Parental Criticism, Doubts about Actions, and Organization. Personal Standards and Organization capture adaptive (as opposed to maladaptive) perfectionism. Items are rated on a 5-point Likert scale. Cronbach's alpha in our sample was .76.

The MAIA, Italian version (Calì et al., 2015) which evaluates interoceptive sensibility with robust psychometric properties, comprises 32 items rated with a 5-point Likert scale and 8

dimensions: Noticing, Not Worrying, Not Distracting, Attention Regulation, Emotional Awareness, Self-Regulation, Body Listening, and Trusting. Its psychometric properties have been evaluated in nonclinical and ED samples (Brown et al., 2017). In the reliability analysis of the study sample, the Not Distracting subscale was negatively correlated with the total test score, as was previously reported (Mehling et al., 2018) so we excluded it. In our sample, the Cronbach's alpha after subscale removal was .77.

The EDI-2, Italian version (Rizzardi M. et al., 1995) which evaluates eating psychopathology and has been widely used in Italian samples with sound psychometric properties, comprises 91 items and 11 subscales: Drive for Thinness (DT), Bulimia (BU), Body Dissatisfaction (BD), Ineffectiveness (IN), Perfectionism, Interpersonal Distrust, Interoceptive Awareness, Maturity Fears, Asceticism (Asc), Impulse Regulation (IR), and Social Insecurity (SI). Cronbach's alpha in our sample was .93.

We used the subscales from these three measures as nodes in the network in this study, comparable to that done in previous research with a similar methodology (Olatunji et al., 2018; Solmi et al., 2018).

2.4 Data analysis

We conducted analyses using R version 4.0.2 in R-Studio 1.3.959. See the supporting information for the code used.

Although general recommendations on sample size have been proposed (Epskamp et al., 2018), no power analysis is available for NAs; therefore, network stability is fundamental (Epskamp et al., 2018). Indeed, the more parameters that are estimated in the NA, the higher the number of participants is required. After node selection (explained below), we introduced 18 nodes (5 perfectionism, 6 interoceptive sensibility, 7 eating psychopathology).

As done in previous research (Levinson, Brosof, et al., 2018; Olatunji et al., 2019), we estimated a main network, using data from all participants. We then calculated separated networks

for patients and HCs and compared them via state-of-the-art techniques to check for structural or connectivity differences.

2.4.1 Data preparation

Preliminary steps

We examined data mean and standard deviation (SD), skewness, and kurtosis. Because the Shapiro–Wilk test revealed nonnormal distribution in many of the variables, we used nonparanormal transformation through the R-package *huge* version 1.3.4.1 as advised (Epskamp et al., 2018). We used the *t* test, $\chi 2$ test and Fisher's exact test to compare the groups.

Nodes selection

Selection of the variables for NA is critical because the inclusion of multiple nodes assessing the same construct can result in inflated centrality (Levinson, Vanzhula, et al., 2018). Current methodology suggests the use of theory and data-driven variable selection, with a preliminary inspection of data by experienced clinicians and the subsequent use of an algorithm to detect topological overlap, which can be done through the goldbricker function contained in the package *networktools* (P. Jones, 2018). In this study, we removed the EDI-2 subscales Perfectionism and Interoceptive Awareness as unidimensional measures of the constructs assessed by FMPS and MAIA.

We then searched the complete database for further redundancies with goldbricker (*networktools* version 1.2.3), which was run by setting the threshold to .20 ($p = .01$). We examined the suggested reductions and, if deemed clinically appropriate, automatically combined these through principal component analysis using the net_reduce function. We opted for this method because it allows for correct network representation, even though it could limit the interpretability of the combined nodes.

Goldbricker returned nine "bad pairs" (see the supporting information). The net_reduce

function produced four combinations considered appropriate by the authors. Here we provide a list of the combined nodes and briefly describe the commonalities that justified their combination from a clinical perspective (only combined node 2. and 3. are further discussed; in parenthesis is indicated how they are referred to in the discussion section).

1. MAIA Emotional Awareness & Noticing (awareness of body sensations and of physiological manifestations of emotions): both dimensions point to the awareness of the connections between body sensations and emotions;
2. FMPS Doubts about Actions & Concern over Mistakes (perfectionistic evaluative concerns): these two dimensions are long recognized to be the main components of maladaptive perfectionism;
3. EDI-2 Asceticism & Drive for Thinness (need for control over self and body): both dimensions points to the self-imposed limitations on physiological needs in order to achieve valued goals;
4. EDI-2 Impulse Regulation & Social Distrust (lack of control over self and over social relationships): these two dimensions refers to untrustworthiness in both personal and relational context.

2.4.2 Network analysis

Network stability

We used R-package *bootnet* version 1.4.3 to estimate network stability (Epskamp et al., 2018). We performed a person-dropping bootstrap to calculate the correlation stability coefficient (CS coefficient) for strength and expected influence (EI), bridge strength, bridge EI, and edges. These indices express the maximum drop proportions to retain a correlation of .7 in at least 95% of the sample and are considered acceptable if above .25 and good from .5 (Epskamp et al., 2018). We performed the nonparametric bootstrap for the difference tests for centrality measures, bridge measures, and network edges.

Network estimation, centrality, and predictability

We estimated the regularized partial correlation networks for the entire sample. In these undirected, weighted networks, an edge between two nodes represents a conditional (i.e., given all other nodes) dependence relationship, whereas an absent edge signifies conditional independence. The strength of the correlation is visualized by the thickness of the edge. We utilized *qgraph* version 1.6.5 (Epskamp et al., 2012), which uses graphical LASSO (least absolute shrinkage and selection operator regularization) in combination with the extended Bayesian information criteria model selection, to visualize the networks. We used the Fruchterman–Reingold algorithm for node positioning to allow for easy visualization.

We utilized centralityPlot and centralityTable functions to inspect centrality measures. We calculated *strength* (the sum of the absolute values of a node connection) and *EI* (similar to strength but considering the positive or negative value of an edge), as other centrality indices have emerged to be less reliable in psychological networks (Bringmann et al., 2019). We chose to report both measures only if they provided meaningfully different information. Because differential node variability could potentially drive node centrality (Epskamp et al., 2018), we checked for correlations between centrality measures and node SD. We used the R-package *mgm* version 1.2-10 to estimate the predictability, a measure indicating how well a node is explained by all other nodes in the network (by computing each node's R^2; Haslbeck & Waldorp, 2018).

Bridge nodes

Elements that connect different predefined clusters ("communities," e.g., symptoms of two separate disorders) in psychopathological networks are called *bridge nodes*, and according to the network theory, they can represent key intervention points to prevent the "spread" from one disorder to the other (P. J. Jones et al., 2019). We used the bridge function of the package *networktools* to calculate *bridge strength* (a node's total connectivity with nodes in other

communities in the network) and *bridge EI* (like bridge strength, but summing positive and negative values; P. J. Jones et al., 2019).

Separated networks estimation and comparison

We used the fused graphical LASSO method to estimate separated networks for patients and HCs. We utilized the R-package *EstimateGroupNetwork* version 0.2.2 (Costantini et al., 2019) to estimate both networks simultaneously and the R-package *NetworkComparisonTest* version 2.2.1 (van Borkulo et al., 2017) to compare the two networks' structure and connectivity.

3. Results

3.1 Participants' characteristics

As shown in Table 1, patients with AN were more frequently single, lived more frequently with the family of origin, had less frequently completed university studies, and were more frequently unemployed than HCs. No gender differences emerged between the patients with AN and the HCs. The percentage of male individuals was consistent with other cited ED NA studies (Brown et al., 2020; Forrest et al., 2019; Vanzhula et al., 2021) and with data on male prevalence in EDs (Sweeting et al., 2015).

Patients had significantly higher scores than did the HCs in all EDI-2 subscales, in all FMPS subscales except for Parental Expectations and Organization, and in the MAIA subscales Attention Regulation, Self-Regulation, Body Listening, and Trusting.

3.2 Network structure

Table 2 shows all the nodes included in the network, with their corresponding abbreviations. The network had good stability (CS coefficient for strength, EI, and edges were all .67). Correlation between EI and strength was high (.94, $p < .001$); hence, only EI is shown (see Table 2 and the supporting information for strength). Correlation between nodes SD and EI was nonsignificant (.35, $p = .15$). Mean predictability was .53. Predictability was highest for IN (.78), as reported in the network plot (Figure 1).

Figure 2 shows the bootstrapped EI differences. The node with the highest EI was IN (1.2), followed by Asc&DT (1.18). These were significantly higher than 77% (Asc&DT) and 65% (IN) of the other nodes. Doubts&Concern (1.12) was significantly higher than 59% of the other nodes; IR&SD (1.08) and SI (1.07) were significantly higher than 53% of the other nodes.

See the supporting information for edge weight matrix and edge difference test. The strongest connections in the network were between Parent_Expect and Parent_Critic (part $r = .49$) and between Standards and Doubts&Concern (part $r = .38$). The strongest connections to

central nodes were SI (part r = .3) for IN and BD (part r = .32) for Asc&DT.

3.3 Bridge nodes

The CS coefficients for both bridge strength and bridge EI were .67, and the correlation between the two was high (.82, $p < .001$). We reported only bridge EI (Table 2). Bootstrapped bridge EI differences are shown in Figure 3. The nodes with the highest bridge EI were Doubts&Concern (.53) and Trust (.52), which were significantly higher, respectively, than 88% and 82% of the other nodes. Asc&DT (.33) was significantly higher than 53% of the other nodes.

Regarding bridge pathways, Doubts&Concern was most strongly connected to Asc&DT (part r =.2), Self_Regul (part r =.11), SI (part r =.08), Not_Worry (part r =.08), IN (part r =.07), IR&SD (part r =.01), Emot&Notice (part r= - .03). Trust was most strongly connected to IN (part r =.18), Asc&DT (part r =.1), BD (part r =.1), SI (part r =.08), Parent_Critic (part r =.07). Asc&DT, beside the connections reported above, was connected to Standards (part r =.04), Organized (part r= .02), Emot&Notice (part r= - .03). Bridge pathways are depicted in Supporting information.

3.4 Jointly-estimated patient and HC networks and NCT

Patients' network was at acceptable levels of stability (CS coefficient .36), whereas that of HCs' was below the threshold (CS coefficient .21). Network invariance test (p = .36) and global strength invariance test (p = .23) were nonsignificant; therefore, no evidence of network differences between the two groups emerged from this analysis. Networks plots and bootstrapped difference tests of the networks estimated for the patient and HC groups are reported in the supporting information.

4. Discussion

We performed an NA to investigate the interactions among perfectionism, interoceptive sensibility, and eating psychopathology in AN. The network calculated from patients with AN and the HCs had good stability and could be interpreted. Ineffectiveness and need for control over self and body were the most central nodes (i.e., supposedly representing the most relevant psychopathological symptoms in the network), whereas perfectionistic evaluative concerns and mistrust in body sensations were the bridge nodes (i.e., the "junctures" between groups of symptoms).The most relevant bridge pathways were between perfectionistic evaluative concerns and need for control over self and body, mistrust in body sensations and ineffectiveness, perfectionistic evaluative concerns and self-regulation, mistrust in body sensations and need for control over self and body and body dissatisfaction. These connections could represent potential ways through which the relationships among perfectionism, interoceptive sensibility, and eating symptoms are maintained. The relevance of these connections is underscored by the relatively-high predictability values. These results confirm the relevance of both perfectionism and interoceptive sensibility for AN and begin to illuminate their complex mutual relationships related to eating symptomatology—expanding the NA literature addressing core AN characteristics and symptomatology.

Central nodes

Consistent with our first hypothesis, ineffectiveness resulted the most central node in the entire network, as found in previous NAs using the EDI-2 (Olatunji et al., 2018; Solmi et al., 2018). As previously proposed by other researchers (Monteleone et al., 2019; Olatunji et al., 2018; Solmi et al., 2018), our findings also highlight the importance of considering not only the main diagnostic criteria but also other psychological elements (e.g., the pervading sense of inadequacy) as central for the maintenance of AN. The concept of ineffectiveness encompasses feelings of worthlessness, insecurity, and negative self-evaluation (Garner et al., 1983; Olatunji et al., 2018) and could

represent the emotional and cognitive ground on which ED behaviours and cognitions are built (Fairburn et al., 2013; Zipfel et al., 2014)

For both ineffectiveness and the second most central node (which contained the core eating symptom of drive for thinness), the strongest connections were internal to the ED community; however, they showed significant direct connections to perfectionism and interoceptive sensibility nodes as described in the "Bridge nodes" section below. The strong connections between ineffectiveness and social insecurity and between drive for thinness and body dissatisfaction are known from previous studies (Olatunji et al., 2018; Solmi et al., 2018) and expected from clinical observation.

Somewhat different from previous NA studies using the Eating Disorders Examination–Questionnaire (EDE–Q; Forrest et al., 2019; Wang et al., 2018) reporting shape and weight concerns as central, in our analysis, the node body dissatisfaction did not have high centrality. This could be determined by the EDI structure and its relationships with the construct introduced in the network, as further discussed below.

Bridge nodes

Our second a priori hypothesis was partially confirmed, as perfectionistic evaluative concerns (Concern over Mistakes empirically combined with Doubts about Actions) was the node most connected to the other communities. This result complements two recently-published ED networks on all FMPS subscales reporting high centrality for perfectionistic strivings (i.e., Personal Standards) in a network where the most central node was a measure related to overvigilance to avoid mistakes (Vervaet et al., 2020) and Doubts about Actions as a bridge between perfectionism and OCD (Vanzhula et al., 2021). Through the study of bridge pathways, the present analysis adds to current literature that perfectionistic evaluative concerns showed a direct connection to a node of core eating psychopathology (need for control over self and body) and only through this node to the other eating symptomatology subscales (i.e., Body Dissatisfaction and Bulimia). Personal standards

although strongly related to perfectionistic evaluative concerns, was only weakly linked to need for control over self and body and failed to show other relevant connections. Therefore, fear of making mistakes and doubt about one's own performance seem to link perfectionism to the need for keeping the body under strict control through externally-evaluable parameters (Duffy et al., 2019).

The connection between parental criticism and parental expectations was the strongest in the entire network; however, only the former showed relationships to the other nodes, suggesting that perceived negative judgments from parents seem more directly relevant to psychopathology than did their unrealistically-high expectations.

This is the first NA study that clearly shows the direct relationship between maladaptive perfectionism and core eating psychopathology previously highlighted in research conducted with different methodologies (Bulik et al., 2003). As described above, the added value of this analysis is the possibility to model both the connection that bridges maladaptive perfectionism to eating symptoms and the internal structure of relationships among perfectionism dimensions. Although what happens in an individual may vary, both in comparison to other individuals (i.e., cross-sectionally), and to the same person (i.e., longitudinally; Levinson, Vanzhula, et al., 2018) this study suggests that it is fearing mistakes and doubting oneself that directly "fuels" eating problems. Alternatively, or rather complementary to this, also the inverse relationship may hold true, in that eating concerns may spill over to preoccupations with self-presentation and performance in a broader context. Even though the present analysis does not allow to infer directionality, previous research highlighted perfectionism as a rather ED-specific vulnerability trait which tends to persist after acute illness (Dahlenburg et al., 2019), and predictively influences eating symptoms (Halmi et al., 2012; Wade et al., 2015) giving support to the first hypothesis both in illness development and in its maintenance.

Our third hypothesis, that mistrust in body sensations would have the highest bridge value overall, was partially confirmed, in that, this node did have the highest bridge value, but was not significantly different from perfectionistic evaluative concerns. In respect to the study by Brown et

al. (2020) investigating interoceptive sensibility and eating symptomatology with EDE–Q, this study adds the bridge pathway between this node and ineffectiveness (not contained as a node in the previous study), which is consistent with the strong connection between ineffectiveness and unidimensional Interoceptive Awareness in another recent NA (Vervaet et al., 2020). Feeling unsafe in one's own body seems, therefore, tightly linked to the belief of being ineffective in the world; this relationship could lead to one feeling unsafe in one's social context (social insecurity) and to eating symptomatology. Alternatively, these insecurities could add to the belief of a general lack of control over one's own life. Interestingly, the link between interoception and social connection has been explored in experimental studies (see Arnold et al., 2019, for a review), and flexibility in engaging interoception in social situations (i.e., shifting attention focus between internal sensations and external events) has been proposed as crucial to overcome feelings of social isolation.

The overarching aim of our study was to model the mutual relationships between interoceptive sensibility and perfectionism on eating symptoms. In this regard, a bridge pathway emerged between perfectionistic evaluative concerns and the interoceptive node self-regulation, which can suggest that perfectionistic evaluative concerns could be related to being unable to use body sensations to ease distressing thoughts. The strong connection between perfectionistic evaluative concerns and need for control over self and body suggests that maintaining one's own self-presentation and performance in subjectively-acceptable ranges could be linked, bypassing interoception, thus, making use of external cues and rules (Barca & Pezzulo, 2020). Maladaptive perfectionism, applied to body parameters, could indeed contribute to determine the general attitude through which AN patients integrate their body perceptions. Given the goal of maintaining body parameters in controlled ranges, body sensations, being too vague for the scope, would not represent a reliable source of information to direct one's actions (and more so in moments of distress). On a similar line, restriction in food intake might represent a way to reduce and manage the otherwise confused and unpredictable body sensations (Barca & Pezzulo, 2020). Further studies are needed to clarify the interactions between these two highly relevant features.

Strengths and limitations

This study has several strengths, such as the use of state-of-the-art methodology and sharing code. We selected nodes in the network using an empirically-validated algorithm and controlled for the differential variability as a potential drive to centrality. Our analysis included predictability highlighting the relevance of the reported connections, and the network was stable. To our knowledge, this is the first NA study to include multidimensional assessments of both perfectionism and interoceptive sensibility.

Limitations include that the cross-sectional nature of the analysis does not allow for the inference of the directionality of the associations, and correlations that emerge at a group level may not reflect the individual level. Even though we controlled for potential overlaps in the variables, the measures introduced were not specifically designed for NAs. Furthermore, all variables were self-reported, so the inclusion of objective measures could help enrich the picture. We did not find significant network differences between the patients and HCs; however, it may be possible that some would emerge with a larger sample size. Nonetheless, the inclusion of a population without ED allows to reflect dynamics that might be common to both affected and healthy individuals and contribute to illness maintenance and development.

Finally, the empirical combination of asceticism and drive for thinness did not allow us to infer the relative strength of the direct connection of perfectionistic evaluative concerns and drive for thinness.

Conclusions and clinical implications

This study provided specific links to key features of AN psychopathology (drive for thinness and ineffectiveness) for perfectionistic evaluative concerns and mistrust in body sensations. The clinical implications of NAs are still a matter of debate (Robinaugh et al., 2020). However, we raise the hypothesis that the psychological therapies recommended for AN could intervene on the nodes

that emerge as important in the network. Enhanced Cognitive–Behavior Therapy and therapies designed for perfectionism could act primarily on the cognitions connected to core ED symptomatology (Fairburn et al., 2013), whereas therapies focusing on feelings of inadequacy in social interactions—as psychodynamic treatment (Zipfel et al., 2014) and interpersonal treatment (Miniati et al., 2018)—could work on the key node of ineffectiveness. In addition, a new model on interoceptive exposure (Boswell et al., 2019) that specifically targets interoception deserves further investigation.

Moreover, the connections highlighted in the network are relevant also in the light of the sample comprising both patients with AN and healthy individuals, since perfectionism and interoceptive traits could be distributed continuously in the population and their extreme concurrent alterations could make it difficult to overcome eating and weight problems, even in the absence of a full-fledged diagnosis (Vacca et al., 2020). Even though identifying ED risk factors and the interplay between them is beyond the scope of the present exploratory analysis, this and other studies hint at the co-occurrence of high maladaptive perfectionism and mistrust in body sensations as particularly relevant for the maintenance of AN symptomatology, and potentially for its development (Duffy et al., 2019). It is worthy of further studies the idea that, rather than just screening for abnormal eating behaviors and concerns, investigating for the presence of high concerns for mistakes, self-doubts and mistrust in body sensations could benefit the prevention and early detection of AN in community and clinical settings.

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Table 1. Clinical characteristics of the sample

Variable	**Total sample (n=260) mean (SD)**	**AN (n=139) mean (SD)**	**HC (n=121) mean (SD)**	**T test† or $\chi 2$**	**p**
Age, years	24.15 (5.95)	22.89 (6.98)	25.61 (4.05)	-3.910	< .001
Females, percentage	93.46%	94.96%	91.74%	-	.324‡
BMI	17.48 (3.84)	14.64 (2.23)	20.74 (2.45)	-20.864	< .001
Duration of illness, years	-	5.20 (6.06)	-	-	-
Marital status				14.368	0.002
single	172	111	61		
relationship	46	19	27		
married	12	3	9		
separated or divorced	1	1	0		
missing	29	5	24		
Living arrangement				35.662	< .001
independent	64	18	46		
living with parents	150	108	42		
other	16	9	7		
missing	30	4	26		
Education level				70.840	< .001
primary school	32	26	6		
high school	80	70	10		
university	119	37	82		
missing	29	6	23		

Employment student employed unemployed missing	 144 61 27 28	 81 28 26 4	 63 33 1 24	20.124	< .001
MAIA Noticing §	1.99 (1.07)	1.98 (1.04)	1.99 (1.1)	-.052	.959
MAIA Not Distracting§	2.67 (.92)	2.53 (1.03)	2.82 (.75)	-2.567	.011
MAIA Not Worrying§	2.54 (1.17)	2.75 (1.23)	2.3 (1.06)	3.170	.002
MAIA Attention Regulation§	2.25 (1.05)	2.51 (1.1)	1.94 (.92)	4.599	< .001
MAIA Emotional Awareness §	1.81 (1.04)	1.83 (1.09)	1.79 (1)	.318	.751
MAIA Self-Regulation§	2.94 (1.19)	3.26 (1.19)	2.58 (1.08)	4.764	< .001
MAIA Body Listening§	2.79 (1.26)	3.09 (1.26)	2.45 (1.16)	4.286	< .001
MAIA Trusting §	2.52 (1.56)	3.4 (1.39)	1.51 (1.03)	12.518	< .001
FMPS Concern over Mistakes	26.39 (10.58)	30.53 (9.96)	21.63 (9.2)	7.490	< .001
FMPS Personal Standards	23.02 (7.24)	24.74 (6.92)	21.03 (7.13)	4.242	< .001
FMPS Parental Expectations	10.64 (5.25)	10.46 (5.37)	10.85 (5.12)	-.600	.549

FMPS Parental Criticism	8.47 (3.98)	9.59 (4.14)	7.18 (3.37)	5.166	< .001
FMPS Doubts About Actions	11.43 (4.24)	12.97 (4.11)	9.65 (3.67)	6.882	< .001
FMPS Organization	22.83 (5.2)	23.38 (5.48)	22.2 (4.81)	1.855	.065
EDI-2 Drive For Thinness	8.04 (8.25)	13.19 (7.48)	2.12 (4.06)	15.088	< .001
EDI-2 Bulimia	2.32 (4.21)	3.6 (5.23)	0.85 (1.63)	5.866	< .001
EDI-2 Body Dissatisfaction	11.03 (8.04)	15.04 (7.02)	6.42 (6.55)	10.243	< .001
EDI-2 Ineffectiveness	8.27 (8.31)	12.78 (8.2)	3.09 (4.59)	11.945	< .001
EDI-2 Perfectionism	5.07 (4.22)	5.94 (4.22)	4.08 (4.03)	3.620	< .001
EDI-2 Social Distrust	5.13 (4.9)	7.33 (4.72)	2.61 (3.76)	8.967	< .001
EDI-2 Interoceptive Awareness	7.19 (7.89)	11.75 (7.88)	1.99 (3.44)	13.186	< .001
EDI-2 Maturity Fears	6.61 (5.9)	9 (6.05)	3.87 (4.32)	7.936	< .001
EDI-2 Asceticism	5.78 (4.91)	8.13 (5.01)	3.08 (3.09)	9.914	< .001
EDI-2 Impulse Regulation	4.51 (5.72)	6.56 (6.26)	2.15 (3.86)	6.927	< .001
EDI-2 Social Insecurity	6.75 (5.25)	9.32 (4.66)	3.8 (4.26)	9.964	< .001

†Welch test

‡ Fisher's exact test

§Values reversed (see Method section)

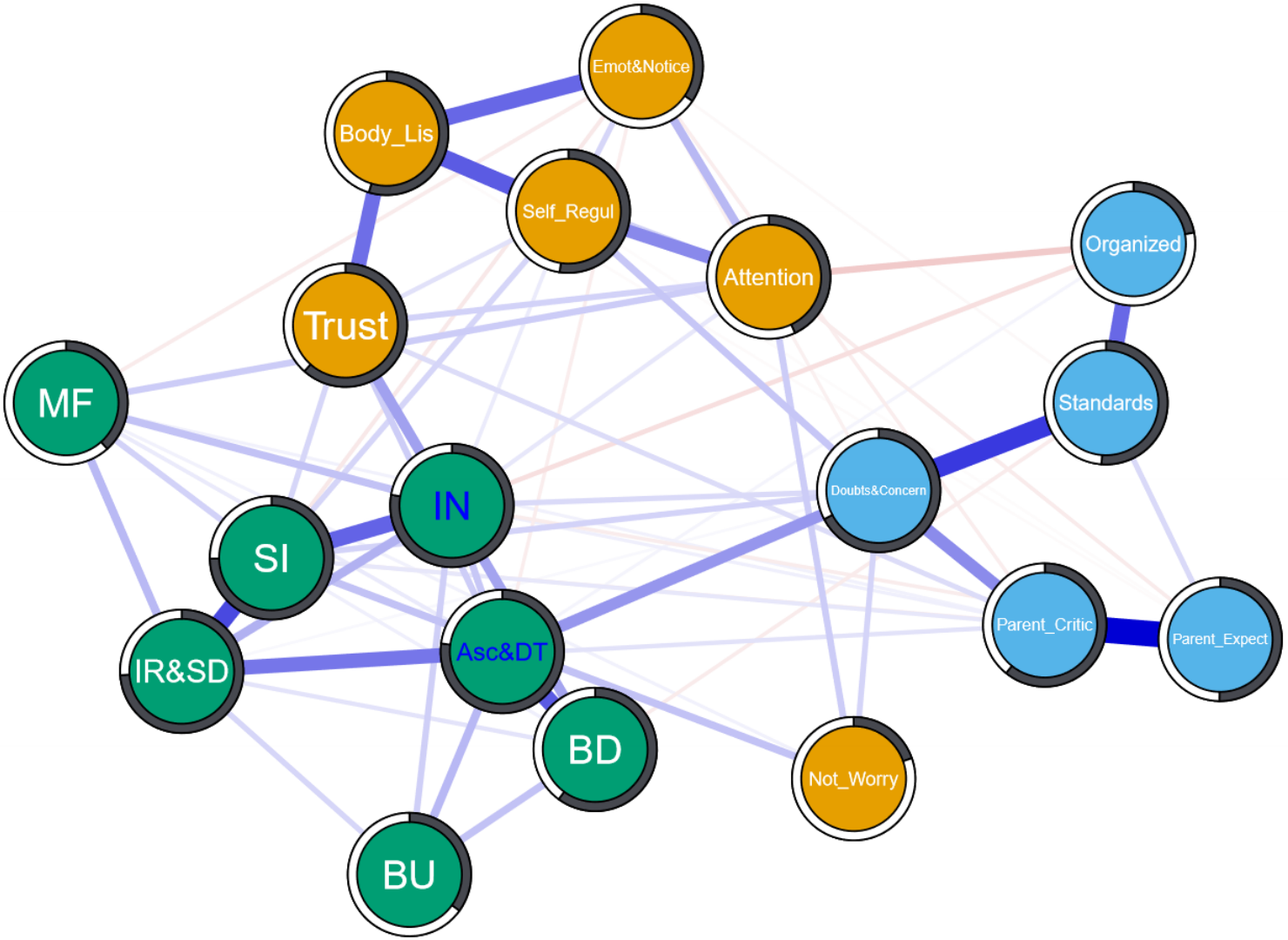
Legend: BMI: Body mass Index; MAIA: Multidimensional Assessment of Interoceptive Awareness; FMPS: Frost Multidimensional Perfectionism Scale; EDI-2: Eating Disorder Inventory-2

Table 2. Expected influence, bridge expected influence, predictability

Node name	Abbreviation	Expected influence	Bridge expected Influence	Predictability
not worrying	Not_Worry	.32	.22	.2
attention regulation	Attention	.64	.01	.44
self -regulation	Self_Regul	.89	.22	.54
body listening	Body_Lis	.97	-.01	.55
mistrust in body sensations	Trust	.94	.52	.62
personal standards	Standards	.73	-.01	.51
parental expectations	Parent_Expect	.44	-.12	.5
parental criticism	Parent_Critic	.9	.19	.61
organization	Organized	.15	-.14	.22
bulimia	BU	.38	-.04	.38
body dissatisfaction	BD	.79	.1	.6
ineffectiveness	IN	1.2	.27	.78
maturity fears	MF	.48	.11	.38

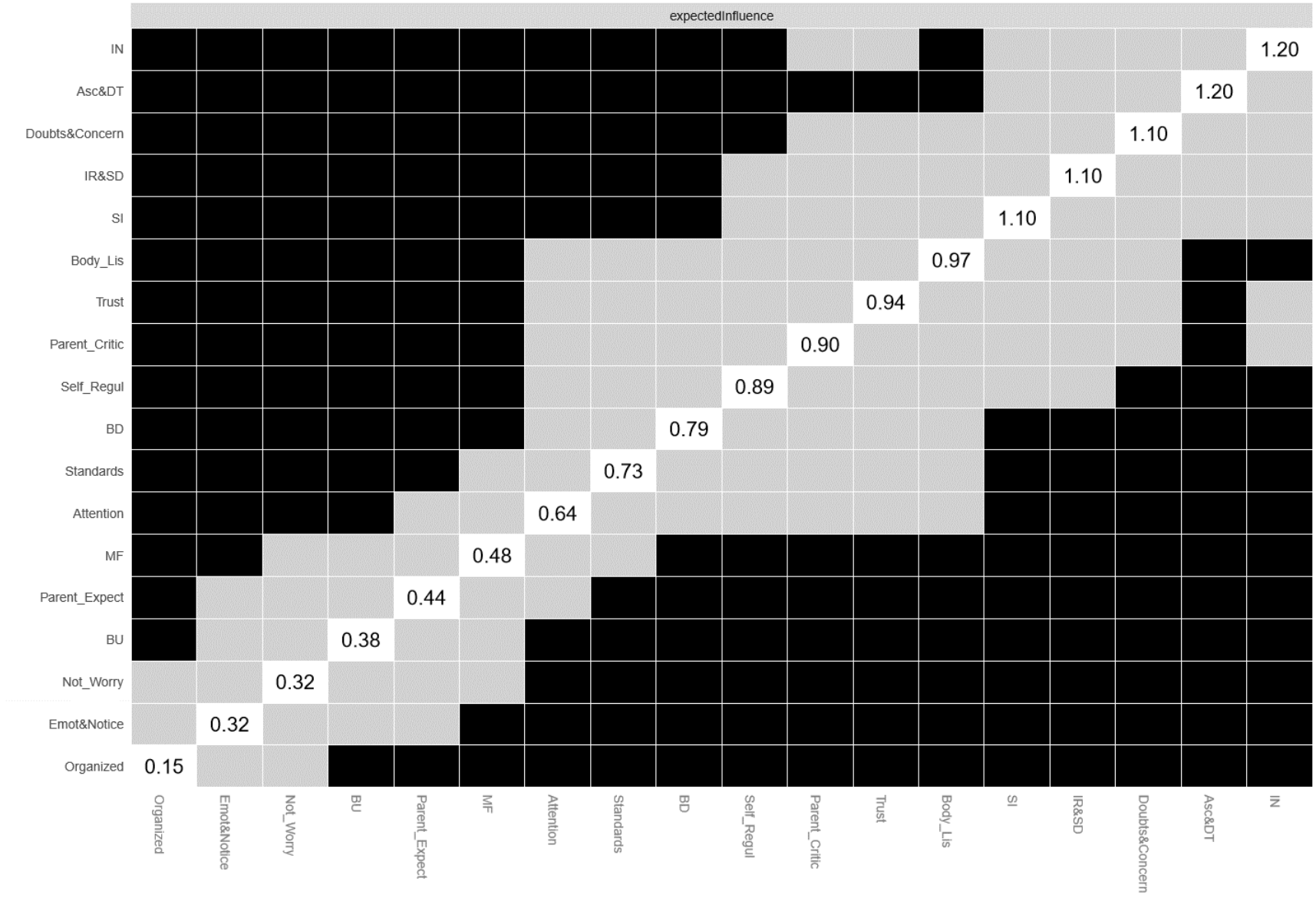
social insecurity	SI	1.07	.32	.75
awareness of body sensations and of physiological manifestations of emotions	Emot&Notice	.32	-.19	.35
need for control over self and body	Asc&DT	1.18	.33	.77
lack of control over self and over social relationships	IR&SD	1.08	.07	.74
perfectionistic evaluative concerns	Doubts&Concern	1.12	.53	.67

Figure 1. Network plot



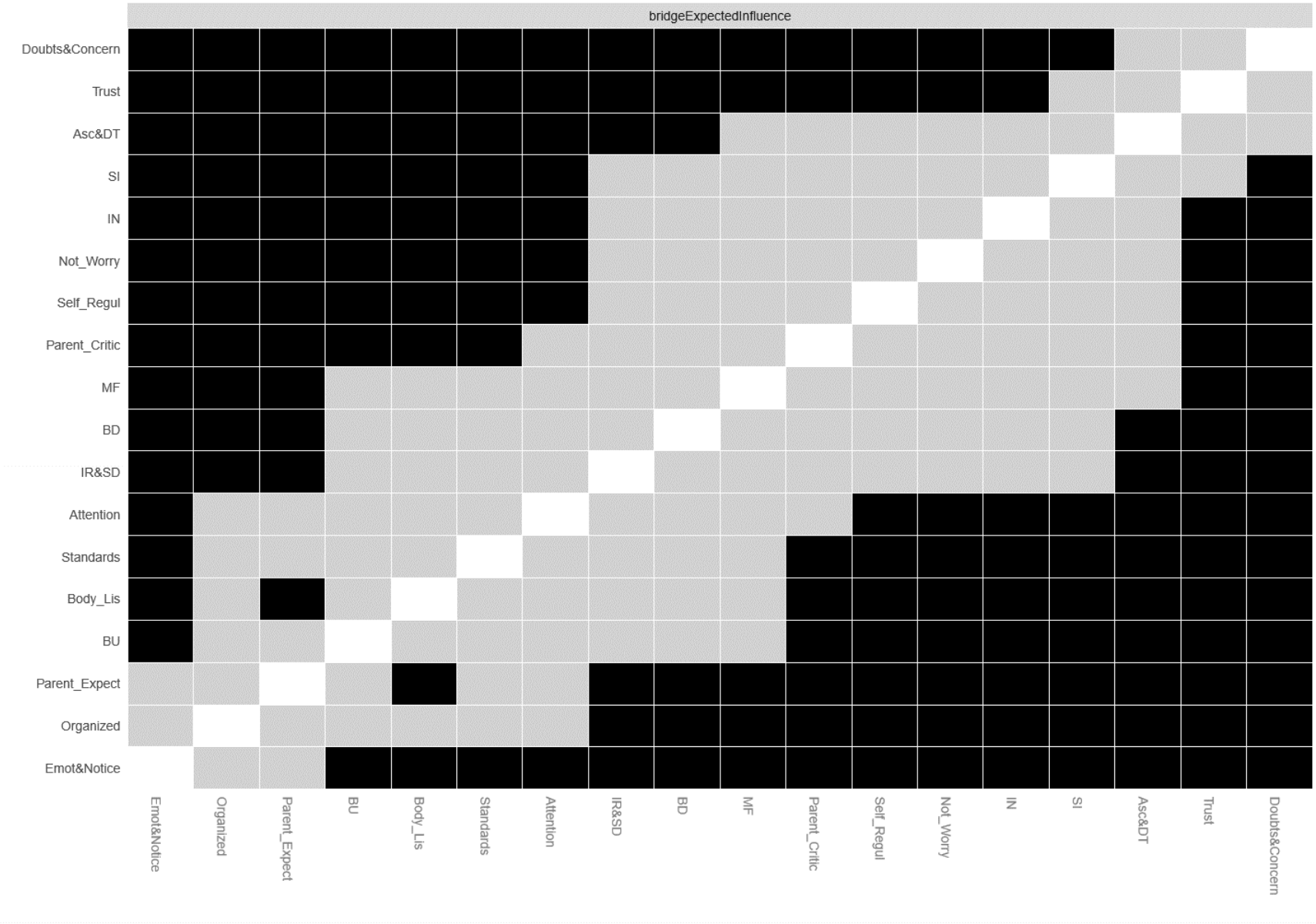
Nodes are represented as circles, color-coded for each community (MAIA: Multidimensional Assessment of Interoceptive Sensibility, FMPS: Frost Multidimensional Perfectionism Scale, EDI-2: Eating Disorders Inventory-2). Blue lines between nodes represent positive association, red lines negative association; thicker lines correspond to stronger associations. Predictability is represented as the shaded area around the circles (higher predictability corresponds to a greater shaded area). Nodes with the highest expected influence values are indicated by the blue label. Not_Worry: Not Worrying; Attention: Attention Regulation; Self_Reg: Self-Regulation; Body_Lis: Body Listening; Trust: Trusting; Standards: Personal Standards; Parent_Expect: Parental Expectations; Parent_Critic: Parental Criticism; Organized: Organization; BU: Bulimia; BD: Body Dissatisfaction; IN: Ineffectiveness; MF: Maturity Fears; SI: Social Insecurity; Emot&Notice: Emotional Awareness & Noticing; Asc&DT: Asceticism & Drive for Thinness; IR&SD: Impulse Regulation & Social Distrust; Doubts&Concern: Concern over Mistakes & Doubts about Actions.

Figure 2. Bootstrapped difference test results for expected influence



Variables are presented in descending order of expected influence values. Black squares represent statistically significant differences. Not_Worry: Not Worrying; Attention: Attention Regulation; Self_Reg: Self-Regulation; Body_Lis: Body Listening; Trust: Trusting; Standards: Personal Standards; Parent_Expect: Parental Expectations; Parent_Critic: Parental Criticism; Organized: Organization; BU: Bulimia; BD: Body Dissatisfaction; IN: Ineffectiveness; MF: Maturity Fears; SI: Social Insecurity; Emot&Notice: Emotional Awareness & Noticing; Asc&DT: Asceticism & Drive for Thinness; IR&SD: Impulse Regulation & Social Distrust; Doubts&Concern: Concern over Mistakes & Doubts about Actions.

Figure 3. Bootstrapped difference test results for bridge expected influence



Variables are presented in descending order of bridge expected influence values. Black squares represent statistically significant differences. Not_Worry: Not Worrying; Attention: Attention Regulation; Self_Reg: Self-Regulation; Body_Lis: Body Listening; Trust: Trusting; Standards: Personal Standards; Parent_Expect: Parental Expectations; Parent_Critic: Parental Criticism; Organized: Organization; BU: Bulimia; BD: Body Dissatisfaction; IN: Ineffectiveness; MF: Maturity Fears; SI: Social Insecurity; Emot&Notice: Emotional Awareness & Noticing; Asc&DT: Asceticism & Drive for Thinness; IR&SD: Impulse Regulation & Social Distrust; Doubts&Concern: Concern over Mistakes & Doubts about Actions.

Supplemental Table 1. Goldbricker results and node combined through PCA

"bad pairs"	**% of different correlations**	**Resulting nodes**	**Description**
MAIA Emotional Awareness & **MAIA Noticing**	.05	combined	awareness of body sensations and of physiological manifestations of emotions
EDI-2 Asceticism & **EDI2 Drive for Thinness**	.05	combined	need for control over self and body
EDI-2 Impulse Regulation & **EDI2 Social Distrust**	.05	combined	lack of control over self and over social relationships
EDI-2 Impulse Regulation & **EDI-2 Asceticism**	.05		
EDI2 Body Dissatisfaction & **EDI2 Drive for Thinness**	.10		
EDI-2 Social Distrust & Body Dissatisfaction	.10		
FMPS Doubts about Actions & **FMPS Concern over Mistakes**	.15	combined	perfectionistic evaluative concerns
EDI-2 Impulse Regulation & **Drive for Thinness**	.15		
EDI-2 Impulse Regulation & Body Dissatisfaction	.15		

Legend: MAIA: Multidimensional Assessment of Interoceptive Sensibility; EDI-2: Eating Disorders Inventory-2; FMPS: Frost Multidimensional Perfectionism Scale. In bold characters variables that were empirically combined.

Table 2. Nodes' mean and SD

Nodes	**Abbreviation**	**Mean (SD) †**
MAIA Not Worrying	Not_Worry	0 (.99)
MAIA Attention Regulation	Attention	0 (1.01)
MAIA Self -Regulation	Self_Regul	-.01 (.99)
MAIA Body Listening	Body_Lis	0 (.99)
MAIA Trusting	Trust	-.01 (.96)
FMPS Personal Standards	Standards	0 (1)
FMPS Parental Expectations	Parent_Expect	.01 (.98)
FMPS Parental Criticism	Parent_Critic	.01 (.98)
FMPS Organization	Organized	-.01 (.98)
EDI-2 Bulimia	BU	.07 (.84)
EDI-2 Body Dissatisfaction	BD	.01 (.98)
EDI-2 Ineffectiveness	IN	.02 (.96)
EDI-2 Maturity Fears	MF	.01 (.98)
EDI-2 Social Insecurity	SI	.01 (.99)
MAIA Emotional Awareness & Noticing	Emot&Notice	0 (1.23)
EDI-2 Asceticism & Drive For Thinness	Asc&DT	0 (1.3)
EDI-2 Impulse Regulation & Social Distrust	IR&SD	0 (1.25)
FMPS Concern Over Mistakes & Doubts About Actions	Doubts&Concern	0 (1.29)

Legend: MAIA: Multidimensional Assessment of Interoceptive Awareness; FMPS: Frost Multidimensional Perfectionism Scale; EDI-2: Eating Disorder Inventory-2.

† Values after nonparanormal transformation

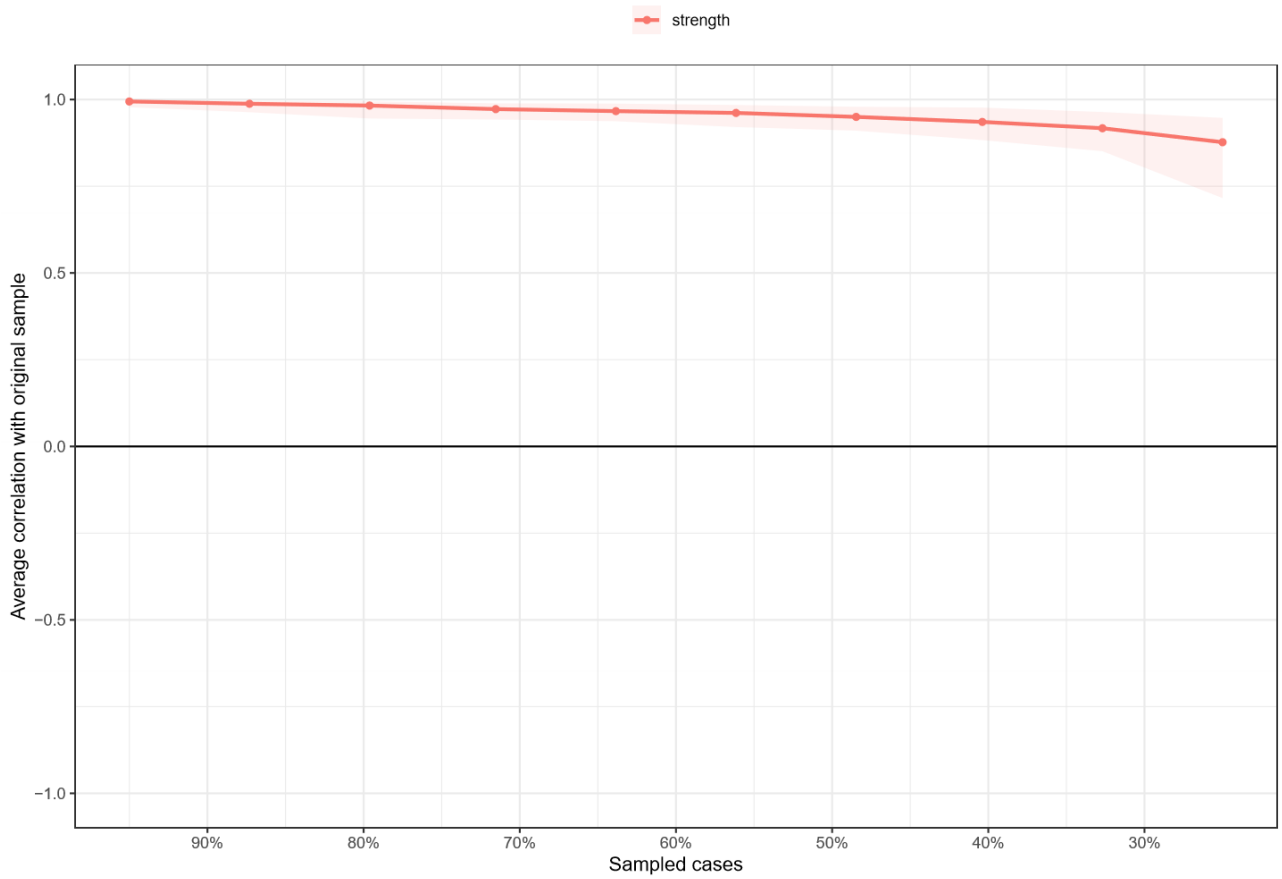
Supplemental Table 2. Weight matrix

BU	Organized	Parent_Criti	Parent_Expe	Standards	Trust	Body_Lis	Self_Regul	Attention	Not_Worry	
0	0	0	0	0	0	0	0	.1	0	**Not_Worry**
0	-.1	0	-.04	0	.08	.09	.22	0	.1	**Attention**
0	0	0	-.01	0	.05	.31	0	.22	0	**Self_Regul**
0	0	0	-.01	0	.28	0	.31	.09	0	**Body_Lis**
0	0	.07	0	0	0	.28	.05	.08	0	**Trust**
-.04	.29	0	.07	0	0	0	0	0	0	**Standards**
0	0	.49	0	.07	0	-.01	-.01	-.04	0	**Parent_Expect**
0	0	0	.49	0	.07	0	0	0	0	**Parent_Critic**
0	0	0	0	.29	0	0	0	-.1	0	**Organized**
0	0	0	0	-.04	0	0	0	0	0	**BU**
.12	0	0	0	0	.1	0	0	0	0	**BD**
.09	-.06	.03	-.04	0	.18	0	.04	.05	0	**IN**
0	0	.02	0	0	0	0	0	.1	.03	**MF**
0	0	.05	-.04	0	.08	0	.08	0	.12	**SI**
0	0	-.03	0	-.01	0	.29	.08	.13	0	**Emot&Notice**
.13	.02	0	0	.04	.1	0	0	0	0	**Asc&DT**
.08	0	.05	0	0	0	0	0	0	0	**IR&SD**
0	0	.22	0	.38	0	0	.11	0	.08	**Doubts&Concern**

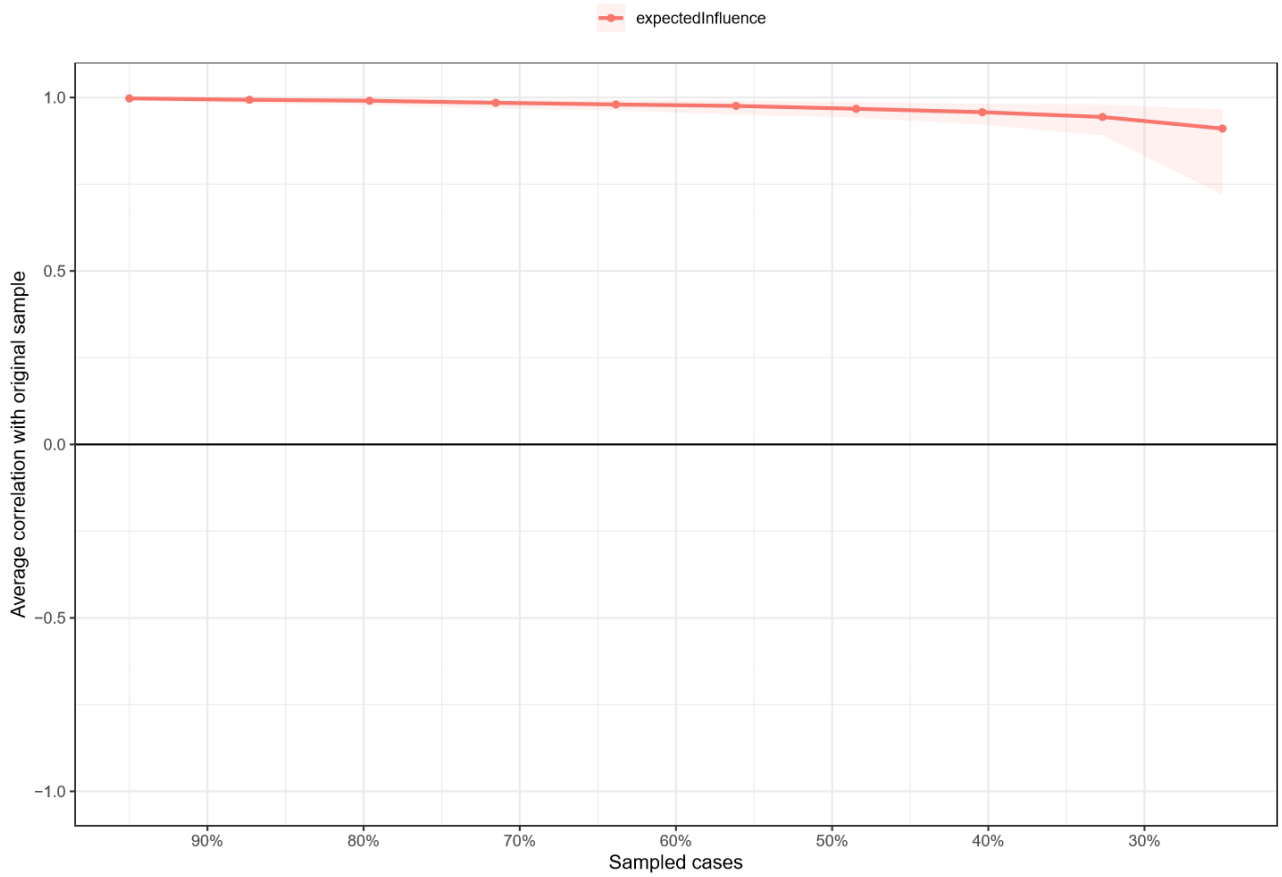
Doubts&Con	IR&SD	Asc&DT	Emot&Notic	SI	MF	IN	BD
.08	0	0	0	.12	.03	0	0
0	0	0	.13	0	.1	.05	0
.11	0	0	.08	.08	0	.04	0
0	0	0	.29	0	0	0	0
0	0	.1	0	.08	0	.18	.1
.38	0	.04	-.01	0	0	0	0
0	0	0	0	-.04	0	-.04	0
.22	.05	0	-.03	.05	.02	.03	0
0	0	.02	0	0	0	-.06	0
0	.08	.13	0	0	0	.09	.12
0	.05	.32	0	.03	0	.17	0
.07	.15	.11	0	.3	.12	0	.17
0	.13	.04	-.04	.08	0	.12	0
.08	.35	0	-.04	0	.08	.3	.03
-.03	0	-.03	0	-.04	-.04	0	0
.2	.26	0	-.03	0	.04	.11	.32
.01	0	.26	0	.35	.13	.15	.05
0	.01	.2	-.03	.08	0	.07	0

Legend: Not_Worry: Not Worrying; Attention: Attention Regulation; Self_Reg: Self-Regulation; Body_Lis: Body Listening; Trust: Trusting; Standards: Personal Standards; Parent_Expect: Parental Expectations; Parent_Critic: Parental Criticism; Organized: Organization; BU: Bulimia; BD: Body Dissatisfaction; IN: Ineffectiveness; MF: Maturity Fears; SI: Social Insecurity; Emot&Notice: Emotional Awareness & Noticing; Asc&DT: Asceticism & Drive for Thinness; IR&SD: Impulse Regulation & Social Distrust; Doubts&Concern: Concern over Mistakes & Doubts about Actions.

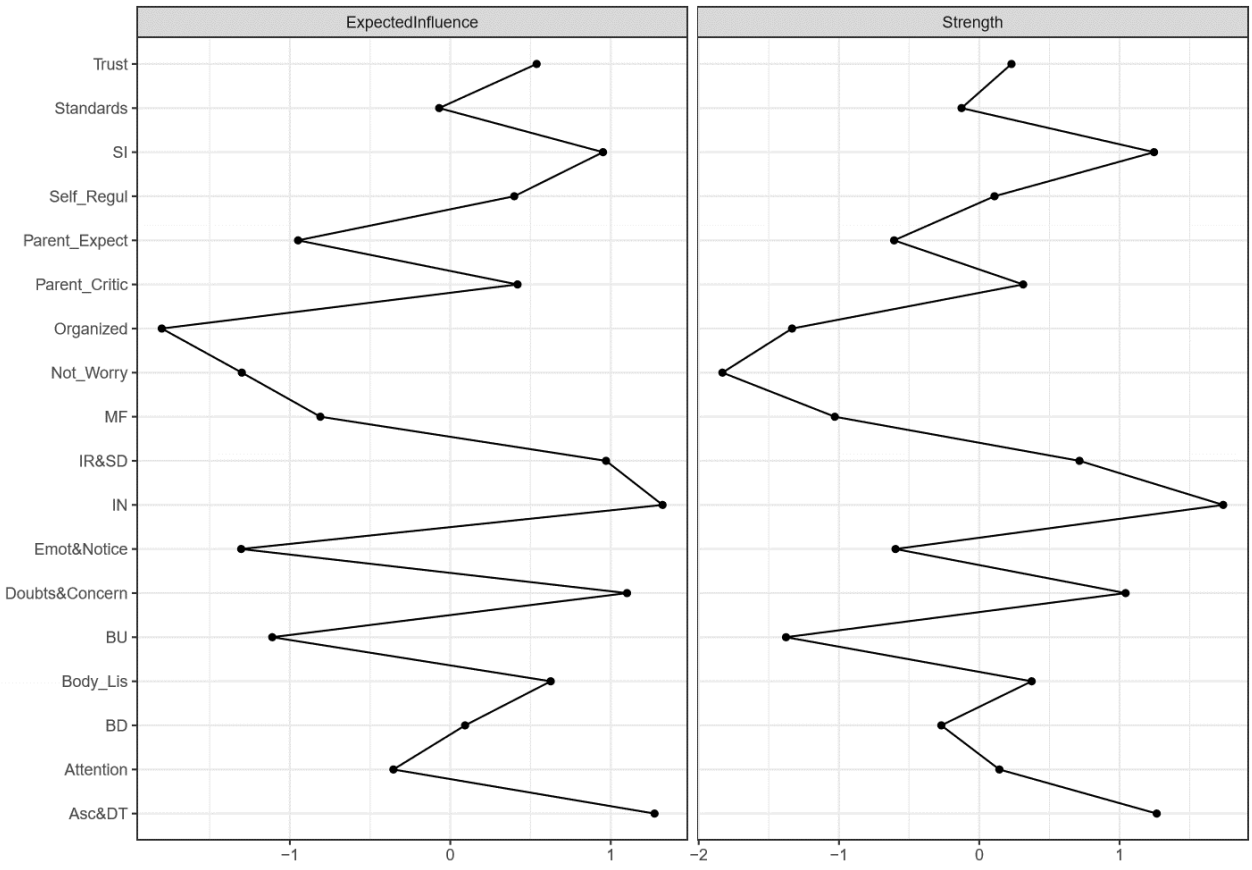
Supplemental Figure 1. Bootstrapped strength stability



Supplemental Figure 2. Bootstrapped expected influence stability



Supplemental figure 3. Strength and expected influence plot

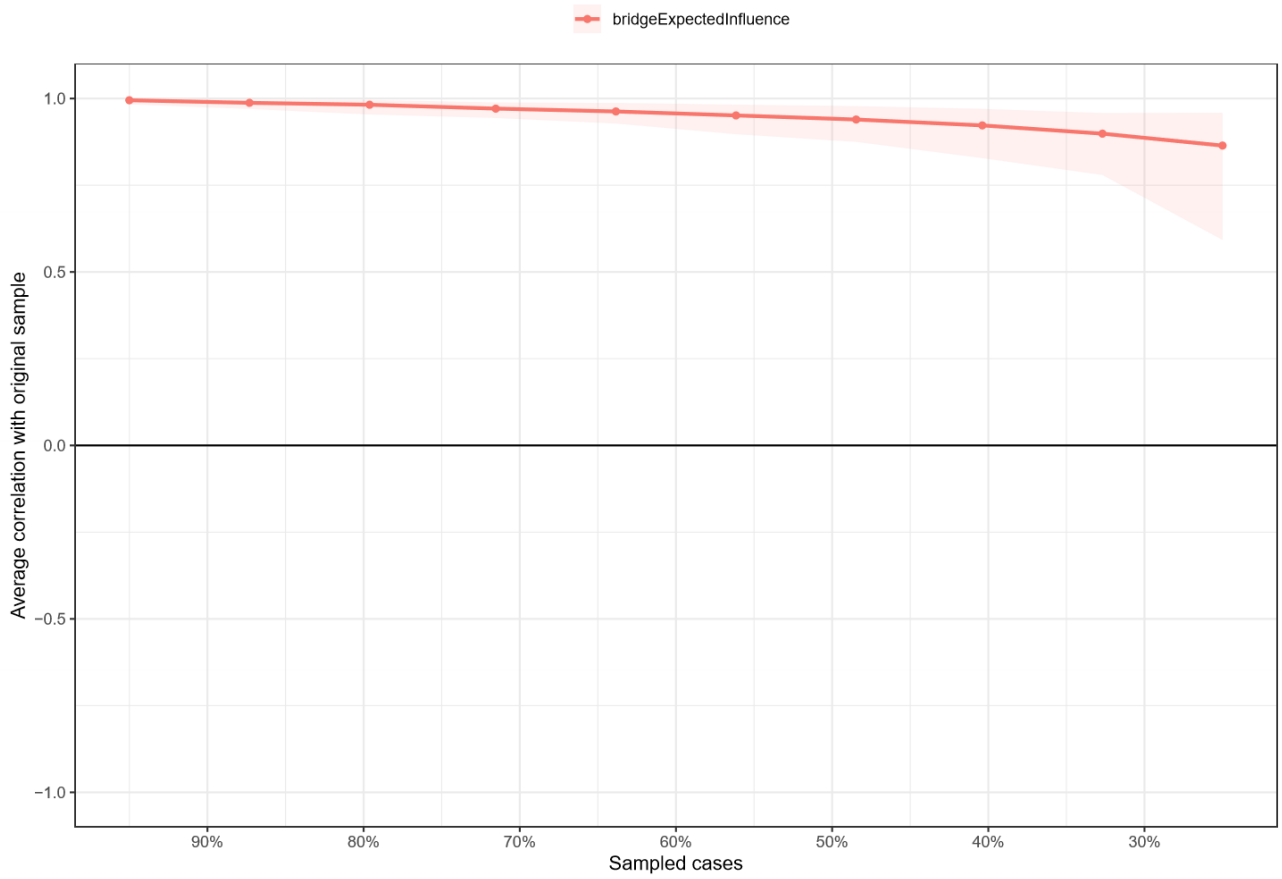


Legend: Not_Worry: Not Worrying; Attention: Attention Regulation; Self_Reg: Self-Regulation; Body_Lis: Body Listening; Trust: Trusting; Standards: Personal Standards; Parent_Expect: Parental Expectations; Parent_Critic: Parental Criticism; Organized: Organization; BU: Bulimia; BD: Body Dissatisfaction; IN: Ineffectiveness; MF: Maturity Fears; SI: Social Insecurity; Emot&Notice: Emotional Awareness & Noticing; Asc&DT: Asceticism & Drive for Thinness; IR&SD: Impulse Regulation & Social Distrust; Doubts&Concern: Concern over Mistakes & Doubts about Actions.

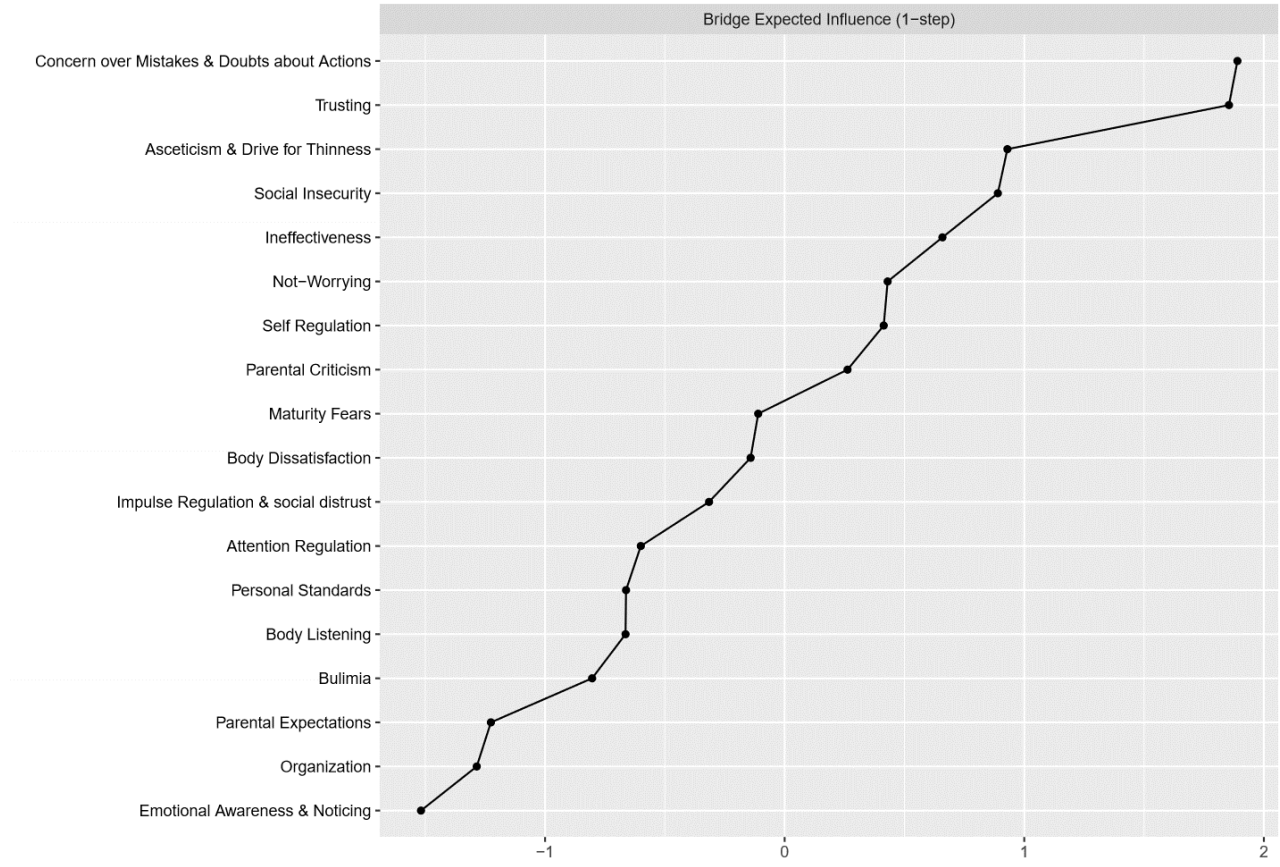
Note: z-scores shown on x axis.

BRIDGE

Supplemental Figure 4. Bootstrapped bridge expected influence stability



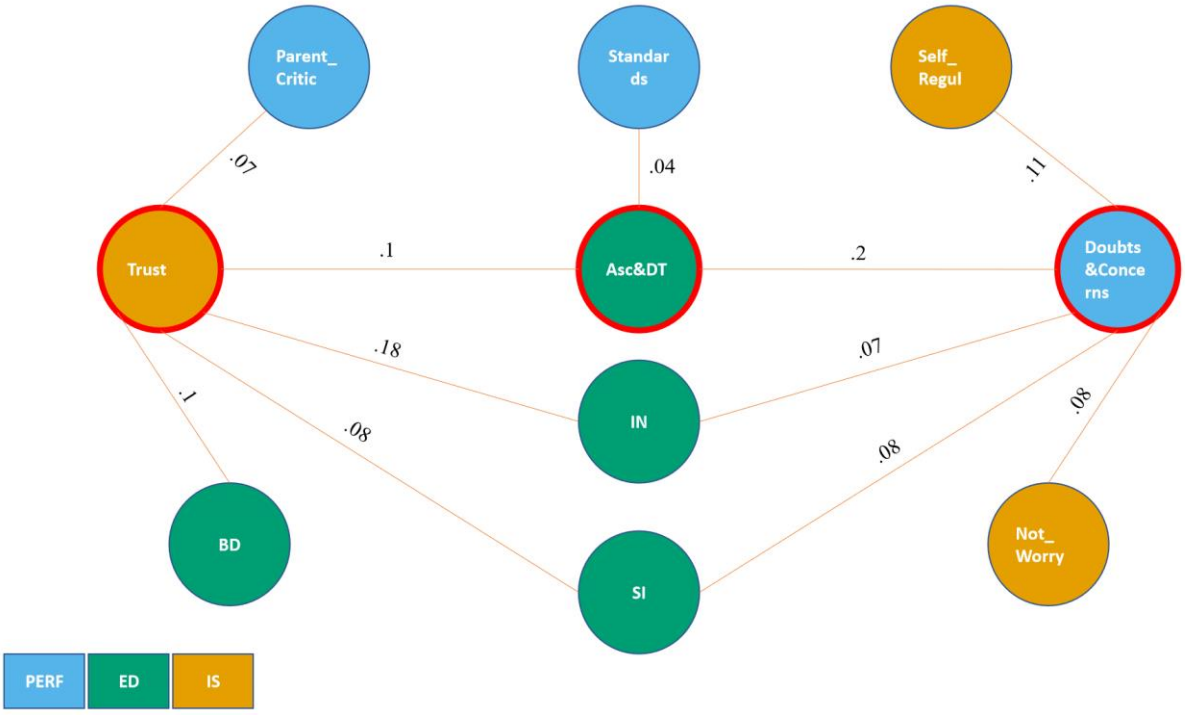
Supplemental Figure 5. Bridge expected influence plot



Legend: Not_Worry: Not Worrying; Attention: Attention Regulation; Self_Reg: Self-Regulation; Body_Lis: Body Listening; Trust: Trusting; Standards: Personal Standards; Parent_Expect: Parental Expectations; Parent_Critic: Parental Criticism; Organized: Organization; BU: Bulimia; BD: Body Dissatisfaction; IN: Ineffectiveness; MF: Maturity Fears; SI: Social Insecurity; Emot&Notice: Emotional Awareness & Noticing; Asc&DT: Asceticism & Drive for Thinness; IR&SD: Impulse Regulation & Social Distrust; Doubts&Concern: Concern over Mistakes & Doubts about Actions.

Note: z-scores shown on x axis.

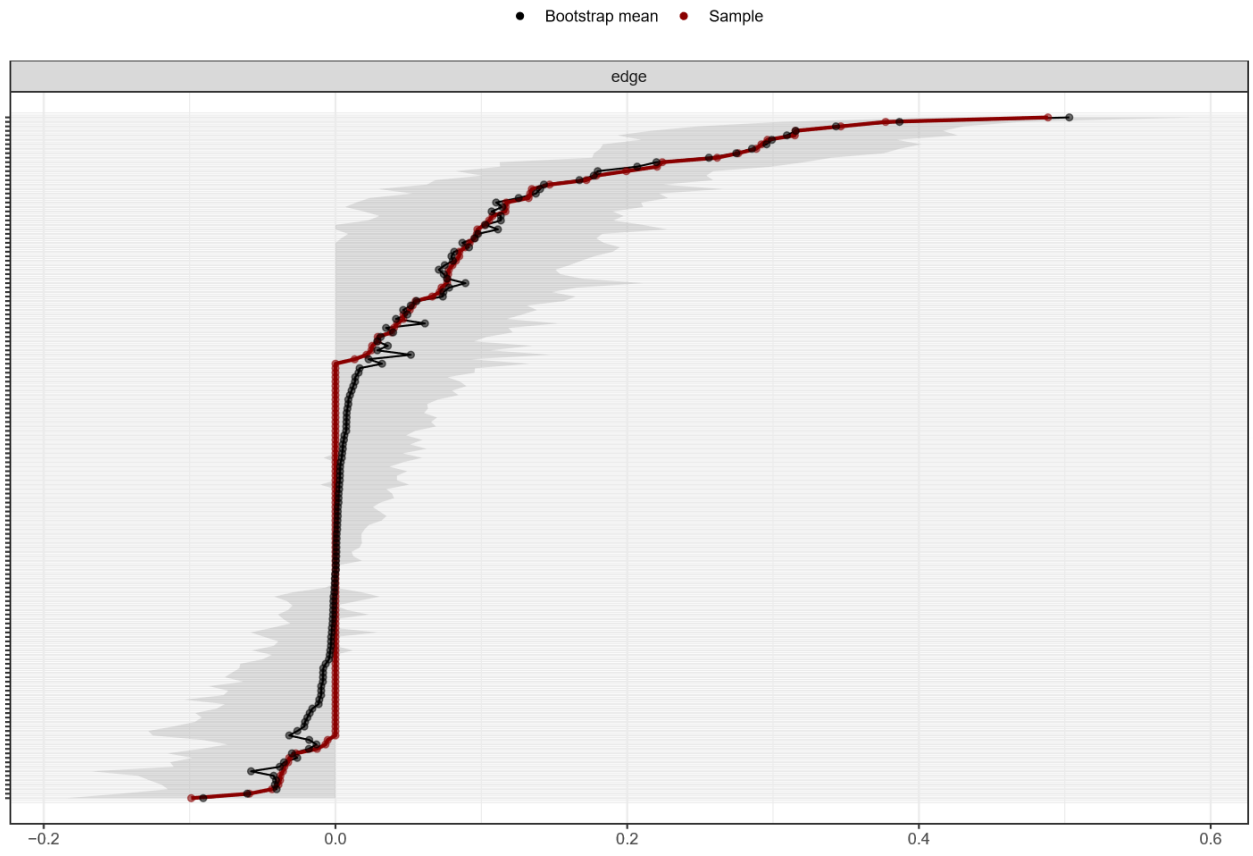
Supplemental Figure 6. Bridge pathways



Nodes are represented as circles, color-coded for each community. Nodes circled in red are those with the highest bridge centrality. Lines between nodes represent partial correlations, whose value is indicated by the number above them. Note: for ease of visualization an arbitrary cut-off of .03 was selected leaving out the following connections: Doubts&Concern and IR&SD (part r =.01), Doubts&Concern and Emot&Notice (part r= - .03), Asc&DT and Organized (part r= .02), Asc&DT and Emot&Notice (part r= - .03).

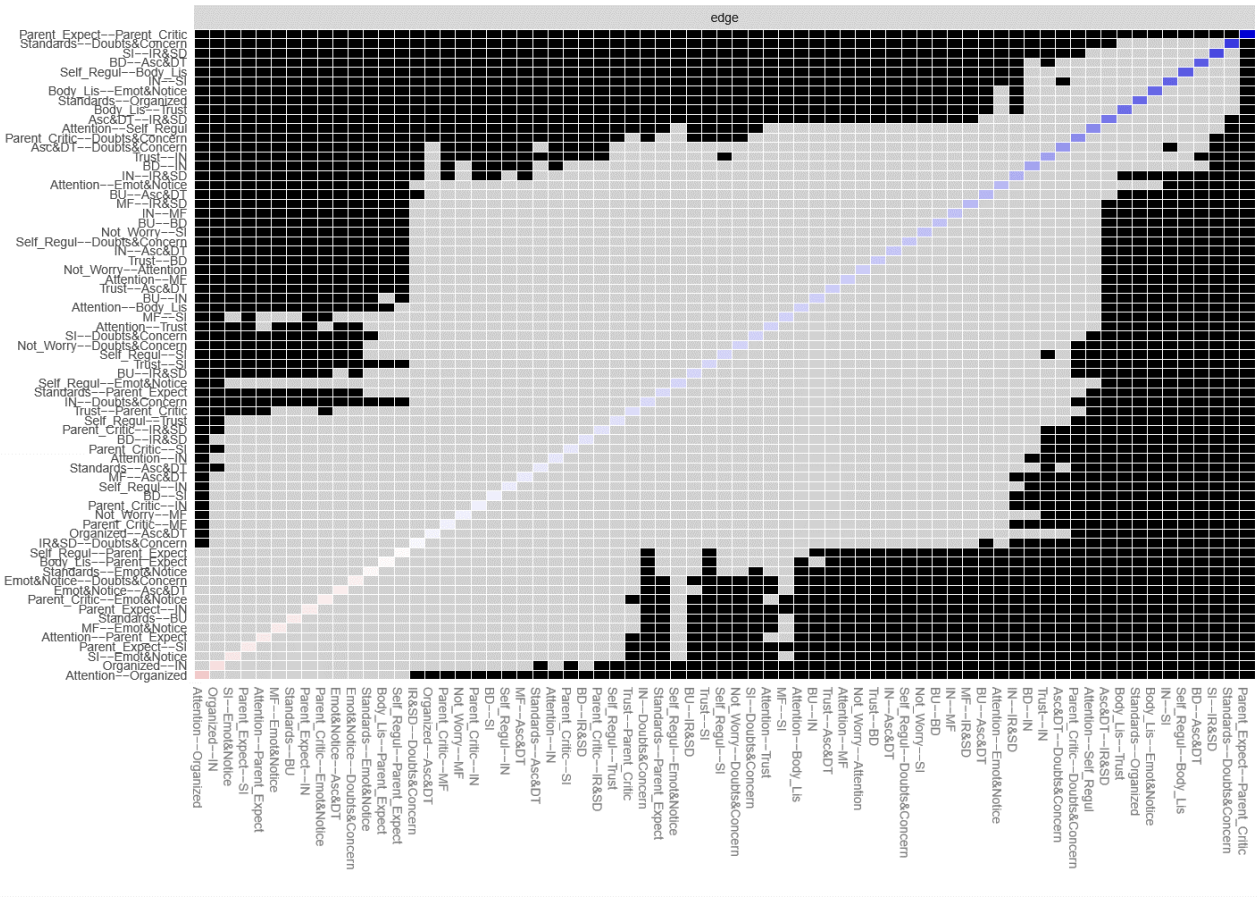
EDGES

Supplemental Figure 7. Bootstrapped confidence intervals of edge weights



Note: grey areas represent confidence intervals

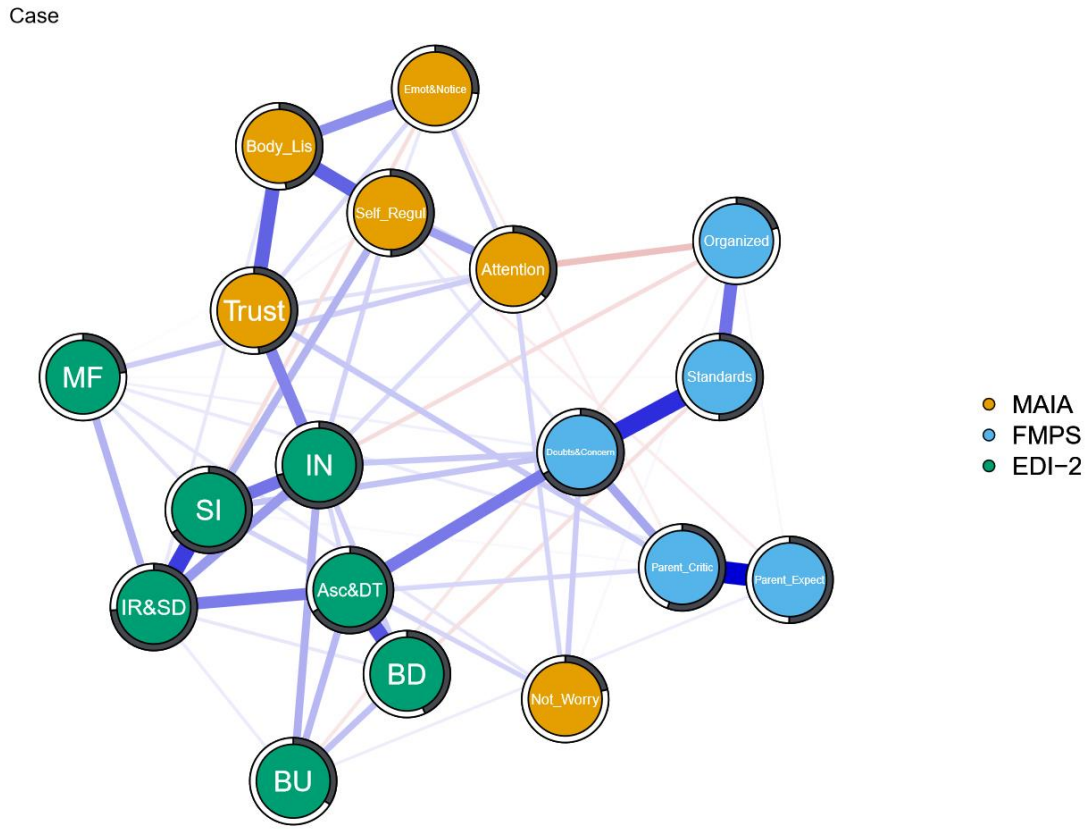
Supplemental Figure 8. Results of edge difference test



Legend: edges are presented in descending order of edge weight value. Black squares represent statistically significant differences. Not_Worry: Not Worrying; Attention: Attention Regulation; Self_Reg: Self-Regulation; Body_Lis: Body Listening; Trust: Trusting; Standards: Personal Standards; Parent_Expect: Parental Expectations; Parent_Critic: Parental Criticism; Organized: Organization; BU: Bulimia; BD: Body Dissatisfaction; IN: Ineffectiveness; MF: Maturity Fears; SI: Social Insecurity; Emot&Notice: Emotional Awareness & Noticing; Asc&DT: Asceticism & Drive for Thinness; IR&SD: Impulse Regulation & Social Distrust; Doubts&Concern: Concern over Mistakes & Doubts about Actions.

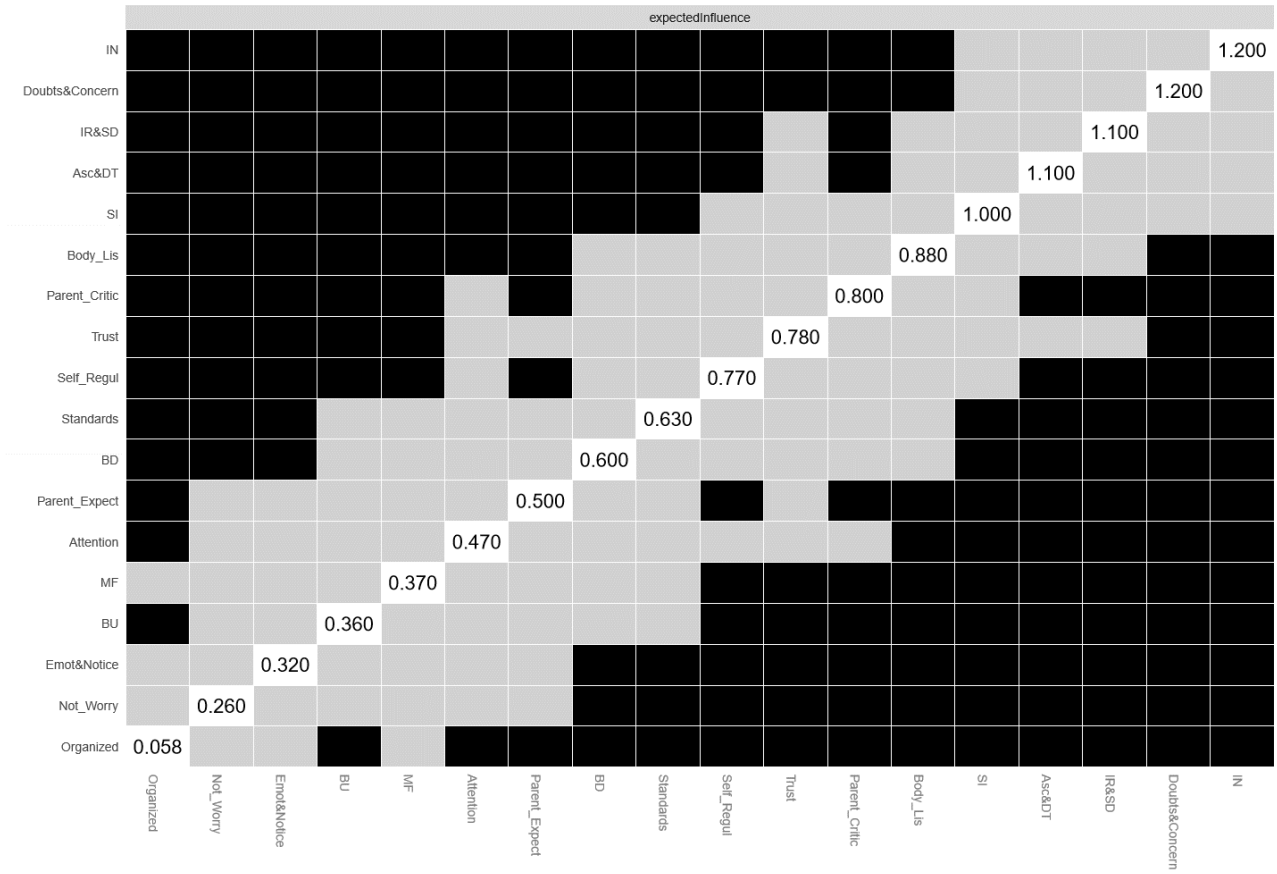
JOINTLY ESTIMATED CASES' AND CONTROLS' NETWORKS

Supplemental Figure 9. Cases' network plot



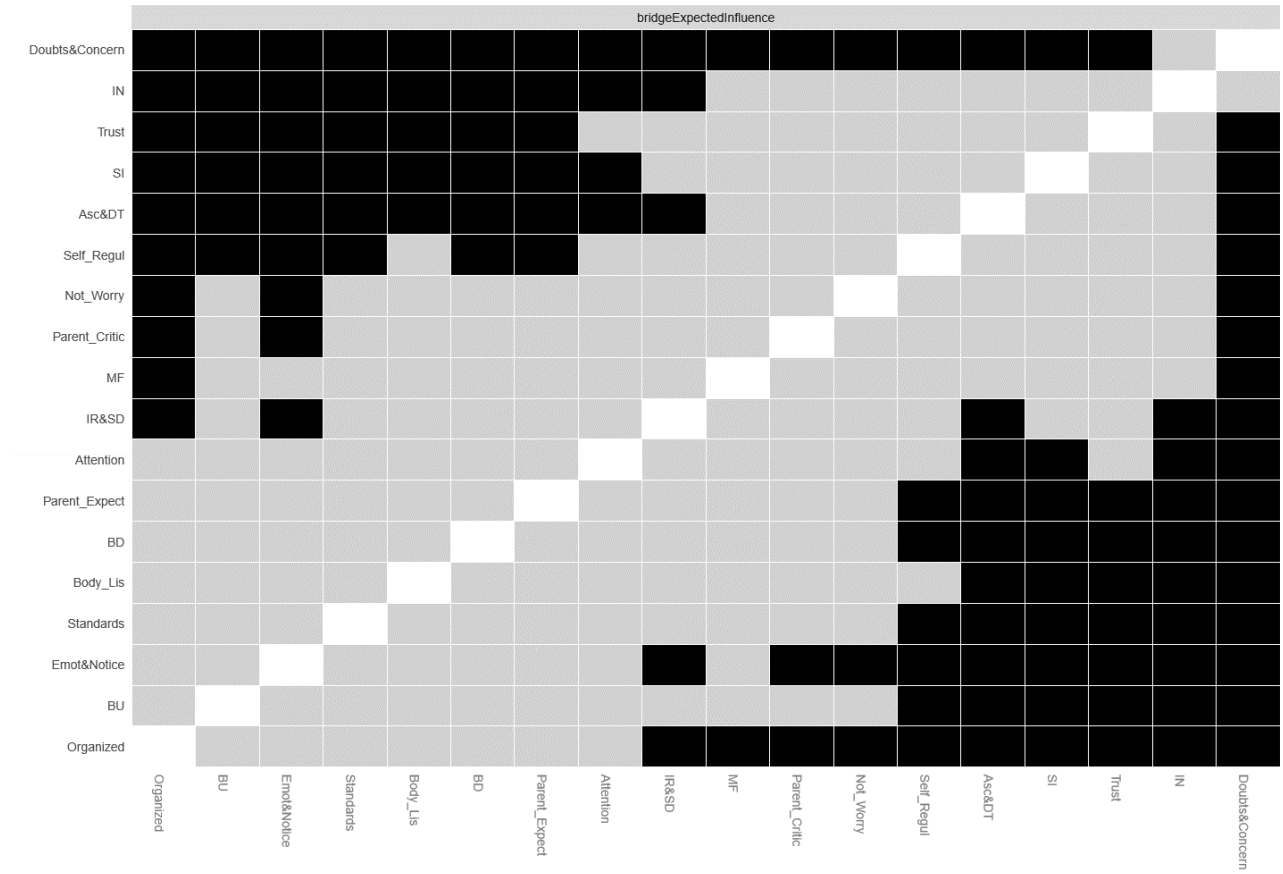
Legend: nodes are represented as circles, color-coded for each community (MAIA: Multidimensional Assessment of Interoceptive Sensibility, FMPS: Frost Multidimensional Perfectionism Scale, EDI-2: Eating Disorders Inventory-2). Blue lines between nodes represent positive association, red lines negative association; thicker lines correspond to stronger associations. Predictability is represented as the shaded area around the circles (higher predictability corresponds to a greater shaded area).

Supplemental Figure 10. Cases' network botstrapped difference test results for expected influence



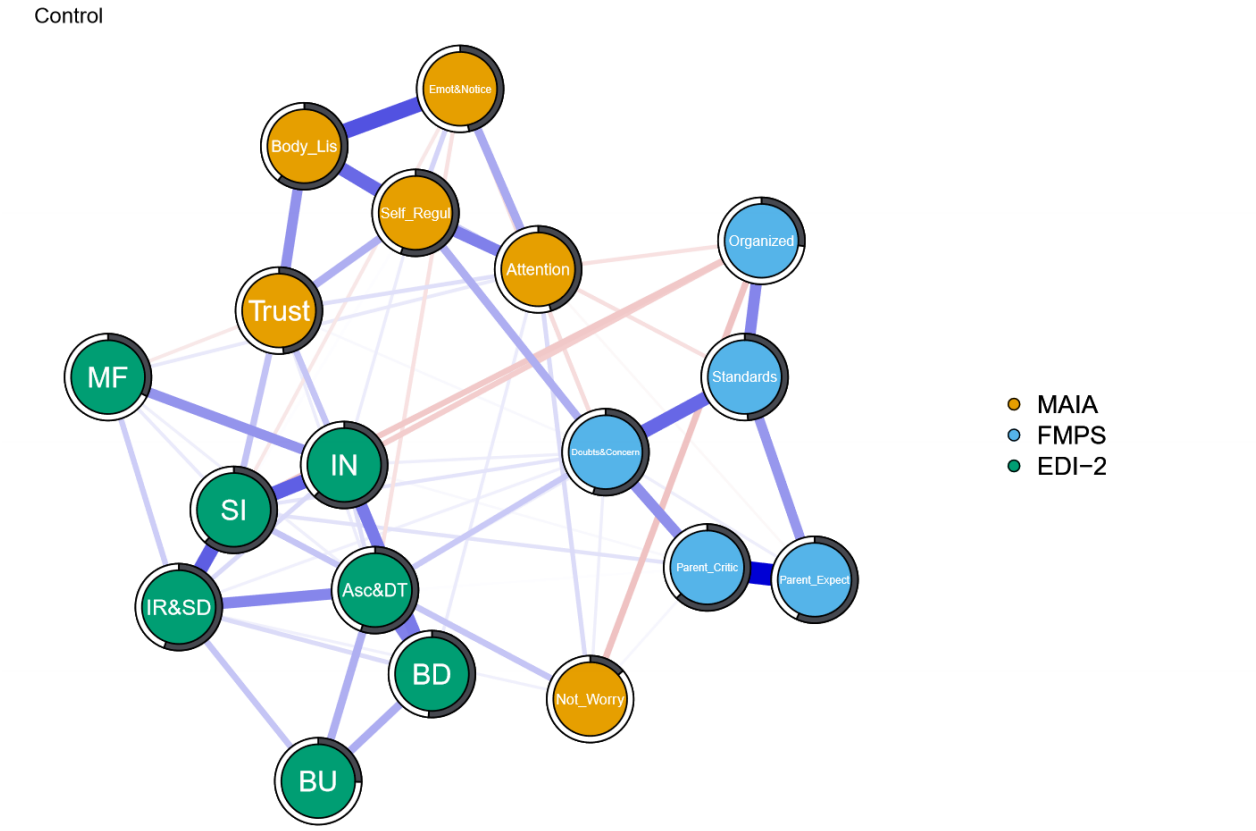
Legend: Variables are presented in descending order of expected influence values. Black squares represent statistically significant differences. Not_Worry: Not Worrying; Attention: Attention Regulation; Self_Reg: Self-Regulation; Body_Lis: Body Listening; Trust: Trusting; Standards: Personal Standards; Parent_Expect: Parental Expectations; Parent_Critic: Parental Criticism; Organized: Organization; BU: Bulimia; BD: Body Dissatisfaction; IN: Ineffectiveness; MF: Maturity Fears; SI: Social Insecurity; Emot&Notice: Emotional Awareness & Noticing; Asc&DT: Asceticism & Drive for Thinness; IR&SD: Impulse Regulation & Social Distrust; Doubts&Concern: Concern over Mistakes & Doubts about Actions.

Supplemental Figure 11. Cases' network bootstrapped difference test results for bridge expected influence



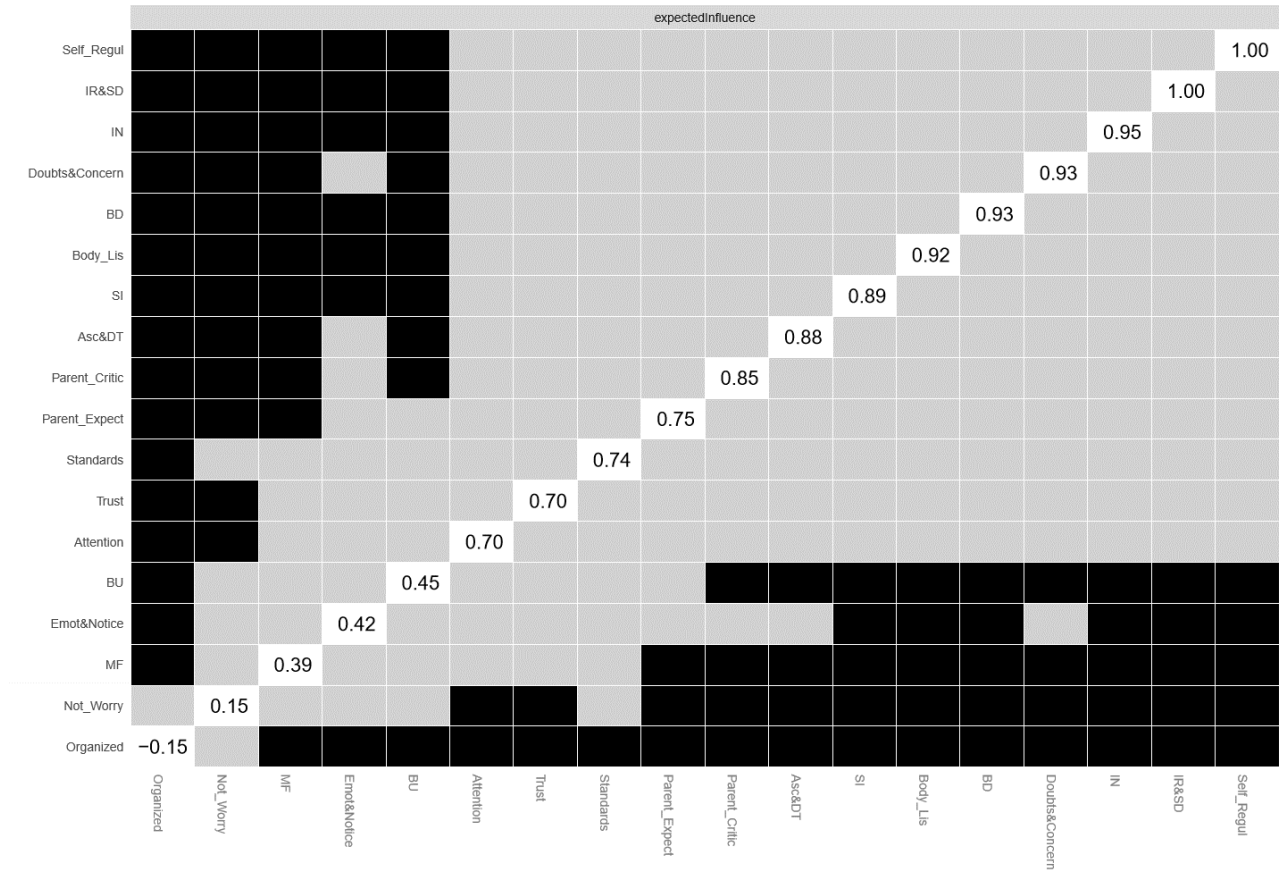
Legend: Variables are presented in descending order of bridge expected influence values. Black squares represent statistically significant differences. Not_Worry: Not Worrying; Attention: Attention Regulation; Self_Reg: Self-Regulation; Body_Lis: Body Listening; Trust: Trusting; Standards: Personal Standards; Parent_Expect: Parental Expectations; Parent_Critic: Parental Criticism; Organized: Organization; BU: Bulimia; BD: Body Dissatisfaction; IN: Ineffectiveness; MF: Maturity Fears; SI: Social Insecurity; Emot&Notice: Emotional Awareness & Noticing; Asc&DT: Asceticism & Drive for Thinness; IR&SD: Impulse Regulation & Social Distrust; Doubts&Concern: Concern over Mistakes & Doubts about Actions.

Supplemental Figure 12. Control's network plot



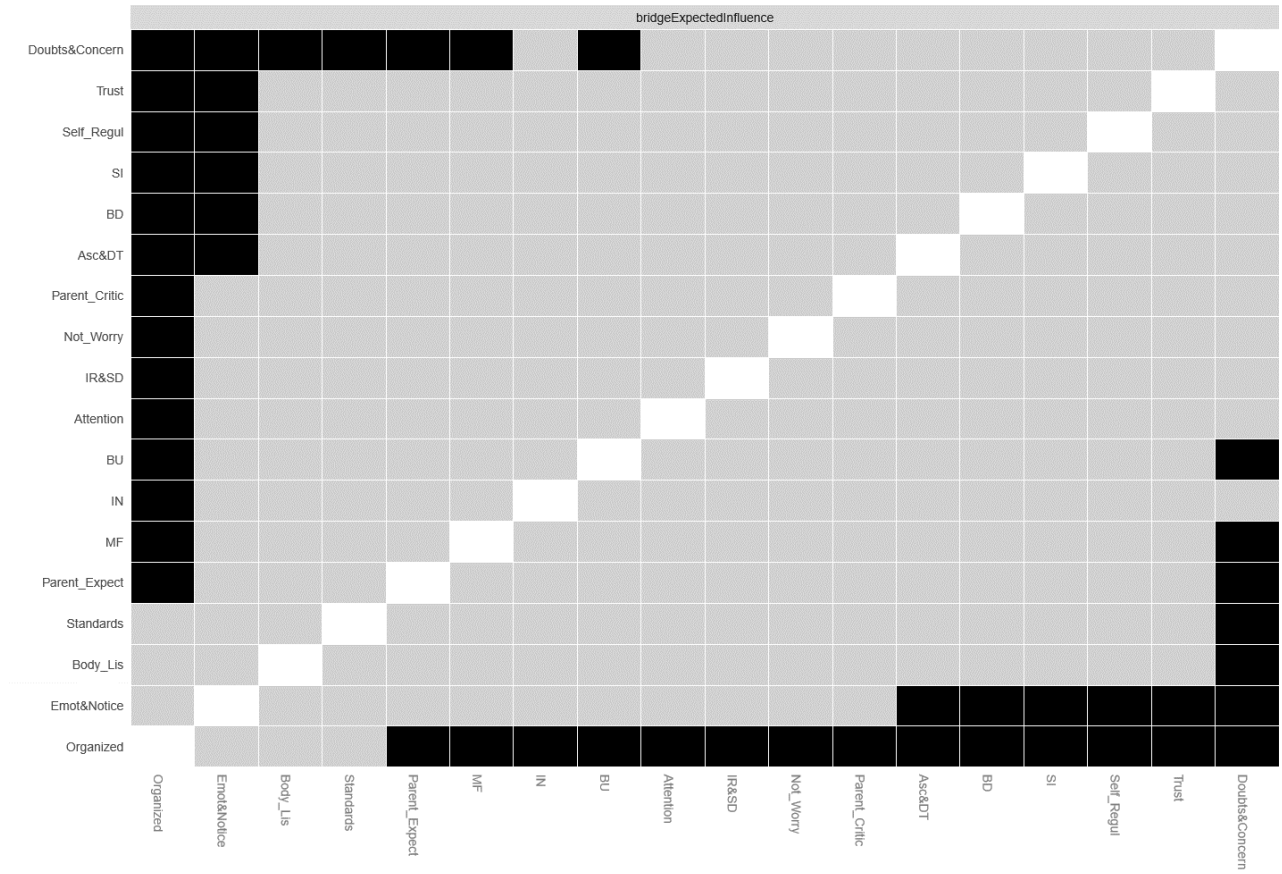
Legend: nodes are represented as circles, color-coded for each community (MAIA: Multidimensional Assessment of Interoceptive Sensibility, FMPS: Frost Multidimensional Perfectionism Scale, EDI-2: Eating Disorders Inventory-2). Blue lines between nodes represent positive association, red lines negative association; thicker lines correspond to stronger associations. Predictability is represented as the shaded area around the circles (higher predictability corresponds to a greater shaded area).

Supplemental Figure 13. Controls' network bootstrapped difference test results for expected influence



Legend: Variables are presented in descending order of expected influence values. Black squares represent statistically significant differences. Not_Worry: Not Worrying; Attention: Attention Regulation; Self_Reg: Self-Regulation; Body_Lis: Body Listening; Trust: Trusting; Standards: Personal Standards; Parent_Expect: Parental Expectations; Parent_Critic: Parental Criticism; Organized: Organization; BU: Bulimia; BD: Body Dissatisfaction; IN: Ineffectiveness; MF: Maturity Fears; SI: Social Insecurity; Emot&Notice: Emotional Awareness & Noticing; Asc&DT: Asceticism & Drive for Thinness; IR&SD: Impulse Regulation & Social Distrust; Doubts&Concern: Concern over Mistakes & Doubts about Actions.

Supplemental Figure 14. Controls' network bootstrapped difference test results for bridge expected influence



Legend: Variables are presented in descending order of bridge expected influence values. Black squares represent statistically significant differences. Not_Worry: Not Worrying; Attention: Attention Regulation; Self_Reg: Self-Regulation; Body_Lis: Body Listening; Trust: Trusting; Standards: Personal Standards; Parent_Expect: Parental Expectations; Parent_Critic: Parental Criticism; Organized: Organization; BU: Bulimia; BD: Body Dissatisfaction; IN: Ineffectiveness; MF: Maturity Fears; SI: Social Insecurity; Emot&Notice: Emotional Awareness & Noticing; Asc&DT: Asceticism & Drive for Thinness; IR&SD: Impulse Regulation & Social Distrust; Doubts&Concern: Concern over Mistakes & Doubts about Actions.

R CODE

```
library(haven)
library("qgraph")
library("networktools")
library("bootnet")
library("dplyr")
library("NetworkComparisonTest")
library("EstimateGroupNetwork")
library("ggplot2")
library("huge")
library("mgm")
library("psych")

##----Data Preparation----
##get data
db <- read_sav("C:/Users/CER_DCA/databases/ MAIA-FROST_EDI2definitivo.sav")
data <- db[,8:33]

##alpha
MAIA <-data[,1:8]
alpha(MAIA)
MAIAndremoved <- select(MAIA,-c(2))
alpha(MAIAndremoved)

FMPS <- data[9:14]
alpha(FMPS)

EDI2 <-data[15:25]
alpha(EDI2)

##data preparation and goldbricker
data_all <-select(data,-c(2,19,21,26)) ##remove EDI-2 P and IA and MAIA not distract
```

```
data_all <- na.omit(data_all)
data_all <- as.data.frame(apply(data_all,2,as.numeric))

data_all <-huge.npn(data_all)
gb <- goldbricker(data_all,threshold=0.20,p=.01)
gb
reduced_data <- net_reduce(data = data_all, badpairs = gb)
reduced_data <- as.data.frame(apply(reduced_data,2,as.numeric))
names(reduced_data) <- c ("Not_Worry","Attention","Self_Regul","Body_Lis","Trust","Standards",
                          "Parent_Expect","Parent_Critic","Organized",
                          "BU","BD","IN","MF","SI","Emot&Notice","Asc&DT","IR&SD","Doubts&Concern")

longnames <-c('Not-Worrying','Attention Regulation','Self Regulation','Body Listening','Trusting',
              'Personal Standards','Parental Expectations','Parental Criticism','Organization',
              'Bulimia','Body Dissatisfaction','Ineffectiveness','Maturity Fears','Social Insecurity',
              'Emotional Awareness & Noticing','Asceticism & Drive for Thinness','Impulse Regulation & social distrust',
              'Concern over Mistakes & Doubts about Actions')



##separate case and controls
data_all1 <-select(data,-c(2,19,21))
data_all1 <- na.omit(data_all1)
data_all1 <- as.data.frame(apply(data_all1,2,as.numeric))

reduced_data1<-reduced_data
reduced_data1['casocontrollo']=data_all1['casocontrollo']

case <- reduced_data1 %>%
  filter(casocontrollo==0)
case <- select(case, -c(casocontrollo))

control <- reduced_data1 %>%
  filter(casocontrollo==1)
control <- select(control, -c(casocontrollo))
```

```
##-----Network----

##1.----boot----
glasso_all<- estimateNetwork(reduced_data, default = "EBICglasso",
                             corMethod = "cor_auto")

set.seed(500)
boot2_all <- bootnet(glasso_all,nBoots = 1000,nCores=8,type="case",statistics = "all",
                     communities=c('1','1','1','1','1','2','2','2','2','3','3','3','3','3','1','3','3','2'))
save(boot2_all, file = "boot2all.Rdata")
corStability(boot2_all)

pdf("boot2.pdf",width = 10)
plot(boot2_all)
dev.off()

pdf("boot2ei.pdf",width = 10)
plot(boot2_all,statistics = "ExpectedInfluence")
dev.off()

pdf("boot2bei.pdf",width = 10)
plot(boot2_all,statistics = "BridgeExpectedInfluence")
dev.off()


boot1_all<- bootnet(glasso_all, nBoots = 1000, type="nonparametric",statistics = "all",
                    communities=c('1','1','1','1','1','2','2','2','2','3','3','3','3','3','1','3','3','2'))
save(boot1_all, file = "boot1_all.Rdata")

pdf("boot1.pdf", width=10)
plot(boot1_all, statistics = "bridgeExpectedInfluence")
dev.off()

bootd_all <- plot(boot1_all, statistics = "expectedInfluence",
```

```
                order = "sample", labels = T)

pdf("bootd.pdf", width=10)
plot(bootd_all)
dev.off()



bootd_all_b <- plot(boot1_all, statistics = "bridgeExpectedInfluence",
                  plot="difference", order = "sample", labels = T)

pdf("bootd_b.pdf", width=10)
plot(bootd_all_b)
dev.off()

bootd_all_e <-plot(boot1_all, statistics = "edge",
                plot="difference", onlyNonZero = TRUE, order = "sample")

pdf("bootd_e.pdf", width=10)
plot(bootd_all_e)
dev.off()

boot1_all_e<-plot(boot1_all, labels=FALSE, order = "sample")

pdf("boot1_e.pdf", width=10)
plot(boot1_all_e)
dev.off()

##2-----predictability----
set.seed(1)
reduceddata_mgm <- mgm(data=reduced_data, type = c(rep("g", 18)),
                     ruleReg = "AND", k=2)
reduceddata_pred_model <- predict(object = reduceddata_mgm,
                              data = reduced_data,
                              errorCon = c("R2"))
```

```
reduceddata_x2 <- as.matrix(reduceddata_pred_model$errors)
reduceddata_error_model <- c(reduceddata_x2[1:18,2])
reduceddata_error_model <- as.numeric(reduceddata_error_model)
reduceddata_error_model <- abs(reduceddata_error_model)

mean(reduceddata_error_model)

corMat <- cor_auto(reduced_data)

mygroups= list("MAIA"=c(1:5,15),"FMPS"=c(6:9,18),"EDI-2"=c(10:14,16,17))

pdf("graph_all.pdf", width=10)
graph_all <- qgraph(corMat, graph = "glasso",layout = "spring", vsize=9,
                    theme="colorblind", sampleSize = nrow(reduced_data), pie=reduceddata_error_model,
                    pieColor = "#46494f", labels = colnames(reduced_data),
                    DoNotPlot=FALSE,
                    label.color=c(rep("white",11),"blue","white","white","white","blue","white","white"), groups=mygroups,
                    nodeNames = longnames,legend=FALSE)
dev.off()

wmatall<-getWmat(graph_all)
wmatall<-as.data.frame(round(wmatall,2))
write.table(wmatall, file = "wmatall.txt", sep = ",", quote = FALSE, row.names=F)

cent_all<- centrality_auto(graph_all)
centralityTable(graph_all)

pdf("strenghtEI.pdf",width = 10)
centralityPlot(graph_all, include = c("ExpectedInfluence", "Strength"))
dev.off()

cor.test(cent_all$node.centrality$ExpectedInfluence,cent_all$node.centrality$Strength)

##4.----bridge----
```

```
bridge_all<- bridge(graph_all,  communities=c('1','1','1','1','1','2','2','2','2','3','3','3','3','3','1','3','3','2'),
                    useCommunities = "all", directed = NULL, nodes=NULL)
plot(bridge_all, include=c("Bridge Expected Influence (1-step)"), order = "value", zscore=TRUE)

pdf("bridgeEI.pdf",width=10)
plot(bridge_all, include=c("Bridge Expected Influence (1-step)"), order = "value", zscore=TRUE)
dev.off()

cor.test(bridge_all$`Bridge Strength`,bridge_all$`Bridge Expected Influence (1-step)`)

##5.----node variance and centrality----
c<- centrality_auto(graph_all)
x <- c$node.centrality$ExpectedInfluence
var <- apply(reduced_data,2,var)
cor(var,x)
cor.test(var,x)

##6.----boot case control----
##boot case
glasso_case<- estimateNetwork(case, default = "EBICglasso",
                              corMethod = "cor_auto")

set.seed(500)
boot2_case <- bootnet(glasso_case,nBoots = 1000,nCores=8,type="case")
save(boot2_case, file = "boot2case.Rdata")
plot(boot2_case)
corStability(boot2_case)

boot1_case<- bootnet(glasso_case, nBoots = 1000, type="nonparametric",
                     statistics = c("strength", "expectedInfluence",
                                    "bridgeStrength", "bridgeExpectedInfluence"),
                     communities=c('1','1','1','1','1','2','2','2','2','3','3','3','3','3','1','3','3','2'))
save(boot1_case, file = "boot1_all.Rdata")

pdf("boot1_case.pdf", width=10)
```

```
plot(boot1_case, statistics = "bridgeExpectedInfluence")
dev.off()

boot3_case <- plot(boot1_case, statistics = "expectedInfluence",
                   order = "sample", labels = T)

pdf("boot3_case.pdf", width=10)
plot(boot3_case)
dev.off()



boot3_case_b <- plot(boot1_case, statistics = "bridgeExpectedInfluence",
                     plot="difference", order = "sample", labels = T)

pdf("boot3_case_b.pdf", width=10)
plot(boot3_case_b)
dev.off()

##boot control
glasso_control<- estimateNetwork(control, default = "EBICglasso",
                           corMethod = "cor_auto")

set.seed(500)
boot2_control <- bootnet(glasso_control,nBoots = 1000,nCores=8,type="case")
save(boot2_control, file = "boot2control.Rdata")
plot(boot2_control)
corStability(boot2_control)

boot1_control<- bootnet(glasso_control, nBoots = 1000, type="nonparametric",
                   statistics = c("strength", "expectedInfluence",
                                  "bridgeStrength", "bridgeExpectedInfluence"),
                   communities=c('1','1','1','1','1','2','2','2','2','3','3','3','3','3','1','3','3','2'))
save(boot1_control, file = "boot1_control.Rdata")

pdf("boot1_control.pdf", width=10)
```

```
plot(boot1_control, statistics = "bridgeExpectedInfluence")
dev.off()

boot3_control <- plot(boot1_control, statistics = "expectedInfluence",
                      order = "sample", labels = T)

pdf("boot3_control.pdf", width=10)
plot(boot3_control)
dev.off()



boot3_control_b <- plot(boot1_control, statistics = "bridgeExpectedInfluence",
                        plot="difference", order = "sample", labels = T)

pdf("boot3_control_b.pdf", width=10)
plot(boot3_control_b)
dev.off()



##7.----predictability case control----
##predictability case
set.seed(1)
case_mgm <- mgm(data=case, type = c(rep("g", 18)),
                    ruleReg = "AND", k=2)
case_pred_model <- predict(object = case_mgm,
                           data = case,
                           errorCon = c("R2"))

case_x2 <- as.matrix(case_pred_model$errors)
case_error_model <- c(case_x2[1:18,2])
case_error_model <- as.numeric(case_error_model)
case_error_model <- abs(case_error_model)

mean(case_error_model)
```

```
## predictability control
set.seed(1)
control_mgm <- mgm(data=control, type = c(rep("g", 18)),
            ruleReg = "AND", k=2)
control_pred_model <- predict(object = control_mgm,
                      data = control,
                      errorCon = c("R2"))

control_x2 <- as.matrix(control_pred_model$errors)
control_error_model <- c(control_x2[1:18,2])
control_error_model <- as.numeric(control_error_model)
control_error_model <- abs(control_error_model)

mean(control_error_model)

##8.----Joint network estimation----
corMatcase <- cor_auto(case)
corMatcontrol <- cor_auto(control)

joint<-EstimateGroupNetwork(list("case"=case, "control"=control),n=c(139,121))

pdf("case_network.pdf", width=10)
g_case<- qgraph(joint$case, layout = graph_all$layout, title = "Case",
                theme="colorblind", pie=case_error_model,
                pieColor = rep("#46494f"), labels = colnames(case),
                label.color="white", groups=mygroups)
dev.off()

pdf("control_network.pdf", width=10)
g_control <- qgraph(joint$control, layout = graph_all$layout, title = "Control",
                  theme="colorblind", pie=control_error_model,
                  pieColor = rep("#46494f"), labels = colnames(control),
                  label.color="white", groups=mygroups)
dev.off()
```

```
#8.----Network comparison test----
set.seed(13)
comparison <- NCT(case,control, it=5000, weighted=TRUE, test.edges=FALSE, edges = 'all')


plot(comparison, what ="network")
```