The network structure of schizotypal personality traits

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Abstract

Elucidating schizotypal traits is important if we are to understand the various manifestations of psychosis spectrum liability and to reliably identify individuals at high-risk for psychosis. The present study examined the network structures of (a) 9 schizotypal personality domains and (b) 74 individual schizotypal items, and (c) explored whether networks differed across gender and culture (North America vs. China). The study was conducted in a sample of 27,001 participants from 12 countries and 21 sites (*M* age= 22.12; *SD*=6.28; 37.5% males). The Schizotypal Personality Questionnaire (SPQ) was used to assess 74 self-report items aggregated in 9 domains. We used network models to estimate conditional dependence relations among variables. In the domain-level network, schizotypal traits were strongly interconnected. Predictability (explained variance of each node) ranged from 31% (odd/magical beliefs) to 55% (constricted affect), with a mean of 43.7%. In the item-level network, variables showed relations both within and across domains, although within-domain associations were generally stronger. The average predictability of SPQ items was 27.8%. The network structures of men and women were similar (*r*=0.74), node centrality was similar across networks (*r*=0.90), as was connectivity (195.59 and 199.70, respectively). North American and Chinese participants networks showed lower similarity in terms of structure (*r*=0.44), node centrality (*r*=0.56), and connectivity (180.35 and 153.97, respectively). In sum, the present paper points to the value of conceptualizing schizotypal personality as a complex system of interacting cognitive, emotional, and affective characteristics.

Keywords: Schizotypy; Schizotypal personality; Psychosis; Network; SPQ; Mental disorders

Introduction

A clear and accurate picture of schizotypal traits is important if we are to understand the various manifestations of psychosis spectrum liability[1] and to reliably identify individuals at high risk for psychosis[2–4]. Schizotypal traits and schizotypal personality disorder (SPD) have been identified as potential risk factors for the onset of psychotic disorders[5–7]. For instance, independent follow-up studies have shown that individuals who report schizotypal traits are at a greater risk for transition to psychosis than are those who do not endorse schizotypal characteristics[5]. In samples with high genetic risk, schizotypal traits improve the individualized prediction of schizophrenia onset above and beyond the predictive capacity of neuroanatomical and neurocognitive variables[8,9]. In high-risk samples, schizotypal traits have also demonstrated psychosis-predictive value[10–12]. Thus, understanding subclinical psychotic experiences and traits may help elucidate relevant etiological mechanisms, risk indicators, and protective factors for psychosis spectrum disorders[6,13].

At the phenomenological level, the psychosis phenotype is distributed along a severity continuum that ranges from psychological well-being to psychosis spectrum disorders[2,14]. Subclinical psychotic manifestations are commonly known as psychotic-like experiences or schizotypal traits[15]. The prevalence and expression of these phenomena vary according to country income and ethnicity[16–18] as well as gender and age[15,19–22]. For instance, African-American students tend to have significantly higher scores on positive and negative schizotypy measures than Caucasian students[23]. Cross-national studies show differences on schizotypal traits among residents of several European countries (e.g., UK, Switzerland, Italy, and Spain)[24,25] as well as between American and Spanish samples[26,27].

Although there is no universal agreement regarding the latent structure of schizotypal personality—for instance, debates continue as to whether the construct is dimensional or categorical[28]—the factor modeling literature has consistently identified multiple facets with a minimum of three dimensions (i.e., Cognitive-Perceptual, Interpersonal, and Disorganized)[29], similar to those found in patients with psychosis[30]. In recent years, a novel conceptual framework has gained attention in clinical psychology and psychiatry: That mental disorders (and other psychological constructs such as personality, intelligence, or attitudes) are emergent properties that arise from causal relations among items [31–35]. This contrasts with current classification systems (e.g., DSM and ICD) and common research practices where symptoms are understood as passive indicators of underlying diseases. The possibility that symptoms or traits are correlated because of direct causal associations is largely overlooked[36,37].

The network approach overcomes these limitations and provides an alternative way to conceptualizing psychological processes and constructs such as psychosis by considering them as complex systems[38–40]. Statistical network models have been added to the analytic toolbox in psychological research, with the goal to identify these structural relationships among variables[38,39]. In this paper, we use the conceptual framework of network theory, and related methods of network psychometrics [41], to model schizotypal personality as a complex system of interacting cognitive, emotional, and affective traits. This is consistent with recent developments in the field[42]: researchers used network analysis to investigate the impact of environmental risk factors (cannabis use, developmental trauma, and urban environment) on psychosis expression and to estimate the network structures of a wide range of psychotic symptoms[36,37,43–46]. Recently, network models have also been used to analyse psychotic-like experiences in a large U.S. sample[47].

So far, the network structure of schizotypal personality traits has not yet been investigated. Given recent concerns about the stability, accuracy and replicability of network models[48–50], such analyses should best be carried out in large samples. To this end, we used state-of-the-art network modeling techniques to estimate the network of self-reported schizotypal traits, assessed via the Schizotypal Personality Questionnaire (SPQ)[51], in a dataset gathered form of 27,001 participants in studies conducted in 12 countries and across 21 sites. In particular, we conducted four sets of analysis. First, we estimated the network structure of 9 domains assessed by the SPQ, which broadly reflect the DSM-5 SPD criteria. The goal of this analysis is to provide novel insights as to how domains relate to each other. Second, we estimated networks of all 74 individual SPQ items. Third, we used graph theoretical measures such as predictability and expected influence (EI) to interpret the network structures. Finally, we estimated and compared network structures between women and men, and between participants from North America and China.

Method

Participants

Table 1 provides a summary of the demographic characteristics of samples that provided data for the omnibus dataset. Item level data were obtained from 21 sites across 12 countries (United States of America, United Kingdom, China, Belgium, Spain, Italy, Tunisia, Australia, New Zealand, Canada, Mauritius, and Greece). See supplementary material for the procedure of data collection.

The overall sample consisted of 27,001 participants (*n*=4,251 drawn from the general population). The mean age was 22.12 years (*SD* = 6.28; range 16-55 years), 15.2% (*n* = 4,113) of participants did not provide age. Only 3.3% (*n* = 849) of the sample was over 35 years. Participant included 37.5% (*n* = 10,126) men and 60.6% (*n* = 16,368) women; 1.9% (*n* = 507) did not specify gender. All demographic information is available in Table 1. Studies were reviewed and approved by institutional review boards or ethics committees of the jurisdictions in which studies were conducted. All participants provided written informed consent prior to participation. Studies were conducted in accordance with the guidelines of the Declaration of Helsinki[52].

Consistent with prior publications on this dataset[29], we deleted from the initial sample those participants with more than two missing values on the 74 SPQ items. Based on the SPSS 22.0 missing value analysis module[53], the relatively few missing values in the data were replaced by regression-based estimates to which an error component was added.

---------------------------------- Insert Table 1 around here ------------------------------------

Instruments

The SPQ measures a broad range of schizotypal traits—originally it targeted nine subordinate traits that are based on the operational definition of DSM-III-R SPD[54]. These domains also represent the main features of DSM-5 SPD criteria[55]. The 74 items of the SPQ are distributed across nine subscales, each containing seven to nine items: odd beliefs or magical thinking, unusual perceptual experiences, ideas of reference, paranoid ideation/suspiciousness, excessive social anxiety, no close friends, constricted affect, odd or eccentric behaviour, and odd speech. The psychometric properties have been examined in a number of nation- or region-specific studies[29]. All individual SPQ items are listed in the supplementary material, and we distinguish the nine subscales by different colors in the network figures below.

In the present study, we used the SPQ versions adapted and validated for each country: English version[51], Spanish[56], Italian[57], Chinese[58], Arabic[59], French[60], Creole[61], and Greek[62].

Data analyses

In our primary analysis, we estimated an SPQ domain network and an SPQ item network in the full sample (*n*=27,001). In a secondary analysis, we compared networks of women (*n*=16,368) and men (*n*=10,126), and of North American (*n*=12,326) and Chinese (*n*=4,907) study participants. For all networks, we investigated two graph theoretical measures: EI and predictability.

All analyses were carried out in *R* version 3.1[63] in R-Studio 1.0.136, and are described below in detail. R-packages and version numbers are listed in the supplementary materials.

General network estimation

A network consists of nodes (in our case the SPQ domains/items) and edges (unknown statistical relationships between nodes that need to be estimated). For the domains, which were constructed by summing items per domain and then standardizing the resulting variable, we estimated a Gaussian Graphical Model (GGM[64]); for the binary items, we estimated an Ising Model[65]. Both models result in conditional dependence relations which are akin to partial correlations: if two nodes are connected in the resulting graph via an edge, they are statistically related after controlling for all other variables in the network; if they are unconnected, they are conditionally independent. Both models entail the estimation of a large number of parameters, but have the goal of describing the network structures parsimoniously. To avoid obtaining false positive associations among items, the models therefore us regularization to shrink all edge weights, setting many exactly to zero[66]. This approach circumvents the problem of estimating spurious relationships and results in a sparse network structure. A detailed explanation of the two models can be found elsewhere[65]. We interpret both models differently. In the domain network, we interpret edges as putative causal associations. That is, if A and B are connected, we hypothesize that this connection comes from A-

>B, A<-B, or A<-> B. For the item-level network, we interpret edges purely statistical (as regularized partial correlations) and not as putative causal pathways. This is because the SPQ contains many items too similar to regard them as separate variables, and the more likely explanation for some edges is that items measure the same construct [49]. For instance, items 18 and 59 both ask a very similar question about whether people feel that others “have it in” for them, and the resulting edge is likely not because endorsing item 18 causes the endorsement of item 59).

For network inference, we estimated two measures: EI and predictability. EI is the sum of all edges of a node[67]. We use EI instead of strength centrality[68] that has been used in prior work because strength centrality uses the sum of *absolute* weights (i.e. negative edges are turned into positive edges before summing), which distorts the interpretation if negative edges are present (such as in the present paper). Predictability, on the other hand, is an absolute measure of interconnectedness: it provides us with the variance of each node that is explained by all its neighbors[69]. Predictability can be understood as an upper bound of controllability: assuming that all undirected edges connected to a node point *towards* this node, predictability quantifies how much impact neighbors have on a focal node by intervening on them. In the figures, dark areas in the circle around nodes can be interpreted akin to R^2 (% of explained variance, in case of the Ising Model, above the marginals)[69].

Network stability

To test network stability and accuracy, we used bootstrapping routines implemented in the R-package *bootnet*[48]. Given the combination of sample size and number of nodes that leads to considerable computational burden and is so far unparalleled in the psychological network literature, we performed bootstrap analyses on a high-performance computer cluster, parallelized over 100 multicore units each running 10 bootstrap samples.

Comparison of subsamples

Because the degree of regularization is dependent on sample size, it is difficult to compare networks estimated on different sample sizes, which was the case for the group comparisons. We therefore subsampled the larger datasets down to the same size as the smaller one ten times, computed an Ising Model each time, and averaged these 10 models into one final network model. We compared the resulting networks in terms of (1) similarity of adjacency matrices (i.e. network structures) and (2) similarity of EI estimates by correlating these parameters across the networks. We used Pearson correlations if the distribution of parameters met assumptions of multivariate normality, and Spearman correlations in the case where normality was violated. Further, we compared SPQ total scores across the subsamples.

Note that it would have been preferable to use the *Network Comparison Test* (https://cran.r-project.org/web/packages/NetworkComparisonTest/) (NCT), a permutation test that investigates whether networks differ from each other. Unfortunately, the test was developed for considerably smaller samples with much fewer items, and we could not use the NCT here due to the prohibitive computational burden. It would be possible to run the test similar to the bootstrapping routines on a high-performance computer cluster if the parallelization of the NCT to multiple cores had been worked out yet, which is not yet the case.

Supplementary materials

We make all model output (e.g. network parameters, item means, centrality, connectivity) available in the supplementary materials, along with all R codes that were used to compute the analyses.

Results

Network structure of 9 schizotypal domains

As Figure 1 shows, the estimated network was interconnected, with strong edges between the domains 'no close friends' and 'constricted affect' (0.50), 'odd/magical beliefs' and 'unusual perceptions' (0.37), and 'ideas of reference' and 'suspiciousness' (0.36). Interestingly, we also obtained two negative edges: between 'ideas of reference' and 'no close friends' (-0.11), and between 'social anxiety' and 'odd/magical beliefs' (-0.09). The most central nodes in terms of standardized EI (i.e. the sum of edges connected to a node) were 'unusual perceptions', 'constricted affect', and 'odd speech'; social anxiety was the least central domain. Predictability (variance of a node explained by its neighbors) ranged from 31% (odd/magical beliefs) to 55% (constricted affect), and average predictability was 43.7% (see Figure 2).

------------------------------ Insert Figure 1 and 2 about here --------------------------------

General network structure of 74 schizotypal items

The full network of 74 SPQ items is depicted in Figure 3. Five results are noteworthy. First, items within each of the 3 higher order dimensions were more closely associated with each other than with items of other dimensions. The average edge weights for the within domain associations were 0.15, 0.15, and 0.27 for positive, interpersonal, and disorganization, respectively. Average edge weights across domains were 0.04 for all three domains (e.g. all weights from items in the positive domain to items outside of the positive domain).

Second, we found a similar, although more pronounced result for the 9 domains: within-scale item relations with 0.33, 0.45, 0.47, 0.26, 0.61, 0.31, 0.37, 0.24 and 0.44 were considerably stronger than associations from items in one of these subscales to all other items (all between 0.04 and 0.07). The subscale 'odd/eccentric behavior' had the strongest average inter-item association (0.61), 'constricted affect' the lowest (0.24).

Third, items 57 ("I tend to keep in the background on social occasions" from the no close friend subscale) and 73 ("I tend to keep my feelings to myself" from the constricted affect subscale) showed numerous negative edges.

Fourth, node predictability varied considerably across SPQ items, ranging from 3% in node 22 to 59% in node 38. The average predictability of SPQ items was 27.8%, implying that substantial variability remained unexplained. Node predictability varied across the nine subscales and ranged from a mean of 15.0% for unusual perceptual experiences to 39.8% for excessive social anxiety.

Fifth, items that stood out in terms of EI (larger or smaller than 1.5 standard deviations) were, in decreasing order: 59 (2.64, suspiciousness), 69 (2.13. odd speech), 23 (1.94, odd behaviour), 71 (1.58, excessive social anxiety), 1 (-1.97, ideas or reference), 10 (-2.03, ideas of reference), 20 (-2.07, excessive social anxiety), 54 (-2.39, excessive social anxiety), and 49 (-2.55, no close friends) (see Figure 4).

------------------------------ Insert Figure 3 and 4 about here --------------------------------

Network structure of schizotypal items across gender

The estimated networks by gender are depicted in Figure 5. The connectivity (sum of all absolute edge values) of both networks was very similar, with values of 195.59 and 199.70 for men and women, respectively. Investigating the similarity of the network structures, we found that the adjacency matrices (the edge weights) were substantially inter-correlated, with a Spearman correlation coefficient of 0.74. EI estimates were correlated 0.90 across the networks. Differences of the networks in terms of EI estimates are summarized in Figure 6; only item 59 (Suspiciousness) was noticeably different across networks, with a difference of 1.80 (male network EI for item 59: 3.26; female network: 1.47). Mean SPQ items differences by gender are shown in supplementary material.

----------------------------- Insert Figure 5 and 6 about here -------------------------------

Network structure of schizotypal items across country

Figure 7 shows networks for North American and Chinese participants. The North American network was substantially denser (connectivity, i.e. sum of all absolute edge values = 180.35) than the Chinese network (153.97). The Spearman correlation coefficient of the network structures was 0.44, which was substantially lower than the correlation between male and female networks. EI estimates were correlated 0.56 across the networks. Differences between the networks (EI estimate West – EI estimate East) are summarized in Figure 6. Items 37 (2.7), 68 (2.05), 57 (1.97), 54 (-2.77), and 44 (-2.87) showed the largest differences.

------------------------------ Insert Figure 7 about here --------------------------------

Network stability

The results of the stability and accuracy analysis[48] available in the supplementary materials indicated that all networks were accurately estimated. The domain network was more accurately estimated than any other psychological between-subjects network in the prior literature: confidence intervals around edge weights were very small, the stability coefficient for EI was at the maximum obtainable value of 0.75, and early all edge weight comparisons were significant (i.e. 528 out of all possible 561 edge weights comparisons indicated significant differences between edges weights).

Discussion

To our knowledge, this is the first study to examine the empirical network structure of schizotypal domains and traits. We use the SPQ to assess the items in a large sample of 27,001 individuals across 12 countries. We are not aware of any network analysis in clinical psychology or psychiatry with a sample size comparable to the one used in the present work. In the following, we propose to understand schizotypal personality as a complex system of cognitive, emotional, and behavioural traits, and argue that psychological network methodology can aid in uncovering this complexity.

Several findings deserve a closer look. First, the nine schizotypal domains were strongly interconnected. In particular, the relationship between nodes showed a three-cluster named Cognitive-Perceptual, Interpersonal, and Disorganized. This network structure was quite congruent with the three-dimensional model proposed in this arena[29]. In addition, predictability values ranged from 31% (odd/magical beliefs) to 55% (constricted affect), where the average predictability was 43.7%. The average predictability found was high compared to previous network literature[69]. In the domain network, we interpret schizotypal traits as putative causal associations. The network perspective proposes that correlations among schizotypal domains are due to causal connections between behaviors, beliefs, and feelings. Here we found that odd speech and odd behavior domains, or magical thinking and unusual perceptions domains were more interconnected in the general schizotypal network than others. These findings can be considered within the network model of onset of psychotic disorder proposed by Linscott and van Os[70]. The onset for the outcome of these disorders can be understood in part as different psychotic-like experiences and traits that causally impact on each other over time. This is congruent with previous research that demonstrated how negative/disorganized symptoms predicted positive symptoms[71] or how hallucinations gave rise to delusions[72]. These findings allow for a deeper understanding of the nature of interactions that take place between the schizotypal traits that contribute to psychosis liability.

Second, in the item-level network, and similar to domain-level, variables showed relations both within and across domains, although within-domain associations were generally stronger. Moreover, overall predictability in the full network was 27.8%, meaning that a substantial portion of the variance of the SPQ items cannot be explained by the nodes in the estimated network. This value is lower than the average predictability found at domain level. Of note, predictability was higher for the facets of excessive social anxiety, ideas of reference, suspiciousness, odd speech, and odd or eccentric behaviour than for the facets of unusual perceptual experiences, constricted affect, odd beliefs or magical thinking, and no close friends. These results may indicate that important variables that could contribute to trait/symptom development are missing in the estimated model. In addition, disorders within the psychosis spectrum are thought to arise from a crucial interplay between genes and environment[73] – it would therefore be expected that part of the missing predictability here is due to the absence of genetic or environmental components in the network. Some of these findings both domain and item level are consistent with previous research using the network framework in patients with psychosis and non-clinical samples[36,37,43–47]. For instance, Murphy et al.[47] found in a study of psychotic-like experiences (PE) in a large US sample that the network of symptom severity ratings revealed strong interconnectivity between PEs, and that paranoia nodes were among the most central in the network.

Third, estimated networks of men and women were similar as well as node centrality and connectivity. In spite of small differences in the network structures, connectivity and centrality estimates in the present study were similar for both men and women, indicating that differences may not lie within the inter-item associations. Research in the field of psychotic disorders often identifies different symptom profiles for men and women, with men presenting with poorer premorbid functioning and worse course of illness[74–76]. In non-clinical populations, however, findings have been more inconsistent, with women seeming to score higher on measures of positive schizotypal features and men seeming to score higher on measures of negative schizotypal features[15,20–22,77]. To date, due to limited data, it was not possible to compare networks of men and women for patients. We hope future research could address this issue—if the network structures and connectivity are found to be different for men and women within a patient population.

Fourth, at country level, North American and Chinese participants networks showed lower similarity than the gender comparison both in terms of structure, node centrality and connectivity In addition, the North American network estimated of SPQ items was substantially denser than the network of Chinese participants, which is particularly interesting in the light of recent work showing that groups with more densely connected networks are likely to have more adverse outcomes in the future (reviewed in: [40]). Previous research has demonstrated that the prevalence and expression of these subclinical psychotic phenomena (e.g., psychotic-like experiences, schizotypal traits) varies according to place, culture, income, and ethnic minority groups[16–18] as well as gender and age[15,19–21], but has also found that schizotypal traits similarly cluster for Chinese and Western samples[78]. Even though our results show a similar network structure for the two populations, we also pinpoint to previously unidentified differences between Western and Eastern countries. It is important to note that our results are exploratory and no other studies to date have compared schizotypal traits between North American and Chinese samples, limiting the degree to which we can situate our findings in the extant literature. Bhugra and colleagues[79,80] found that Asian patients diagnosed with schizophrenia display better pre-morbid functioning than do Caucasian patients; future research could investigate whether the symptom network is also less densely connected in Chinese than in North American patient samples, potentially supporting the idea of a more resilient network structure. Broadly, however, we believe that comparison of schizotypal traits among people from different cultures has the potential to provide us with information on cultural differences in social and affective functioning[42] that could ultimately prove highly valuable in clinical practice.

The results of the present study should be interpreted in the light of the following limitations. First, the majority of the participants were college students and this characteristic may affect the generalization of the results to other populations of interest. Second, the study is subject to the problems inherent to any research based on self-reports. This fact notwithstanding, self-report has the advantages of being free of independent observer biases and potentially more sensitive than other assessment approaches to underlying causal processes[81]. Third, the infrequency scale to screen out participants who responded in a random manner was not systematically employed in all samples. Fourth, it was not possible to use the novel network comparison test to investigate *statistical* differences across networks because the test cannot currently deal with a very large number of participants. Instead, and consistent with prior publications (e.g.[50,82]), we report the correlation of the network structures as a measure of similarity. Fifth, as discussed in more detail elsewhere, psychological networks model single items that are prone to measurement error [49]. While some of the issues surrounding measurement error are unresolved[83,84], it is noteworthy that the average predictability in the main network presented in this study was 27.4%, which is somewhat lower than the average predictability identified in a re-analysis of 25 datasets from 18 prior psychopathology network studies[69]. Interestingly, across all analyzed studies, psychosis had the lowest average predictability of 28%, remarkably similar to our result. The authors of the reanalysis concluded that not only excluding important variables from the network can result in lower average predictability (a lot of variance of the nodes remains unexplained), but also measurement error. Sixth, as highlighted in the methods section, an edge between two items of very similar content cannot be understood as putative causal pathway. Since the SPQ contains many item pairs that are very similar in nature, especially relations within the domains should only be interpreted statistically, i.e. as regularized partial correlation coefficients. Edges across domains, however, are consistent with standard network-theoretical interpretations. In addition, these domains are common across almost all schizotypal and psychosis (risk) inventories; thus, we hope this analysis will enable future research to investigate how the domain network structure obtained here replicate or generalize using different measuring instruments and samples. Finally, the between-subjects network analysis of one large aggregated dataset in cross-sectional data means that we can neither draw strong conclusions about the dynamic nature of associations, nor do we know whether the network structure generalizes to within-person processes.

Conclusions

This study is the first to comprehensively examine the network structure of the self-reported schizotypal traits using a large multinational sample. The results are consistent with the conceptual notion of schizotypal personality as a complex network structure of cognitive, emotional and behavioural traits. This study also offers a deeper understanding of the subclinical psychosis expression or schizotypy (psychosis liability).

Even though it is only at the beginning of the road, the research in the domain of psychopathology has embraced network theory and methodology as a pair of matching tools with the goal to shed light on the complexity of the psychosis spectrum phenotype and, ultimately, to contribute to advancements in clinical practice. We hope that this will open new avenues for nosology, etiological research, assessment strategies, prevention, and treatment.

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Table 1. Demographic characteristics of the sample.

Study	Country	Main researcher	*n*	Sampling/ procedure	Mean age (*SD*)	Age range	Males *n* (%)
1	US	Cicero	3,162	College	20 (3.7)	16-55	997(31.5)
2	US	Kwapil	1,556	College	19.5 (2.9)	16-54	363 (23.3)
3	Spain	Fonseca-Pedrero	1,123	College	20.2 (2)	18-29	224 (19.9)
4	US	Compton	1,190	College	20.9 (4)	16-52	284 (23.9)
5	US	Chmielewski	556	College	-	-	102 (18.3)
6	Mauritius	Raine	1,201	Birth cohort	23.4 (1.2)	21-27	688 (57.3)
7	Italian	Preti	649	College	24.3 (3.5)	19-38	305 (47)
8	Australia	Wuthrich	445	College	22.6 (6.3)	17-53	126 (28.3)
9	US	Cohen	1,458	College	19.3 (2.2)	16-53	531 (36.4)
10	Belgium	Larøi	357	General	25 (10.3)	17-55	110 (38.8)
11	Australia	Badcock	342	General	36.1 (11.6)	17-55	182 (53.2)
12	Belgium	Laloyaux	536	General	24.9 (8.1)	18-55	135 (25.2)
13	Tunisia	Mechri	458	College	20.4 (1.4)	18-29	137 (29.9)
14	New Zealand	Linscott	1,648	College	20.1 (3.1)	17-51	515 (30.3)
15	UK	Barkus	774	General	21.6 (4.4)	17-49	291 (37.6)
16	Australia	Barkus	1,144	College	-	-	326 (28.5)
17	US	Suhr	1,169	College	-		299 (27.3)
18	China	Chan	4,907	College	19.7 (1.6)	16-24	2973 (60.6)
19	Canada	Zhang	1,849	College	20.8 (2.9)	18-53	562 (30.4)
20	US	Zhang	1,386	MTurk	31.9 (9.5)	18-55	586 (42.3)
21	Greek	Tsaousis	1,041	General	32.4 (9.9)	18-55	390 (37.5)

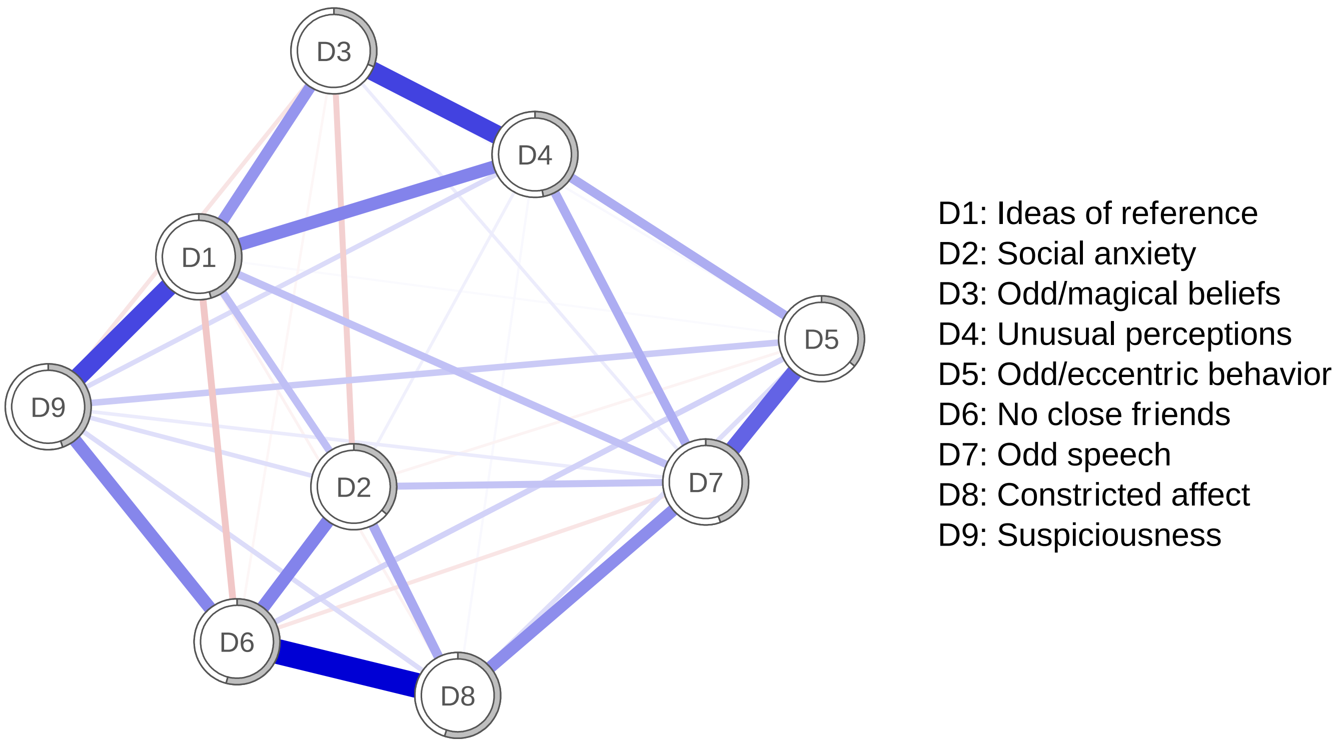


Figure 1. Gaussian graphical model of 9 schizotypal domains. Blue edges are positive associations, red edges negative ones. Thickness and saturation of edges depicts strength of associations. The filled part of the circle around each node depicts predictability: the variance of the nodes explained by all its neighbors.

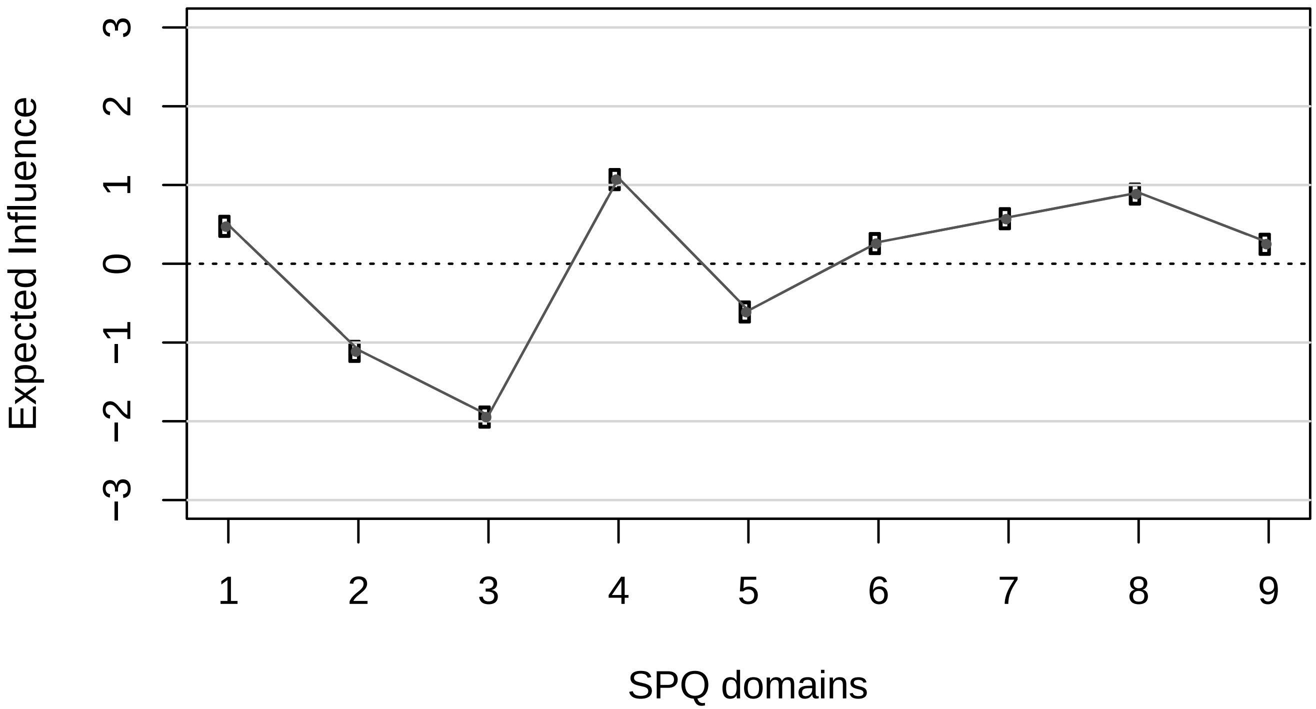


Figure 2. Expected Influence of the 9 domains schizotypal network depicted in Figure 1.

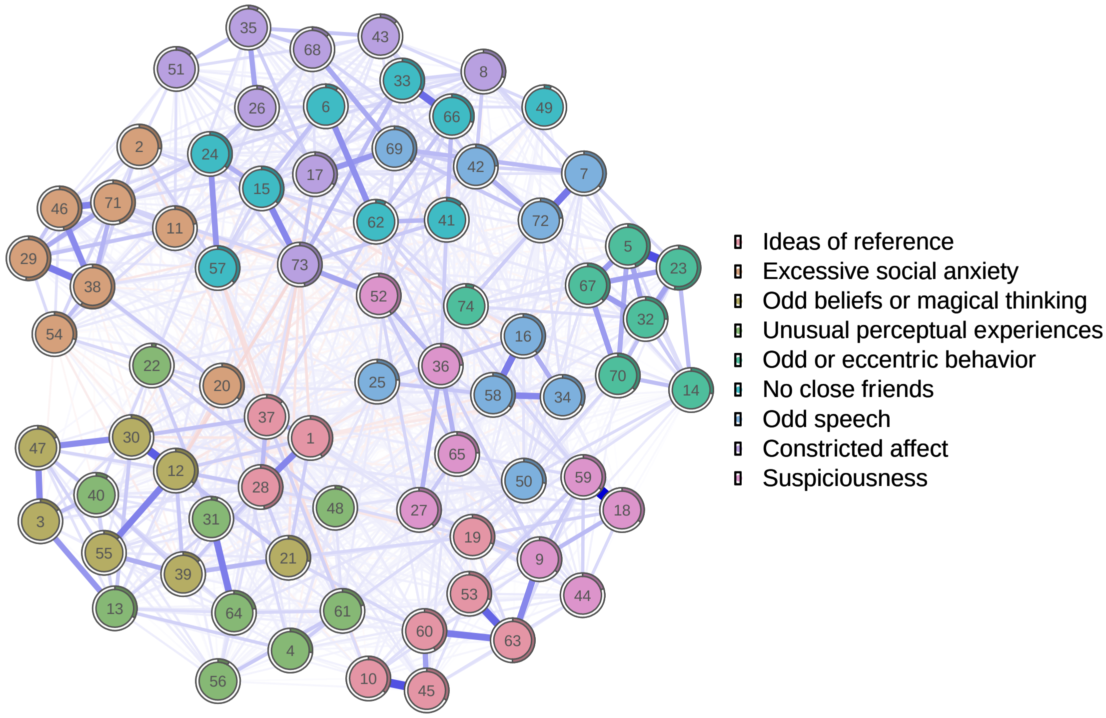


Figure 3. Ising Model of 74 SPQ items. Blue edges are positive associations, red edges negative ones. Thickness and saturation of edges depicts strength of associations. The filled part of the circle around each node depicts predictability: the variance of the nodes explained by all its neighbors. The numbers refer to the SPQ items provided in supplementary material.

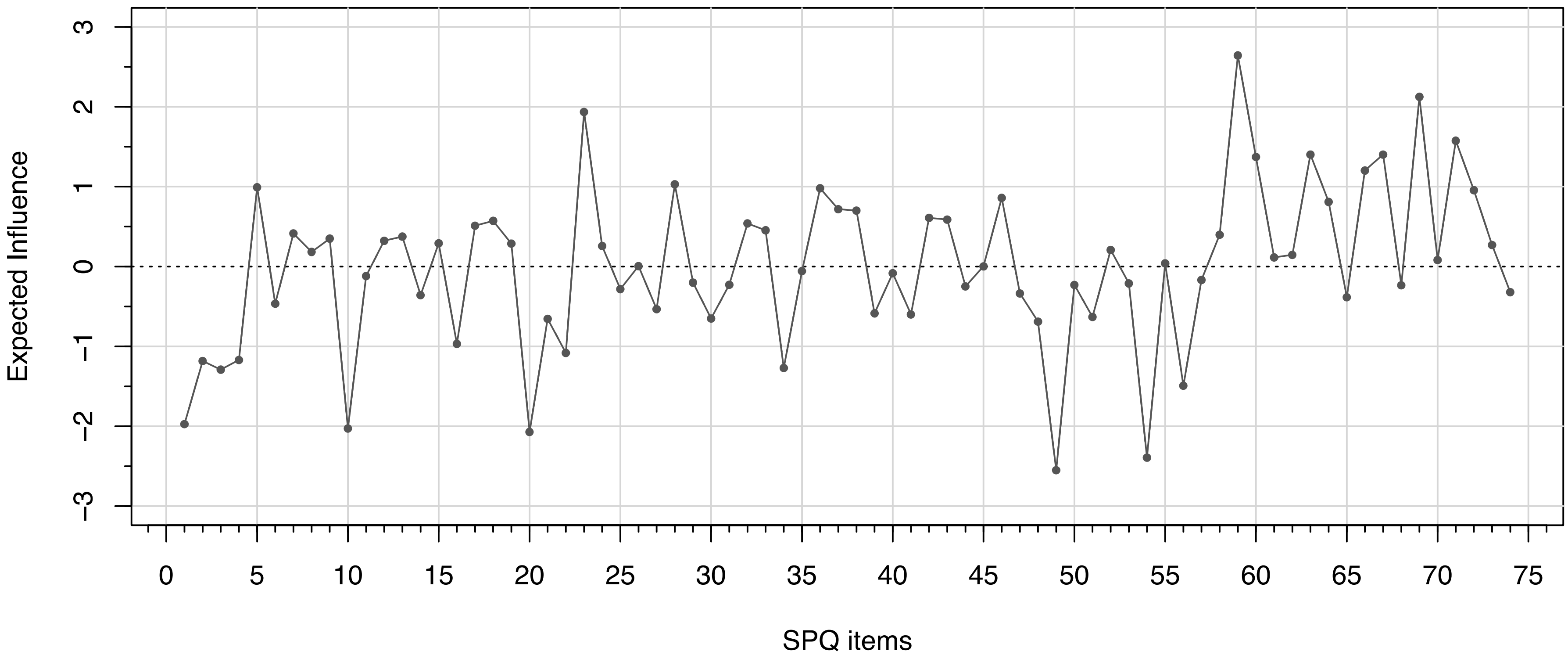


Figure 4. Expected Influence of the full 74 SPQ item network depicted in Figure 3.

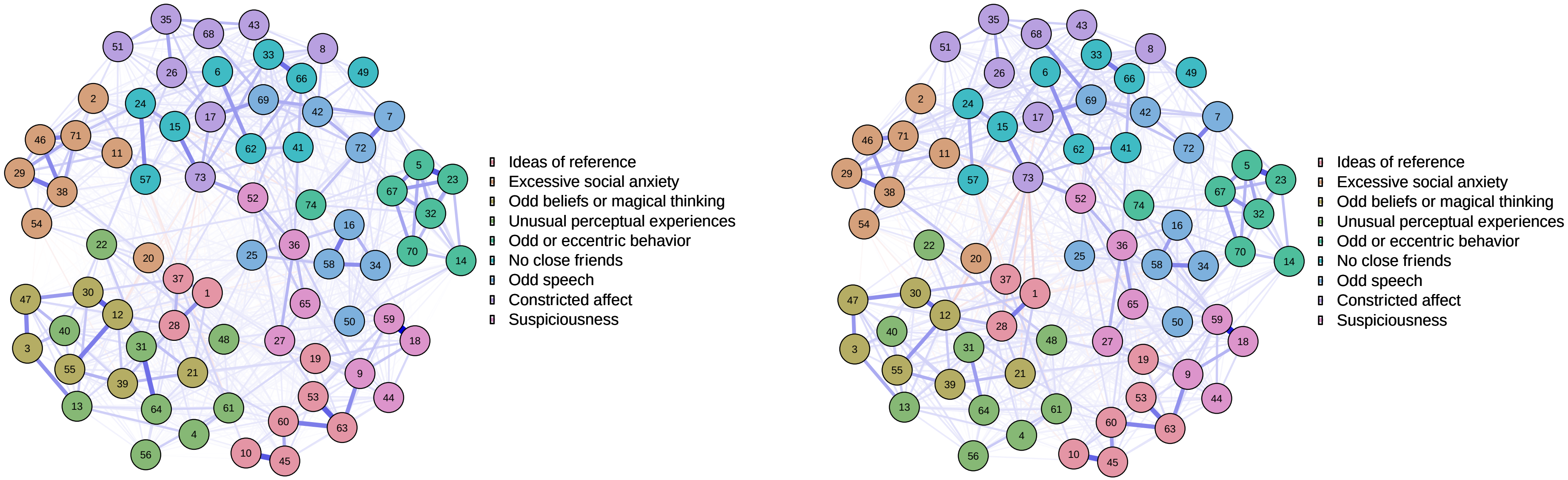


Figure 5. Ising Models of women (left) and men (right). Blue edges are positive associations, red edges negative ones. Thickness and saturation of edges depicts strength of associations. The numbers refer to the SPQ items provided in supplementary material.

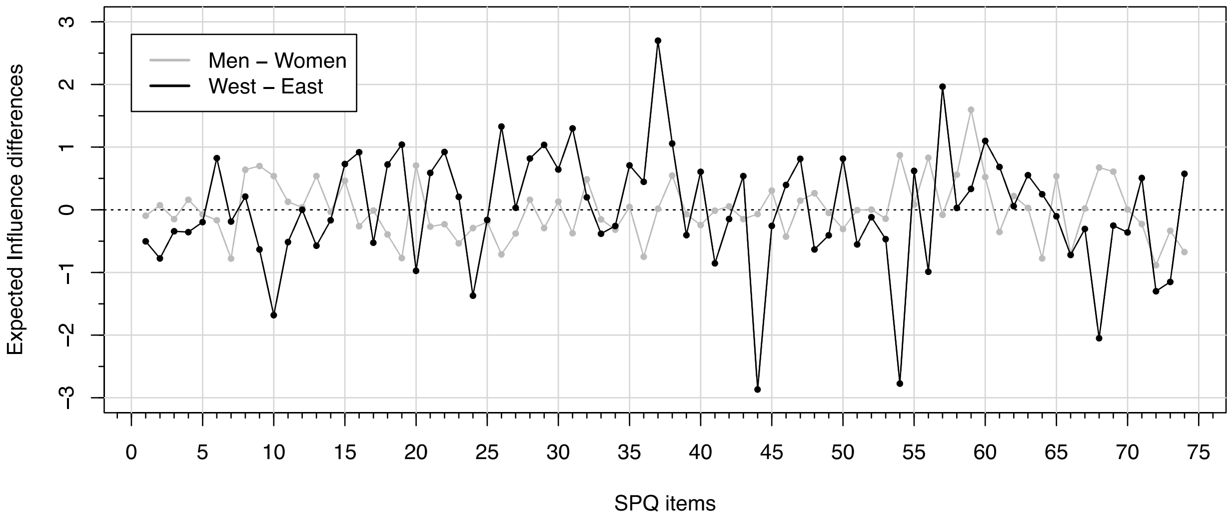


Figure 6. Differences of the Expected Influence estimates for men minus women and North America (“West”) minus China (“East”). E.g., the positive value on item 59 implies that it was more central in the Ising Model estimated in men than the Ising Model estimated in women.

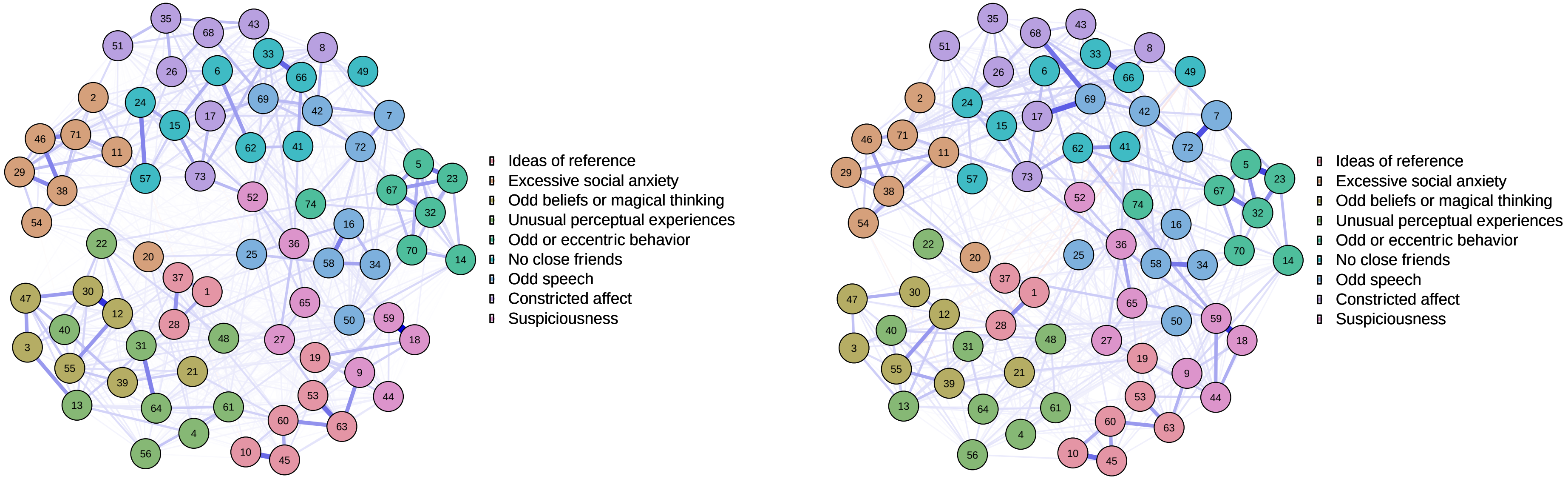


Figure 7. Ising Models of North America (left) and China (right). Blue edges are positive associations, red edges negative ones. Thickness and saturation of edges depicts strength of associations. The numbers refer to the SPQ items provided in supplementary material.

Supplementary Materials for:

The network structure of schizotypal personality traits

Fonseca-Pedrero et al., *Schizophrenia Bulletin*

This document contains:

1. Information about all the samples in the study
2. Items and subscales of the Schizotypal Personality Questionnaire (SPQ)
3. The results of the bootstrapping pipeline using the R-package *bootnet* explained in detail in: Epskamp, S., Borsboom, D., & Fried, E. I. (2017). Estimating Psychological Networks and their Accuracy: A Tutorial Paper. *Behavior Research Methods*, 1–34. DOI 10.3758/s13428-017-0862-1, for the 9-item domain network and the 74-node item networks. For the comparisons of men vs. women, and North America vs. China, we present stability analyses for the smaller sample each: men and China. Edge weights and centrality difference test as not depicted due to the large number of symptoms (plots become uninformative). We are happy to share all individual parameters upon request.
4. Mean item differences for men vs. women and North America vs. China

1) Study procedure

Study 1 (D. Cicero). Undergraduates at a large Pacific, public university participated in exchange for partial completion of a course requirement.
Study 2 (T. Kwapil). University of North Carolina at Greensboro received course credit for participating. The questionnaires were completed by all participants in mass screening sessions during five semesters.
Study 3 (E. Fonseca-Pedrero). The Spanish sample was composed of university students enrolled in different courses at three Spanish institutions, the University of Oviedo (Educational Sciences and Psychology), the University of La Rioja (Educational Sciences), and the University of La Laguna (Psychology). Participants received no type of incentive for taking part.
Study 4 (M. Compton). Participants who were enrolled in introductory psychology classes of Georgia State University were invited to volunteer via a recruitment statement posted to an online program used to manage the undergraduate research participation pool. Participating students received course credit, though students were not required to participate in this or any other study.
Study 5 (M. Chmielewski). Participants were undergraduate students who were enrolled in various psychology courses at the University of Iowa.
Study 6 (A. Raine). Participants consisted of a sample of adults in the community in Mauritius undergraduates who received course credit for filling out the SPQ derived from a birth cohort, and were representative of the country as a whole on gender and ethnicity
Study 7 (A. Preti). This study was part of the Cagliari – Psychosis: Investigation on Risk Emergence (CAPIRE). The sample included participants from the first two waves of the CAPIRE study and targeting young adults attending the Cagliari University. These undergraduate samples were enrolled via a snowball procedure. Participation was voluntary and no compensation was given for taking part

in the study.
Study 8 (V. Wuthrich). Psychology students at the Macquarie Centre for Cognitive Science, Macquarie University, Sydney (Australia) participated in return for a course credit. All participants completed the computerized Likert version as part of other studies.
Study 9 (A. Cohen). Participants were undergraduate students enrolled at Louisiana State University. Freshmen and sophomore students (N = 8,591) were approached by email to participate in an on-line survey, and offered a chance to win monetary compensation as part of a lottery (10 prizes of $25US). A five-point Likert scale of the full SPQ was administered in either computerized or standard paper and pencil formats.
Study 10 (F. Larøi). Participants were selected from the general non clinical population.
Study 11 (J. C. Badcock and A Jablensky). Participants consisted of a randomly selected sample of adults from the general community in Perth, Western Australia, taking part in the Western Australian Study of Schizophrenia. Participants were recruited by advertising or telephone screening in the local area. Inclusion criteria included age older than 18 years and fluency in English. Exclusion criteria included either a personal or family history of psychotic illness or a history of substance abuse/dependence, neurological disorder or head injury. Questionnaires were completed either at the study site or at participants' homes.
Study 12 (J. Laloyaux). Participants were selected from general population. The data are from an online study. Any person with a psychiatric disorder was excluded (based on self-report) from the study.
Study 13 (A. Mechri). Participants were Tunisian students from the Faculty of Medicine and the Health Sciences High School of Monastir. Of 800 copies of the SPQ that were distributed, 524 were returned, of which 34 were not completely filled. The participation rate was 61.25%.
Study 14 (R. Linscott). Participants were New Zealand born undergraduates. There were no exclusion criteria related to psychosis, other psychopathology, or substance use. All participants completed a range of

questionnaires and tasks, including the SPQ.
Studies 15 and 16 (E. Barkus). Participants were from the University of Wollongong, Australia.
Study 17 (J. Suhr). Participants were unselected undergraduates from Ohio University enrolled in various psychology courses, who completed a large group screening that included many other psychological measures. Participants received course credit for participation.
Study 18 (R. C.J. Chan). Undergraduates of five local universities in Beijing, Guangzhou, and Zhuhai were approached to take part in the current study. They were recruited by the mental health counseling centers of each university to take part in a survey of "everyday worries about others". The survey was conducted in classrooms under the supervision of a counselor from the mental health counseling centers of the universities and research assistants.
Study 19 (L. Zang). The participants completed an online questionnaire. The participants were recruited from the University of British Columbia (UBC) student community through the UBC Psychology human subject participant pool. Students were compensated with course credit for their participation.
Study 20 (L. Zang). Participants were North Americans recruited through the Amazon Mechanical Turk website.
Study 21 (I. Tsaousis). Participants were collected from a community sample as part of the Prefrontally-Mediated Endophenotypes (PreMES) study. Exclusion criteria included a personal history of head trauma, medical, or neurological condition; use of prescribed/recreational drugs; and having a first-degree relatives with a history of a DSM Axis I disorder.

2) Items and subscales of the Schizotypal Personality Questionnaire (SPQ)

Ideas of Reference
1. Do you sometimes feel that things you see on the TV or read in the newspaper have a special meaning for you?
10. I am aware that people notice me when I go out for a meal or to see a film.
19. Do some people drop hints about you or say things with a double meaning?
28. Have you ever noticed a common event or object that seemed to be a special sign for you?
37. Do you sometimes see special meanings in advertisements, shop windows, or in the way things are arranged around you?
45. When shopping do you get the feeling that other people are taking notice of you?
53. When you see people talking to each other, do you often wonder if they are talking about you?
60. Do you sometimes feel that other people are watching you?
63. Do you sometimes feel that people are talking about you?

Excessive Social Anxiety
2. I sometimes avoid going to places where there will be many people because I will get anxious.
11. I get very nervous when I have to make polite conversation.
20. Do you ever get nervous when someone is walking behind you?
29. I get anxious when meeting people for the first time.
38. Do you often feel nervous when you are in a group of unfamiliar people?
46. I feel very uncomfortable in social situations involving unfamiliar people.
54. I would feel very anxious if I had to give a speech in front of a large group of people.
71. I feel very uneasy talking to people I do not know well.

Odd Beliefs or Magical Thinking
3. Have you had experiences with the supernatural?
12. Do you believe in telepathy (mind-reading)?
21. Are you sometimes sure that other people can tell what you are thinking?
30. Do you believe in clairvoyancy (psychic forces, fortune telling)?
39. Can other people feel your feelings when they are not there?
47. Have you had experiences with astrology, seeing the future, UFOs, ESP, or a sixth sense?
55. Have you ever felt that you are communicating with another person telepathically (by mind-reading)?

Unusual Perceptual Experiences
4. Have you often mistaken objects or shadows for people, or noises for voices?
13. Have you ever had the sense that some person or force is around you, even though you cannot see anyone?
22. When you look at a person, or yourself in a mirror, have you ever seen the face change right before your eyes?
31. I often hear a voice speaking my thoughts aloud.
40. Have you ever seen things invisible to other people?
48. Do everyday things seem unusually large or small?
56. Does your sense of smell sometimes become unusually strong?
61. Do you ever suddenly feel distracted by distant sounds that you are not normally aware of?
64. Are your thoughts sometimes so strong that you can almost hear them?

Odd or Eccentric Behavior
5. Other people see me as slightly eccentric (odd).
14. People sometimes comment on my unusual mannerisms and habits.
23. Sometimes other people think that I am a little strange.
32. Some people think that I am a very bizarre person.
67. I am an odd, unusual person.
70. I have some eccentric (odd) habits.
74. People sometimes stare at me because of my odd appearance.

No Close Friends
6. I have little interest in getting to know other people.
15. I prefer to keep myself to myself.
24. I am mostly quiet when with other people.
33. I find it hard to be emotionally close to other people.
41. Do you feel that there is no one you are really close to outside of your immediate family, or people you can confide in or talk to about personal problems?
49. Writing letters to friends is more trouble than it is worth.
57. I tend to keep in the background on social occasions.
62. I attach little importance to having close friends.
66. Do you feel that you cannot get "close" to people?

Odd Speech
7. People sometimes find it hard to understand what I am saying.
16. I sometimes jump quickly from one topic to another when speaking.
25. I sometimes forget what I am trying to say.
34. I often ramble on too much when speaking.
42. Some people find me a bit vague and elusive during a conversation.
50. I sometimes use words in unusual ways.
58. Do you tend to wander off the topic when having a conversation?
69. I find it hard to communicate clearly what I want to say to people.
72. People occasionally comment that my conversation is confusing.

Constricted Affect
8. People sometimes find me aloof and distant.
17. I am not good at expressing my true feelings by the way I talk and look.
26. I rarely laugh and smile.
35. My "nonverbal" communication (smiling and nodding during a conversation) is not very good.
43. I am poor at returning social courtesies and gestures.
51. I tend to avoid eye contact when conversing with others.
68. I do not have an expressive and lively way of speaking.
73. I tend to keep my feelings to myself.

Suspiciousness
9. I am sure I am being talked about behind my back.
18. Do you often feel that other people have it in for you?
27. Do you sometimes get concerned that friends or coworkers are not really loyal or trustworthy?
36. I feel I have to be on my guard even with friends.
44. Do you often pick up hidden threats or put-downs from what people say or do?
52. Have you found that it is best not to let other people know too much about you?
59. I often feel that others have it in for me.

65. Do you often have to keep an eye out to stop people from taking advantage of you?

3.1) 9-node domain network stability analyses

Note that bootstrapping routines pertaining to Expected Influence (EI) only became available the very day we needed to resubmit the revision of this paper to Schizophrenia Bulletin (February 26th 2018). This did not give us sufficient time to repeat all analysis for the 74-item networks, which required a high-performance computer cluster. We therefore report degree, betweenness, and closeness centrality for the 74-item networks and not EI. However, EI should perform very similar to degree, as it is (unlike betweenness and closeness) not computed on the shortest path lengths, but simply the sum of edges (vs sum of absolute edges, degree).

We did, however, find the time to update all our bootnet analyses of the 9-item domain network to focus on EI.

Figure S1. Bootstrapped edge-weights for the total sample (9-node domain network). The red line depicts point estimates of the edge weights, the grey bar 95% confidence intervals.

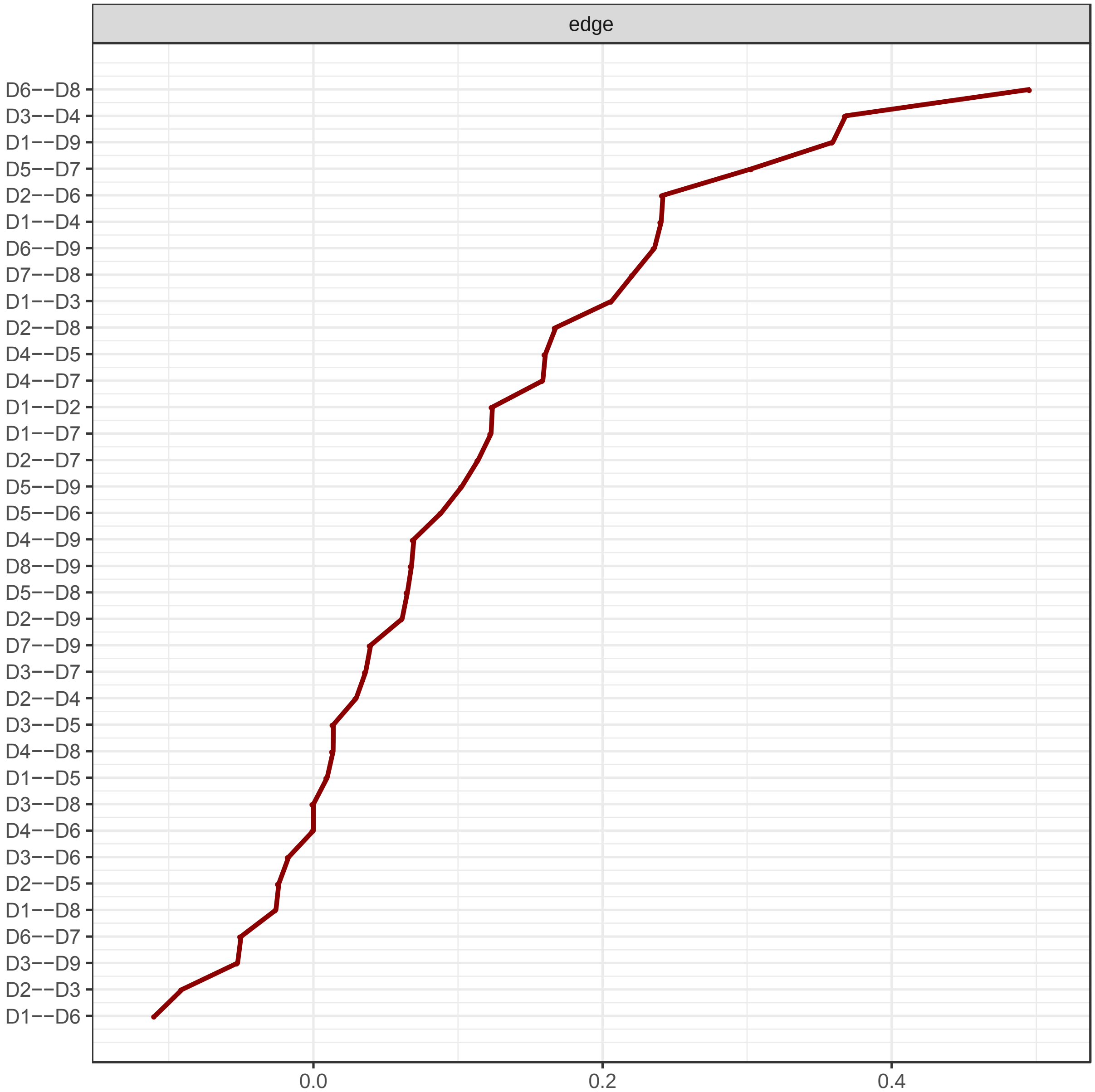


Figure S2. Edge weights difference test, i.e. bootstrapped significance (α = 0.05) between edges (9-node domain network). Each row and column indicates an edge. Black boxes represent significant differences and gray boxes represent non-significant differences. The color in the diagonal corresponds with the edge colors in the original network figures. This test does not control for multiple testing, and results should be interpreted with care.

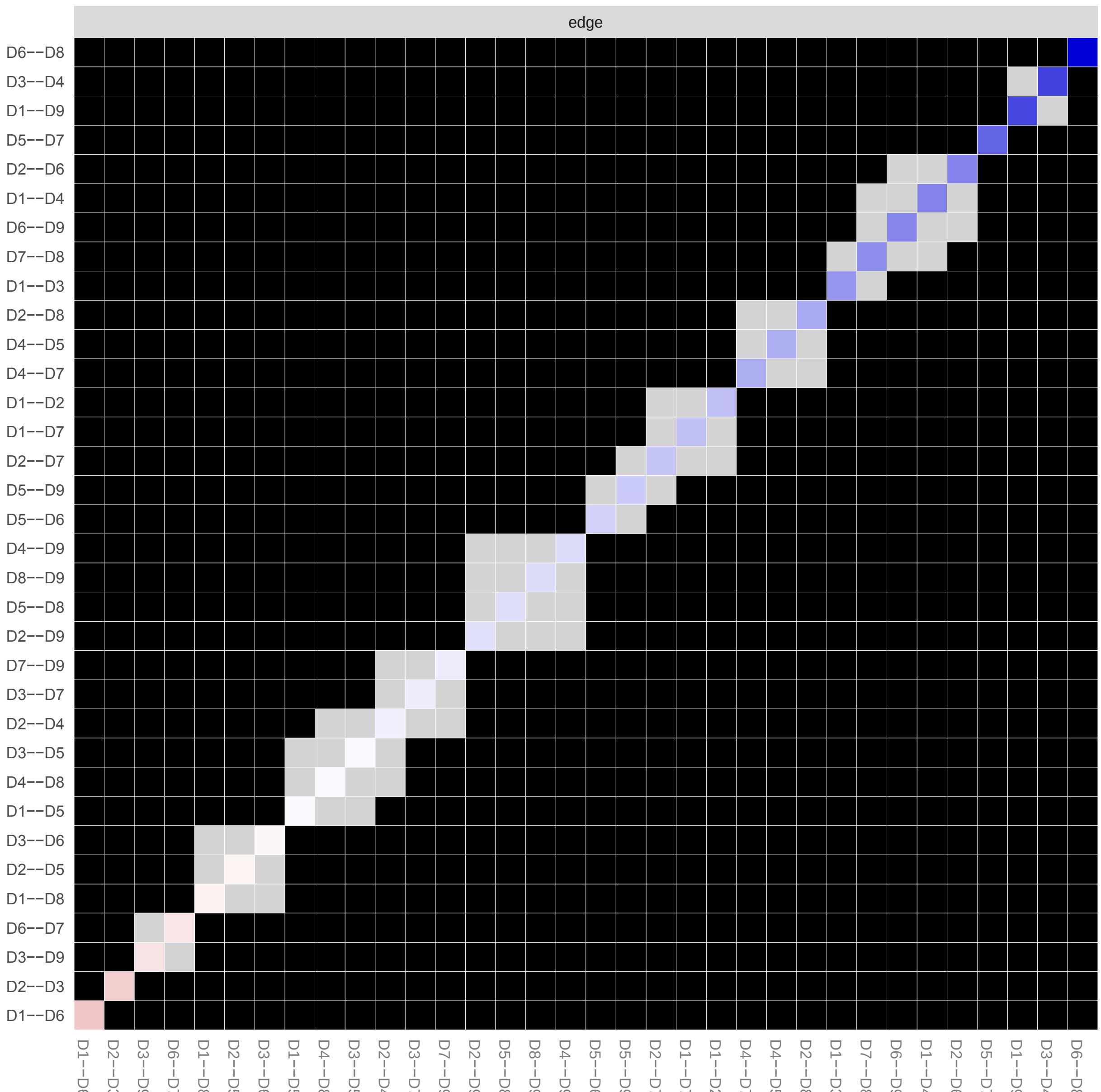
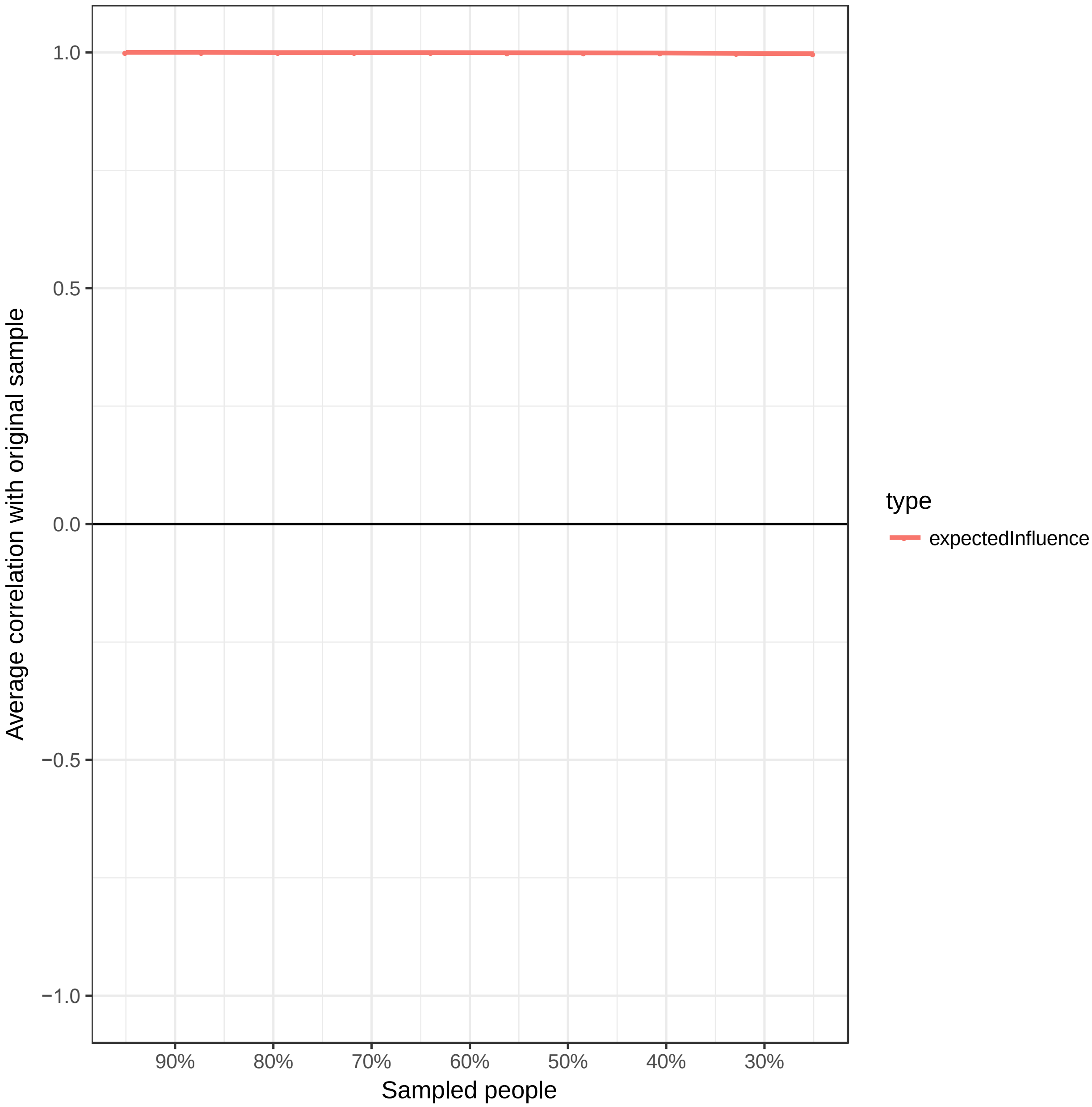
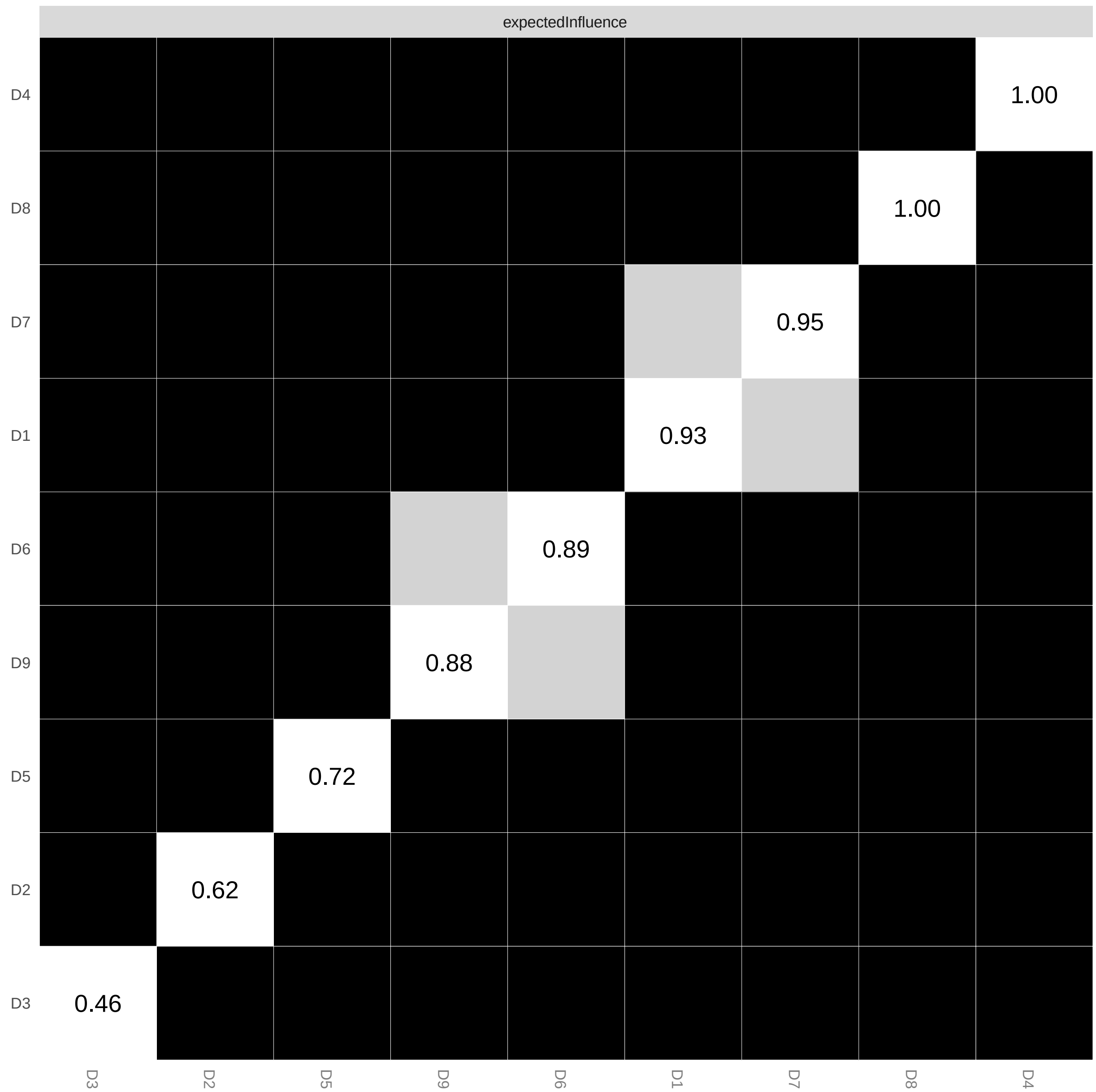


Figure S3. The correlation between the original EI, and EI after dropping a percentage of subjects at random from the data in the male subsample (9-node domain network). The stability centrality coefficient (i.e. % of cases that can be dropped to retain with 95% certainty a correlation of 0.7 of centrality between network estimated on original data and network estimated on subsampled data) for EI was 0.75.



1.0
0.5
0.0
−0.5
−1.0
Average correlation with original sample
90%
80%
70%
60%
50%
40%
30%
Sampled people
type
expectedInfluence

Figure S4. Centrality difference test; similar to Figure S2, but instead for EI values.



3.2) 74-node item network stability analyses

Figure S5. Bootstrapped edge-weights for the total sample (74-node item network). The red line depicts point estimates of the edge weights, the grey bar 95% confidence intervals.

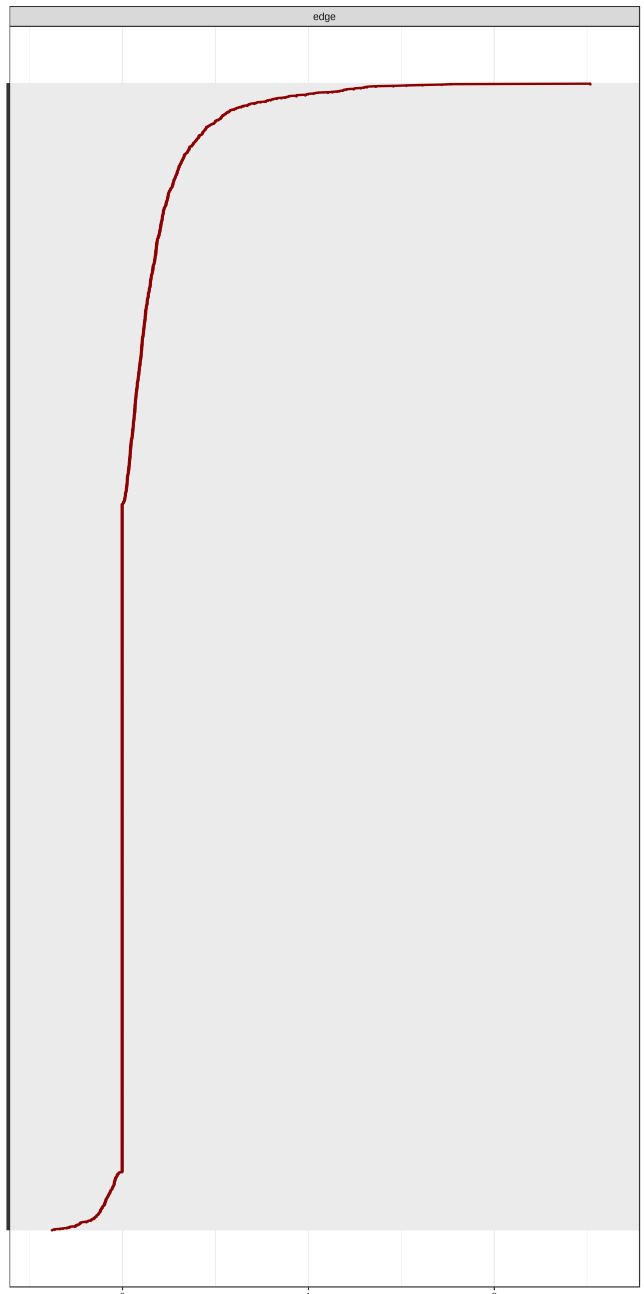


Figure S6. Bootstrapped edge-weights for the male subsample (74-node item network). The red line depicts point estimates of the edge weights, the grey bar 95% confidence intervals.

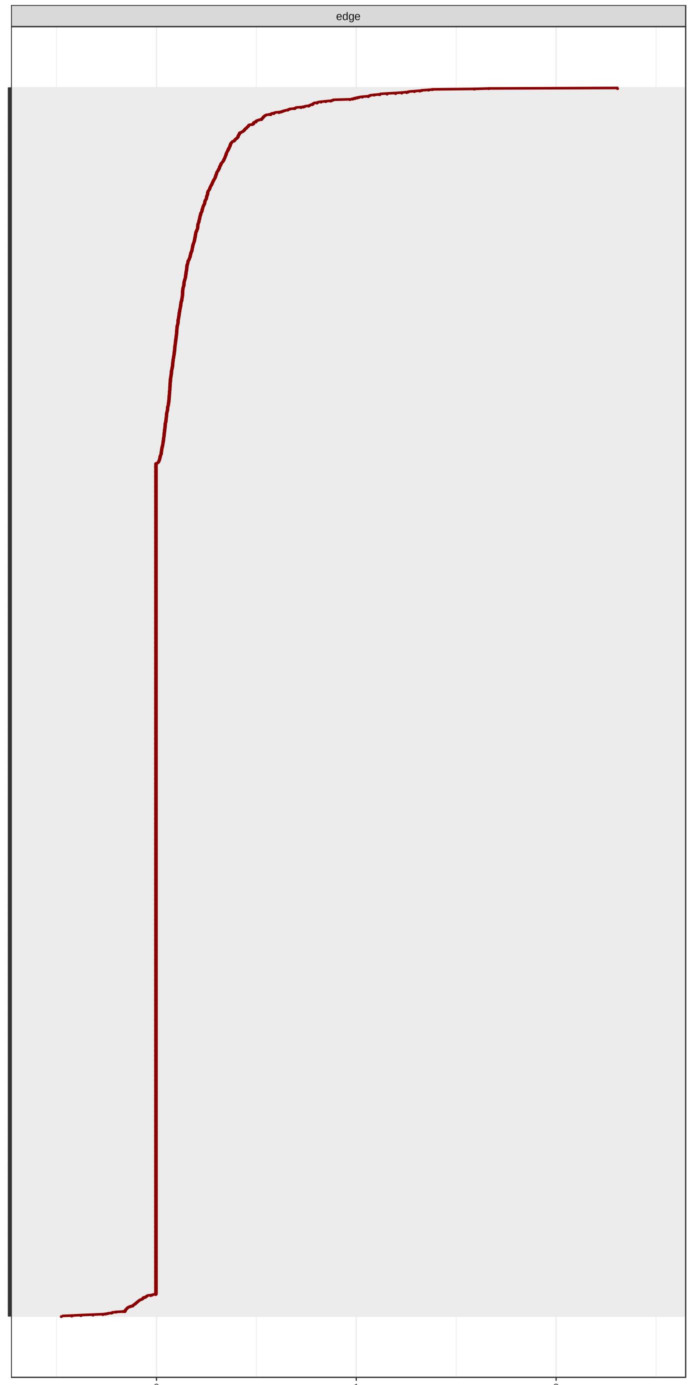


Figure S7. Bootstrapped edge-weights for the China subsample (74-node item network). The red line depicts point estimates of the edge weights, the grey bar 95% confidence intervals.

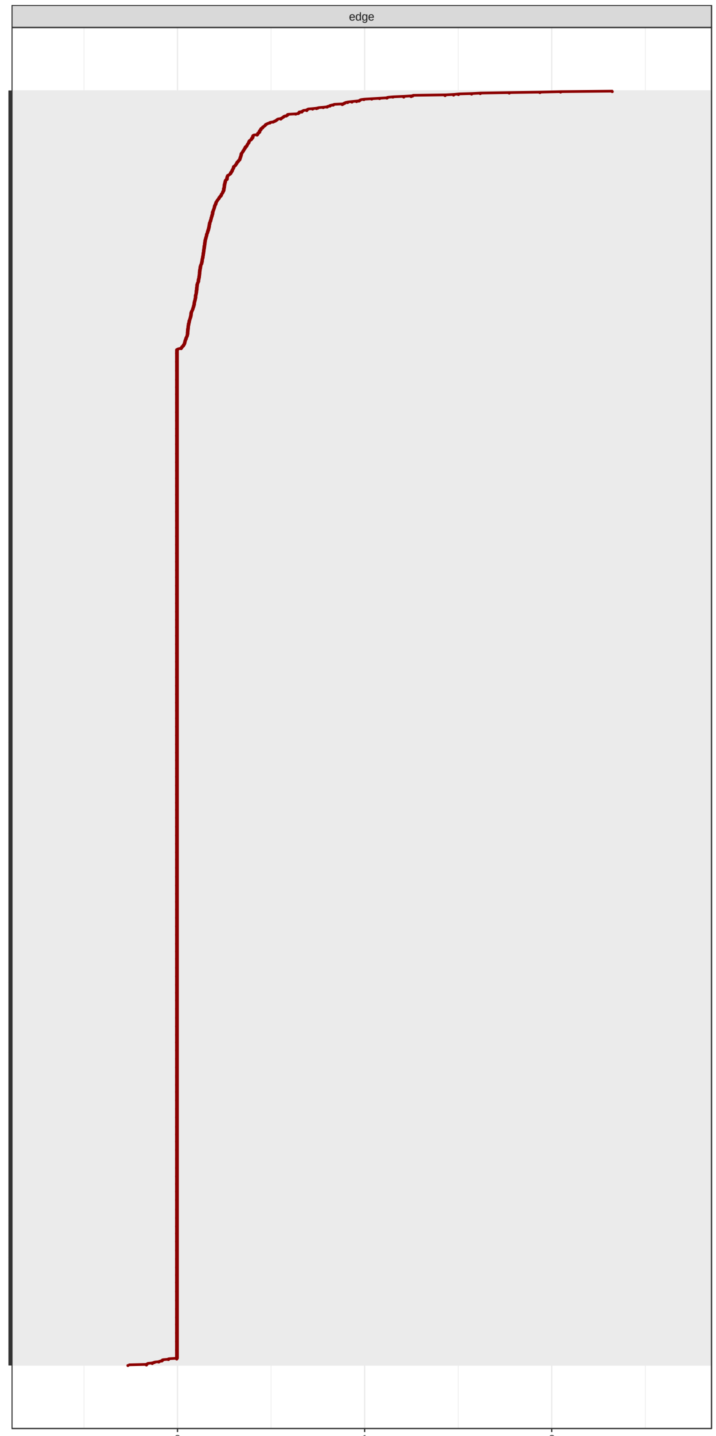


Figure S8. The correlation between the original centrality index and the centrality index after dropping a percentage of subjects at random from the data in the full dataset (74-node item network). Stability centrality coefficients (i.e. % of cases that can be dropped to retain with 95% certainty a correlation of 0.7 of centrality between network estimated on original data and network estimated on subsampled data) for the total dataset were 0.75 for betweenness, closeness and degree.

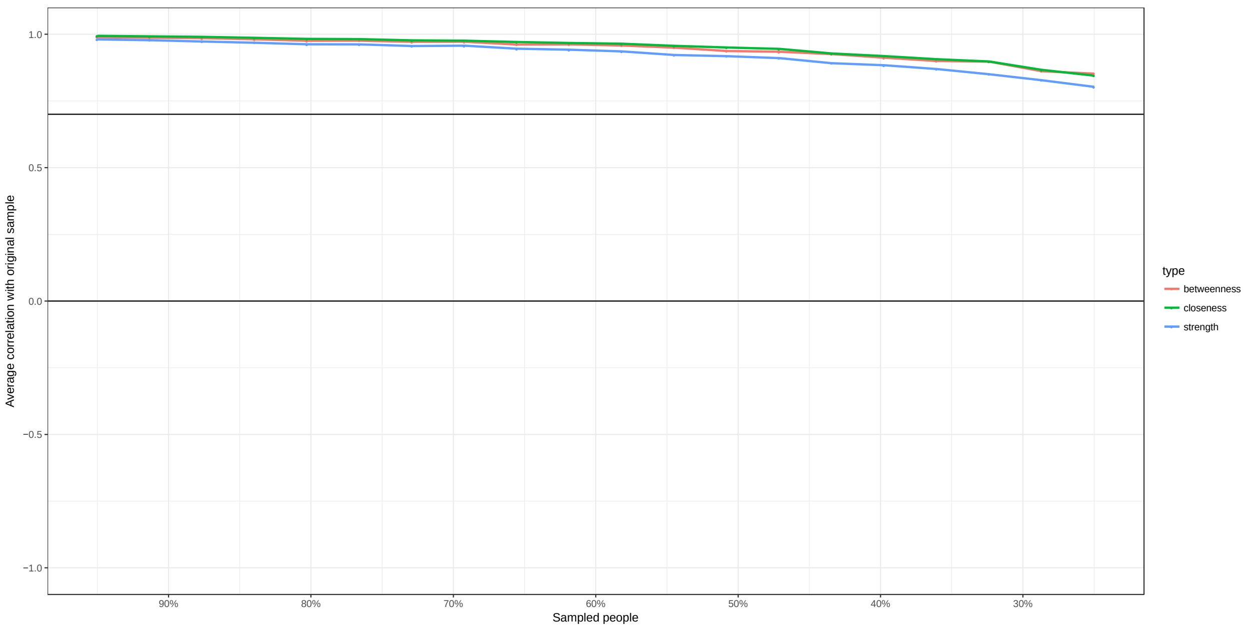


Figure S9. The correlation between the original centrality index and the centrality index after dropping a percentage of subjects at random from the data in the male subsample (74-node item network). Stability centrality coefficients (i.e. % of cases that can be dropped to retain with 95% certainty a correlation of 0.7 of centrality between network estimated on original data and network estimated on subsampled data) for the male subsample were 0.75 for betweenness, closeness and degree.

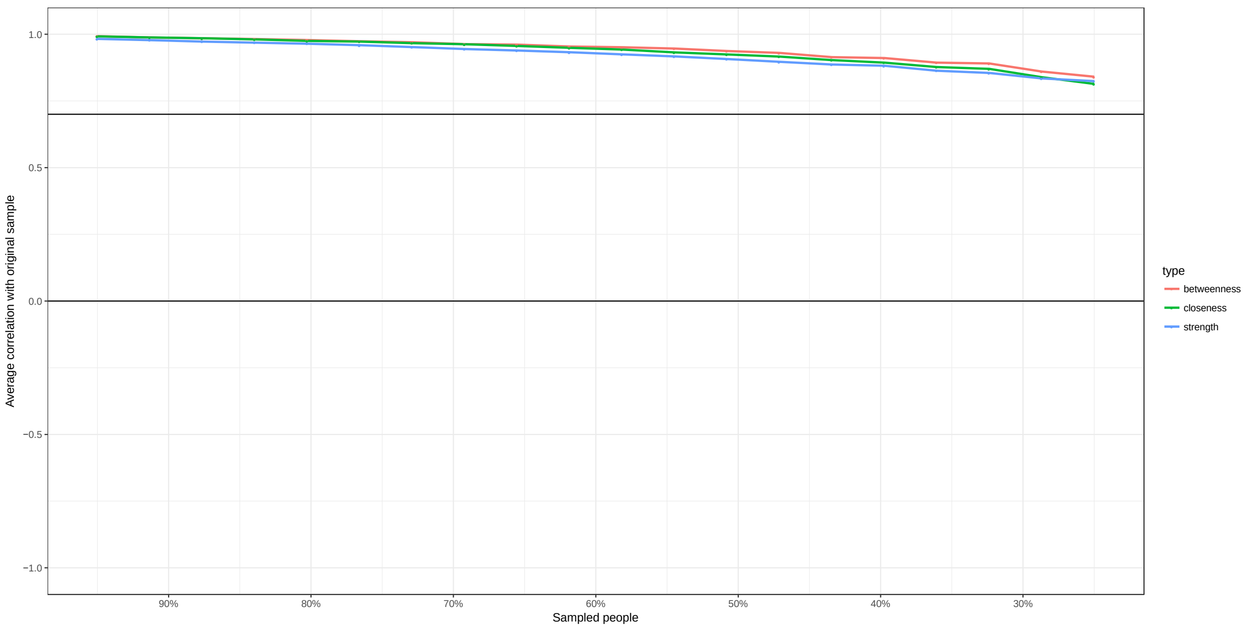
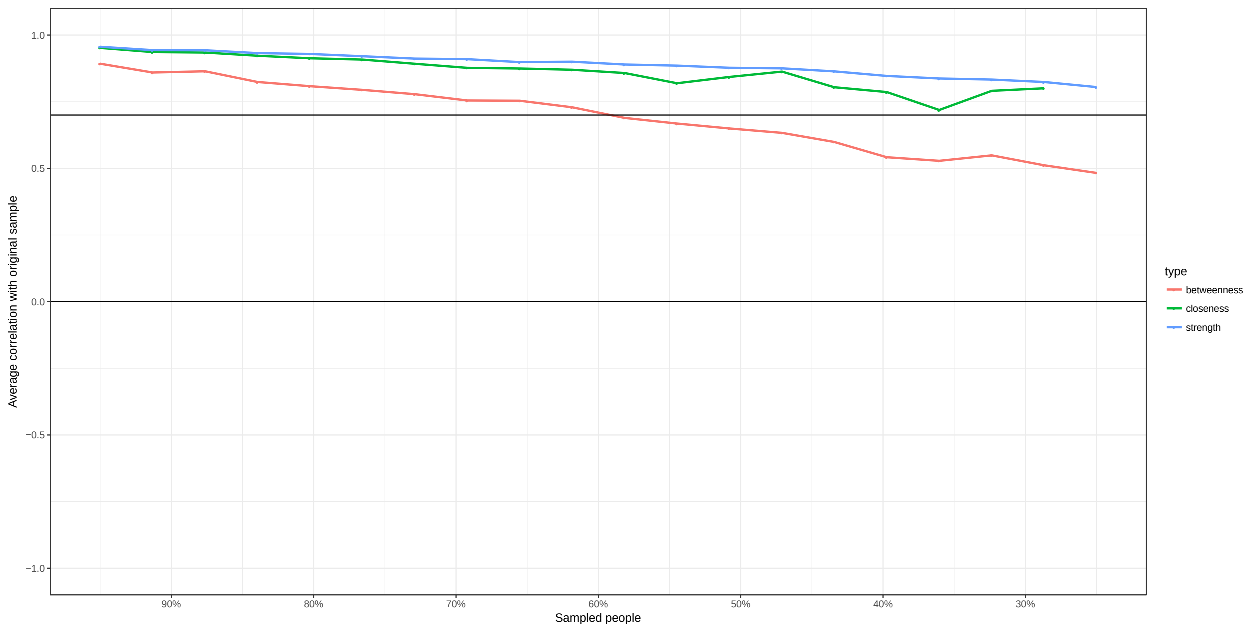


Figure S10. The correlation between the original centrality index and the centrality index after dropping a percentage of subjects at random from the data in the China subsample (74-node item network). Stability centrality coefficients (i.e. % of cases that can be dropped to retain with 95% certainty a correlation of 0.7 of centrality between network estimated on original data and network estimated on subsampled data) for the China subsample was 0.16 for betweenness, 0.12 for closeness and 0.75 for degree.



4) Item mean differences

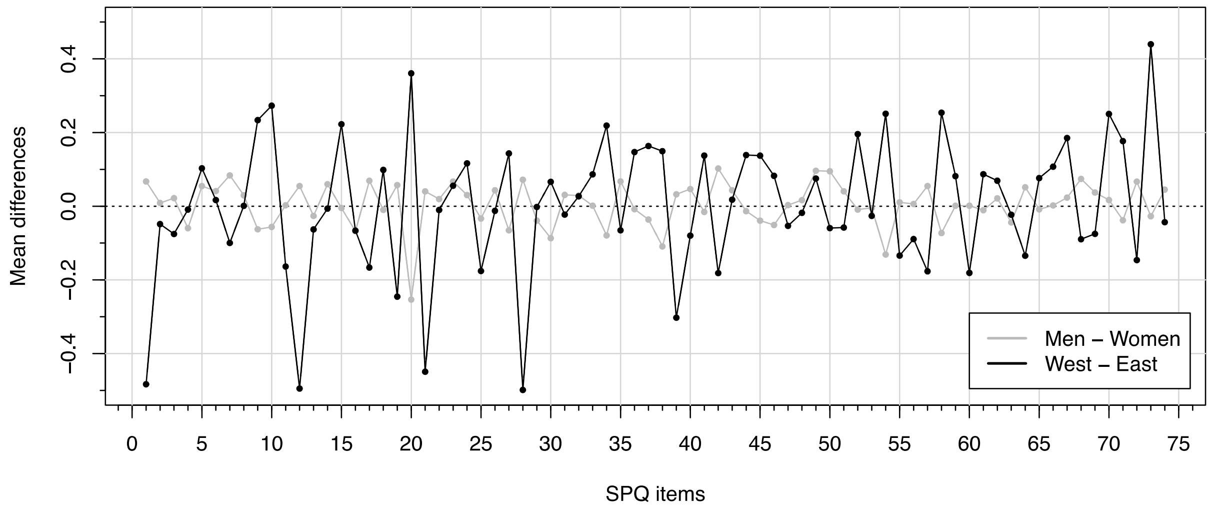


Figure S11. Mean item differences for men minus women and North America ("West") minus China ("East"). E.g., the positive value in black on item 20 implies that the mean item value in the West dataset was about 0.4 points higher than in the East dataset.