



Revisiting the overlap between autistic and schizotypal traits in the non-clinical population using meta-analysis and network analysis

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ABSTRACT

The present study aimed to explore the relationship between autistic and schizotypal traits in the non-clinical population. We first conducted a meta-analysis to quantify the correlation between self-reported autistic traits and the three dimensions of schizotypal traits (positive, negative and disorganization). The strongest correlation was found between autistic traits and negative schizotypal traits ($r = 0.536$, 95% CI [0.481, 0.586]), followed by the disorganization ($r = 0.355$, 95% CI [0.304, 0.404]) and positive ($r = 0.256$, 95% CI [0.208, 0.302]) dimensions. To visualize the partial correlations between dimensional behavioural traits, we constructed a network model based on a large sample of college students ($N = 2469$). Negative schizotypal traits were strongly correlated with autistic social/communicative deficits, whereas positive schizotypal traits were inversely correlated with autistic-like traits, lending support to the psychosis-autism diametrical model. Disentangling the overlapping and diametrical structure of autism and schizophrenia may help to elucidate the aetiology of these two neurodevelopmental disorders.

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1. Introduction

The relationship between schizophrenia spectrum disorders (SSD) and autism spectrum disorders (ASD) is controversial. On the one hand, these two neurodevelopmental disorders share considerable overlaps in social-cognitive dysfunctions, including impaired emotion perception from facial expressions (Okada et al., 2015; Rhodes et al., 2018) and bodily cues (Hubert et al., 2007), deficits in theory of mind (Baron-Cohen, 2000; Sprong et al., 2007), social anhedonia (Blanchard et al., 2001; Chevallier et al., 2012; Novacek et al., 2016) and poor communication skills (Muralidharan et al., 2018; Tager-Flusberg et al., 2005). Convergent evidence also indicates common genetic (Carroll and Owen, 2009) and environmental (Kerns et al., 2015; McLaughlin et al., 2012) risk factors for ASD and SSD. On the other hand, Crespi and Badcock's theory places SSD, especially those with positive symptoms (e.g., paranoia, unusual perceptual experience and magical ideation) and ASD at opposite ends of a single spectrum (Crespi and Badcock, 2008). According to this perspective, social cognition and mentalization are underdeveloped in ASD

(reduced empathy and mental-state modelling), but hyper-developed to dysfunction in SSD (over-attribution of intentions and paranoia) (Crespi and Badcock, 2008). Further evidence for this diametrical model includes divergent patterns of brain development (e.g., overgrowth in ASD but undergrowth in SSD) and opposite effects of the same genes implicated in both disorders (Crespi et al., 2009). Moreover, children with comorbid ASD and SSD have been found to outperform both ASD and SSD groups in attentional set-shifting and social-pragmatic abilities, indicating attenuated impairment and compensatory effect (Abu-Akel et al., 2018).

One useful tool to explore the complex relationship between ASD and SSD is to study autistic and schizotypal traits in the non-clinical population, which avoids the confounding effects of illness duration and medication exposure. Similar to the clinical symptoms found in patients with schizophrenia, schizotypal traits also have a multidimensional structure consisting of at least three components (e.g., cognitive-perceptual, interpersonal and disorganization schizotypal traits) (Raine et al., 1994). On the other hand, individuals with elevated autistic traits are characterized by reduced social reciprocity, pragmatic use of language and behavioural inflexibility (Losh et al., 2008).

Research has shown a moderate positive correlation between autistic and global schizotypal traits (*Gong et al., 2017; *Hurst et al.,

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2007), with the strongest correlation found between the social/interpersonal facets of autistic traits and negative schizotypal traits (*Mealey et al., 2014; *Russell-Smith et al., 2011). Disorganization schizotypal traits also demonstrate a moderate-to-weak correlation with autistic-like social and communicative impairments (*Dinsdale et al., 2013; *Hurst et al., 2007). However, inconsistent findings make it difficult to understand the relationship between autistic and positive schizotypal traits. While most studies found a weak but significant correlation between self-reported autistic and positive schizotypal traits (*Russell-Smith et al., 2011; *Wakabayashi et al., 2012), others failed to find any association (*Claridge and McDonald, 2009; Rawlings and Locarnini, 2008). Moreover, there is increasing evidence supporting the diametrical autism-psychosis model. For example, autistic and positive schizotypal traits may have opposing effects on perspective-taking abilities (*Abu-Akel et al., 2015) and saliency cost (Abu-Akel et al., 2017), such that co-occurrence may have a sub-additive effect where individuals with high levels of both autistic and positive schizotypal traits perform similarly to those with low levels of both traits. Other opposing cognitive and behavioural patterns between autistic and positive schizotypal traits include local vs global processing (Russell-Smith et al., 2010), reduced vs increased perception of agency (Gray et al., 2011) and long-term vs short-term mating strategy (*Del Giudice et al., 2010). Factor analysis of a mixture of scales measuring autistic and schizotypal traits suggests that after extracting a social difficulty phenotype shared by both autistic and schizotypal traits, the second principal component has opposite loadings from positive schizotypal to autistic trait subscales, with disorganization and negative schizotypal traits situated in between the diametrical psychotic–autistic continuum (Crespi and Hurd, 2015; *Del Giudice et al., 2014; *Dinsdale et al., 2013).

Based on the above findings, some researchers argue that ASD and the negative dimension of SSD may be situated at one extreme, while the positive dimension of SSD is situated at the other extreme of a continuum (Tordjman, 2008). However, no meta-analysis has systematically examined the relationship between autistic-like traits and global schizotypal traits, let alone the direction (negative or positive) and strength of correlations when dividing schizotypal traits into positive, negative and disorganization dimensions. Therefore, we conducted two independent but related studies to examine this issue. We first conducted a meta-analysis to quantitatively analyze the associations between self-reported autistic and schizotypal traits. We also examined the potential moderating effects of age, gender, ethnicity and types of measurement used. Then we used empirical data, which were previously reported in *Gong et al. (2017)'s study to test the diametrical model of ASD and SSD. Exploratory factor analysis (EFA) of scores on a set of scales capturing autistic and schizotypal traits was conducted to examine whether a clear-cut autistic-psychosis diametrical component can be found as in previous research (Crespi and Hurd, 2015; *Del Giudice et al., 2014; *Dinsdale et al., 2013). Network analysis (Borsboom and Cramer, 2013) was then conducted to further illustrate how different dimensions of schizotypal and autistic traits interact with each other. The network approach is a novel conceptual framework emphasizing the causal interplay between symptoms, which may have the potential to overcome the limitations of traditional clinical practice where symptoms are only regarded as passive manifestations of a common underlying disease factor and the associations between different symptoms are largely overlooked (Borsboom and Cramer, 2013). Useful information such as the centrality of a specific symptom (i.e., which symptom is most central in a network) could also be obtained from such networks. Recently, this network model has been applied to examine the multidimensional structure of schizotypal traits (Christensen et al., 2018; Fonseca-Pedrero et al., 2018b). During our network construction, co-varying factors like anxiety and depression were also taken into account because previous findings have

indicated that both autistic and positive schizotypal traits are associated with higher levels of anxiety and depressive symptoms (Lewandowski et al., 2006; Liew et al., 2015). The diametrical hypothesis may predict a negative correlation between autistic and positive schizotypal traits after controlling for the effects of other nodes in the network. For the network models, we also examined the importance of specific traits/symptoms (i.e., centrality of nodes) and the robustness and accuracy of the network (i.e., stability).

2. Methods

2.1. Meta-analysis

We used the Preferred Reporting Items for Systematic Review and Meta-analysis Protocols (PRISMA-P) for guidance when reporting the search, extraction and synthesis of results in the current meta-analysis (Moher et al., 2016).

2.1.1. Study selection

Pubmed, Web of Science and Elsevier were searched for original articles written in all languages published or accessed online before November 2018. The search term used was (“schizotypal” OR “schizotypy”) AND (“autistic” OR “autism”). In addition, the reference lists of all included studies were manually searched for further relevant studies. The most commonly used scale to capture autistic traits in non-clinical populations is the Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001), which comprises five subscales: *social skills*, *attention switching*, *attention to detail*, *communication* and *imagination*. The Schizotypal Personality Questionnaire (SPQ) (Raine, 1991), on the other hand, is one of the most commonly used scales to capture schizotypal traits. The SPQ contains three factors: the cognitive-perceptual factor comprising items capturing positive schizotypal traits (four subscales: *unusual perceptual experience*, *magical thinking*, *ideas of reference and suspiciousness*), the interpersonal factor comprising items capturing negative schizotypal traits (three subscales: *excessive social anxiety*, *no close friends and constricted affect*), and the disorganization factor (two subscales: *odd speech and odd behaviour*), corresponding to DSM-based constructs of schizophrenia symptoms (Raine et al., 1994). Other measures of schizotypal traits include the Oxford–Liverpool Inventory of Feelings and Experiences scale (O-LIFE) (Mason and Claridge, 2006), the Community Assessment of Psychic Experiences (CAPE) questionnaire, the Rust Inventory of Schizotypal Cognitions (RISC) (Rust, 1988), and the Chapman Psychosis-Proneness scales (Chapman et al., 1976, 1978; Eckblad and Chapman, 1983). Specific inclusion and exclusion criteria can be found in the Supplementary text. In brief, research papers using the abovementioned measures and reporting correlations between self-reported autistic and schizotypal traits in non-clinical populations were included. For papers published within five years, but without sufficient data, we contacted the corresponding authors via email for the original data. If the authors did not reply within a month, the papers concerned were excluded. Two authors (HYZ and HXY) independently completed the process of study selection and data extraction.

2.1.2. Data analysis

The pooled effect sizes based on correlations were calculated separately between autistic traits and global schizotypal traits, and its three dimensions (i.e., positive, negative and disorganized schizotypal traits). It should be noted that the practice of using “global schizotypal traits” may not be very informative as it is a structure with multiple facets. However, we still included the analysis of global schizotypal traits for the sake of comparison with ‘global’ autistic traits. Therefore, in total, four separate meta-analyses were conducted. All analyses were conducted using Comprehensive Meta-Analysis (version 2.2.064).

Each correlation coefficient, r , was first converted to the Fisher's z scale, and all analyses were performed using the transformed values. The summary effect and its 95% confidence interval were then converted back to correlations for presentation. The pooled estimates were obtained by weighting each individual study according to the random-effects model in consideration of potential heterogeneity (Hedges and Vevea, 1998).

The four meta-analyses were examined for publication bias and heterogeneity. Subgroup analysis (for ethnicity and measurement types) and meta-regressions (for age and gender ratios) were conducted to further explore potential sources of heterogeneity. More details of the methods can be found in the Supplementary text.

2.2. Network analysis

2.2.1. Participants and measurements

A total of 2469 Chinese college students (27.7% males; mean age = 18.75 years, SD = 1.1 years) completed a set of psychological questionnaires. This data-set has been reported in a published paper investigating the relationship between childhood trauma and autistic and schizotypal traits (*Gong et al., 2017). More details about demographic characteristics and the process of participant recruitment can be found elsewhere (*Gong et al., 2017; Liu et al., 2017) or in the online Supplementary text.

The self-report measures included the 50-item Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001) and the 74-item dichotomous Schizotypal Personality Questionnaire (SPQ) (Raine, 1991). The AQ has five subscales, each containing 10 items, and each item is scored on a four-point Likert scale. An item is scored "1" each time the person responds in the coded direction that is considered "autistic-like", e.g., indicative of poor social skills, low imagination, etc. The SPQ contains nine subscales, which comprise the positive, negative and disorganization factors described earlier. A higher score on the AQ and SPQ indicates higher levels of autistic and schizotypal traits respectively. The SPQ had good internal consistency in the current sample ($\alpha = 0.93$), which is comparable with previous studies from different countries (e.g., Chinese ($\alpha = 0.95$, Chen et al., 1997); Greek ($\alpha = 0.92$, Tsaousis et al., 2015); Italian ($\alpha = 0.87$ – 0.90 , Fossati et al., 2003). The AQ had a relatively low internal consistency ($\alpha = 0.61$) in the current sample. Additionally, all participants also completed the Self-rating Depression Scale (SDS) (Zung, 1965) and Self-rating Anxiety Scale (SAS) (Zung, 1971). Both scales are 20-item 4-point Likert scales that measure depressive and anxiety symptoms respectively. A higher score indicates more severe depressive or anxiety symptoms. The internal consistency of the SDS ($\alpha = 0.82$) and the SAS ($\alpha = 0.82$) in this study was good.

2.2.2. Principal Component Analysis of mixed AQ and SPQ

We followed *Dinsdale et al. (2013)'s procedure to conduct a Principal Component Analysis (PCA) based on the correlation matrix of five AQ subscales and nine SPQ subscales in SPSS 18.0.

2.2.3. Network construction and stability assessment

The standard guidelines (Epskamp and Fried, 2018) were followed in constructing our network with the qgraph package in R. Five AQ subscale scores, nine SPQ subscale scores, coupled with anxiety and depression scores were represented as nodes in the network. Edges represented partial correlations between nodes, which controlled for the influence of all the other nodes in the network; the least absolute shrinkage and selection operator (LASSO) network was finally presented, assigning penalties to partial correlations by making small correlations automatically shrink to zero (Epskamp et al., 2012).

To plot the network, the Fruchterman-Reingold algorithm was used to create a layout where nodes with more and stronger connections were placed in a more central position (Kobourov, 2012). The links were colored either green to indicate positive partial

correlations or red to indicate negative ones. The thickness of the edges was proportional to the strength of the partial correlations, with thicker lines representing stronger associations.

For each node in the network, we assessed three centrality measures: strength, closeness and between-ness. In addition, predictability of the nodes was also calculated to quantify the variance of each node that can be explained by all remaining nodes in the network. In the graph, the filled part of the circle around each node indicates the predictability measure (i.e., R^2 , variance of the nodes explained by all its neighbours) (Haslbeck and Fried, 2017). We also evaluated the accuracy of edge-weights and the stability of the centrality indices with the method described by Epskamp et al. (2017). More details on centrality and stability assessment can be found in the Supplementary text.

3. Results

3.1. Meta-analysis

3.1.1. Study characteristics

The study selection process is illustrated in Fig. 1. A total of 24 papers were included in the final meta-analysis. As *Russell-Smith et al. (2011)'s and *Abu-Akel et al. (2018)'s paper examined the relationship between autistic and schizotypal traits in two separate groups of participants, we had a total of 26 studies. All except *Shi et al. (2017)'s study were cross-sectional in design. Shi et al.'s study conducted a one-year follow-up to examine the stability of the co-occurrence of autistic and schizotypal traits (*Shi et al., 2017). As the test-retest reliability was good in Shi et al.'s study, we only included the correlations at baseline in our meta-analysis. *Karvelis et al. (2018)'s study used the RISC scale to measure positive schizotypal cognitions in the whole sample ($N = 83$) and additionally, used the SPQ in a subsample of participants ($N = 39$) to capture global schizotypal traits. Therefore, we included the RISC and SPQ results in the meta-analysis of positive schizotypal and global schizotypal traits, respectively. Detailed characteristics of all the included studies are summarized in Table 1.

All but Rawlings and Locarnini (2008)'s study assessed autistic and schizotypal traits in college students and young adults (mean age range: 18.5–26.3 years). Females accounted for approximately half or more of the whole sample in all studies (female: 44%–91%). As for the ethnicity of the population, most participants were Caucasians from America, Europe and Australia, with three exceptions focusing on Asian participants (Chinese: *Gong et al. (2017) and *Shi et al. (2017); Japanese: *Wakabayashi et al. (2012)).

Of these 26 studies, 19 studies reported the correlations between autistic and global schizotypal traits in a pooled sample of 10,262 participants. The number of studies reporting the relationship between autistic traits and positive, negative and disorganization schizotypal traits were 23, 21, and 17, respectively (the total sample sizes were 10,241, 10,185 and 9518).

3.1.2. Correlation between autistic and schizotypal traits

Our results revealed significant mean correlations between all schizotypal dimensions and autistic traits. The mean correlation between autistic traits and global schizotypal traits was 0.482 (95% CI [0.431, 0.530]; $Z = 15.9997$, $p < .001$). The largest effect size was found for the correlation between negative schizotypal dimensions and autistic traits ($r = 0.536$, 95% CI [0.481, 0.586]; $Z = 15.864$, $p < .001$), followed by disorganization schizotypal traits ($r = 0.355$, 95% CI [0.304, 0.404]; $Z = 12.733$, $p < .001$) and positive schizotypal traits ($r = 0.256$, 95% CI [0.208, 0.302]; $Z = 10.255$, $p < .001$). Individual study estimates are presented in forest plots, which can be found in Supplementary Figs. 1–4. The various schizotypal (three dimensions)-autistic correlations differed in strength as suggested by the non-overlapping confidence intervals.

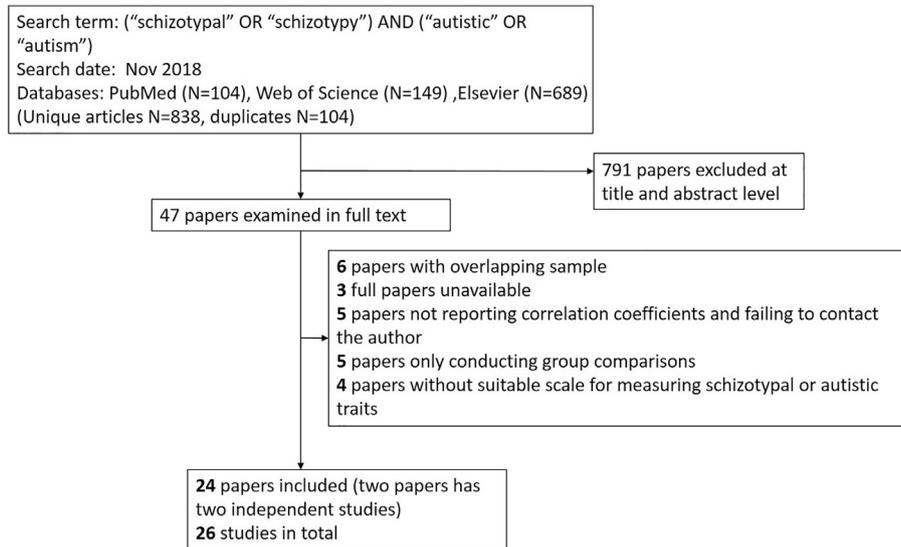


Fig. 1. Flow diagram of study selection process.

3.1.3. Publication bias, heterogeneity and effects of moderator variables

The regression tests for funnel plot asymmetry were non-significant for the relationship between autistic traits and all schizotypal dimensions (all $ps > 0.30$), suggesting that publication bias

was not a major concern (see Supplementary Fig. 5). Considerable heterogeneity was found across studies reporting relationships between schizotypal and autistic traits (global: $\chi^2 = 172.02$, $df = 18$, $p < .001$, $I^2 = 89.54\%$; positive: $\chi^2 = 117.91$, $df = 22$, $p < .001$, $I^2 = 81.34\%$; negative: $\chi^2 = 252.95$, $df = 20$, $p < .001$, $I^2 = 92.09\%$;

Table 1

Summary of all 23 studies included in our meta-analysis reporting the relationship between autistic and schizotypal traits.

Study	Measurements for schizotypal traits	Measurements for autistic traits	Sample size N	Male%	Mean age (years)	Country	Reported correlation coefficients between autistic traits and (total or three dimensions of) schizotypal traits			
							Global	Positive	Negative	Disorganized
*Abu-Akel et al. (2015)	CAPE_positive	AQ	201	21.4	21.37	UK	/	0.31	/	/
*Abu-Akel et al. (2018) (study 1)	CAPE_positive	AQ	58	22.4	20.95	UK	/	0.442 ^a	/	/
*Abu-Akel et al. (2018) (study 2)	CAPE_positive	AQ	69	27.5	26.26	UK	/	0.215 ^a	/	/
*Blain et al. (2017)	SPQ	AQ-10	107	29.9	19.73	US	0.4	0.28	0.36	0.36
*Butler et al. (2015)	SPQ-B	AQ-10	194	43.8	21.31	UK	0.249 ^a	0.155 ^a	0.197 ^a	0.249 ^a
*Choteau et al. (2016)	SPQ	AQ	347	55.9	21.8	France	0.550 ^a	0.294 ^a	0.605 ^a	0.368 ^a
*Claridge and McDonald (2009)	O-LIFE	AQ	77	42.9	20.7	UK	/	/	0.5	/
*Del Giudice et al. (2010)	SPQ	AQ	199	49.7	25.9	Italy	/	0.24 ^b	0.63 ^b	/
*Del Giudice et al. (2014)	SPQ	AQ	151	50.3	22.6	Italy	0.473 ^a	0.2 ^a	0.619 ^a	0.322 ^a
*Dinsdale et al. (2013)	SPQ-BR	AQ	605	37.2	19.4	Canada	0.43	0.21	0.5	0.29
*Ford and Crewther (2014)	SPQ	AQ	449	36.1	23.48	Australia	0.654	0.409 ^a	0.579 ^a	0.355 ^a
*Ford et al. (2017)	SPQ	AQ	835	25.3	26.15	Australia	0.679 ^a	0.494 ^a	0.733 ^a	0.614 ^a
*Gong et al. (2017)	SPQ	AQ	2469	27.7	18.75	China	0.419	0.213	0.515	0.353
*Hurst et al. (2007)	SPQ	AQ	607	22.2	19.27	USA	0.47	0.25	0.53	0.32
*Karvelis et al. (2018)	RISC	AQ	83	49.4	25.7	UK	/	0.074 ^a	/	/
	SPQ	AQ	39	38.5	23.0	UK	0.602 ^a	/	/	/
			(subsample)							
*Mealey et al. (2014)	SPQ	AQ	144	41.7	25.3	Australia	0.54	0.41	0.6	0.36
*Melchers et al. (2015)	CAPE	AQ	107	9.3	22.21	Germany	0.583 ^a	0.354 ^a	0.591 ^a	/
*Rawlings and Locarnini (2008)	Short O-LIFE	AQ	64	51.6	41.16	Australia	/	0.05	0.52	0.21
*Raynal et al. (2016b)	SPQ-B	AQ-short (29 items)	294	33.7	20.31	France	0.414	0.142 ^a	0.448 ^a	0.303 ^a
*Raynal et al. (2016a)	SPQ-B	AQ-10	466	18.9	20.58	France	0.317 ^a	0.226 ^a	0.233 ^a	0.272 ^a
*Russell-Smith et al. (2013)	O-LIFE: Introversive Anhedonia	AQ: social skills	284	28.2	20.1	Australia	/	/	0.74	/
*Russell-Smith et al. (2011) (study 1)	Short O-LIFE	AQ	362	24.0	18.7	Australia	0.46	0.15	0.51	0.37
*Russell-Smith et al. (2011) (study 2)	Short O-LIFE	AQ	639	30.7	19.1	Australia	0.51	0.19	0.56	0.38
*Shi et al. (2017)	SPQ	AQ	864	41.7	18.48	China	0.443	0.249 ^a	0.529 ^a	0.381 ^a
*Sierro et al. (2016)	Short O-LIFE	AQ	921	27.8	22.2	France	0.419	0.199	0.479	0.355
*Wakabayashi et al. (2012)	SPQ	AQ	662	49.5	18.9	Japan	0.483	/	/	/

Notes: SPQ = Schizotypal Personality Questionnaire; O-LIFE = Oxford–Liverpool Inventory of Feelings and Experiences; CAPE = Community Assessment of Psychic Experiences; RISC = Rust Inventory of Schizotypal Cognitions; AQ = Autism-Spectrum Quotient.

^a The correlation coefficients were not reported in the original papers but were obtained after contacting the corresponding author for further statistical information.
^b *Del Giudice et al. (2010)'s study reported the correlations between autistic and (positive and negative) schizotypal traits for male and female subgroups separately. We combined the correlational coefficients using Fisher's Z transformation.

disorganized: $\chi^2 = 110.269$, $df = 16$, $p < .001$, $I^2 = 85.49\%$).

Meta-regressions and subgroup analyses indicated the overlap between autistic and schizotypal traits was independent of participants' ethnicity, gender and the types of measurement used (please see Supplementary text and Supplementary Table 1 for more details). As for the age effect, after excluding Rawlings and Locarnini (2008)'s study whose participants were middle-aged adults (mean age = 41 years), we found that the correlation between autistic and schizotypal traits became stronger with increasing age from 18 to 25 years (range of regression coefficients = 0.029–0.040, all $ps < 0.001$). Similar age effects were also found when Rawlings and Locarnini (2008)'s study was included. More details about the meta-regression analysis of age can be found in the Supplementary text.

3.2. Empirical data of combined AQ and SPQ

3.2.1. Principal Component Analysis (PCA)

Using a large dataset of Chinese college students ($N = 2469$), we conducted PCA of combined AQ and SPQ subscales, which demonstrated two components with eigenvalues larger than 1 (5.00 and 2.11), accounting for 50.81% of the total variance. We did not perform further rotations as in other research because the loading patterns were already interpretable. Table 2 shows the loadings of each subscale on the first and second component. Replicating previous findings (*Dinsdale et al., 2013; *Del Giudice et al., 2014), the first principal component demonstrated positive loadings on all AQ and SPQ subscales, with the strongest loading on social dysfunction (AQ: social skills; SPQ: constricted affect, no close friends, odd speech, social anxiety), resembling the “social difficulty” component proposed by *Ford and Crewther (2014). In contrast, the second component showed both negative and positive loadings from two questionnaires. Specifically, all AQ subscales, except for ‘attention to detail’, loaded positively on the second component, whereas the positive SPQ dimensions (especially magical thinking and unusual perceptual experience) loaded negatively on this second component. This result indicated a clear diametrical structure with autistic traits and positive schizotypal traits situated at two opposite ends of a continuum.

3.2.2. Network model

A regularized partial correlation network was constructed based on scores of autistic and schizotypal traits, and anxiety/depression symptoms (Fig. 2). The weights of all edges and the predictability values of all nodes in our regularized network can be found in Supplementary Table 2. Three negative schizotypal nodes were closely correlated with each other (edge values = 0.06–0.37) and positively correlated with social and communicative dimensions of autistic traits (edge values = 0.002–0.21). The odd speech node from

the SPQ disorganization factor was also positively correlated with AQ: communicative deficits (edge value = 0.08). However, positive schizotypal traits showed negative correlations with several autistic nodes, lending support to the psychosis-autism diametrical model. For example, higher levels of magical thinking and ideas of reference were correlated with better social skills and improved capacity of imagination (i.e., lower scores of AQ subscales) (edge values = -0.03 – -0.1). Interestingly, the ‘attention to detail’ node from the AQ, quite distant from other autistic nodes, was negatively correlated with other autistic dimensions and seemed to capture something more similar to positive schizotypal traits. This is consistent with our PCA, where the ‘attention to detail’ subscale loaded negatively on component 2 as most positive schizotypal subscales did. Finally, anxiety and depression symptoms were strongly correlated with each other (edge value = 0.62), but were relatively weakly correlated with autistic and schizotypal traits (all edge values < 0.096), and therefore stayed peripheral in the network.

As indicated by the centrality measures (Supplementary Fig. 6), ‘ideas of reference’ and ‘unusual perceptual experience’ from the positive subscales of the SPQ, ‘constricted affect’ from the negative subscales of the SPQ and ‘social skills’ from the AQ played central roles in the network. Two of the autistic nodes, ‘imagination’ and ‘attention to detail’ were peripheral and had very low values across all three centrality indices.

By performing a stability check, we concluded that our network was stable for the following two reasons. First, we obtained narrow bootstrapped CIs around the estimated edge-weights, indicating relatively accurate edge-weights (Supplementary Fig. 7). Secondly, the correlation stability coefficients (CS-coefficients) for the three centrality indices suggested that strength ($CS(\text{cor} = 0.7) = 0.75$) and closeness ($CS(\text{cor} = 0.7) = 0.75$) were stable during case-dropping bootstrapping. However, the correlation stability coefficient for betweenness was much lower ($CS(\text{cor} = 0.7) = 0.36$), indicating that the order of node betweenness should be interpreted with caution. The plot of centrality stability can be found in Supplementary Fig. 8.

4. Discussion

Converging evidence from our meta-analysis and network analysis suggests that autistic traits are largely overlapping with negative schizotypal traits at the phenotype level. Disorganization schizotypal traits characterized by odd speech and behaviour also show a moderate correlation with autistic traits, as these are concerned with communication impairment. Although higher levels of self-reported positive schizotypal traits are weakly (though significantly) correlated with higher levels of autistic traits as indicated in the meta-analysis, both PCA and partial correlation network support the diametrical model of autistic and positive schizotypal traits.

Table 2

Unrotated factor loadings of AQ and SPQ subscales on the first and second principal components.

Measure	Subscales	Principal Component 1 (social difficulty)	Principal Component 2 (positive schizophrenia–autism)
AQ	Social skills	0.425	0.624
	Communications	0.551	0.449
	Attention switching	0.397	0.484
	Imagination	0.156	0.354
	Attention to detail	0.063	−0.499
	SPQ	No close friend (N)	0.744
	Excessive social anxiety (N)	0.700	0.201
	Constricted affect (N)	0.807	0.157
	Odd speech (D)	0.759	−0.084
	Odd behaviour (D)	0.743	−0.216
	Suspiciousness (P)	0.724	−0.152
	Ideas of reference (P)	0.653	−0.356
	Unusual perceptual experience (P)	0.650	−0.487
	Magical Thinking (P)	0.372	−0.618

Notes. The first and second principal components are orthogonal (unrelated). P = positive schizotypal traits; N = negative schizotypal traits; D = disorganized schizotypal traits.

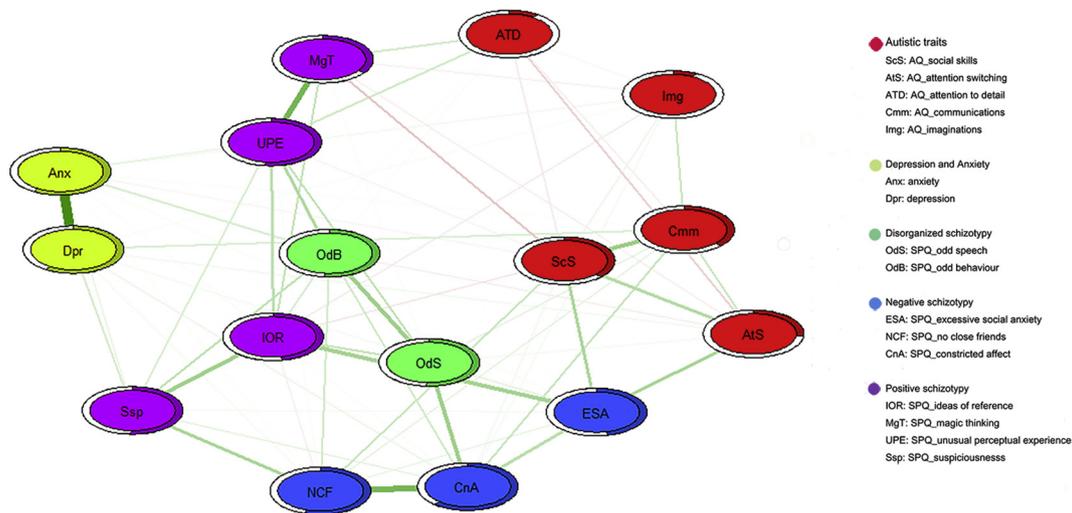


Fig. 2. Regularized Partial Correlation Network of autistic traits, schizotypal traits, anxiety and depression ($N = 2469$ college students). The color of nodes refers to a specific trait/state domain (see legend). The edges are colored either green for positive correlations or red for negative correlations. Thicker lines represent stronger associations. The filled part of the circle around each node represents the predictability value (i.e., % variance of the nodes explained by all other nodes in the network). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

At the psychometric level, the strongest overlap was between negative schizotypal traits and the social-communicative impairment of autistic traits. Such overlap has been conceptualized as “Social Difficulty” (*Ford and Crewther, 2014). Individuals with high levels of social difficulty have been demonstrated to have impaired attention, atypical auditory processing (Ford et al., 2017c, 2017d, 2018) and disrupted excitatory glutamate and inhibitory gamma aminobutyric acid (GABA) concentrations in the superior temporal lobes (Ford et al., 2017b). However, some researchers have argued that such phenotypic overlap may be superficial and merely due to item similarity (*Del Giudice et al., 2010, 2014). Scales for non-clinical behavioural traits provide little information about the underlying reasons for a given behaviour. Taking the shared feature of ‘social isolation’ as an example, autistic individuals may minimize their social interactions as a result of impaired theory of mind and reduced empathy (Gaigg, 2012). On the other hand, patients with schizophrenia may find it hard to experience interpersonal/social pleasure and therefore avoid social activities and isolate themselves. Both processes can lead to similar behavioural results but the underlying reasons are quite different. In addition, despite shared impaired social function, negative schizotypal and autistic traits have their own specific social-emotional associations (*Russell-Smith et al., 2013). Extending to clinical populations, comparable deficits in social cognition are associated with different brain mechanisms in ASD and schizotypal personality disorders (SPD) (Stanfield et al., 2017). Future research should investigate the underlying mechanisms of the observed overlap between negative schizotypal traits and autistic social deficits.

As indicated by our meta-analysis, most studies (except *Karvelis et al. (2018) and Rawlings and Locarnini (2008)) using self-report measures have demonstrated positive correlations between autistic and positive schizotypal traits. However, weak associations at the psychometric level may be partly due to co-varying emotion and social factors (e.g., anxiety and obsessive symptoms) (*Del Giudice et al., 2010), and spurious and vague item wordings used in the questionnaires (*Del Giudice et al., 2014). In addition, the reported relationships in previous studies are not partial correlations. Researchers did not control for the effect of negative schizotypal traits when calculating the correlation between positive schizotypal and autistic traits; neither did they control for other potential confounders such as anxiety and depression (Lewandowski et al., 2006; Liew et al., 2015). In fact, our findings from the PCA and the partial

network model converge to support the diametrical model of autism and psychosis (Crespi and Badcock, 2008). Consistent with previous PCA results of mixed autistic and schizotypal measures (*Del Giudice et al., 2014; *Dinsdale et al., 2013), we found a clear-cut diametrical structure of positive schizotypal and autistic traits after extracting the shared ‘social difficulty’ component. In addition, the relatively stable network model we constructed indicates that after ruling out the effect of anxiety, depression and negative/disorganization schizotypal dimensions, autistic traits show negative correlations with positive schizotypal traits (magical thinking and ideas of reference). Specifically, the strongest correlation is between SPQ: magical thinking and AQ: social skills (edge value = -0.10). Magical thinking includes beliefs in mind-reading and in the ability to communicate with others telepathically. Such beliefs, if not excessive, may lead to better empathetic and perspective-taking abilities in social interactions and may in turn result in better social skills (Dinn et al., 2002). Similarly, although excessive attribution of intentions or self-referential meanings to others (i.e., ideas of reference) can lead to misinterpretation of other people’s social behaviour (Montag et al., 2011; Park et al., 2011), a much milder form of idea of reference in healthy individuals may reflect enhanced social-emotional sensitivity and thus may also improve the ability to infer others’ intentions and emotions (Thakkar and Park, 2010). Moreover, consistent with our estimated network, positive schizotypal individuals also exhibit enhanced imagination/fantasy-proneness and creativity (Mohr and Claridge, 2015), which is contrary to characterization of autistic individuals’ reduced imagination and symbolic play (Blanc et al., 2005; Crespi et al., 2016; Losh and Capps, 2003).

It is interesting to note that ‘attention to detail’, one dimension of autistic traits, is more strongly correlated with positive schizotypal traits rather than other autistic characteristics. One possible explanation may be the shared impairment in predictive coding in both schizophrenia (Fletcher and Frith, 2009) and autism (Sinha et al., 2014). Specifically, a preference for sensory details at the cost of integrative processing may undermine effective statistical learning based on the Bayesian model, in which current sensory input and prior experiences should be weighed in balance (Stevenson et al., 2017). Such overweighing of sensory input can result in a failure to update one’s perceptions and beliefs, and in turn, foster and exacerbate positive symptoms of schizophrenia (Fletcher and Frith, 2009). Additionally, our findings are consistent with Hoeksta et al.’s hierarchical model for autistic traits, suggesting that the ‘attention to

detail' dimension is separate from a broad 'social interaction' factor with four other subscales clustering together (Hoekstra et al., 2008).

As indicated by the centrality indices, schizotypal traits may play a much more important role than autistic traits in the network. Some positive, negative and disorganization dimensions of schizotypal traits were central in the network whereas except for the 'social skills' and 'communication' subscales, other autistic traits (e.g., imagination and attention to detail) were quite peripheral and less connected to the rest of the network. A further examination suggests that the more closely the nodes were associated with social and communicative skills, the more central they were in the network. It may reflect the fundamental role played by "social dysfunction" in this combined autistic and schizotypal network model.

Several limitations of this study should be noted in the meta-analysis. All studies included rely exclusively on self-report data, which may be biased by social desirability. Besides, the studies were largely from Western countries and had a female-biased gender ratio. Gender imbalance (male: 27.7%) was also present in our sample for network analysis. As personality traits may be influenced by cultural context (Fonseca-Pedrero et al., 2018a, 2018b), cross-cultural studies could help to clarify this issue. Gender differences in schizotypal and autistic traits have been extensively reported in previous research, with males reporting significantly more autistic and negative schizotypal traits (e.g., Baron-Cohen et al., 2001; Bora and Baysan Arabaci, 2009; Guo et al., 2011), and females reporting more social anxiety and positive psychotic symptoms (e.g., Bora and Baysan Arabaci, 2009; Mata et al., 2005). Taking the gender effect into consideration, future research could consider reporting the correlational results in males and females separately. In addition, the SPQ 'excessive social anxiety' subscale might reflect both positive and negative schizotypy (Brown et al., 2008) and some have argued that anxiety is less essential to the negative syndrome than anhedonia (Cicero et al., 2016). Future studies could use the revised physical and social anhedonia scales (Chapman et al., 1976; Eckblad et al., 1982) and/or Anticipatory and Consummatory Interpersonal Pleasure Scale (ACIPS; Gooding and Pflum, 2014) to exclusively investigate the relationship between anhedonia and autistic traits. Another limitation of this study was that there was considerable heterogeneity among the included studies, which was not explained by subgroup and meta-regression analyses. Thus the pooled results should be interpreted with caution. In the network study, the relatively low internal consistency of the AQ ($\alpha = 0.61$) in the present sample might also have biased our results. To address this issue, we did additional analysis by excluding four subscales of the AQ which had a low internal consistency ($\alpha < 0.5$) and only included the 'social skills' subscale ($\alpha = 0.61$) in the network. The resulting network replicated our original findings where scores of social skill impairments were negatively correlated with positive schizotypal traits (see Supplementary Fig. S9). Moreover, we only included anxiety and depression as potential confounders. Future research can take into account more co-varying factors (e.g., neuroticism, introversion (*Sierro et al., 2016) to gain a better understanding of the relationship between autistic and schizotypal traits. Finally, our cross-sectional data provide no information about how the network changes over time. As indicated by our meta-analysis, the correlations between autistic and schizotypal traits may become stronger with increasing age during early adulthood. Given that most previous studies have focused on college students, future cross-sectional and longitudinal studies are needed to compare networks across different ages.

Despite the limitations, our meta-analysis and network data provide strong evidence suggesting a large overlap between autistic traits (especially impaired social/communicative skills) and negative schizotypal traits in the non-clinical population. Although

autistic traits also exhibit a weak overlap with positive schizotypal traits at the psychometric level, further examination via network analysis supports the diametrical model, with autistic and positive schizotypal traits representing two opposite extremes of the same continuum. However, it should be noted that the aforementioned overlapping and diametrical relationships between ASD and SSD only reflect findings from non-clinical populations. In clinical samples, while some autistic children and adolescents do meet the criteria for schizophrenia (Barneveld et al., 2011; Gadow, 2012), few individuals with SSD (especially paranoid schizophrenia) meet the criteria for autism (Konstantareas and Hewitt, 2001). One speculation is that hyper-mentalizing brains in patients with SSD may be a protective factor, decreasing the possibility of developing autism, which warrants further investigation.

Contributors

Han-yu Zhou completed the process of study selection, data extraction and data synthesis in the meta-analysis, analyzed and interpreted the data in both meta-analysis and network analysis, and wrote up the first draft of the manuscript. Han-xue Yang independently did the paper research and extracted data for the meta-analysis. Jing-bo Gong collected the data of college students for network analysis. Eric Cheung, Diane Gooding, and Sohee Park interpreted the findings and contributed significantly to the writing up of the manuscript. Raymond Chan generated the idea, interpreted the findings and commented significantly to the different drafts of the manuscript. All authors have approved the final article.

Role of the funding source

The funding source(s) had no involvement in the study design, in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.schres.2019.07.050>.

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¹ The papers included in the final meta-analysis were marked with *.

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