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ADHD and ASD are both indirectly associated with sensory changes through anxiety

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Abstract

Objective: This study investigated the relationship between Attention Deficit Hyperactivity Disorder (ADHD) and Autism Spectrum Disorder (ASD) via their impact on sensory processing, which previous simple correlational analysis suggests is affected in both. **Methods**: We examined adults from the general population without clinical diagnoses, using a broad-based self-report survey methodology, looking at the symptoms of ADHD and ASD, SP and a range of other issues (anxiety, reward sensitivity and schizotypy) which are reliant on sensory processing. Their relationship was explored using Exploratory Graph Analysis, a method which assesses whether survey responses cluster into 'communities'. **Results**: We found three communities, reflecting typical inter and intrapersonal ADHD/ASD problems. Although ADHD/ASD did not form a community with sensory processing, the model suggested ADHD/ASD are connected to sensory processing through intermediary conditions, such as panic anxiety. The model suggested that disorganised thought, speech and behaviour, and challenges in social interaction, use anxiety as a bridge with sensory processing, through aberrant attentional deployment and biases in cognitive processes, which can induce anxious states and therefore manifest in behaviour typical of ADHD/ASD. **Conclusion:** Previous simple correlational analyses overestimate the direct relationship between ADHD/ASD and sensory processing changes.

Key words: ADHD, ASD, sensory processing, network psychometrics, EGA

Introduction

Attention Deficit Hyperactivity Disorder (ADHD) and Autism Spectrum Disorder (ASD) are highly comorbid neurodevelopmental disorders persisting into adulthood, characterised by a pattern of attentional deficits alone or in combination with hyperactivity and/or impulsivity (ADHD) and deficits in social communication and restrictive patterns/ behaviours (ASD) (DSM-V, APA, 2013; Panagiotidi, Overton, Stafford, 2019). ADHD and ASD map similarly onto sensory processing as well, and their symptoms in clinical cases are often intertwined and manifest with sensory integration difficulties (Panagiotidi, Overton, Stafford, 2017; Ben -Sasson et al., 2009; Billstedt & Gillberg, 2007; Dellapiaza et al., 2020). ADHD and ASD are reported to present with problems in processing sensory stimuli across all modalities (visual, auditory, tactile, olfactory, taste, vestibular, and proprioceptive) resulting in abnormal sensory processing states (Miller & Schoen, 2009; Dunn, 1999). As these states cause significant problems in academic achievement, occupations and other domains of life (Butera et al., 2020; Mangeot et al., 2001, Dunn & Bennett, 2002), it is important to fully characterise the nature of sensory processing difficulties in ADHD and ASD. Thus far, however, research has mainly concentrated on clinical and very young populations, largely excluding general and adult populations.

Many characteristics of psychiatric disorders are observed in healthy individuals (Coghill & Sonuga-Barke; 2012). ADHD and ASD traits such as hyperactivity, inattention, impulsivity, repetitive and disorganised behaviour, social interaction problems and sensory problems have been suggested to spread on a continuum (Kern et al., 2015). Such traits grade into the general population, with clinical cases clustering at the extreme end of this continuum (Levy et al.,1997). Following from this, of interest to our work are sub-clinical groups, an under-researched group in the context of ADHD/ASD.

Such dimensional disorders and their inter-relationship have traditionally been investigated by factor analytic methods, including the Kaiser–Guttman rule (eigenvalues > 1), minimum average partial procedure, and parallel analysis (PA) (Christensen & Golino, 2021). A newly introduced method, showing far superior performance in the detection of dimensions and based in the field of network psychometrics is the exploratory graph analysis (EGA; Golino & Epskamp, 2017; Golino & Demetriou, 2017). This method shows superior performance, because it is not dependent on rotation methods (the choice of which can result in differing factor structures) or choice of factor number from the interpretation of eigenvalues and/or associated scree plots. The community extraction process does not require the researcher to interpret a factor loading matrix before assigning items to different communities. Communities are also visualised and therefore easier to interpret. This method also applies bootstrapping techniques to further investigate the stability and robustness of communities and variables within them.

Following from the above, we investigate here, using EGA, the relationship between ADHD, ASD and sensory processing difficulties, focusing on the extent to which the disorders have similar (or dissimilar) relationships with sensory processing difficulties, suggestive of a common neural substrate for conditions that are currently considered to be separate. The target group is adults from the general, sub-clinical population, who have not had a clinical diagnosis of either ADHD or ASD, but who exhibit a range of ADHD/ASD traits. We conduct a broad-based survey using self-report measures to look at how intertwined the symptoms of ADHD and ASD are with sensory processing issues and a range of other issues (anxiety, reward sensitivity and schizotypy) that are reliant on sensory processing. EGA assesses the extent to which survey responses cluster into 'communities'. This approach is compared with standard correlational analysis used in previous studies that has found strong correlations between the ADHD and ASD scales and sensory processing (Panagiotidi, Overton, Stafford, 2017, 2019).

Methods

Participants

Participants in the study were recruited via social media (40 participants), the departmental online research participation system for credits (90 participants), the university's volunteers list for both staff and students (53 participants) and the largest recruitment solution, the platform Prolific Academic (Prolific.co), where 170 responses were collected. All responses were collected via the Qualtrics survey and data collection platform. Only participants who do not have a clinical diagnosis for ADHD/ASD and those who have not used National Health Service (NHS) mental health services in relation to those were asked to participate. Two participants were excluded on that basis.

The final set of participants consisted of 351 adult persons from the general population between the ages of 18 and 65 with mean age of 29.74 (SD 11.98). 212 participants indicated "female" as their gender, while 141 participants indicated "male" as their gender. 52 participants chose "Asian" as ethnic background, 274 chose "White" ethnic background, 17 chose "Mixed" ethnicity and 10 chose "Black" as ethnicity. As the highest level of education, 150 participants indicated A-levels, 32 indicated GCSE, 116 indicated undergraduate level and 55 indicated postgraduate level.

Procedure

Participants were asked to fill out a set of questionnaires within the battery, presented in a randomised order. On average it took 25-26 minutes to respond to all questions. The battery was accessible on mobile devices, iPads, computers and was not in person. There was no time limit for completing the battery, except for the fact that participants could only save and return to complete it later within a 24 hour period, after which their responses would be removed automatically by the system. Responding to all items was mandatory and participants had the option to refuse to continue participation at any point. Non-completed questionnaires were not included in the final count. All participants were asked to sign the University of Sheffield's Ethics committee approved consent form and read an information sheet. They were then presented with the randomised questionnaires. At the end of the survey they were given a debrief form approved by the Ethics Committee.

Measures

The study used a funnel model to select scales for inclusion in the battery. Only scales developed for adult populations were considered. Initially over 70 scales were selected and after careful consideration and review of items, 6 scales were shortlisted for inclusion. Responses for all scales were recorded on Likert scales, where participants were asked how much a given statement applied to them, considering the past 6 to 12 months. For ADHD traits, both sub-scales ADHD-A (inattention) and ADHD-B (hyperactivity/impulsivity) of the Adult ADHD Self Report Scale (ASRS) were used (Kessler et al., 2005). For ASD traits, The Broad Autism Phenotype Predict scale (BAPQ) (Hurley et al., 2007) was used, of which all sub-scales- aloof personality, pragmatic language and rigid behaviour were included. For sensory processing events, the Glasgow Sensory Questionnaire was used (Robertson & Simmonds, 2013), of which all sub-scales- visual, auditory, gustatory, olfactory, tactile vestibular and proprioceptor were included. For anxiety, the sub-scales for panic/somatic anxiety and social anxiety from the Screen for Adult Anxiety Related Disorders (SCAARED) (Angulo et al., 2017) were used. For reward sensitivity the Sensitivity to Reward subscale from the Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ; Torrubia, Avila, Molto, & Caseras, 2001) was used. Finally, for schizotypy, the Schizotypal Personality Questionnaire-Brief (SPQ-BR; Cohen et al., 2010), was used, of which all sub-scales- magical thinking, unusual perception, ideas of reference, eccentric behaviour, odd speech, social anxiety and no close friends- were included. Table 1 contains detailed description of what each subscale measures and the response types, as well as abbreviations used in this study.

EGA Stepwise Data Analysis Plan

To interrogate our data with EGA, first we need to estimate the network model (Yang et al., 2016). Psychological networks always require estimation from the data, as the relationships between the variables are unknown (as opposed to relationships between family members in social networks; Burt et al., 2013). In accordance with Epskamp's psychological networks theory (Epskamp, 2017), networks are presented as concentration graphs (Cox & Wermuth, 1994), also called Gaussian graphical models (GGM; Lauritzen, 1996), and are part of a more general class of statistical models called pairwise Markov random fields (Koller & Friedman, 2009; Murphy, 2012). Such a network is undirected, meaning that the relationships between variables (nodes) are bi-directional (A influences B and B can influence A). These relationships are represented by edges and can differ in strength of connection. These are called edge weights. Edge weights indicate if the relationship between two nodes is strong (visualised with thick edges) or weak (thin, less saturated edges) and positive (green edges) or negative (red edges) (Epskamp et al., 2017; Constantini et al., 2015). As the structure of the network depends on the relationships between the variables, the GGM graphical model is a weighted network, based on the unique weights of the edges (encoded by the weights matrix). In weighted networks, two nodes are connected only if the strength of connection between them is nonzero; a value of zero in the weights matrix encodes no connection between two nodes. In order to ensure that if an edge is present in the network it can be trusted to represent a structural relation between the variables, a regularisation technique originating in the field of machine learning called the graphical least absolute shrinkage and selection operator (GLASSO) (Epskamp et al., 2018) is used, which also applies the Extended Bayesian Information Criterion

(EBIC; Chen et al., 2008) to select the best fitting model. The EBICglasso is housed in the qgraph R package.

For its community detection, EGA employs the walktrap algorithm housed in the igraph (Csardi and Nepusz, 2006) R package. The walktrap algorithm conducts random walks over the estimated network and is able to form boundaries between nodes and form communities of different clusters of nodes, deterministically allocating variables to communities (Golino & Christensen, 2021; Golino & Epskamp 2017). Each node is repeatedly used as a starting point, with jumps from one node over the edge of another to form the community boundaries. Communities then become formed of highly interconnected variables. This algorithm is deterministic in that the number and content of communities are allocated without a researcher having to direct and guide the process.

Once the model is estimated and communities detected, bootstrapping is applied through the bootNET R package. This approach allows for the investigation of stability of the estimated model (Golino & Christensen, 2021) by generating a sampling distribution of network models using a non-parametric procedure in its generation process (resampling with 1000 iterations as recommended by Golino & Christensen, 2021). The bootEGA has two purposes- to evaluate the stability of the network's communities and the robustness of each item’s placement within these communities. It then employs the EGA algorithms described above on the sampling distribution of networks- namely the walktrap algorithm. This method provides a set of statistics analysing the network’s stability such as confidence intervals and indicates the frequency of the estimated number of communities- that is the frequency of occurrence of the estimated community in the sampling distribution. Finally the item and community stability statistics give us more information on the replicability and strength (relevance) of variables.

Level of analysis

We are interested in the relationship between general traits rather than individual items in the scales, and hence our analytical focus is at the subscales level. Subscales represent general traits and can also be considered as latent variables. Epskamp et al. (2017) recommend estimating network models on latent variables for scales developed in the factor model tradition because of how they were developed- usually by obtaining high Cronbach's alpha, which means that the items in the scale are highly interrelated, forming a unique entity (e.g. visual sensory processing). The total scores of all 22 subscales were calculated and then subjected to EGA. All analysis was performed in R studio, version 4.1.0.

Results

Exploratory Graph Analysis

We first estimated the EGA network (model) and employed the EBIClglasso algorithm using the qgraph R package, followed by the walktrap algorithm in the igraph package. Figure 1 provides visual representation of the estimated network and its communities. The network presented in Figure 1 suggests a three community model- shown in different colours. Stronger (thicker) connections are visible mainly within the communities and weaker connections are mostly visible between them. Of interest to this work are the thicker edges as they represent stronger relationships (i.e. higher edge weights). Table 2 provides the Edge Weights for all variables, with values of -1 to 1, where 0 denotes no connection between the respective nodes.

Community 1 consists of the hyperactivity and attention ADHD nodes, ASD's pragmatic language and schizotypy variables as well as panic and the negatively connecting reward sensitivity. To note here is that variables are either directly or indirectly connected with three central nodes- unusual perception, ideas of reference and ultimately panic/somatic anxiety. The attention and hyperactivity nodes, for example, connect stronger only with unusual perception and odd speech, the latter connecting with ASD's pragmatic language and ideas of reference, which in turn interacts well with unusual perception and panic anxiety. Unusual perception connects through ideas of reference and eccentric behaviour with no close friends, which in turn has a strong connection with ASD's typical aloof personality traits, tapping in the anti-social ASD aspects. Such interaction between speech, schizotypy and ADHD reflects the disorganised speech and thought patterns affected by attention. In this model, therefore, peculiar speech mannerisms and socially unexpected modes, typical for ADHD/ASD are largely assisted by unusual perception while anxiety is present throughout.

Community 2 consists of ASD's rigid behaviour and aloof personality scales plus the two social anxiety scales from the schizotypy and SCAARED questionnaires. It taps into the anti-social aspects of ASD and is connected with community 1 and 3 through panic anxiety and no close friends, reflecting the difficulty individuals with ASD experience in social interactions and suggesting it is further assisted by schizotypy traits affecting disorganised speech and thought as well as attention.

Community 3, sensory processing, while relatively independent, interacts in bi-directional manner with the other communities through panic anxiety, which acts as a bridge (likely modulating through selective information processing). Community 3 consists of relatively moderately inter-connected nodes within it. They do not intertwine with the other two communities directly, except through panic anxiety and the weaker but direct connection with attention, which also connect with each other within their own community. The three communities are connected primarily via the panic anxiety node, suggesting it may have a multidimensional nature and therefore act as modulatory variable, not only assisting in, but playing an important role for manifesting sensory processing changes.

Based on the variables within each community, we have tentatively named the communities as follows: In Community 1, most nodes tend to cluster around the notion of abnormal perception associated with ADHD's inattentive and hyperactive traits and ASD's peculiar speech patterns, which is why we propose the name for this community as Abnormal perception and attention traits (APAT). Community 2 shows a strong association between interpersonal factors affecting social behaviour, therefore the suggested name for this community is (rigid) Social and autistic traits (SAT). Community 3 consists of only sensory processing scales, the suggested name for it therefore is Sensory processing traits (SPT).

Bootstrapping analysis

Community stability

Following from the estimated model, we applied the bootstrapping technique which allows for further investigation of the robustness of the nodes and community stability. It also indicates potential multidimensional variables, which act as bridges connecting the communities. These are important as our model suggests there are no substantial direct links between ADHD/ASD and the SAT community, however they seem to be connected through third factors, such as panic anxiety and schizotypy traits, which falls in line with the interactive nature of networks suggested by Epskamp (Epskamp, 2017). Such a result would suggest the significant role of anxiety in sensory processing and ADHD/ASD established in clinical studies.

First, we look at the stability of the number of communities through the bootEGA R package's descriptive statistics of the sampling distribution (see Table 3) of 1000 iterations. The number of communities is confirmed to be indeed 3, with relatively narrow confidence intervals (CI95% 1.89-4.10) with SE 0.59. Based on this output, the 3 community model is confirmed. We further investigated the number of communities detected, by looking at their frequency, or how prevalent they were during the bootstrapping. Table 4 shows that a 3 community solution was found 72% of the time, while a 4 and 5 community solutions were found in only 22% and 5% of the time respectively.

Structural stability

Once the number of communities had been confirmed, the structural stability of items within them was computed. This approach allowed us to determine the stability of items that are appropriately identified in the correct community solution. Using the EGAnet and NetworkToolbox R packages, replicability of variables within the communities was established. For a variable to be considered stably associated with its community, meaning it cannot be a product of interaction in any other community, it needs to replicate in that community above the range 0.65- 0.75. Replicating below or within this range, variables are considered unstable and their instability needs to be further examined by looking at their replication across all dimensions in Table 5. Figure 2 shows that the sensory processing variables have stable replication on their respective community (SAT; replication magnitude of 1) in accordance with the network model in Figure 1. The ADHD hyperactive and inattentive, ASD and most schizotypy variables replicate well on the SAT (0.92- 0.99) and APAT (0.75-0.92) communities respectively. However, three variables are just above the replication stability range- magical thinking (MT), panic anxiety and reward (0.75-0.77). Panic anxiety is of specific interest here, as it seems to be a bridge between the communities as suggested by the network model in Figure 1, therefore being close to the replication threshold, it might mean it indeed has a multidimensional nature. No close friends did not reach the threshold and therefore will need further investigation in order to understand why. This means it likely belongs to and impacts multiple communities. To do that and to inspect if variables replicate on more than one communities, we refer to Table 5.

Table 5 provides details through the item replicability function in the bootEGA R package as to whether any of the variables replicate on more than one community in addition to the strength of replication on their assigned communities. Here we will only stop on the ones that indicate replicating on multiple communities. According to Table 5, magical thinking (MT) strongly replicated on community 1 (APAT), but has a small chance (0.16) for replication on community 3 (SPT). However, it's more likely path to SPT, as suggested by our model, seems to be via unusual perception, ideas of reference and panic anxiety, which is in accordance with existing literature on ADHD/ASD and schizotypal personality disorder (Hall, 2017), therefore it's suggested membership of the APAT community is confirmed. Panic anxiety replicated well on the APAT community (0.75) only, although with a small chance of replication on community 3 (0.16), which however did not reach the minimum range. This can be attributed to its stronger connections with the schizotypy and ADHD related disorganised behaviour and speech. However, its relevance to both SAT and APAT communities will need to be investigated through the cross loading statistics in Table 6.

The no close friends subscale, which Figure 2 showed did not reach the threshold for stable replication onto its suggested APAT community (0.38), is confirmed here to have a relatively similar replication onto the SAT community (0.30). This is not surprising because this scale has two aspects- first the interpersonal one, which is part of the ASD's social interaction challenges (Bottema-Beutel, 2017) (SAT community). It also has an intrapersonal aspect- it connects to eccentric behaviour of APAT, which in the original SPQ questionnaire forms the disorganised thoughts and behaviours higher order scale, meaning difficulty concentrating and maintaining a train of thought, characteristic of ASD and ADHD, and also influencing social behaviour in both.

Network cross loadings

The last stability statistic we will look into deals with how relevant variables are with regards to their communities and is called network cross loadings. They can be interpreted as strength measures, complementing the methods above. Loadings are different from replication statistics in that they look at how strongly variables are associated within and between different communities based on the sum of connections to a node (also called strength of a node) and are calculated for each item's connections within its specified community and between every other community. Average node strength is retrieved across all replica networks in the sampling distribution. Items that have higher average node strength (equal to or greater than 0.15; Golino & Christensen, 2021) within their community could be interpreted as relevant to and well associated with that community. If an item has a greater proportion of strength across multiple communities, it could indicate that it has higher or similar relevance across these communities, therefore affecting them and might be interpreted as multidimensional.

As per Table 6, all items show good strength and relevance onto their assigned communities, with sensory processing confirming their relative independence from ADHD/ASD. Panic anxiety shows similar strength and relevance across all three communities. Although it replicated stronger on the APAT community, likely due to its stronger connections with the variables in this community, it is equally relevant for the SAT and SPT communities. This can be accepted as a confirmation of its multidimensional nature, suggesting, as per our model, it plays a modulatory role for the interaction of ADHD, schizotypy and sensory processing but also social interaction and should be considered as a bridge, equally affected by and an affecting factor for all communities, rather than a product of only one of the factors. In previous research such variables have been described to form their own entity within the community (Rozgonjuk & Sinderman, Christensen, 2020)

To note here are magical thinking and reward sensitivity, which do not show sufficient strength on any of the communities, explaining their distant positioning within the model as well. The no close friends scale suggests an interesting positioning. Although it replicated well onto community 1 (APAT), the cross loading suggests that it has a greater influence and relevance for the interpersonal scales forming the social problems aspect of our model. therefore suggesting that aloof personality, in combination with social anxiety and rigid behaviour, are connected to and result in no close friends.

Comparison of EGA results and correlational analysis

Following from the EGA, we compared the results to those achieved by linear, correlational analysis, as previous studies have found strong correlations between ADHD/ASD and sensory processing (Panagiotidi, Overton, Stafford, 2017), to confirm that our dataset is comparable to those that have gone before. After establishing the normal distribution of the data using a Kolmogorov-Smirnoff test, Pearson correlations were performed in R studio, v. 4.1.0. Table 6 shows detailed statistics for each variable.

The ASD scales (lines 18,19,20 in Table 7) show weak to moderate but significant correlation with sensory processing, while the two ADHD scales (lines 21, 22) show moderate positive correlation with the sensory processing scales with the exception of proprioceptory processing. Anxiety in turn correlates only weakly with all other scales (line and column 9). These results are in contrast with our EGA results, first because the EGA results did not group sensory processing and ADHD/ASD together, but more importantly because they associate an increase in ADHD/ASD with sensory processing issues, but fail to inform us as to why this comes about. The EGA method paints a much richer picture of how traits interact and influence each other.

Discussion

This work aimed to investigate how intertwined ADHD and ASD traits are with sensory processing issues in a sample of 351 participants from the general, non clinical, adult population using EGA. The analysis took place in two stages- first we estimated the model from the data and applied the community detection algorithm, through the igraph and qgraph R packages, resulting in a three community network with ADHD/ASD, anxiety and schizotypy spread across community 1 and 2 and sensory processing variables clustering solely on community 3. Second- we applied bootstrapping analysis through the bootEGA R package to analyse the stability of the network and thus confirmed the replicability and strength/relevance of variables across the communities. The communities were respectively named based on the key interactions within them. Community 1 was named Abnormal perception and attention traits (APAT), community 2-(rigid) Social and autistic traits (SAT) and community 3- Sensory processing traits (SPT).

Community 1 reflected the intrapersonal difficulties in behaviour between ADHD/ASD, where poor conversational turn-taking and lack of coherence and organisation in speech and thought (ADHD connection with odd speech and pragmatic language) were underlined in our model by unusual perception and anxiety. These peculiar speech mannerisms and socially unexpected modes, in combination with disorganised behaviour and thoughts resulting in the inability to keep a train of thought are typical for ADHD/ASD (Solomon, Carter, Caplan; 2008), and in our model are largely assisted by abnormal perceptual patterns with anxiety being a significant contributor throughout.

Our model suggested behaviour of interaction in community 1 and 2 similar to current models of interpersonal and intrapersonal challenges in ADHD/ASD. The SAT community reflected the social and interpersonal difficulties present in ASD, where social anxiety in combination with inability to incorporate new information (node rigid behaviour) and aloof personality trait result in poorer social skills and functioning (Bottema-Beutel, 2017). Such poor social functioning results in fewer close friends (the connection between social anxiety and node no close friends) which in turn connected well with eccentric behaviour of the APAT community. In the original SPQ questionnaire, both nodes (no close friend and eccentric behaviour) formed the disorganised thoughts higher order scale, which in our model was in line with the connections between attention, speech and schizotypal nodes observed in the APAT community. Such disorganised thoughts and behaviour affect social situations as well and are typical for ADHD/ASD (Shean, 2013; Pallati & Salermo, 2015).

Sensory processing on the other hand, stayed relatively independent in community 3, as confirmed from our bootstrapping statistics, and only connected with the other communities through panic anxiety (the strongest) and less so, attention. In fact, our model suggested panic anxiety has a multidimensional nature and acts as a modulating factor in the interaction between ADHD/ASD, schizotypy and sensory processing. This was further confirmed by the cross loading and replication statistics in the bootstrapping analysis. There are a few lines of support for this in the literature. First, panic /somatic anxiety has been reported to relate to abnormal sensory processing, especially in the integration of sensory stimuli (Engel-Yeger & Dunn, 2011), shown to be aberrant in ADHD/ASD as it causes feelings of sensory flooding and triggers panic/somatic anxiety (Panagiotidi, Overton, Stafford, 2017). Second, panic anxiety is also considered to cause disorganised thinking and behaviour but also to be a result of inefficient deployment of attentional resources in schizotypy (Pollanti & Salermo, 2015; Eley, Gregory & Clark, 2007). It also has a strong connection to social anxiety (Potter et al., 2014) and from there with our community 1.

Panic anxiety's modulatory nature as observed in our model can be due to selective information processing of potential threat- biases in the content of cognitions such as distorted interpretations as in unusual perception and ideas of reference, or biases in the cognitive processes, such as in the deployment of attentional resources to perceived threat. As our model is an undirected network, meaning that the edge between two nodes is influenced by both, we therefore conclude that anxiety is not a product of ADHD, schizotypy or sensory processing, but rather a bridging, equally affected by and affecting factor. In other words, both sensory processing and typical ADHD/ASD, through aberrant attentional deployment and biases in cognitive processes, can “induce” anxious states and therefore manifest in hyperactive/ inattentive/ socially inadequate behaviour typical for ADHD/ASD, which in turn can result in anxiety induced tantrums affecting social functioning. In previous research such variables have been described as forming their own entity within the community they were assigned to, meaning that they belong to a community due to the interactions within this community and the network as a whole, but are a causal entity on their own and therefore have specific significance to the model (Rozgonjuk & Sinderman, Christensen, 2020).

Specific attention in this model should be paid to the connection of ADHD nodes with reward sensitivity and vestibular sensory processing. With regards to the latter, node ADHD-A’s connection to vestibular processing is not surprising as vestibular systems play a big role in paying attention, focus and alertness (Bigelow et al., 2015). Vestibular systems are also involved in balancing gross motor skills and tonus, and are stimulated by physical activity, which further affects attention (Wiener-Vacher et al., 2013). This suggests that ADHD-H has an indirect connection to vestibular processing via ADHD-A. With regards to reward sensitivity, it connected negatively with ADHD-H, which is in contrast to their relationship in clinical populations (Tripp & Aslop, 2001), it can be considered that ADHD and reward have a different relationship in non-clinical adults, however further research is needed.

Overall, our results suggest a rejection of hypothesis 1, as ADHD/ASD did not intertwine and form a common community with sensory processing traits. However, the results did support our the second hypothesis as ADHD/ASD did form common communities with the other factors, which themselves are strongly reliant on sensory processing, and show that interpersonal and intrapersonal aspects widely reported as problematic in clinical ADHD/ASD are mediated in adult sub-clinical populations by anxiety and schizotypy traits, connecting them with sensory processing indirectly rather than sensory processing directly causing the typical ADHD/ASD manifestations.

As in the previous literature that demonstrated relationships between ADHD/ASD and sensory processing via correlational analysis (Panagiotidi, Overton, Stafford, 2017), our dataset was consistent with that. However, our model suggests that these disorders seem to be connected to sensory processing through intermediary conditions, as both ADHD and ASD showed similar behaviour. In our correlational analysis, we found significant correlations between the ADHD and ASD scales and sensory processing, but the power of EGA is that it shows simple correlations do not tell anywhere near the whole story, as they show only the linear relationship between constructs, while EGA has the power to illustrate how variables interact with each other based on their strength and relevance.

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Tables:

Table 1. Questionnaires included in battery- a total of six questionnaires measuring sensory processing, anxiety, reward sensitivity, schizotypal traits, ADHD and ASD. Questionnaires were appropriate for use on adults populations only.

Glasgow Sensory Questionnaire			
Sub-Scale	Abbreviation	Brief measure indicator	Response type
Visual	Visual	processing of lights, shapes, colours	"Never–Rarely–Sometimes–Often–Always"
Auditory	Auditory	processing of sounds and frequencies	
Gustatory	Gustatory	recognition and processing of taste(s)	
Olfactory	Olfactory	processing of odours	
Tactile	Tactile	processing of touch	
Vestibular	VSTBL	processing movements and balance	
Proprioceptor	Propri	processing of muscles and joints	
Screen for Adult Anxiety Related Disorders (SCAARED)			
Sub-Scale	Abbreviation	Brief measure indicator	Response type
Panic/Somatic Anxiety	ANXpanic	physical manifestation of anxiety	"Not true", "Sometimes true", "Very true"
Social Anxiety	ANXsocial	overwhelming fear of social situations	
Reward sensitivity			
Sub-Scale	Abbreviation	Brief measure indicator	Response type
Reward sensitivity	Reward	over exaggerated responsivity to rewards	"Yes/No"
Schizotypal personality questionnaire- Brief			
Sub-Scale	Abbreviation	Brief measure indicator	Response type
Magical Thinking	MT	belief that ideas and thoughts can influence course of events	"Strongly disagree", "Disagree", "Neutral", "Agree" and "Strongly agree"
Unusual Perception	UnP	abnormal and distorted perceptions	
Ideas of Reference	IoR	irrational, random thoughts about oneself	
Eccentric Behaviour	ACb	unusual, odd behaviour	
Odd Speech	ODDSp	unusual and situationally inappropriate speech	
Social Anxiety	SocAnx	schizotypy related social fears	

No Close Friends	NCF	inability to make close friendships	
Adult ADHD self report scale (ASRS)			
Sub-Scale	Abbreviation	Brief measure indicator	Response type
ADHD_A	ADHD.A	measure of (in)attentional traits	“Never”, “Rarely”, “Sometimes”, “Often”, “Very often”
ADHD_B	ADHD.H	measure of hyperactive/impulsive traits	
The Broad Autism Phenotype Predict scale (BAPQ)			
Sub-Scale	Abbreviation	Brief measure indicator	Response type
Aloof Personality	AIP	distant and reserved personality, detached	"Very rarely", "Rarely", "Occasionally", "Somawhat often", "Often", "Very often"
Pragmatic Language	PL	the use of appropriate communication (what, when)	
Rigid Behaviour	RigBeh	inability to incorporate new information, inability to understand others's viewpoint, compulsions	

Weights matrix

	Variable	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**	**11.**	**12.**	**13.**	**14.**	**15.**	**16.**	**17.**	**18.**	**19.**	**20.**	**21.**	**22.**
1.	visual	.																					
2.	auditory	.07	.																				
3.	gustatory	.06	.03	.																			
4.	olfactory	.29	.22	.04	.																		
5.	tactile	.1	.14	.32	.07	.																	
6.	vestibular	.3	.21	.1	.16	.08	.																
7.	propri	.26	.16	.19	.1	.08	.03	.															
8.	reward	.	.	-.02	.	.	-.03	.	.														
9.	ANX_panic	.05	.03	.14	.02	.	.1	.	.	.													
10.	socanx	.	.	.	.	.	.	.	.06	.14	.												
11.	ideas_of_reference	.	.04	.08	.	.	.	.	-.1	.19	.	.											
12.	no_close_friends	.	.	.	.01	.08	.	.01	.05	.	.08	.11	.										
13.	accentric_beh	.01	.02	.	.05	.	.	.05	.	.	.	.	.16	.									
14.	social_anxiety	.	.	-.05	.	.	.01	.	.	.06	.54	.1	.	.	.								
15.	magical_thinking	.	.06	.03	.	.05	.	.02	.	.	.	.09	.	.03	.	.							
16.	odd_speach	.	.	.	.	.	.04	.	.	.	.	.16	.	.07	.05	.	.						
17.	unusual_perception	.07	.03	.	.02	.	.	.05	.	.	.	.26	.	.13	.	.15	.01	.					
18.	aloof_pers	.	.	-.01	.	.	.	.	.08	.	.08	-.01	.31	.08	.26	-.01	-.06	.	.				
19.	rigid_behav	.	.01	.02	.	.08	.	.	.	.08	.04	.04	.	.	.13	.	.	.	.15	.			
20.	pragmatic_langl	.04	.	.	.03	.01	.	.03	-.05	.07	.05	.05	.01	.05	.	.	.29	.03	.12	.01	.		
21.	attention	.	.	.	.	.	.11	.01	-.06	.06	.	.	.07	.	.01	-.11	.09	.	.	.	.12	.	
22.	hyperact	.03	.	.	.	.	.06	.04	-.08	.07	-.07	.05	.	.09	.	.	.18	.11	.	.	.03	.47	.

Table 2. Weights matrix. Weight for each node between the range of -1 and 1. An empty value, denoted usually by 0 or a ., indicates no connection between nodes was found during the network analysis .

Table 3. Descriptive statistics of bootstrap analysis via BootNet R Package, v. 4.1.0. Over 1000 iterations a 3 community network is confirmed with CI 1.89-4.10, standard error 0.59. Note: n.Boots= number of iterations; med.dim= medium number of dimension; SE.dim= standard error; CI.dim= confidence internal for dimension; Lower/Upper CI= lower and upper confidence intervals; Lower/Upper.Qntl= number of dimensions in first and last 25% of resampling distribution

n.Boots	med.dim	SE.dim	CI.dim	Lower.CI	Upper.CI	Lower.Qntl	Upp.Qntl
1000	3	0.5922793	1.162254	1.897746	4.102254	3	5

Table 4. Frequencies of communities following bootstrapping analysis. The Community solution column shown the number of possible communities detected. Frequency = how many times in a 1000 resamples they appeared

Factor/Community solution	Frequency
3	0.721
4	0.221
5	0.053

Table 5. Replication of variables on each community, achieved through item replicability function in bootEGA R package, v. 4.1.0. Note: Visul=Visual; Auditory=Auditory; Gustatory= Gustatory; Olfactory=Olfactory; Tactile=Tactile; Vestibular=Vestibular; Propri=Proprioceptory; Reward= Reward; ANXpanic= Panic Anxiety; ANXsocial= Social Anxiety; IoR= Ideas of Reference; NCF=no close friends; ACb=accentric behaviour; SocAnx=Social Anxiety;MT=Magical Thinking; ODDSp=odd speech; UnP= Unusual perception; ADHD a= ADHD A; ADHD b= ADHD b; AIp= aloof personality; RigBeh= rigid behaviour; PL=pragmatic language

	Community 1	Community 2	Community 3
ADHD.A	0.92		
ADHD.H	0.92		
ODDSp	0.92		
PL	0.91		
IoR	0.87		
ACb	0.86		
UnP	0.82	0.094	
MT	0.77	0.002	0.16
Reward	0.76	0.094	
ANXpanic	0.75	0.092	0.16
NCF	**0.38**	**0.3**	
ANXsocial		0.99	
SocAnx		0.99	
AlP		0.98	
RigBeh		0.92	
Visual			1
Auditory			1
Gustatory			1
Olfactory			1
Tactile			1
Vestibular			1
Propri			1

Table 6. Average network loading for all variables across all communities. Note: Bold values are network loadings greater than or equal to a small effect size (0.15)

	Dimension	1	2	3
Auditory	3	0.058	0.003	**0.313**
Tactile	3	0.042	0.042	**0.306**
Visual	3	0.065	0	**0.298**
VSTBL	3	0.109	0	**0.292**
Olfactory	3	0.043	0	**0.29**
Gustatory	3	0.081	-0.011	**0.278**
Propri	3	0.065	0	**0.274**
ADHD.H	1	**0.338**	-0.018	0.049
IoR	1	**0.301**	0.067	0.046
ADHD.A	1	**0.297**	0.002	0.041
ODDSp	1	**0.255**	0.023	0.015
PL	1	**0.227**	0.079	0.042
UnP	1	**0.219**	0	0.066
Acb	1	**0.167**	0.033	0.05
NCF	1	**0.124**	**0.204**	0.035
ANXpanic	1	**0.141**	**0.111**	**0.128**
MT	1	**0.103**	0	0.054
Reward	1	-0.093	0.066	-0.018
SocAnx	2	0.062	**0.477**	-0.008
ANXsocial	2	**0.107**	**0.34**	0
AlP	2	**0.178**	**0.247**	0
RigBeh	2	0.044	**0.159**	0.032

Table 7. Correlational analysis.

Correlational analysis

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	visual	1.																					
2	auditory	.56**	1.																				
3	gustatory	.65**	.54**	1.																			
4	olfactory	.61**	.68**	.56**	1.																		
5	tactile	.67**	.60**	.64**	.60**	1.																	
6	vestibular	.61**	.61**	.57**	.58**	.58**	1.																
7	propri	-.13**	-.20**	-.19**	-.10*	-.23**	-.15**	1.															
8	reward	.48**	.51**	.46**	.46**	.54**	.43**	-.16**	1.														
9	ANX_panic	.24**	.15**	.23**	.23**	.21**	.17**	.11*	.45**	1.													
10	socanx	.46**	.47**	.37**	.39**	.44**	.42**	-.25**	.53**	.33**	1.												
11	ideas_of_reference	.32**	.32**	.33**	.38**	.28**	.34**	.06	.35**	.43**	.43**	1.											
12	no_close_friends	.36**	.26**	.37**	.33**	.35**	.38**	-.10*	.30**	.19**	.34**	.43**	1.										
13	accentric_beh	.29**	.14**	.28**	.26**	.32**	.20**	.07	.45**	.76**	.43**	.43**	.28**	1.									
14	social_anxiety	.28**	.26**	.20**	.27**	.19**	.26**	-.03	.16**	.07	.30**	.10*	.21**	.06	1.								
15	magical_thinking	.29**	.29**	.32**	.30**	.45**	.29**	-.22**	.43**	.21**	.52**	.24**	.39**	.34**	.15**	1.							
16	odd_speach	.43**	.40**	.40**	.38**	.41**	.43**	-.15**	.38**	.18**	.57**	.33**	.42**	.26**	.33**	.41**	1.						
17	unusual_perception	.23**	.13**	.25**	.28**	.20**	.26**	.12*	.29**	.54**	.23**	.57**	.36**	.61**	.02	.15**	.21**	1.					
18	aloof_pers	.28**	.29**	.25**	.33**	.27**	.23**	-.06	.38**	.39**	.33**	.27**	.22**	.45**	.05	.19**	.16**	.42**	1.				
19	rigid_behav	.35**	.36**	.41**	.39**	.44**	.41**	-.21**	.48**	.36**	.49**	.39**	.40**	.38**	.11*	.60**	.41**	.40**	.30**	1.			
20	pragmatic_langl	.37**	.30**	.39**	.32**	.52**	.40**	-.27**	.47**	.23**	.40**	.37**	.37**	.31**	-.02	.54**	.35**	.28**	.16**	.52**	1.		
21	attention	.42**	.39**	.42**	.37**	.53**	.44**	-.29**	.48**	.11*	.50**	.31**	.42**	.21**	.14**	.58**	.47**	.21**	.22**	.51**	.73**	1.	
22	hyperact	.46**	.42**	.39**	.42**	.37**	.53**	.44**	-.29**	.48**	.11*	.50**	.31**	.42**	.21**	.14**	.58**	.47**	.21**	.22**	.51**	.73**	1

**. Correlation is significant at the 0.01 level (2-tailed)./ *. Correlation is significant at the 0.05 level (2-tailed).

Figures

Figure 1. EGA Network model of 22 nodes and 3 communities, generated by igraph and qgraph R packages, v. 4.1.0, over data from 351 participants. Community 1 in red - Abnormal perception and attention traits (APAT), Community 2 in blue- (rigid) Social and autistic traits (SAT), Community 3 in green- Sensory processing traits (SPT). Green edges represent positive and red negative connection. Their thickness and saturation indicates the strength of the connection. Note: Visul=Visual; Auditory=Auditory; Gustatory= Gustatory; Olfactory=Olfactory; Tactile=Tactile; Vestibular=Vestibular; Propri=Proprioceptory; Reward= Reward; ANXpanic= Panic Anxiety; ANXsocial= Social Anxiety; IoR= Ideas of Reference; NCF=no close friends; ACb=accentric behaviour; SocAnx=Social Anxiety;MT=Magical Thinking; ODDSp=odd speech; UnP= Unusual perception; ADHD a= ADHD A; ADHD b= ADHD b; AIp= aloof personality; RigBeh= rigid behaviour; PL=pragmatic language.

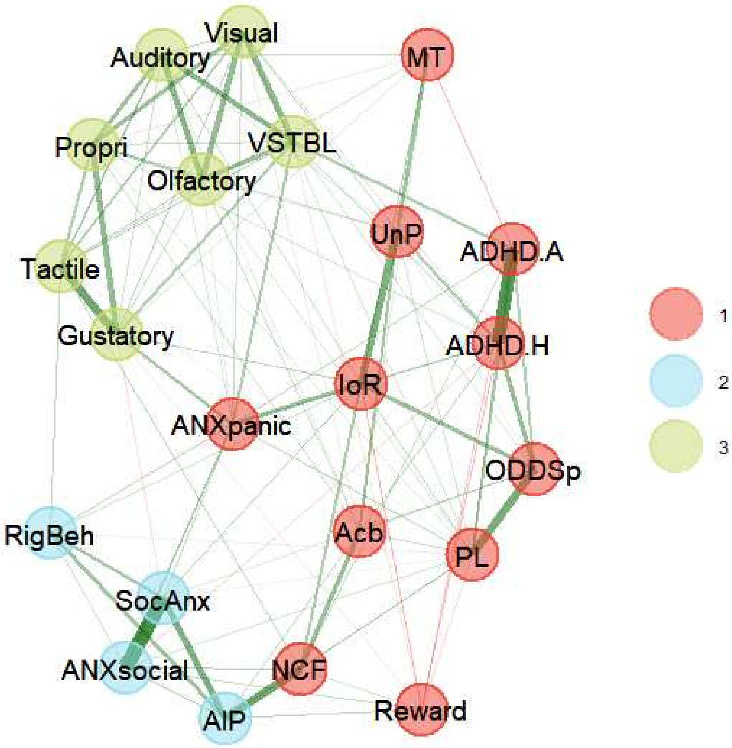

Figure 2. Replication of items on their deterministically assigned communities in the sampling distribution, achieved through item replicability function in bootEGA, EGAnet and NetworkToolbox R packages, v. 4.1.0**. Note: Items under the range of** 0.65- 0.75 are considered unstable, maximum replicability value = 1.