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ORIGINAL ARTICLE

Exploring the Link Between Sensory Processing and Psychopathology in a Community Sample of Young Adults: Bayesian Network Analyses

Andrea Escelsior[1,2] · Martino Belvederi Murri[3] · Luis Polena[2] · Giulia Petrilli[2] · Alessio Zizzi[2] · Alberto Inuggi[2] · Juxhin Bode[2] · Batya Engel-Yeger[4] · Beatriz Pereira da Silva[2] · Monica Gori[5] · Mario Amore[1,2] · Gianluca Serafini[1,2]

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Abstract
Sensory processing is a fundamental aspect of human experience, and varies significantly between individuals, potentially affecting individual functioning, behaviour, and mental health. This study investigated the associations between sensory processing and psychopathology in a sample of the general population. Participants responded to a general psychiatric screening tool (DSM-5 Self-Rated Level 1 Cross-Cutting Symptom Measure-Adult) and to the Adolescent/Adult Sensory Profile (AASP) questionnaire. The sample comprised 1108 young adults (77.25% females, mean age 22.6). Data were analysed using item response theory and Bayesian network analyses, revealing specific associations between sensory profiles and psychopathological dimensions. Specifically, we detected associations between the low registration sensory profile and the dimensions of psychosis, substance use, and mania. Sensation seeking was associated with mania. Sensory sensitivity was related to depression and mania, while sensation avoiding was inversely correlated with mania. These findings suggest that reduced external sensory awareness may be linked to a predisposition to psychosis, while a multifaceted sensory processing pattern may indicate vulnerability to mood disorders. Assessing sensory processing could yield crucial insights into individual susceptibilities to mental disorders and help identify targeted preventive and therapeutic strategies

Keywords Sensory profile · Network analysis · Psychopathology · Psychosis · Mania

Depression has been linked with sensory numbing, while mania is traditionally linked to increased sensory acuity. Schizophrenia has been associated with auditory dysfunctions and increased sensitivity to noise (Javitt & Sweet, 2015) These findings hint at a relationship between sensory processing and vulnerability towards mental disorders, an understudied area of research which might provide insights with clinical utility.

Sensory processing refers to the neurobiological processes that underlie the detection and interpretation of incoming sensory information (Amadeo et al., 2022) involving multiple sensory channels, including hearing, sight, smell, taste, touch-pressure, proprioception,

Extended author information available on the last page of the article

thermoception, balance, and pain sensation (Cermak 1988). As a fundamental aspect of human neurobiology, sensory processing enables the body to interact with external stimuli and plays a central role in perception, cognition, and motor responses (Harrison et al., 2019). Sensory processing is essential for understanding how individuals perceive and respond to their environment (Miller et al., 2007). Sensory preferences impact daily life, including functioning, working activities, and socialisation (Miller et al., 2007). Dunn's four-quadrant model of sensory processing was developed to categorize individuals into four sensory processing styles, based on their responses to various sensory inputs (Dunn et al., 2016). It is based on two key elements: the *neurological threshold*, which depends on the minimal intensity of stimuli that are needed to elicit a response by the nervous system, and the *behavioural response*, representing individual strategies of responses to the environment (Brown et al., 2001). This model has been operationalised using the Adolescent/Adult Sensory Profile (AASP), an assessment instrument that explores the patterns of sensory reactivity in respondents across the lifespan (Dunn, 2001; Brown et al., 2001; Miller et al., 2007; Royeen 1991). Studies have elucidated a significant correlation between individual differences in the sensory profile and variations in white matter, suggesting a potential neurobiological basis for sensory processing differences (Escelsior et al., 2023; Shiotsu et al., 2021). In this regard, information processing has been suggested as a candidate marker of individual vulnerability to certain dimensions of psychopathology. A retrospective analysis identified associations between sensory processing patterns and major psychiatric disorders like schizophrenia, bipolar disorder, and major depressive disorder. This investigation revealed the complex interaction between sensory processing abnormalities and the onset of these psychiatric conditions, underscoring the potential importance of sensory processing assessments in comprehending and early detecting mental health disorders (Brown et al., 2020). Additionally, a recent meta-analysis of 33 studies revealed a consistent pattern of elevated low registration, sensory sensitivity, and sensation avoiding , along with decreased behavioural responses associated with the sensation seeking profile in individuals with various psychiatric conditions (van den Boogert et al., 2022). To our knowledge, however, there has been little research on large samples of individuals comprising the entire spectrum of clinical severity, i.e., individuals who may be at risk for psychiatric disorders, individuals with subclinical symptoms, and healthy subjects. This may be particularly relevant to establishing whether a relationship exists between certain sensory profiles or modalities and the vulnerability towards specific dimensions of psychopathology. This might have clear clinical relevance for prognostic or therapeutic applications at the clinical level. Advanced modelling methods, such as network analysis (Biggio et al., 2023) and item response theory analyses (Belvederi Murri et al., 2022) may be particularly suited to shed light on the complex relationships between these aspects.

Aims of the Study

This study aims to examine the association between sensory processing patterns, assessed within the framework of Dunn's four-quadrant model, and the primary psychopathological dimensions. Our hypothesis was that individuals with vulnerability towards mood disorders and psychotic disorders would exhibit distinct patterns of associations between cardinal symptoms, sensory profiles, and sensory modalities.

Material and Methods

Participants

This cross-sectional study used data from a sample of 1108 people (856 F, 252 M) with a mean age of 22.62 ± 3.32 years. The sample was mainly drawn from students and their acquaintances. Inclusion criteria encompassed individuals over 18 years of age, willing to participate, and proficient in the Italian language. Exclusion criteria involved refusal of informed consent and a diagnosis of major psychiatric disorders. Participants provided informed consent voluntarily after receiving a comprehensive explanation of the study's procedures and objectives.

Measures

Participants completed the DSM-5 Self-Rated Level 1 Cross-Cutting Symptom Measure-Adult, a psychiatric assessment tool that evaluates relevant mental health domains for diagnostic purposes, aiding treatment evaluation (Narrow et al., 2013). It consists of a 23-item questionnaire assessing 13 domains of psychopathology, demonstrating validity and utility in identifying common mental health issues (Clarke & Kuhl, 2014; Doss & Lowmaster, 2022).

Individual sensory processes were assessed with the Adolescent/Adult Sensory Profile (AASP) (Brown et al., 2001). The AASP consists of a 60-item scale assessing taste/smell, movement, vision, touch, activity level, and auditory processing, measuring responses to sensory events. The AASP assesses sensory responses in multiple domains, identifying four profiles: *low registration* (high threshold, passive response, difficulty expressing emotions, perceived as calm and submissive), *sensation seeking* (high threshold, active response, pleasure from sensory experiences, viewed as impulsive and prone to risky behaviour), *sensory sensitivity* (low threshold, strong reaction to sensory stimuli, distractibility, discomfort, but no active avoidance), and *sensation avoiding* (low threshold, active avoidance of overwhelming stimuli, negative and aggressive responses to intense). The way individuals perceive and react to stimuli may influence their daily choices, mood, temperament, and organisational styles. Each set of items relative to a sensory profile includes items related to different sensory modalities: for instance, among items related to sensation avoiding, we found "I only eat familiar foods", "I keep the blinds down during the day when I'm home", and "I avoid or wear gloves during activities that will make my hands dirty". These can be attributed to the taste, visual, and haptic/tactile sensory modalities, respectively. For the purpose of this study, we sought to explore sensory modalities in detail, by modelling the variability of scores due to sensory profiles and to sensory modalities jointly, i.e. using a cross-classified model. To this end, we planned to further classify each item in the questionnaire based on the dominant sensory modality. The classification of items was to be based on an a priori consensus procedure between authors, from the following domains: "*Auditory*", "*Touch*", "*Visual*", "*Kinaesthesia*", "*Taste*", "*Smell*", "*Peripersonal*" (Bisio et al., 2017), and "*Time Concentration*" describing the modality related to detachment from surroundings and the subjective flow of time (Hancock et al., 2019).

The study was approved by the Local Ethical Committee.

Statistical Analysis

Data from the AASP was analysed under the *item response theory* (IRT), which focuses on the relationship between individual scoring of individual items and the respondent level on a trait that items were designed to measure (Fox, 2010; Reise & Waller, 2009). In particular, we modelled data using *Bayesian multilevel analyses with a multidimensional graded response model*, with nesting of items score within each subject, item, and latent dimension(s) (Bürkner, 2021). This approach improves the reliability of estimates and provides measures of parameter uncertainty. Individual scores were extracted as the median of the *theta* parameter for each subject (Belvederi Murri et al., 2020). The first analyses relied on the conventional four sensory profiles as defined by Dunn's sensory profiles, while the second was based on a cross-classified model. Here, each item was simultaneously assigned to a sensory profile and a sensory modality, allowing to extract two sets of *theta* values, one for each classification per subject.

To model the relationship between sensory processing and psychopathology, we used network models. In a symptom network, symptoms (item scores) are represented as nodes (circles), and the relationships between them are represented as edges (lines). Edges can be weighted or unweighted, where unweighted edges simply connect the symptoms, while weighted edges indicate the strength of the connection with a coefficient. The thickness of the edge represents the strength of the association between two nodes, conditional on the value of all other nodes in the network, with thicker edges indicating stronger associations. Associations can be positive (green) or negative (red). We first analysed the relationship between psychopathology domains, symptoms, and sensory profiles. Then, we estimated another model including scores relative to sensory modalities. Network analyses were based on exploratory Bayesian network analyses as in the 2.0.3 version BGGM package in R (Williams & Mulder, 2020). Age and sex were included as covariates. Network analyses are based on the Gaussian graphical model (GGM) (Fonseca-Pedrero, 2017).

Results

Grouping of Items According to Sensory Modality

Table S1 (see Supplementary materials) reports the results of the consensus procedure between the authors (A.E., M.B.M, A.Z.) to classify items according to the prevalent sensory modality. Table 1 includes the characteristics of the sample, including scores from the AASP divided by sensory profiles and sensory modalities, as well as scores of the psychopathological dimensions of the DSM-5 Self-Rated Level 1 Cross-Cutting Symptom Measure-Adult.

The first network (Fig. 1) analysed data from the sensory profile models (sensation seeking, sensation avoiding, sensory sensitivity, and low registration) and psychiatric disorder symptom clusters. As expected, the network analyses detected the strongest connections between nodes from the AASP dimensions. A positive connection was found between sensation seeking and sensation avoiding (strength of 0.09). We also found a positive correlation between sensation avoiding and low registration (0.65), both profiles exhibiting avoidance responses, and between low registration and sensory sensitivity (0.51), both profiles having a high response threshold. Analysing the relationships between symptom domains

Fig. 1 Network of sensory profiles and psychiatric disorders

and sensory profiles, the following patterns emerged: low registration was positively connected with personal functioning (0.12), memory (0.1), and substance use (0.09) while displaying a negative correlation with depression (−0.06). Sensory sensitivity exhibited positive correlations with both mania (0.14) and depression (0.06) but showed negative correlations with personal functioning (−0.07) and anxiety (−0.1). Sensation avoiding demonstrated a positive correlation with anger (0.07) while displaying negative correlations with mania (−0.13) and personal functioning (−0.08). Sensation seeking showed positive correlations with mania (0.11) and personal functioning (0.1) while exhibiting a negative correlation with anger (−0.07). We also found a positive correlation between sensation avoiding and low registration (0.65), both profiles exhibiting avoidance responses, and between low registration and sensory sensitivity (0.51), both profiles having a high response threshold. However, there is a negative correlation between the two groups that differ in both registration threshold and stimulus response, namely, low registration- sensation seeking (−0.4) and sensation avoiding-sensory sensitivity (−0.25). The last link was between sensation seeking and sensory sensitivity (0.97). The supplement reports all weighted adjacency matrices for networks (Tables S1, S2, S3).

In the second network analysis (Fig. 2), we examined the relationships between sensory modalities and psychopathology. The dimension of psychosis was the prevalent domain with specific connections with sensory modalities. It positively correlated with the auditory (0.08) and visual modalities (0.07), but negatively correlated with

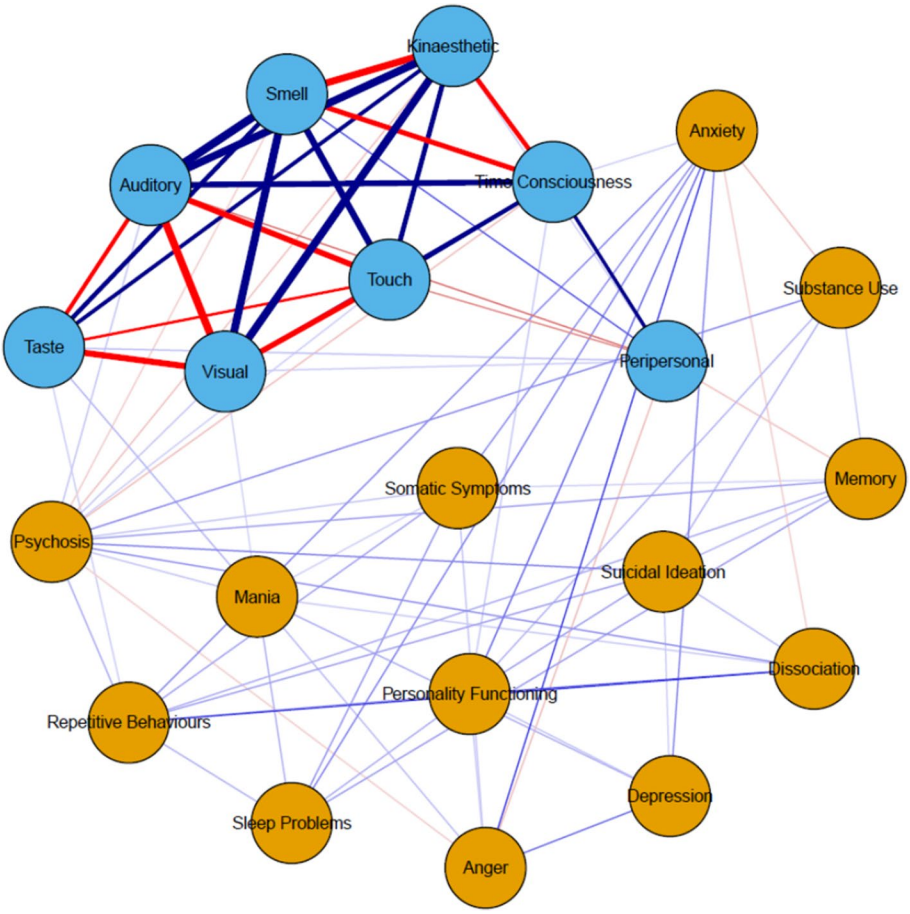

Fig. 2 Network of sensory modalities and psychiatric domains

proprioception (− 0.08) and time/concentration (− 0.08). As expected, we also detected strong connections within the domain of sensory modalities. Other relevant correlations were those between mania and taste (0.1) and between anxiety and time concentration (0.07).

The final network analysis comprised the sensory profiles, sensory modalities, and psychopathology ratings (Fig. 3). We detected limited differences in the connections between sensory profiles and psychiatric ratings, compared with the first and the second networks. However, the following associations were preserved after reciprocal adjustment between sensory profiles and modalities. Low registration was positively connected with psychosis (0.09) and mania (0.07), whereas sensation avoiding exhibited a negative correlation with mania (− 0.14). In addition, personality functioning was associated with reduced sensory sensitivity (− 0.08). The network included, as expected, strong interconnections between sensory modalities and sensory profiles.

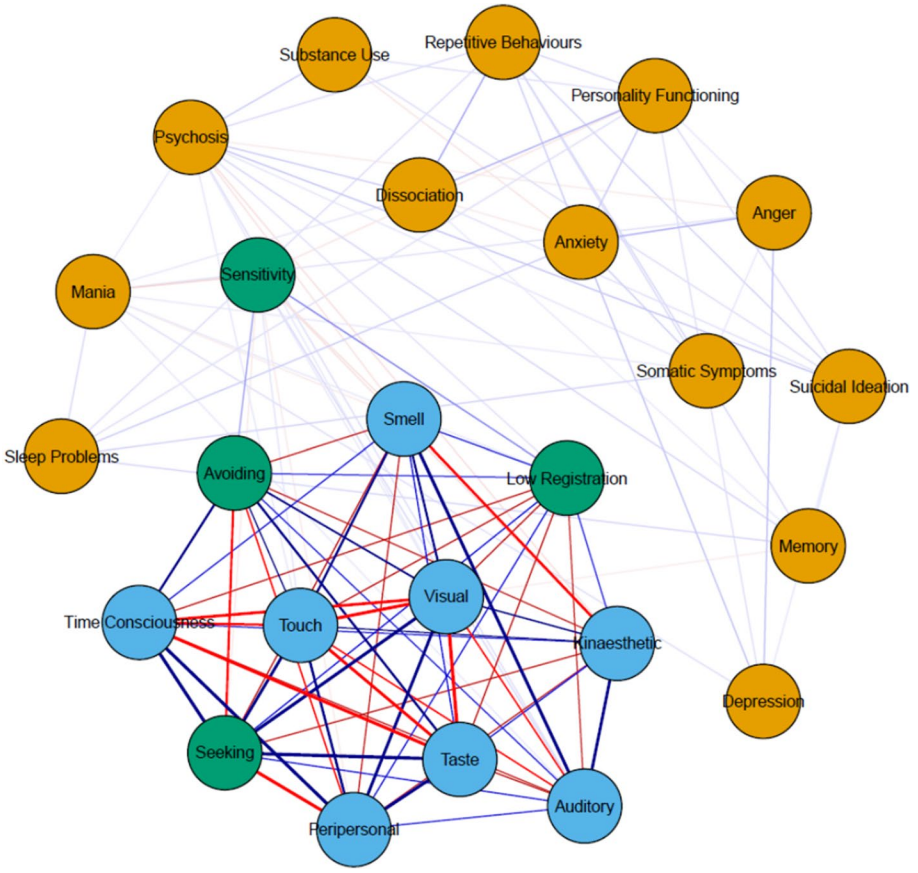

Fig. 3 Network of sensory profiles, sensory modalities, and psychopathology

Discussion

In a large population study, the vulnerability towards mania and psychosis was associated with low registration, a tendency to reduce processing of sensory information, as well as different preferences for specific sensory modalities (e.g. reduced preference for the olfactive modality and heightened auditory sensitivity). Both individuals with manic symptoms and maladaptive personality traits reported reduced sensory sensitivity. Differences in sensory information processing may constitute an integral part of the vulnerability towards mental health conditions and may offer potential therapeutic mechanisms.

Our results are consistent with those of previous studies suggesting that information processing is altered among individuals with psychiatric disorders (Baker et al., 2014; McTeague et al., 2020; Palaniyappan et al., 2013). A retrospective analysis examined five studies revealing a general pattern of increased sensory sensitivity, sensation avoiding, low registration, and reduced sensation seeking among individuals with schizophrenia, high risk of psychosis, bipolar disorder, and major depressive disorder, and the AASP questionnaire scores were significantly different between patients and controls, although with some variability in sensory processing preferences (Brown et al., 2020). Our study detected a

Table 1 Sample characteristics

Sample characteristics	Mean	Standard Dev
Age	22.62	3.32
Sensory profiles (mean ± SD)		
Low registration	27.77	7.84
Sensory seeking	40.54	7.63
Sensory sensitivity	35.41	9.38
Sensory avoidance	34.82	8.55
Sensory modalities (mean ± SD)		
Taste	2.52	0.68
Kinaesthesia	2.29	0.58
Visual	2.27	0.55
Auditory	2.35	0.63
Smell	2.29	0.62
Touch	2.16	0.49
Time concentration	2.58	0.57
Peripersonal	2.14	0.70
DSM-5 screening (mean ± SD)		
Depression	4.51	1.25
Anger	1.88	1.18
Mania	2.75	2.14
Anxiety	5.43	3.23
Somatic symptoms	2.15	2.19
Suicidal_ideation	0.46	0.95
Psychosis	0.39	1.19
Sleep_problems	1.39	1.34
Memory	0.60	1.02
Repetitive thoughts behaviour	1.93	2.21
Dissociation	0.65	1.09
Personality functioning	2.67	2.27
Substance use	1.69	2.38

relationship between low registration and psychotic symptoms. Individuals with a high risk for psychosis often report a reduced disposition to perceive external stimuli or subjective abnormalities in sensory processing (Jahshan et al., 2012). A tendency to strive for sensory deprivation may also constitute a possible reaction to abnormal subjective experiences in the sensory realm, a contributing factor in the vulnerability for psychosis, which is known to correlate with psychiatric disorders (Sahoo et al., 2022). The relative deficit in perceiving external inputs has traditionally been interpreted as a relatively greater focus towards internal stimuli, congruent with the notion of schizophrenic "autism". More recently, this phenomenon has been recast within the Bayesian brain framework as a tendency to over-reliance on prior information, rather than on sensory data that is also elegantly documented in psychosis (Haarsma et al., 2020). Multisensory integration deficits are also well known in psychosis and may contribute to the relative insensitivity towards general or specific stimuli (Postmes et al., 2014; Tseng et al., 2015). Sensory processing in psychosis may also be related to a lack of awareness towards internally generated stimuli (the bodily self), self-disorders, and reduced illness insight (Belvederi Murri & Amore, 2019). Interestingly,

it seems possible to train sensory processing abilities in adults (O'brien et al., 2023), which might pave the way for novel rehabilitation strategies, for instance, based on physical activity (Soundy et al., 2014).

In our study, mania was positively connected with sensation seeking and sensory sensitivity while being negatively connected with sensation avoiding. Sensory perception has been involved in emotional processes (Serafini et al., 2017a, 2017b). In a recent study, depression was predicted by sensation avoiding score, while hyperthymic temperament was correlated with sensation seeking. Hypo- or hyper-sensitivity is a trait personality marker of vulnerability for severe affective disorders (Engel-Yeger et al., 2016, 2017). This study confirms the connection between sensation seeking and mania, a condition characterised by risky behaviours to enhance sensory stimulation above the higher sensory threshold. Surprisingly, we did not detect associations between sensation avoiding and depression, which instead correlated with sensory sensitivity. High sensory sensitivity bias towards negative stimuli, however, may also constitute a vulnerability that affects the quality of life in depression. This, for instance, manifests also towards somatic sensations, such as those that manifest during physical illnesses (Belvederi Murri et al., 2020). Interestingly, during the recent pandemic, disparities in sensitivity levels moderated the psychological effects of lifestyle changes during the lockdown. Little to no negative effects were observed among individuals with anxiety and depressive disorders, suggesting that individuals with depression may be particularly vulnerable to external stimuli (Bordarie et al., 2022). This led authors to hypothesise that they may be unable to filter out negative inputs. This study is strengthened by a rigorous analytic approach that for the first time combined cross-classified Bayesian item response theory analyses with network analyses (Fonseca-Pedrero, 2017). The network theory of mental disorders challenges the view that symptoms are passive results of a common underlying cause (Borsboom & Cramer, 2013) but rather considers symptoms as interconnected components of a dynamic, complex system. This approach is particularly fit to study factors that shape the vulnerability (Cramer et al., 2016) towards mental illness such as sensory profiles and modalities. Our approach allowed us to uncover previously undetected associations between sensory profiles and psychosis risk in a large general population of young individuals. Clinical assessments of sensory profiles and modalities may be relevant to extend the knowledge of individuals at risk for psychosis and mood disorders, either to facilitate early detection or to guide personalised treatment. Various psychosocial and pharmacological strategies may take advantage of a tailored approach that takes into account the individual sensory profile or their potential neural correlates. These include psychotherapy, physical exercise, psychoeducation, behavioural activation, and somatic treatments such as TMS.

Strengths and Limitation

This study, one of the few available to use a robust methodology and a large sample to examine the intricate interplay between sensory processing and psychopathology, is strengthened by a rigorous analytic approach that for the first time combined cross-classified Bayesian item response theory analyses with network analyses.

This study has at least some main limitations that should be acknowledged. Firstly, the sample considered may not be generalizable to the broader population as it primarily consists of young, educated individuals, and there is an imbalance in sex representation. Secondly, due to the cross-sectional nature of the study design, causality cannot be established,

and it is challenging to infer temporal relationships between sensory processing and psychopathology. Additionally, although the AASP is a wellvalidated tool, more precise externally administered measures of sensory evaluation could have been beneficial for enhancing the depth of our findings.

Conclusions

In conclusion, our findings suggest that specific alterations in sensory processing are associated with specific psychopathological dimensions in a community sample of young adults. This observation aligns with the existing literature on psychiatric disorders, which reported alterations in sensory processing among affected individuals, including heightened awareness or sensitivity to external stimuli. Within this framework, it is possible that specific sensory processing patterns could be a susceptibility factor for the development of psychiatric disorders.Research, however, is still needed to explore the relevance and role of sensory processing alterations for early identification, clinical characterisation, and treatment personalization (van den Boogert et al., 2022). Novel therapeutic strategies may, in fact, be helpful in modulating specific sensory processing modalities before or after the onset of mental disorders, aiming to improve clinical outcomes.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11469-024-01316-x.

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Data Availability The data that support the findings of this study are available upon reasonable request, subject to a formal data-sharing agreement.

Declarations

Ethics Approval and Consent to Participate The study was approved by the Local Ethical Committee. Participants provided informed consent voluntarily after receiving a comprehensive explanation of the study's procedures and objectives.

Conflict of Interest The authors declare no competing interests.

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Authors and Affiliations

Andrea Escelsior[1,2] · Martino Belvederi Murri[3] · Luis Polena[2] · Giulia Petrilli[2] · Alessio Zizzi[2] · Alberto Inuggi[2] · Juxhin Bode[2] · Batya Engel-Yeger[4] · Beatriz Pereira da Silva[2] · Monica Gori[5] · Mario Amore[1,2] · Gianluca Serafini[1,2]

✉ Alessio Zizzi
z.alessio98@gmail.com

Andrea Escelsior
andrea.escelsior@unige.it

Martino Belvederi Murri
martinobelvederi@gmail.com

Luis Polena
luis.polena@gmail.com

Giulia Petrilli
giulia.petrilli@icloud.com

Alberto Inuggi
alberto.inuggi@gmail.com

Juxhin Bode
ginobode96@gmail.com

Batya Engel-Yeger
bengel@univ.haifa.ac.il

Beatriz Pereira da Silva
pereira.riabilitazionepsi@gmail.com

Monica Gori
monica.gori@iit.it

Mario Amore
mario.amore@unige.it

Gianluca Serafini
gianluca.serafini@unige.it

[1] IRCCS Ospedale Policlinico San Martino, Genoa, Italy

[2] Department of Neuroscience, Rehabilitation, Ophthalmology, Genetics, Maternal and Child Health (DINOGMI), Section of Psychiatry, University of Genoa, Largo Rosanna Benzi, 10, 16132 Genoa, Italy

[3] Institute of Psychiatry, Department of Biomedical and Specialty Surgical Sciences, University of Ferrara, Ferrara, Italy

[4] Department of Occupational Therapy, Faculty of Social Welfare and Health Sciences, University of Haifa, Haifa, Israel

[5] U-VIP Unit for Visually Impaired People, Fondazione Istituto Italiano Di Tecnologia, Genoa, Italy