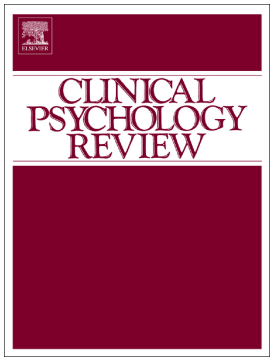

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Yixin Chen, Zhenyang Xi, Rob Saunders, David Simmons, Vasiliki Totsika, Will Mandy

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A Systematic Review and Meta-Analysis of the Relationship Between Sensory Processing Differences and Internalising/Externalising Problems in Autism

Yixin Chen[a,*], Zhenyang Xi[b], Rob *Saunders*[a], David *Simmons*[c], Vasiliki Totsika[d], Will Mandy[a]

[a]Department of Clinical, Educational and Health Psychology, University College London, 1-19 Torrington Place, London, UK

[b]Department of Experimental Psychology, University College London, 26 Bedford Way, London, UK

[c]School of Psychology and Neuroscience, University of Glasgow, 62 Hillhead Street, Glasgow, UK

[d]Division of Psychiatry, University College London, Maple House, 149 Tottenham Court Road, London, UK

*Corresponding author

Email address: yixin.chen.17@ucl.ac.uk

Postal address: Department of Clinical, Educational and Health Psychology, University College London, 1-19 Torrington Place, London, UK

Declaration of interest: none

Abstract

There is evidence to suggest that sensory processing differences (SPDs) to external stimuli are a plausible underlying mechanism for mental health problems among autistic people. In the current systematic review, we examined the associations between, on the one hand, eleven types of SPDs and, on the other hand, internalising and externalising problems. The literature search was conducted on five databases (MEDLINE, PsycINFO, Web of Science, EMBASE, and CINAHL) between 1990 and August 2024. Studies with autistic people aged under 65 years-old that reported correlations between SPDs and internalising/externalising problems were included. Three-level and random-effects meta-analyses and narrative synthesis were conducted. In total, we included 63 articles (11,659 participants) in the current review. Overall, higher levels of all SPD subtypes were found to be associated with greater internalising/externalising problems. Hypersensitivity, visual, auditory, and tactile sensitivities were strongly associated with internalising/externalising problems, while smaller effects were observed for unusual processing of smell and taste. Sensation seeking was highly linked with externalising problems, whereas it was the least associated sensory subtype with internalising problems. Future studies could address the limitations in the extant literature (e.g., heterogeneity in the estimates of associations, a lack of externalising problem investigations and longitudinal studies) to further advance our understanding of the role of SPDs in the aetiology, development, and treatment of internalising/externalising problems in autism.

Keywords

Autism; Sensory processing; Internalizing; Externalizing; Meta-analysis

Introduction

Autistic people are at substantially elevated risk of experiencing mental health difficulties compared to their non-autistic peers (Lai et al., 2019). In a community sample of autistic children, 70% were found to meet criteria for at least one co-occurring mental health diagnosis, with 40% having two or more (Simonoff et al., 2008). This high risk of co-occurring mental health problems persists into adulthood, as evidenced by the high observed rates of a range of psychiatric challenges amongst autistic adults (Lai et al., 2019). It is notable that, across their lifespan, the mental health risks of autistic people cover a broad spectrum of problems, encompassing anxiety, depression, psychosis, bipolar disorder, sleep problems and impulse-control challenges (Lai et al., 2019). The mental health problems of autistic people substantially impact upon their quality of life and functioning, and are associated with negative and harmful life experiences, such as unemployment and victimisation (Griffiths et al., 2019). Currently, there is a limited evidence base to inform interventions for autistic mental health problems (Linden et al., 2023). This partly arises because our understanding of the mechanisms underlying the emotional and behavioural difficulties of autistic people is limited. As such, the development of a better understanding of the mechanisms underlying mental health risk is a key priority for the autistic community, clinicians, and researchers (James Lind Alliance, 2016; Mandy, 2022).

The behavioural, emotional, and social problems associated with a range of psychopathologies have been clustered into two broad-band symptom dimensions: internalising and externalising problems (Achenbach & Edelbrock, 1981). Generally, internalising problems are characterised by over-controlled behaviours (e.g., anxiety, depression, social withdrawal), while externalising problems are characterised by under-controlled behaviours (e.g., aggression, hyperactivity, impulsion). This influential and widely-used description of mental health problems has a number of advantages. First, it is empirically grounded, based on factor analyses of symptom data and has been widely replicated with both clinical and non-clinical samples (Achenbach, 1966; Achenbach & Edelbrock, 1981; American Psychiatric Association, 2013). Second, compared to assigning several categorical mental health diagnoses to a person, using an internalising/externalising

framework helps accommodate the fact that individuals commonly meet criteria for multiple mental health diagnoses (Achenbach et al., 2016). Third, as a dimensional model, internalising/externalising symptom measurement captures the continuous, as opposed to categorical, nature of most mental health problems across the life span (Forbes et al., 2016). On this basis, these two broad-band internalising/externalising groups were applied in the current review.

Attempts to understand the internalising and externalising problems of autistic people have tended to rely upon models of psychopathology derived from non-autistic people (Mazefsky & Herrington, 2014). It is likely that this is an incomplete approach, given emerging evidence that there are autism-specific risk factors that cause and maintain mental health problems (Mandy, 2022). For example, intolerance of uncertainty, linked to the core autism diagnostic feature of resistance to change, appears to play a prominent role in the anxiety disorders of autistic people (Rodgers et al., 2018); and autism-related proprioceptive difficulties are likely implicated in the development of autistic women's restrictive eating disorders (Brede et al., 2020). The current review seeks to contribute to understanding of autistic internalising and externalising difficulties by investigating the role of one autism-specific putative risk factor, namely sensory processing differences (SPDs).

Sensory processing differences to external stimuli are one of the core, diagnostic features of autism, identified since the earliest descriptions of the condition (Asperger & Frith, 1991; Kanner, 1943); and are a plausible risk factor for autistic internalising and externalising problems. The estimated prevalence of sensory symptoms among autistic people varies between studies, ranging from 30% to over 96% (Dawson & Watling, 2000; Marco et al., 2011; Tavassoli et al., 2016; Tavassoli et al., 2018). For both autistic and non-autistic people, the mismatch between contextual demands from external stimuli and the individual's own internal information processing capacities results in impaired abilities to engage with other people or in activities (Tomchek & Dunn, 2007). For example, in non-autistic people, problems in regulating sensory input is associated with food fussiness (Rendall et al., 2022) and temper tantrums (Critz et al., 2015). Research with autistic people has found a wide array of negative impacts of atypical sensory processing, including on socialisation, communication, social processing,

flexibility, and academic attainment (e.g., Ashburner et al., 2008; Rossow et al., 2021; Tavassoli et al., 2018). Numerous studies have examined the relationship between autistic sensory processing difficulties and internalising/externalising problems. For example, conduct problems (Foley & Baz, 2021), anxiety, and depression (Mazurek et al., 2013; Pfeiffer et al., 2005; Rossow et al., 2021) were found to be associated with SPDs. However, it should be acknowledged that such associations likely reflect varied and complex relationships between sensory processing and mental health problems. To take depression as an example, hypersensitivity (e.g., Rossow et al., 2021), hyposensitivity (e.g., Lane, 2002), and sensory seeking (e.g., Rossow et al., 2022) in an autistic sample were all previously found to be significantly related to depression. Therefore, although previous primary studies have clearly supported the relationship between SPDs and internalising/externalising problems among autistic people, the subtypes of SPDs could play different roles in the development and maintenance of internalising/externalising problems. SPDs have been classified by two approaches: Dunn's model of sensory processing approach and the modality-specific approach.

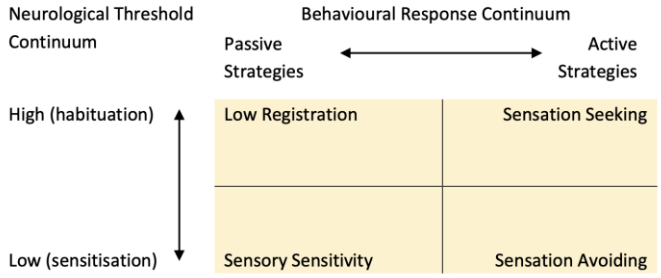
Dunn's model of sensory processing approach

Dunn (1997) considered the interaction of two dimensions: people's neurological thresholds and self-regulation behavioural strategies. Neurological (sensory) thresholds refer to the intensity of a stimulus required for the sensory system to notice or react to the input. Behavioural strategies indicate the way that people respond to the thresholds (Dunn, 1997). As shown in Fig. 1, in Dunn's model, all SPDs can be mapped into one of four sensory quadrants, described by the orthogonal intersection of these two continua. These four quadrants are defined as follows: low registration (high neurological threshold and a passive behavioural strategy), sensation seeking (high neurological threshold and an active behavioural strategy), sensory sensitivity (low neurological thresholds and a passive behavioural strategy), and sensation avoiding (low neurological thresholds and an active behavioural strategy). Both sensory sensitivity and avoiding represent sensory hypersensitivity (i.e., low neurological thresholds), while low registration and sensation seeking combine for hyposensitivity (i.e., high neurological thresholds) (Dunn, 1997). In this review, we use the

term ‘sensory reactivity’ to represent the full range of sensory processing differences as conceptualised by Dunn’s model, i.e., the four quadrants and hyper/hyposensitivity.

Fig. 1

Adapted representation of Dunn’s Model of Sensory Processing.



Sensory modality-specific approach

Although Dunn’s model of sensory processing in studies with autistic children and adults (e.g., Ben-Sasson et al., 2007; Ben-Sasson et al., 2019; Crane et al., 2009; DeBoth & Reynolds, 2017) helps understand sensory processing and design occupational therapies for autistic people (Ben-Sasson et al., 2007; DeBoth & Reynolds, 2017), this approach fails to capture some elements of SPDs. Combining sensory symptoms across sensory modalities could miss modality-specific challenges experienced by autistic people, and thereby constrains our ability to test for associations between individual modalities and developmental outcomes. For example, auditory-specific sensory processing differences may be especially influential on language development (Marco et al., 2011), tactile hypersensitivity has been observed to be specifically associated with inflexible behaviours, repetitive verbalisation, and abnormal focused attention (Baranek et al., 1997), and taste/smell sensitivity plays a particular role in eating behaviours (Nimbley et al., 2022). Therefore, investigation by sensory modalities, such as visual, tactile, auditory, and so on, provides a fine-grained approach to understanding the nature and impact of SPDs of autistic people (DeBoth & Reynolds, 2017; Lane et al., 2010). However, fewer previous primary studies on SPDs have applied the modality-specific approach compared to Dunn’s sensory processing model, and therefore existing reviews and meta-analyses have tended not to focus on SPDs across sensory modalities (e.g., Ben-Sasson et al., 2019; van den Boogert et al., 2022). Our inclusion of a modality-specific

approach to SPDs classification, in addition to Dunn's model, could fill the research gap in the understanding of the relationship between sensory modality subtypes and internalising/externalising problems among autistic people, which enables researchers to gain further insights into the possible sensory mechanisms of certain developmental outcomes (Lane et al., 2010).

The associations between SPDs and mental health problems could be influenced by moderating factors. Although there was not enough consistent evidence in the previous literature for us to predict the directions of potential moderating effects, we prioritised investigating the following clinical, demographic, and methodological moderators. First, looking at clinical characteristics, the co-occurrence of intellectual disability (ID) was previously found to associate with certain SPDs (Werkman et al., 2022) and elevated risks of mental health problems (LoVullo & Matson, 2009), and therefore the relationship between sensory experiences and internalising/externalising problems could plausibly differ between autistic people with and without ID. Second, although sensory and internalising/externalising problems are experienced by autistic people of all genders, across the lifespan, their manifestations and associations with each other appear to vary according to age and gender (Kern et al., 2006; Tomchek & Dunn, 2007; Woodman et al., 2016). Last, the choices of study methods made by researchers (e.g., informant, autism diagnostic method, publication year) may also lead to different estimates of the association between SPDs and internalising/externalising problems.

Longitudinal studies collecting data from multiple timepoints could provide insight into the risk pathway—a high level of SPDs may increase the risk of developing later internalising/externalising problems or vice versa. For example, anxiety could be a result of SPDs; but, also, anxiety itself may amplify reactivity to sensory stimuli (Ayres, 1972; Joosten & Bundy, 2010). Such a bi-directional association would maintain both SPDs and anxiety overtime. Longitudinal investigations help understand the development of mental health problems experienced by autistic people, and thus we sought to review and synthesise longitudinal studies of the relationship between SPDs and internalising/externalising.

Objectives

To summarise, although previous primary studies and reviews have reached consensus that SPDs are associated with various developmental outcomes, including internalising/externalising problems, among autistic people, the current review aimed to extend our understanding from four perspectives. First, although previous reviews have considered the psychological correlates of SPDs in autistic populations (Glod et al., 2015), e.g., adaptive behaviour and attention skills (Dellapiazza et al., 2018), eating behaviour (Nimbley et al., 2022), and anxiety (Williams et al., 2021), the current review will be the first meta-analysis that simultaneously focuses on both internalising and externalising problems and that examines statistical similarities and differences in their associated SPDs. To further map clinical and research needs, internalising subtypes, namely anxiety and depression, which have been extensively targeted in research and clinical practice and will likely continue to be the focus of future autism mental health research, were investigated as well. Second, for the first time, we reviewed the literature by conceptualising SPDs within two frameworks—we were concerned not only with sensory reactivity as operationalised by Dunn's sensory processing model, but also took a sensory modality approach, which has not been the focus of previous reviews. We aimed to learn if specific aspects of SPDs (including specific sensory modalities) are differentially associated with internalising and externalising problems. Third, effects of clinical (co-occurring ID), demographic (age and gender), and methodological (informant, diagnostic method, publication year) factors were investigated as moderators of the magnitude of associations. Last, the longitudinal investigations of the association between SPDs and internalising/externalising problems in autism were summarised.

This review had four objectives:

1. To examine the associations between sensory reactivity subtypes and internalising/externalising problems in autism.
2. To examine the associations between sensory modality subtypes and internalising/externalising problems in autism.
3. To examine the effects of clinical, demographic, and methodological moderators on the sizes of association between SPDs and internalising/internalising problems in autism.
4. To review longitudinal studies to examine relationships over time between SPDs and

internalising/internalising problems in autism.

Method

This systematic review was reported according to the Preferred Reporting Items for Systematic reviews and Meta-analyses (PRISMA) standards (Page et al., 2021). The protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO), registration number CRD42022366191. Any deviations from the protocol are noted.

Search strategy

The literature search was conducted on English studies published on MEDLINE (Ovid), PsycINFO (Ovid), Web of Science Core Collection (Web of Science), EMBASE (Ovid), and CINAHL (EBSCOhost) databases between 1990 and August 2024 (last searched on 8th August 2024). The search terms were developed by the first author, drawing on search terms used in prior relevant reviews (e.g., Backman et al., 2021; Bower et al., 2011; Spain et al., 2017). Similar search terms were used for all database searches. The search terms combined text words and MeSh terms/subject headings (depend on the databases). The searc focused on three main areas: autism spectrum disorder (example terms: autis*, asperger*), SPDs (example terms: sensation, sensory*), and internalising/externalising problems (example terms: internali*, externali*). The text words were only searched in title and abstract to reduce the number of unqualified records. The full search strategy and limits applied to the search strategy are provided in Appendix A.1.

Eligibility criteria

Five inclusion criteria were applied.

1. Participant characteristics: Participants should have reported a diagnosis of autism according to The Diagnostic and Statistical Manual of Mental Disorders (DSM IV, DSM IV-TR, DSM 5, DSM 5-TR; American Psychiatric Association, 1994, 2000, 2013, 2022) or International Classification of Diseases (ICD-10 or ICD-11; World Health Organization, 2016, 2019) criteria and/or confirmed by clinical assessment tools (e.g., The Autism

Diagnostic Observation Schedule [ADOS]; Lord et al., 2012). Studies with self-reports of autism diagnosis without clinical evidence or which measured autistic traits in the general population were excluded. Participants under 65 years-old were included. There were no constraints on the co-occurring conditions in autistic participants. Studies were only included when data were presented separately for autistic and non-autistic participants.

2. Sensory processing differences: In the current review, we classified SPDs according to two approaches: (1) sensory reactivity, from Dunn's model of sensory processing approach, and (2) sensory modality, from the modality-specific approach. Sensory reactivity subtypes refer to four sensory quadrants from Dunn's model: 'low registration', 'sensation seeking', 'sensory sensitivity', and 'sensation avoiding', plus two umbrella terms: 'hypersensitivity' and 'hyposensitivity'. Sensory modality subtypes are senses based on the five sensory organs (eyes, ears, nose, mouth, and skin) and are 'visual', 'auditory', 'smell', 'taste', and 'tactile'. Other senses such as sense of balance, body position, and pain were not included because the modalities from five sensory organs were more widely examined in previous studies using various sensory questionnaires (e.g., Sensory Profile [Dunn, 1999], Short Sensory Profile [McIntosh et al., 1999], etc.), enabling sufficient data for meta-analysis. To be included, studies needed to include measurements of at least one of these sensory subtypes. Studies reporting overall sensory scores were excluded. Perceptual impairments due to biological/physical impairments (e.g., brain injury, partial sightedness, deafness) were excluded. No restrictions were imposed in terms of the measurement tools of SPDs, or the informants used.

3. Internalising/externalising problems: Full details of internalising/externalising problems are given in Appendix A.2. Studies only reporting combined scores across internalising/externalising categories were excluded. No restrictions were imposed in terms of the measurement of internalising/externalising problems, or the informants used.

4. Study characteristics: Studies should have reported sufficient statistical data on the association between SPDs and internalising/externalising problems, i.e., correlation or statistics that could be transformed into a correlation coefficient such as odds ratio. For

studies that appeared to meet the above-mentioned inclusion criteria while the published paper reported multivariate associations or regression, corresponding authors were contacted via email for bi-variate correlation data without controlling variables (i.e., unadjusted bivariate correlations). Because the selection of covariates varied greatly among different studies, correlation with covariates cannot be directly applied to the current meta-analysis. The exploration of associations between SPDs and internalising/externalising problems was not required to be the primary goal of studies, so long as relevant data were presented.

5. Data characteristics: Although observation and/or physiological measurements of sensory and internalising/externalising problems were applied in some studies, these measurements significantly varied between studies and the results may not be quantitatively comparable with data from questionnaires (Woodman et al., 2016). Therefore, we included studies that measured sensory and internalising/externalising data via questionnaires only.

Study selection

The screening was conducted in two steps. First, titles and abstract of all identified articles were screened according to the inclusion criteria. The reference lists of reviews on related topics were manually scanned for additional articles. Then, the full texts of articles were retrieved and assessed for eligibility. A second reviewer independently screened 20% of randomly selected records from stage 1 and inter-rater reliability was assessed by Cohen's kappa (Cohen, 1960). The study selection process was conducted using Endnote 20 (The EndNote Team, 2013).

When multiple studies (from independent sample groups) were published in one paper, we included them as separate studies for meta-analysis. We used the term 'article' for the full text publication and the term 'study' for independent sample with complete dataset. Longitudinal relationships between SPDs and internalising/externalising problems observed from studies employing longitudinal analyses were discussed narratively. When multiple articles reported findings from a shared group of participants, we only included the article that was published

earlier.

Data extraction

Study information and quantitative data for meta-analysis were extracted. The extracted descriptive information included: study details (authors, publication year, country, ethnicity/race), participant characteristics (sample size, age, gender, diagnostic method, co-occurring conditions, IQ), and measurements (measurements tools, measured subtypes, and informants). The study characteristics are presented in the Appendix B of this report (Table B.1), except for diagnostic method and informants, which were extracted for meta-analysis. Diagnostic methods were classified into three categories: studies with participants meeting DSM (American Psychiatric Association, 1994, 2000, 2013, 2022) or ICD (World Health Organization, 2016, 2019) criteria were coded as 'DSM/ICD'; studies reporting 'clinical diagnosis of autism' but not specifying DSM/ICD criteria were coded as 'clinical diagnosis'; and studies which used only clinical assessment results (e.g., ADOS; Lord et al., 2012) were coded as 'clinical assessment'. The correlations between any of the SPDs and any of the internalising/externalising problems were collected. When data from multiple informants for the same sample were reported, self-report data were prioritised, followed by caregiver-report data and then other-report data (e.g., from teacher, social worker, etc.). For longitudinal studies, baseline data (i.e., timepoint 1) were extracted for use in meta-analysis. The correlations were keyed into the same direction—a positive correlation suggested that more severe sensory difficulties relate to greater internalising/externalising problems, which was in line with the hypotheses. The second reviewer independently extracted data from 20% of the included articles, the inter-rater agreement was measured by Cohen's kappa (Cohen, 1960).

Risk of bias assessment

Risk of bias assessment was performed using Risk Of Bias In Non-randomized Studies – of Exposures (ROBINS-E) (2022), which examines the 'strength of evidence about a potential effect of an exposure on an outcome'. There are seven domains of potential bias: bias due to confounding (D1), bias arising from measurement of the exposure (D2), bias in selection of participants into the study (D3), bias due to post-exposure interventions (D4), bias due to

missing data (D5), bias arising from measurement of the outcome (D6), and bias in selection of the reported result (D7). Each domain was rated with 'low', 'some concern', or 'high' risk of bias. An overall risk of bias was generated for each article. The reasons for rating were recorded and summarised. The second reviewer independently assessed 10% of included studies and the inter-rater reliability was measured by weighted Cohen's kappa (Cohen, 1968). The summary plot and traffic-light plot were generated to display results (McGuinness & Higgins, 2021). Studies were included regardless of their risk of bias, while sensitivity analyses on risk of bias were conducted to ascertain the impact.

Data analysis

The analyses were performed in the statistical software R (R Core Team, 2022), version 4.2.1. Effect sizes were represented as correlation coefficient *r*. Statistics other than correlation (e.g., odds ratios) were first transformed into correlation *r*, and then correlation coefficients were recoded into Fisher's *z*-values (Lipsey & Wilson, 2001) before pooled effect sizes were calculated. Sampling variance of the effect sizes were estimated following Borenstein et al. (2021). Results were displayed in tables and forest plots.

Associations between SPDs and internalising/externalising problems (Objective 1&2)

In the first stage of this review, meta-analyses were conducted to estimate the associations between SPDs and internalising/externalising problems. As most studies assessed more than one subtype of internalising/externalising problems, correlations between one sensory subtype and multiple subtypes of internalising/externalising problems were reported within one study. As such, multiple correlations derived from a single sample are not independent, which violates the assumption of traditional meta-analysis (Lipsey & Wilson, 2001). Common strategies for dealing with this include averaging the effect sizes within one study or selecting only one effect size from each study. However, although both, for example, anxiety and social withdrawal, are subtypes of internalising problems, some differences may exist between them, which may not be addressed by a mean effect size. Therefore, considering the nested nature of the data, a three-level meta-analytic model was applied. This model enables using all effect sizes reported in the primary studies, accounting for the fact that some of these effect sizes clustered within the same study and so were not independent, so all information was

preserved in analyses to achieve maximum statistical power (Assink & Wibbelink, 2016).

In the three-level meta-analytic model, the lowest level of the model (level 1) included the correlations between each sensory subtype and each internalising subtype. At level 2, these level 1 correlations between each sensory subtype and internalising problems were nested within study. The nesting procedure was the same for associations with externalising problems. Lastly, the aggregated effect sizes for each study were pooled into the overall correlation between one sensory subtype and internalising/externalising across all studies (level 3). Fisher's *z*-values were transformed back into correlation coefficients *r* at the end of analyses for the purpose of interpretation. In total, twenty-two associations were generated, with six pairs of 'sensory reactivity – internalising, six pairs of 'sensory reactivity – externalising', five pairs of 'sensory modality – internalising, and five pairs of 'sensory modality – externalising'. The correlation *r*, 95% Confidence Interval, and *p*-value for each association were reported in tables. To understand which sensory subtype correlated with internalising/externalising problems significantly more than others, we conducted Wald-type tests to compare between the estimates of associations.

Three sources of variance were generated from the three-level meta-analytic model: the sampling variance within individual effect size (level 1); variance between effect sizes within study (level 2); and variance between studies (level 3) (Cheung, 2014). The presence of heterogeneities was examined by Cochran's Q (i.e., deviation of observed effect size from the overall effect, weighted by the inverse of variance), I^2 (i.e., proportion of real observed dispersion), and τ^2 (i.e., variance of true effect sizes). The I^2 and τ^2 value for the between-study variance (level 3) and within-study variance (level 2) were reported. Since the importance of the I^2 depends on several factors (e.g., size and direction of estimates, strength of evidence for heterogeneity), the interpretation of I^2 follows Deeks et al. (2022): 0% to 40% as not important, 30% to 60% as moderate heterogeneity, 50% to 90% as substantial heterogeneity, and greater than 75% as considerable heterogeneity.

Associations between SPDs and anxiety/depression

The relations between SPDs and anxiety/depression were calculated with random-effects

meta-analysis. Random-effects models were chosen because of the expected high heterogeneity across studies due to differences in study designs, use of measurements, and the variability in autistic population. Besides the change in model, all the data transformation (correlation *r* and Fisher's *z*-values), test of heterogeneity, and report of results followed the same procedure as for broad-band internalising/externalising. In total, another twenty-two associations were generated between each of sensory subtypes and anxiety/depression respectively. The analyses of associations between SPDs and anxiety/depression were not pre-described in the protocol.

For all tests, $p<.05$ was considered statistically significant. Effect sizes around $r=.10$ were considered as small, effect sizes around $r=.30$ as medium, and effect sizes around $r=.50$ as large (Cohen, 2013). Tables and forest plots were used to display results.

Moderator analyses (Objective 3)

Six moderators were assessed at study-level using three-level mixed effects models (i.e., adding each moderator into the original three-level models). Separate three-level mixed models were fitted for each moderator as including multiple categorical moderators could inflate Type II error rates (Raudenbush & Bryk, 2002). Moderator analyses were only conducted when there were more than 3 studies in the subgroups of the potential moderators and when heterogeneity tests suggested substantial between-studies variances. Depending on the types of moderating variables (continuous or categorical), meta-regression and subgroup analyses were applied. Meta-regressions used Wald tests based on *t*-distribution (Assink & Wibbelink, 2016) were used to examine the effect of continuous variables. Subgroup analyses compared the effect sizes of between subgroups of categorical variables using omnibus tests based on the *F*-distribution (Assink & Wibbelink, 2016). Results of moderator and Cochran's Q tests are reported in tables. For all moderating analyses, $p<.05$ was considered statistically significant. Besides age, five additional moderating variables were added to the protocol.

Sensitivity analyses

There were three sensitivity analyses, testing the influences of study quality based on results

from risk of bias assessments, effects of outliers, and publication bias across associations between SPDs and internalising/externalising problems. Test statistics were given in tables and funnel plots (for publication bias).

To investigate the effect of risk of bias on the overall effect size, we conducted the associations from only low risk-of-bias studies and then compared with the overall primary associations to reflect the influence of adding studies with 'some concern' and 'high risk-of-bias' on overall effect sizes. Subgroup analyses between studies with 'low risk-of-bias', 'some concern', and 'high risk-of-bias' were conducted to ascertain whether the level of risk of bias significantly impacted on the pooled estimates.

Possible outliers within each of the primary associations were manually examined. Individual effect sizes with a 95% confidence interval lying outside the 95% confidence interval of the overall effect size were regarded as outliers. For associations with outliers, the overall effect sizes with and without outliers were compared to determine whether the outliers had unusually large influences on the pooled estimates.

Publication bias was assessed in four ways. First, an adapted version of Egger's regression tests (Egger et al., 1997) was conducted by re-estimating the three-level meta-analytic models and including the sampling variance as a moderator. Significant results (p<.05) suggested possible of publication bias. Second, funnel plots (which describe studies observed effect sizes against standard error) for each of the primary associations were created and inspected. Asymmetrical distribution of studies in the funnel plots suggested possibility of publication bias. For associations showing possibility of publication bias from funnel plots and Egger's regression tests, another two methods were further applied: (1) the trim-and-fill method (Duval & Tweedie, 2000) estimated whether studies with smaller effect sizes were not published and re-calculated an adjusted overall effect size that considers the influence of publication bias, and (2) the fail-safe N value computes the number of additional studies with effect size of zero that should be added into the model to yield a non-significant overall effect (Rosenthal, 1979). If the result exceeds Rosenthal's benchmark of 5N+10 (N for number of studies), then it is suggested the significant meta-analyses findings are robust and may not be threatened by the

exclusion of studies due to publication bias (Rosenthal, 1979).

When considering certainty of the evidence, we used the GRADE approach (Schünemann et al., 2022), focusing on five domains: risk of bias, unexplained heterogeneity, indirectness of evidence, imprecision of results, and publication bias.

Narrative synthesis (Objective 4)

Results from longitudinal studies were synthesised narratively. Whether SPDs and internalising/externalising problems predict the development of each other was discussed separately.

Results

To assess the association between SPDs and internalising/externalising problems, meta-analyses and narrative synthesis were conducted. The results are described in following sections.

Study selection

In total, 11797 records were identified from databases. After removing 3873 duplicates manually, 7924 articles were further screened and assessed for eligibility. The full text of 698 articles from electronic databases and 8 from reference lists of reviews on related topics were retrieved and assessed for eligibility. Sixty-three articles were finally included in the current review. Of the included 63 articles, three articles by Bitsika and colleagues (Bitsika et al., 2020; Bitsika et al., 2016a, 2016b) and two articles by MacLennan and Rossow et al. (MacLennan et al., 2021; Rossow et al., 2021) were, respectively, likely to have same sample group. Therefore, only Bitsika et al. (2016a), Bitsika et al. (2016b), and Rossow et al. (2021) were included in the meta-analysis as they were published earlier. In addition, Green (2015), Mazurek and Petroski (2015), and Pfeiffer et al. (2005) reported complete datasets from two independent sample groups, respectively. Therefore, the current systematic review meta-analysis included 64 studies from 63 articles. The PRISMA flowchart of study selection process is presented in Fig. 2 (Page et al., 2021). The inter-rater reliability for study selection and data extraction were κ=.94 and .86, respectively (Cohen, 1960).

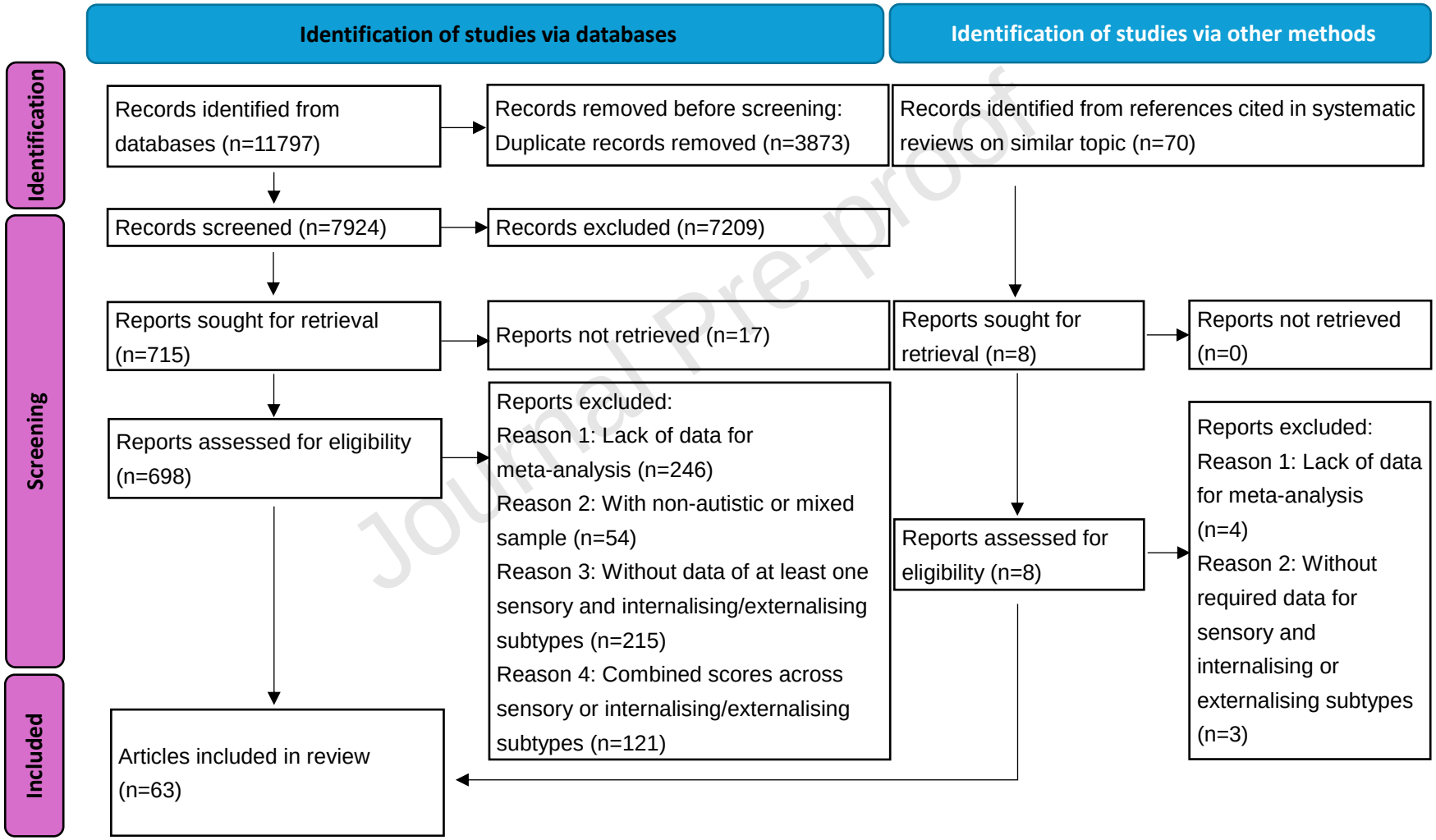
Study characteristics

The study characteristics are presented in Appendix B, Table B.1 (including for articles not included in the meta-analysis). All included articles were published after 2005, with the majority (51 of 63, 81%) published from 2015 onwards. Only 25 (39.1%) of the 64 included studies reported on the ethnicity or race of their participants. White/Caucasian participants were included in 21 studies (*M*=83.9%, *SD*=14.2), with 11 studies reporting over 90% of their participants being White/Caucasian and 2 studies recruiting only White/Caucasian people. Asian/American Asian (*M*=17.3%, *SD*=30.6) and Black/African/African American (*M*=5.0%, *SD*= 2.4) participants were reported in 10 and 9 studies, respectively, with one study reporting 100% of its participants as Asian. The total sample size for all included studies was 11659 (the

individual sample size ranged from 19 to 2973, *M*=181.8, *SD*=458.1). Studies were predominantly conducted with autistic children and adolescents (age: *M*=13.6, *SD*=9.5); only ten studies recruited autistic adults (See Appendix B Table B.1). Gender and sex were assumed to be the same for participants in the included primary studies, and thus 'male' and 'female' are used for discussing gender issues throughout current review, whilst we acknowledge that the literature does not currently afford the opportunity to tease apart effects of sex and gender (Lai et al., 2015). Male participants constituted the majority of sample groups in nearly all studies: 76.0% of participants in the current meta-analysis were male.

Fig. 2

PRISMA flowchart of literature search and article selection.



For 20 articles (out of 63, 31.7%) for which co-occurring conditions were reported, anxiety (9 articles), ID (11 articles), and attention deficit hyperactivity disorder (ADHD; 7 articles) were the most common co-occurring conditions. Intellectual ability was reported in 42 out of 64 studies (65.6%). Of these, mean IQ score in the sample group was reported in 24 studies, with an overall mean IQ of 101.5 (range=82.5-114.4, *SD*=9.1). Two studies (Gonthier et al., 2016; Walkingshaw, 2022) only recruited autistic participants with ID and six studies reported the proportion of autistic participants with ID (*M*=21.1%, *SD*=15.3%). The remaining ten studies reported a minimum IQ requirement of 70 for study entry. Participants were recruited from mixed settings, ranging from psychiatric clinics to local communities.

One set of related measures of SPDs was especially commonly used across included articles: 47 out of 64 articles (73.4%) used some version of The Sensory Profile. Of these 47 articles, 20 articles used The Short Sensory Profile (Dunn, 1999; McIntosh et al., 1999) or Short Sensory Profile-2 (Dunn, 2014), 16 articles used The Sensory Profile (Dunn, 1999) or Sensory Profile 2 (Dunn, 2014), and 11 articles used the Adolescent/Adult Sensory profile (Brown & Dunn, 2002). The Sensory Over-Responsivity Scale (Schoen et al., 2008) and Sensory Processing Scale Inventory (Schoen et al., 2017) were used in six and four articles, respectively. For SPD measurements that conflate smell and taste sensitivities (e.g., taste/smell sensitivity in the Short Sensory Profile in Khaledi et al., 2022), we analysed them as smell and taste sensitivity scores separately. Depending on the research objectives and the selection of sensory measurements in primary studies, sensory reactivity subtypes were reported by more studies than sensory modality subtypes, especially for smell and taste which were only reported by 10 and 12 articles respectively, compared to 33 for hypersensitivity.

The internalising/externalising measures were more varied. Fifteen articles (out of 64) used The Child Behavior Checklist (Achenbach & Rescorla, 2000, 2001), followed by The Child and Adolescent Symptom Inventory (Gadow & Sprafkin, 2010; Gadow et al., 2002; Sukhodolsky et al., 2008) and The Spence Children's Anxiety Scale (Nauta et al., 2004; Spence, 1998; Spence et al., 2003) being used by nine and seven articles respectively. Internalising problems (61/64 articles; 95.3%) were reported by over three times more articles than externalising problems (18/64 articles; 28.1%). Anxiety (48/64 articles; 75%) and depression (14/64; 21.9%)

were the two most commonly assessed subtypes of internalising problems. See Appendix B Table B.2 for more details regarding the measurement tools and measured subtypes.

Results of meta-analyses (SPDs and internalising/externalising problems)

The effect sizes from each study (see forest plots) and results of meta-analyses and heterogeneity tests for associations between SPDs and internalising/externalising problems are depicted in Table 1a and 1b and in Appendix C, Fig. C.1 to C.4. Instead of showing each single effect size within all studies (elements in the plot would become too small for identification), forest plots show effect sizes aggregated to study level. The associations between each of the SPDs and internalising/externalising problems were all positive (internalising: correlations ranged from *r*=.20 to *r*=.48; externalising: correlations ranged from *r*=.22 to *r*=.44). The associations were mostly significant, except for externalising relations with hyposensitivity, smell, and taste.

For both internalising and externalising problems, the estimates of associations with hypersensitivity (internalising: *r*=.48, externalising: *r*=.33; medium effect sizes) were greater than hyposensitivity (internalising: *r*=.24, externalising: *r*=.22; small effect sizes). The comparison was significant for internalising but not externalising. Hypersensitivity was significantly more strongly associated with internalising than externalising. For the four sensory quadrants in Dunn's model, hypersensitivity subtypes (avoiding and sensitivity) were generally related more strongly to internalising than hyposensitivity subtypes (low registration and seeking), with sensation seeking significantly showing the smallest effect size across four quadrants (*r*=.20). In contrast, although not statistically significant, sensation seeking had the highest correlation coefficient with externalising problems, followed by sensation avoiding and sensitivity (medium effect sizes), with low registration showing the smallest effect size (*r*=.23). For sensory reactivity subtypes, significance testing of differences between associations is presented in the Appendix B Table B.3a. Of the associations between sensory modalities and internalising/externalising problems, smell and taste had smaller effect sizes with both internalising and externalising (correlations ranged from *r*=.11 to *r*=.21) than visual, auditory, and tactile; all had small to medium effect sizes (ranged from *r*=.24 to *r*=.43). The comparison tests results for sensory modalities are presented in the Appendix B, Table B.3b.

Results of heterogeneity tests

Heterogeneity tests were calculated for both within- (level2) and between-studies (level 3) variances. Following the structure of the three-level meta-analytic model in the current meta-analysis, within-study variances (level 2) refer to the heterogeneities between effect sizes within a single study and between-studies variances (level 3) suggest differences in size of associations across studies. Of the associations between SPDs and internalising, the between-study differences (I^2 ranged from 16.15% to 83.60%; τ^2 ranged from 0.01 to 0.05) were moderate to substantial, mostly greater than within-study differences (I^2: 2.51% to 65.06%; τ^2: <.001 to 0.04). Cochran's Q test results were significant for all internalising associations. Of the associations between SPDs and externalising, except for smell whose association with externalising had almost zero within- and between-study heterogeneities, most variances in the remaining associations were from between-study (level 3) variances (I^2 ranged from 38.25% to 86.49%; τ^2 ranged from <.001 to 0.09). These between-study differences were moderate to substantial as well. Cochran's Q test results were significant for associations with four sensory quadrants, hyposensitivity, auditory, and tactile.

Table 1a

Association between Sensory Processing Differences and Internalising Problems - summary results of three-level meta-analyses.

SPDs subtypes	N	Number of studies	Number of effect sizes	Effect size			Heterogeneity analyses					
				r	95% CI	*p*	Cochran's Q	*p*	Level 2		Level 3	
									τ^2	I^2	τ^2	I^2
Low registration	2049	17	28	.35	[0.27; 0.43]	**<.001**	Q(27)=83.25	**<.001**	<.01	5.00%	0.02	62.25%
Sensation seeking	3305	29	57	.20	[0.13; 0.27]	**<.001**	Q(56)=201.04	**<.001**	0.01	24.11%	0.02	52.25%
Sensory sensitivity	2382	20	32	.38	[0.30; 0.45]	**<.001**	Q(31)=111.91	**<.001**	<.01	8.14%	0.03	68.21%
Sensation avoiding	2106	18	30	.40	[0.31; 0.48]	**<.001**	Q(29)=147.32	**<.001**	0.04	65.06%	0.01	16.15%
Hypersensitivity	8076	32	59	.48	[0.43; 0.52]	**<.001**	Q(53)=144.68	**<.001**	0.01	25.36%	0.01	50.46%
Hyposensitivity	3013	18	35	.24	[0.13; 0.35]	**<.001**	Q(33)=139.51	**<.001**	<.01	2.51%	0.05	83.60%
Visual	1197	13	22	.39	[0.28; 0.49]	**<.001**	Q(21)=57.21	**<.001**	0.01	12.18%	0.03	64.90%
Auditory	1070	13	22	.43	[0.32; 0.53]	**<.001**	Q(21)=61.29	**<.001**	0.01	13.32%	0.03	63.79%
Smell	927	8	15	.21	[0.06; 0.36]	**.019**	Q(14)=33.29	**.003**	<.001	4.19%	0.04	76.87%
Taste	996	10	19	.20	[0.08; 0.31]	**.004**	Q(18)=31.77	**.023**	<.001	4.44%	0.02	64.63%
Tactile	1229	14	26	.35	[0.22; 0.46]	**<.001**	Q(25)=71.03	**<.001**	<.001	4.99%	0.05	76.92%

Note. CI=Confidence Interval, bold p-values denote statistically significant.

Table 1b

Association between sensory processing differences and Externalising Problems - summary results of three-level meta-analyses.

SPDs subtypes	N	Number of studies	Number of effect sizes	Effect size			Heterogeneity analyses					
				r	95% CI	*p*	Cochran's Q	*p*	Level 2		Level 3	
									τ^2	I^2	τ^2	I^2
Low registration	405	5	8	.23	[0.05, 0.39]	**.039**	Q(7)=21.54	**.003**	<.001	<.001%	0.03	68.54%
Sensation seeking	1223	11	18	.44	[0.28, 0.58]	**<.001**	Q(17)=72.90	**<.001**	<.001	0.49%	0.09	81.69%
Sensory sensitivity	419	5	7	.31	[0.14, 0.46]	**.013**	Q(6)=16.14	**.013**	<.001	<.001%	0.03	68.83%
Sensation avoiding	462	6	9	.32	[0.10, 0.50]	**.020**	Q(8)=45.78	**<.001**	<.001	<.001%	0.06	81.27%
Hypersensitivity	305	6	12	.33	[0.19, 0.45]	**<.001**	Q(11)=16.42	.126	<.001	<.001%	0.02	51.10%
Hyposensitivity	165	3	6	.22	[-0.15, 0.54]	.291	Q(5)=22.06	**<.001**	<.001	<.001%	0.10	82.96%
Visual	774	5	8	.24	[0.11, 0.35]	**.007**	Q(7)=9.51	.218	<.001	<.001%	0.01	38.25%
Auditory	826	6	9	.38	[0.14, 0.58]	**.017**	Q(8)=36.24	**<.001**	<.001	<.001%	0.09	86.49%
Smell	649	3	5	.11	[0.03, 0.19]	.052	Q(4)=3.73	.444	<.001	<.001%	<.001	<.001%
Taste	774	5	8	.15	[-0.02, 0.31]	.133	Q(7)=14.03	.051	<.001	<.001%	0.02	61.32%
Tactile	884	7	12	.33	[0.22, 0.44]	**<.001**	Q(11)=24.01	**.013**	<.001	<.001%	0.02	51.90%

Note. CI=Confidence Interval, bold p-values denote statistically significant.

Results of meta-analyses (SPDs and anxiety/depression)

Anxiety and depression are narrow-band conditions within the broad-band internalising construct, and therefore were expected to present similar sensory association patterns as internalising problems. See Table 2a, Table 2b, and Appendix C, Fig. C.5 to C.8 for the details of associations and heterogeneity tests and Appendix B, Table B.4a and Table B.4b for the results of comparisons between associations. In general, the associations between SPDs and anxiety/depression were positive and mostly significant. Similar to the associations with internalising problems, hypersensitivity related to both anxiety and depression with medium to large effect sizes (anxiety: r=.46, depression: r=.51), that were also stronger for hyposensitivity (anxiety: r=.21, depression: r=.24; small effect sizes). This comparison was significant for anxiety and nearly significant for depression (p=.077). Looking at the four sensory quadrants, sensation seeking associated with anxiety/depression with small effect sizes, lower than other subtypes (the comparisons were significant in anxiety but not depression). Of the sensory modality subtypes, visual/auditory/tactile associated with both anxiety and depression in small to medium effect sizes (ranged from r=.24 to r=.39). Taste and smell were again the two least associated modalities for both conditions, with small effect sizes (ranged from r=.06 to r=.23). This association pattern was the same as the relation between sensory modality and internalising/externalising.

In summary, across broad-band internalising/externalising groups and narrow-band anxiety/depression conditions, associations with hypersensitivity were always greater than hyposensitivity. Sensation seeking showed the greatest association with externalising problems and the smallest relation with internalising and its subtypes, namely anxiety and depression. Of the sensory modalities, visual, auditory, and tactile were found to be related to all internalising/externalising problems and taste and smell were always the least associated modalities.

Table 2a

Association between Sensory Processing Differences and Anxiety - summary results of meta-analyses.

SPDs subtypes	N	Number of studies	Effect size			Heterogeneity analyses			
			r	95% CI	*p*	Cochran's Q	*p*	r^2	I^2
Low registration	1969	14	.34	[0.24, 0.44]	**<.001**	Q(13)=44.05	**<.001**	0.03	76.07%
Sensation seeking	2479	21	.15	[0.07, 0.23]	**<.001**	Q(20)=55.59	**<.001**	0.02	65.53%
Sensory sensitivity	2012	15	.37	[0.27, 0.47]	**<.001**	Q(14)=65.28	**<.001**	0.04	81.30%
Sensation avoiding	2026	15	.39	[0.25, 0.51]	**<.001**	Q(14)=96.21	**<.001**	0.08	88.55%
Hypersensitivity	6072	28	.46	[0.42, 0.51]	**<.001**	Q(27)=54.14	**.001**	0.01	64.90 %
Hyposensitivity	999	13	.21	[0.05, 0.36]	**.010**	Q(12)=56.13	**<.001**	0.07	83.12%
Visual	449	8	.39	[0.25, 0.51]	**<.001**	Q(7)=14.85	**.004**	0.02	54.38%
Auditory	472	9	.39	[0.28, 0.49]	**<.001**	Q(8)=12.69	.123	0.01	35.49%
Smell	400	6	.23	[0.08, 0.37]	**.004**	Q(5)=10.36	.066	0.02	53.69%
Taste	398	6	.20	[0.07, 0.33]	**.004**	Q(5)=8.39	.136	0.01	40.39%
Tactile	570	9	.34	[0.17, 0.49]	**<.001**	Q(8)=28.00	**<.001**	0.05	75.31%

Note. CI=Confidence Interval, bold p-values denote statistically significant

Table 2b

Association between Sensory Processing Differences and Depression - summary results of meta-analyses.

SPDs subtypes	N	Number of studies	Effect size			Heterogeneity analyses			
			r	95% CI	*p*	Cochran's Q	*p*	r^2	I^2
Low registration	574	6	.45	[0.32, 0.57]	**<.001**	Q(5)=15.28	**.009**	0.03	69.14%
Sensation seeking	739	10	.23	[0.00, 0.44]	**.046**	Q(9)=126.24	**<.001**	0.13	89.36%
Sensory sensitivity	531	5	.42	[0.32, 0.50]	**<.001**	Q(4)=7.02	.135	0.01	34.71%
Sensation avoiding	574	6	.42	[0.24, 0.57]	**<.001**	Q(5)=24.45	**<.001**	0.05	81.82%
Hypersensitivity	237	5	.51	[0.32, 0.65]	**<.001**	Q(4)=11.38	**.023**	0.04	65.27%
Hyposensitivity	187	5	.24	[-0.09, 0.53]	**.158**	Q(4)=23.34	**<.001**	0.12	79.98%
Visual	257	3	.32	[0.21, 0.43]	**<.001**	Q(2)=1.57	.456	<.001	0.01%
Auditory	257	3	.31	[0.16, 0.45]	**<.001**	Q(2)=3.07	.215	0.01	28.98%
Smell	178	2	.06	[-0.09, 0.20]	.465	Q(1)=0.01	.908	<.001	<.001%
Taste	257	3	.10	[-0.02, 0.23]	.104	Q(2)=1.23	.542	<.001	<.001%
Tactile	329	4	.24	[0.08, 0.39]	**.004**	Q(3)=6.13	.106	0.01	50.16%

Note. CI=Confidence Interval, bold p-values denote statistically significant.

Results of moderator analyses

After examining the characteristics of each included study, we found that only two included studies specifically focused on autistic people with ID, which constrained our ability to test for the moderating effects of ID. Therefore, the association between SPDs and internalising/externalising among autistic people with ID is synthesised narratively. Looking at the informants, we focused on comparisons between caregiver-report and self-report subgroups. Studies with mixed informants (e.g., caregiver reported SPDs and participants reported internalising/externalising problems) or other informants (e.g., teacher, social worker, etc.) were not included in the moderator analysis because of insufficient data for these subgroups. Appendix B, Tables B.5 and B.6 present the results of moderator analyses for associations with internalising and externalising problems. In general, none of the proposed potential moderator variables consistently and significantly explained heterogeneity in primary associations. Age significantly moderated the most associations (5/19 associations). Looking at internalising problems, the associations with seeking and avoiding were moderated by both age and informant in the same directions, with greater estimates of associations in younger participants and caregiver-report studies. Of the associations with externalising that had substantial between-study variations, age significantly influenced how externalising related to sensitivity, auditory, and tactile, with younger participants showing greater estimates of associations.

Results of sensitivity analyses

To test the robustness of the estimated association effects, sensitivity analyses were conducted on the risk of bias, outliers, and publication bias.

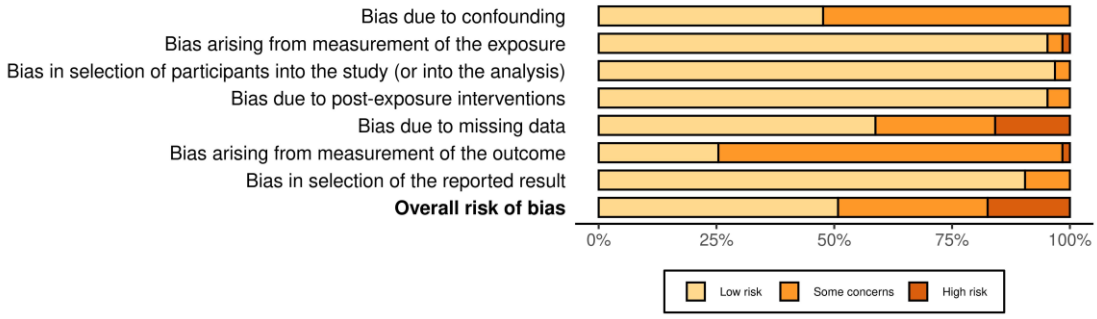
Risk of bias assessment

In summary, 50.8% of articles were rated as ‘low risk of bias’ (meaning that they have low risk of bias in all domains except for some concerns in Domain 1 and/or 6); 31.7% were rated as ‘some concerns’ (meaning that at least one domain is at ‘some concerns’ but no domains are at high risk); 17.5% were rated as ‘high risk of bias’ (meaning that at least one domain is at high risk) (see Fig. 3 and Appendix C Fig. C.9).

The inter-rater reliability was κ=.69, reflecting substantial agreement (Cohen, 1968). The majority of articles (>90%) were rated as 'low risk of bias' in D2, D3, D4, and D7. Half of articles did not collect and control sufficient variables, such as levels of autism traits, ethnicity/race, and IQ, which were rated as having some concerns in the risk of confounding variables. In terms of missing data, around 40% of articles lost some data during the study procedure, especially for the follow-up data collection in longitudinal studies. The current meta-analysis only collected data at baseline in longitudinal studies, which were not affected by the loss of data. Although some solutions for the missing of data were explained, whether the final results were biased was not discussed by primary authors. The most common bias across the included articles was the bias arising from whether the outcome (i.e., internalising/externalising) assessors were aware of participants' exposure history (i.e., SPDs). Most articles included in the current meta-analysis collected both types of data from the same informant, which makes it hard for outcome assessors to be 'blinded' with participants' exposure history, and therefore resulted in generally higher risk of bias (73.0% with 'some concern' and 1.6% with 'high risk') in the domain of bias arising from measurement of the outcome across articles.

Fig. 3

Summary plot of ROBINS-E



Sensitivity analyses were conducted on the risk of bias results (see Appendix B Table B.7 and Table B.8). After removing 'some concern' and 'high risk' studies, three-level meta-analyses were conducted again. Most associations between internalising and SPDs (except for smell: r=.21, p=.054; and taste: r=.18, p=.142) from 'low risk' studies remained positive and significant. The association with sensory sensitivity (r=.51, p<.001) was outside the 95% CI of

the original overall effect sizes. Of the associations with externalising from 'low risk' studies, only sensation seeking (r=.39, p=.003), hypersensitivity (r=.21, p=.015), and tactile (r=.43, p=.026) still significantly related to externalising. The association with visual (r=.37, p=.151) fell outside the 95% CI of the original overall effect sizes. The associations between SPDs and internalising/externalising problems across 'low risk' studies were not significantly different from the estimates from all included studies. Meanwhile, the differences in estimates of associations between 'low risk' studies, 'some concern' studies, and 'high risk' were mostly non-significant (except association between hyper/hyposensitivity and externalising). Therefore, we did not find concrete evidence that the associations between SPDs and internalising/externalising problems were affected by risk of bias. However, nearly all associations with externalising had less than three articles in each of the risk subgroups. The statistical power for the sensitivity analyses for study quality was relatively low, and thus the influence of risk of bias on the estimates of associations with externalising problems required cautious interpretation.

Outliers

By checking the individual 95% Confidence Interval in each association, several outliers were identified (see Appendix B Table B.9). Removing the outliers did not significantly change the overall effect sizes. Therefore, the pooled effect size was not influenced by the inclusion of outliers.

Publication bias

Publication bias was assessed in four ways. Egger's regression tests and funnel plots (see Appendix B Table B.10 and Appendix C Fig. C.10 to C.13) were examined for all primary associations. Combining the results from Egger's tests and inspection of funnel plots, there may have been some degrees of publication bias in the association between tactile and externalising. The trim-and-fill method did not retrieve additional studies and the adjusted effect size remained unchanged. In addition, the fail-safe N showed that 396 studies with mean zero effect size would be added to yield non-significant effects for this association, exceeding the Rosenthal (1979) benchmark of 45 (5*number of studies+10). Therefore, the association between tactile and externalising was robust to the threat of non-significant effects

from additional studies due to publication bias.

Narrative synthesis

Associations between SPDs and internalising/externalising problems were investigated in some longitudinal studies and suggested potential predictive relationships between these two sets of constructs. Two longitudinal studies were included in the narrative synthesis (Green et al., 2012; Rossow et al., 2022). The baseline data were collected when participants were aged between 1 and 5 years old, and the follow-up data were collected after about one year. The focal conditions were different between the two studies: Rossow et al. (2022) reported associations between, on the one hand, hypersensitivity, hyposensitivity, and seeking and, on the other hand, depression; Green et al. (2012) focused on the relationship between sensory over-responsivity (SOR) and anxiety. In general, significant associations between SPDs and anxiety/depression were found at both timepoints. Examining relationships between the level of SPDs and anxiety/depression between baseline and follow-up data, these two studies found evidence for some predictive relationship between them. Both studies suggested that higher level of SPDs predicted the occurrence of anxiety/depression at a later stage (Green et al. [2012]: B=.11, p=.026; Rossow et al. [2022]: r=.72, p<.001). Therefore, SPDs may emerge earlier than internalising problems, and predict later development of internalising problems (Green et al., 2012). The predictive relationship in the converse direction was only found between depression and sensory seeking (Rossow et al., 2022). The cyclical relationship between depression and sensory seeking reported by Rossow et al. (2022) suggested that sensory seeking without effective intervention contributes to the development of depressive symptoms, which in turn strengthened sensory seeking as a regulation strategy for autistic people. However, these two studies recruited autistic participants at different ages, which may influence the findings. Also, the length of interval between testing timepoints varied between studies. The duration of study period can influence the development of sensory or internalising/externalising problems manifested by autistic people, especially children. The stability of SPDs among autistic children over the study period limits studies' ability to detect the predictive relationship (Green et al., 2012). Overall, a higher level of SPDs could be a potential risk factor for later anxiety and depression experienced by autistic people, while the

results of predictive relationship in the other direction were mixed, depending on the psychiatric condition, age of participants and duration of study.

Although a substantial percentage of autistic individuals present with co-occurring intellectual disability (Maenner et al., 2020), few studies have investigated the association between SPDs and internalising/externalising problems in autistic people with ID. Of the included studies, only two studies recruited autistic participants with co-occurring ID (Gonthier et al., 2016; Walkingshaw, 2022). These two studies focused on associations between, on the one hand, sensory reactivity subtypes and, on the other hand, internalising (e.g., anxiety) and externalising (e.g., aggression and school avoidance) problems. Both studies suggested that SPDs were positively associated with internalising and externalising problems among autistic people with ID. However, since (1) both studies did not make comparisons between autistic people with and without ID, and (2) the limited number of studies constrained our ability to test for the influence of ID, putative differences in the size or nature of associations between autistic people with and without ID remain unclear.

Certainty of evidence

In addition to the risk of bias and publication bias mentioned above, the certainty of evidence following the GRADE approach (Schünemann et al., 2022) could be further influenced by the following domains. First, there are some unexplained heterogeneities in the current meta-analysis. Possible explanations for the non-significant moderating tests are further considered in the Discussion section. Second, although the exploration of associations between SPDs and internalising/externalising problems was not required to be the primary goal of included studies, examining certain sensory and mental health outcomes among autistic people was a part of the original objective for all included studies, supporting the directness of evidence. Last, the imprecision of results, which can be examined by the width of confidence intervals, varied between associations in the current meta-analysis. In general, most associations with broad-band internalising/externalising problems had relatively narrow confidence intervals. Associations with internalising subtypes, such as depression, which were investigated by fewer studies, presented wider confidence intervals.

Discussion

The current review focused on the association between sensory processing differences (SPDs) and internalising/externalising problems in autistic people. Overall, higher levels of all SPD subtypes were observed to be associated with greater internalising/externalising problems. In particular, hypersensitivity was strongly associated with internalising and externalising problems, significantly greater than the associations with hyposensitivity. Looking at the sensory quadrants in Dunn's model, we found that externalising problems were highly linked with sensation seeking, whereas this was the least associated sensory subtype with internalising and its subtypes, namely anxiety and depression. In studies using a modality-specific approach, visual, auditory, and tactile all predicted both internalising and externalising problems. By contrast, unusual processing of smell and taste were less strongly related to internalising/externalising problems. We only found weak evidence for moderating effects of age on the estimates of associations. In a narrative synthesis, we reviewed previous longitudinal studies and suggested a possible predictive relationship between SPDs and internalising problems. Although relatively few included studies have recruited autistic people with ID, the associations between SPDs and internalising/externalising problem were observed among autistic people with co-occurring ID as well. In the following sections, we consider key findings in our meta-analysis and discuss limitations and suggestions for future research.

Hypersensitivity, which is explained as heightened awareness of and response to sensory stimuli, is currently evidenced to be prominently related to internalising problems, including the subtypes of internalising, namely anxiety and depression. This is consistent with the idea that internalising problems of autistic people, such as anxiety, could be the manifestations of hyper-vigilance to the external environment (Green & Ben-Sasson, 2010). Our narrative synthesis of the longitudinal studies in this area supports the idea that hypersensitivity could be a risk factor for internalising problems, since it appears to precede the development of internalising problems. But it is less clear whether bi-directional effects are also in operation, since Green et al. (2012) did not find evidence supporting internalising problems that result partly from hypersensitivity then result in the intensification of hypersensitivity. Therefore, the

mechanisms by which hypersensitivity and internalising problems are linked is currently unclear, and work is required to elucidate causal processes.

In contrast to the solid association between hypersensitivity and internalising problems, how hyposensitivity relates to internalising problems is more ambiguous. In the current review, the significant, but smaller association with hyposensitivity was found for broad-band internalising and anxiety but not for depression. There are several possible explanations for this divergence. First, there are fewer studies looking at the relationship between hyposensitivity and depression, compared to those investigating broad-band internalising and anxiety. Although the magnitudes of correlations with anxiety and depression were very similar, the correlation with depression was not statistically significant. Therefore, our lack of a significant association with depression could reflect a low statistical power in these meta-analyses. Second, it is possible that the association between hyposensitivity and internalising is driven by other internalising subtypes such as somatic complaints (e.g., Feldman et al., 2020). Third, anxiety and depression are based on the discrete diagnostic categories of which diagnosis requires sufficient manifestation of symptoms to reach the threshold (Eaton et al., 2015), while internalising/externalising is a dimensional model, using continuous symptom-level measures (Forbes et al., 2016), that detects the risk level of potential problems. Therefore, the significant association between hyposensitivity and internalising but not depression may reveal the differences in the sensitivity of detecting mental health problems between two models. Our finding of a very small and non-significant positive relationship between hyposensitivity and depression is in contrast to some previous empirical and theoretical work (e.g., Lane, 2002; Pfeiffer et al., 2005). Therefore, hyposensitivity may be a less substantial risk factor for internalising problems in autism and its association with internalising problems requires further evidence.

Looking at sensation seeking, its association with externalising was found to be significantly greater than with internalising problems. As an interaction of ‘high sensory threshold’ and ‘active behavioural strategy’ in Dunn’s model, sensation seeking is characterised by engaging in behaviours to increase people’s sensory experiences to counteract high sensory thresholds (Dunn, 1997). One possible interpretation is that actively seeking for sensory stimuli to meet

sensory needs may act as both a cause and a regulating method for externalising problems manifested among autistic people (Rossow et al., 2021). However, we should be cautious when making this assumption. Considering the 'double empathy problem', there can be disjunction in understanding between people of different neurotypes (Milton, 2012). Therefore, it is possible that behaviours which simply reflect autistic people's needs of seeking for sensory stimuli are being misinterpreted as signs of externalising problems by non-autistic people, such as hyperactivity or aggression, thereby contributing to a strong relation between sensation seeking and externalising problems. Another possible mechanism for investigation in future research is that some sensation seeking behaviours could be deemed socially inappropriate or dangerous by those around the autistic person, and that their attempts to limit these behaviours could sometimes evoke aggression.

To understand the sensory modality-specific challenges experienced by autistic people, we also analysed the associations between SPDs across sensory modalities and internalising/externalising problems. Overall, sensory modalities were found to be related to both internalising and externalising problems in a similar pattern. Of the five sensory modalities, visual, auditory, and tactile stimuli significantly associated with all forms of mental health difficulty examined, namely, internalising, externalising, anxiety, and depression. Previous studies have found that visual/auditory/tactile relate to a wide range of developmental outcomes, including in the domains of social communication (e.g., Foss-Feig et al., 2012), learning experience and emotion (e.g., Howe & Stagg, 2016), and speech perception (e.g., Stevenson et al., 2018). As such, difficulties in these areas may partially mediate the relationship between the processes linking visual/auditory/tactile and worse mental health.

Smell and taste, on the other hand, appear to have small associations with internalising and externalising problems. Nevertheless, before ruling these out as putative risk factors for mental health problems of autistic people, we should consider a wider range of mental health outcomes than were addressed in the current review. In particular, smell and taste may play an important role in the development of eating problems that are common amongst autistic people (Lane et al., 2014; Nimbley et al., 2022; Rendall et al., 2022). There is evidence that SPDs are influential on Avoidant Restrictive Food Intake Disorder (ARFID) and fussy eating

among autistic people (Bourne et al., 2022). Also, autistic women with anorexia nervosa commonly report that their sensory processing of the smell, taste and texture of food was implicated in the development and maintenance of their eating disorder (Brede et al., 2020; Kinnaird et al., 2019). Therefore, smell and taste stimuli may pose a greater risk to eating disorders and associate less with internalising/externalising problems in autism. It is notable that SPD measurement tools sometimes conflate smell and taste sensitivities as a single construct, which may mask differential relationships between these two sensory modalities and mental health outcomes. Future research assessing and reporting smell and taste sensitivities separately will be instructive.

Moderating effects on the estimates of associations

The current meta-analysis considered the moderating effect of five variables. We only found weak evidence for the moderating effect of age on the relation between some associations, with young participants reporting greater size of association. However, this finding requires more evidence from future longitudinal studies. In terms of the effect of co-occurring ID on the estimates of associations, the limited number of studies highlighted the research barriers to participation for autistic people with ID. Russell et al. (2019) recommended that to increase the accessibility of autism research, researchers could develop some adapted measures, such as using non-verbal tasks or technology, for more autistic people with ID to participate in research and report their experiences.

There are several possible explanations for the non-significant moderating tests in the current meta-analysis. First, young and male participants were relatively over-represented, with other demographic groups being correspondingly under-represented. A high male-to-female ratio was also reported in the previous review by Ben-Sasson et al. (2019). Therefore, these non-significant results may reflect a lack of statistical power in meta-regression for moderating tests in both previous and current reviews (Ben-Sasson et al., 2019; Schmidt, 2017). Second, there are some unmeasured moderators, such as autism traits and ethnicity/race, that may explain between-study differences. The level of autism traits was previously evidenced to moderate the association between hypersensitivity and anxiety/OCD/fears, which suggested a possible overlap between SPDs, internalising/externalising problems, and autism traits levels

(MacLennan et al., 2021). Meanwhile, as White/Caucasian participants were over-represented across the included studies that have reported information on ethnicity or race, it is currently uncertain the extent to which the current findings generalise to autistic people with a wider range of ethnic/racial identities (see Donohue et al., 2019; Harrison et al., 2017). Future studies could investigate if the variability in the sizes of associations between SPDs and internalising/externalising problems among autistic people originates from individual differences in autism traits, and should seek to recruit (and report on) more diverse samples.

Limitations and implications

Limitations of this review reflect features of the extant literature considered. First, there were recruitment biases on the age, gender, and intelligence level of autistic participants across autism studies. Future studies could address these biases to improve the power of detecting the differences in the estimates of associations across sample groups. Second, to reduce the variability in the measurements, we only included questionnaire-based studies for current meta-analysis, and therefore retrospective questionnaires were used in all included studies. However, retrospective questionnaires could possibly miss some daily experiences (see Khor et al., 2014). Some techniques such as ecological momentary assessment could be used to capture more valid and detailed 'in-the-moment' sensory, emotional, and behavioural experiences. Third, externalising problems were investigated by fewer studies, and thus future studies could focus more on externalising problems and its subtypes, such as aggression and impulsivity, among autistic people, and examine the associations with SPDs. Last, the associations in the current meta-analysis used cross-sectional data, which cannot generate conclusions about predictive relationships. Whether SPDs are the precursor, consequence, or companion of internalising/externalising problems among autistic people deserves further investigation.

Looking at the measurement tools, the interchangeable and inconsistent terms used to describe sensory experiences (e.g., sensitivity, reactivity, responsivity) in the extant sensory measurement tools and literature pose difficulties in understanding and discussing sensory differences. He et al. (2023) proposed a hierarchical taxonomy and differentiated these related sensory constructs, and such conceptual clarifications should influence future research.

Moreover, we should be cautious when interpreting the associations considering the conceptual interplay between sensory processing and mental health conditions. As discussed in van den Boogert et al. (2022), low registration could, at least in part, function as a measurement of neurocognitive problems relating to mental health problems (Trivedi, 2006) such as depression (American Psychiatric Association, 2013); and sensory sensitivity might be associated with a broad-band of mental health conditions through stress sensitivity. Therefore, whether this plausible conceptual overlap between sensory processing and mental health constructs has served to inflate some of the associations we observed deserves future investigation.

From a clinical perspective, the current findings suggest the importance of incorporating measurement of SPDs in assessment of autistic clients seeking treatment for mental health difficulties. SPDs should then be considered when individualised formulations are derived. The findings synthesised in this review are largely cross-sectional and observational, and so do not allow for the conclusion that SPDs are a causal risk factor for autistic mental health problems. However, our findings show this is a plausible hypothesis for testing in further research. Longitudinal studies measuring both SPDs and mental health at multiple time points are needed. Further, experimental studies in which sensory-related distress is reduced (e.g., through environmental modifications) and mental health monitored as an outcome will be useful, both for shedding light on whether SPDs are implicated in the development of mental health problems and for the development of new interventions to improve autistic wellbeing.

Conclusion

Overall, the current review focused on the associations between SPDs and internalising/externalising problems among autistic people. The positive and significant relationships provide evidence for possible underlying mechanisms of both sensory and internalising/externalising problems. On this basis future studies, in particular those that are longitudinal, could further advance the understanding of the aetiology and development of sensory and internalising/externalising problems, and can inform the development of mental health interventions for autistic people.

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Contributors

Yixin Chen: conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing-original draft, writing-review&editing, visualization

Zhenyang Xi: investigation

Rob *Saunders*: methodology, writing-review&editing

David *Simmons:* writing-review&editing

Vasiliki Totsika: writing-review&editing

Will Mandy: conceptualization, methodology, validation, writing-review&editing, supervision, project administration

Conflict of Interest

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Highlights

- Investigation of an autism-specific factor of mental health problem, namely sensory processing differences.
- Sensory processing differences are associated with internalising and externalising problems in autism.
- Hypersensitivity and sensation seeking are strongly related to internalising and externalising, respectively.
- Unusual processing of smell/taste are less related to internalising/externalising than visual, auditory, and tactile.