Sensory modulation difficulties and assessment in children with attention deficit hyperactivity disorder: a systematic review

ABSTRACT

BACKGROUND: This systematic review aims to (1) establish how different types of assessment measure sensory modulation difficulties in children with ADHD, and (2) to examine whether sensory modulation difficulties can be separated from ADHD symptomatology.

METHOD: The review protocol was registered with PROSPERO (CRD42018091730). PRISMA guidelines were used. Three databases (PsycINFO, PubMed, CINAHL) were searched using a predetermined search string from 1980 to 2020. Twenty-five studies met inclusion criteria.

RESULTS: Sensory modulation difficulties are more likely to be reported when caregiver-report or behavioural measures are used, relative to physiological methods. Despite the focus to date on difficulties in auditory and tactile processing in this patient population, the reported studies show no evidence for these difficulties being more prevalent than difficulties in other sensory domains. Caregiver reports show evidence for differences in children with sensory modulation difficulties and ADHD, and those with ADHD only.

CONCLUSION: This review reports variability in the prevalence of sensory modulation difficulties in children with ADHD that is dependent on the tools used to measure this domain. Approaches to the assessment of sensory modulation, and the implications for clinical practice, are considered.

Key words: attention deficit hyperactivity disorder, ADHD, child, sensory processing, systematic review.

INTRODUCTION

ADHD is a neurodevelopmental disorder characterised by pervasive and impairing symptoms of inattention, hyperactivity, and impulsivity that interfere with daily functioning and development (American Psychiatric Association, 2013). ADHD is a common disorder, with prevalence rates estimating between 5.29% and 7.2% of children worldwide have ADHD (Polanczyzk et al., 2007; Thomas et al., 2015). Children with ADHD may be more likely than typically developing children to experience sensory processing difficulties (Mangeot et al., 2001; Dunn & Bennett, 2002). Given that sensory processing difficulties can impact the development of behavioural, emotional, motor, and cognitive domains, it is important to identify potential difficulties at an early stage (Jorquera-Cabrera et al., 2017).

Sensory processing disorder

Ayres originally theorised that sensory integration dysfunction resulted from difficulties in processing and organization within the central nervous system (Ayres, 1979). Many models of sensory processing dysfunction have emerged since Ayre's seminal work in this area (e.g. Dunn, 2014; Baranek et al., 2001), the most recent of which comes from Bundy and Lane (2020). Bundy and Lane focus on two major categories of sensory integration: dyspraxia and sensory modulation dysfunction. Ayres (1979) defined sensory modulation as the central nervous system's regulation of its own activity. Sensory modulation dysfunction, which arises when an individual has difficulty regulating sensory input, can be further broken down into distinct patterns of overresponsivity and underresponsivity (Bundy & Lane, 2020).

Both the Diagnostic Manual for Infancy and Early Childhood (Interdisciplinary Council on Development and Learning Disorders, 2005) and DC:0-5 Diagnostic Classification of Mental Health and Developmental Disorders of Infancy and Early Childhood (Zero to Three, 2016) describe disorders of sensory processing, which can be further categorised by sensory overresponsivity, sensory underresponsivity and sensory seeking patterns. There is some debate over the inclusion of a specific sensory seeking pattern. For example, there is a suggestion that sensory seeking behaviours may be a compensatory mechanism to moderate high arousal levels (Liss et al., 2006) or that these behaviours are an outcome of overresponsivity and underresponsivity (Bundy & Lane, 2020). To date, sensory processing dysfunction has not been included in the DSM or ICD. However, hyporesponsiveness (underresponsive) and hyperresponsive (overresponsive) behaviours were added as a criteria for autism spectrum disorders (ASD) in the latest version of the DSM (APA, 2013; Niedzwiecka et al., 2019).

There is considerable inconsistency in the use of terms surrounding sensory integration, sensory modulation, and sensory processing. This review will focus on sensory modulation difficulties (SMD) in line with the overresponsive and underresponsive patterns outlined by Bundy and Lane (2020), Interdisciplinary Council on Development and Learning Disorders (2005), and Zero to Three (2016). For the purpose of this review, while specific studies refer to some of the previously stated terms such as sensory sensitivity and sensation seeking, the term SMD will be used to describe abnormal sensory modulation in a general sense.

SMD and ADHD

Previous research suggests that children with ADHD are more likely to experience SMD relative to typically developing children (Ben-Sasson et al., 2017; Ermer & Dunn, 1998). However, it is difficult to distinguish between symptoms stemming from SMD and symptoms linked to an ADHD diagnosis (Lane et al., 2010). Neither SMD or ADHD are homogenous, and both are typically diagnosed through observational or behavioural criteria (Koziol & Budding, 2012). Miller and colleagues (2012) report similarities between sensory modulation patterns and ADHD subtypes. In particular, the sensory seeking pattern and ADHD hyperactive-impulsive subtype can often both display poor impulse control, and inappropriate movement and touch; the overresponsive pattern and ADHD inattentive subtype both feature symptoms of distractibility and difficulty focusing; the underresponsive pattern and inattentive ADHD subtype both present with a lack of awareness when being spoken to or following directions. Investigating differences between individuals with ADHD, individuals with SMD, and those with co-occurring ADHD and SMD is necessary to determine whether sensory modulation difficulties can be reliably distinguished from the behaviours of ADHD (Lane et al., 2010; Koziol & Budding, 2012).

Sensory modulation difficulties can exacerbate the functional impairments already experienced by children with ADHD. SMD has been associated with poorer social participation, increased delinquency and aggression (Mangeot et al., 2001), and increased anxiety (Reynolds & Lane, 2009) in children with ADHD. Early detection and management of sensory modulation difficulties can help to improve everyday functioning in children with ADHD (Ghanizadeh, 2011). Thus, understanding SMD in children with ADHD is an important initiative to improve long term outcomes in this population.

Assessment of SMD in children

A recent systematic review identified 21 available tools for evaluating sensory processing in all children aged 3-11, of which 15 are supported by psychometric studies (Jorquera-Cabrera et al., 2017). More recently, there has been an influx in the number of available sensory assessments, increasing from one publication a year between 2006 and 2009 to seven publications in 2014 (Jorquera-Cabrera et al., 2017). This may be due to an increased interest in sensory processing as part of the new DSM criteria for ASD. It may also reflect a focus on research examining the association between sensory processing and domains such as child development and mental health (Jorquera-Cabrera et al., 2017; Harrison et al., 2019). The most common method of assessing SMD is through parent-report questionnaires (Soto et al., 2018) such as Sensory Profile (Dunn, 1999), Sensory Profile 2 (Dunn, 2014), Sensory Experiences Questionnaire (Baranek, 2018), Sensory Processing Measure (Parham et al., 2007), Sensory Overresponsivity Scale (Schoen et al., 2008), or Sensory Processing Scale Assessment (Schoen et al., 2014). Research has also attempted to use physiological measures to examine sensory overresponsitivty (SOR) (Lane et al., 2010; Ben-Sasson et al., 2017). The most common physiological assessment is the Sensory Challenge Protocol (McIntosh et al., 1999a). However, although this unique laboratory paradigm has not been standardized, it has since been used in a number of sensory processing studies, including studies with autistic children (e.g. Reynolds et al., 2010; Schaaf et al., 2015; Schupak et al., 2016; Bizzell et al., 2020). Research with ADHD populations has typically focused on examining electrodermal responses during the Sensory Challenge Protocol. One recent study suggests that caregiver reports have established differences between children with ADHD and typically developing controls in terms of SMD but that physiological findings have been less consistent (Lane & Reynolds, 2019).

The current review

There has only been one review to date that has looked at sensory modulation difficulties in children with ADHD (Ghanizadeh, 2011). As the field of sensory modulation has gained momentum in recent years (Jorquera-Cabrera et al., 2017), a more comprehensive, up-to-date systematic review of the literature is timely and necessary. Importantly, no review to date has considered the influence of the choice of assessment on the detection of SMD in children with ADHD (Eeles et al., 2013). Given the ongoing debate surrounding ADHD and SMD as distinct diagnoses, understanding the tools used to assess SMD in this population can provide further insight as to whether they should be considered distinct disorders. The findings of this review could aid clinicians in selecting the most appropriate tool for measuring SMD in this population (Miller et al., 2007).

The aims of this review are twofold. Firstly, to establish how SMD is assessed in children in ADHD and whether the choice of measure has an influence on the detection of SMD in this population. As mentioned previously, there is a suggestion that caregiver reports have established significant differences between controls and children with ADHD, while findings are less consistent using physiological measures (Lane & Reynolds, 2019). This review will systematically review the literature in order to compare measures of SMD across studies of children with ADHD. Secondly, this review will focus in on studies which include participants with dual diagnoses of ADHD and SMD and those with SMD only or ADHD only to investigate whether these diagnoses can exist independently of one another.

METHOD

The review protocol was registered with PROSPERO (CRD42018091730). PRISMA guidelines were followed (Moher et al., 2009). The search was conducted by the primary author with assistance from a librarian at the primary author's institution. Articles were required to be published in English, based on human research, from the January 1980 to December 2019. The year 1980 was decided upon as it marked the publication of the Diagnostic and Statistical Manual III, whereby ADHD was classified. Sample included children under the age of 18 with a diagnosis of ADHD (see Table 1). After several scoping searches to develop an appropriate search string, articles were retrieved from PubMed, CINAHL, and PsycINFO in November 2020. These three databases were selected by reviewing the common databases used in systematic reviews concerning ADHD and sensory modulation literature as of June 2020. An example of the search string used is outlined in the supplementary material (Table S1).

In addition to searching the databases, a hand-search was conducted of the reference lists of the original studies which met the eligibility criteria. The titles and abstracts of studies identified in the initial search were screened by two of the authors. The full text of the remaining studies were then screened by the same reviewers independently. Papers not identified by both reviewers as eligible for inclusion were marked and discussed, with disagreements resolved through this discussion. Data extraction was completed by the lead author on the studies which met the inclusion criteria. Quality, scientific rigor, and risk of bias were assessed using a Risk of Bias Tool developed from the Cochrane Collaboration (Higgins & Green, 2011) and DeBoth and Reynolds (2017). Each of the studies was rated based on a series of twelve questions under the broad categories of selection bias, performance bias, attrition bias, detection bias, and reporting bias. The lead author determined whether the risk of bias was high or low, or whether there were some concerns present in each study. A series of twelve questions were rated according to this criteria under the broader categories of selection bias (four questions), performance or statistical bias (two questions), attrition bias (two questions), detection bias (three questions), and reporting bias (one question). Results of the risk of bias assessment are presented in Figure 2 (further details on risk if bias assessment are present in supplementary material [Figure S1]). Double data extraction and risk of bias assessments were completed by the second reviewer for a proportion of the included studies (n=5, 22.73%) to verify that the correct data had been extracted. This partial double data extraction resulted in a 90% agreement rate, in line with recommendations outlined by Schlosser (2007), with any disagreements resolved through discussion.

TABLE 1 HERE

RESULTS

The initial electronic search yielded 345 results (see Figure 1). Eighteen additional studies were retrieved through hand-searching the reference lists of included studies. All abstracts were screened by the lead author and an independent reviewer. After screening of titles and abstracts, 68 articles were obtained for full-text screening of eligibility. All full-text articles were assessed by the same two reviewers. Forty-three articles were excluded from final analysis. The remaining 25 studies, all of which were quantitative, are included in the current review. Data extraction was completed by the main author and cross-checked by an independent reviewer. Of the 25 studies, ten were conducted in America, six in Israel, three in Iran, one in Brazil, one in the Netherlands, one in China, one in Spain, one in India, and one in Taiwan. Nineteen of the studies used a case-control design to compare children with ADHD to typically developing controls. Three studies examined a single group of children with ADHD without matched controls. One study was conducted with a representative birth cohort, and 2 studies compared children with SMD and ADHD. The age of participants included across all studies ranged from 3-15 years. The characteristics of the 25 studies are summarised in Table 2.

FIGURE 1 HERE

TABLE 2 HERE

Critical appraisal

No study was shown to have an extremely high risk of bias (see Figure 2). The most common concern was that confounding variables were not always collected using valid measures. For example, May Benson and colleagues (2020) rely on parent report of co-occurring diagnoses, and did not include a standardised assessment for co-occurring disorders in their population of children with SPD. The studies of Ghanizadeh (2008, 2009, 2013) utilised newly developed questionnaires which had not been assessed previously for validity or reliability. No study was excluded after the risk of bias assessment was carried out.

FIGURE 2 HERE

Measures of sensory processing

Of the 25 included studies, n=24 (96%) of studies used a parent-report measure and n=1 (4%) used a self-report measure to assess SMD. Five studies (20%) also included a physiological measure, while one study (4%) included both a parent-report and behavioural measure. Only one study (4%) included parent-report, physiological, and behavioural measures. A summary of the main results of each study, including the type of assessment used, is presented in Table 3.

TABLE 3 HERE

Caregiver reports

Sensory Profile/Short Sensory Profile/Sensory Profile-2. Fifteen studies administered the Sensory Profile (n=7), the Short Sensory Profile (n=5), the Sensory Profile 2 (n=2), or Short Sensory Profile 2 (n=1). The seven studies which included the Sensory Profile, developed by Dunn (1999), were Ben-Sasson et al., 2017; Dunn & Bennett, 2002; Yochman et al., 2004; Cheung & Siu, 2009; Lin et al., 2013; Shimizu et al., 2014, and Iyer et al. (2020). Internal consistency of section scores ranges from .47 to .93 (Dunn, 1999). The complete Sensory Profile consists of 125 items investigating a variety of sensory categories: general processing, auditory, visual, tactile, vestibular, and oral sensitivity processing. A lower score on the Sensory Profile is indicative of greater difficulty with sensory processing. All seven studies employed various methods of scoring the Sensory Profile. Cheung and Siu (2009) and Lin et al. (2013) used the Chinese Sensory Profile, which contains eight subscales – six relating to sensory systems and two behavioural subscales. Cheung and Sui (2009) analyse their results by item. Similarly, Dunn and Bennett (2002) analysed their results by item, as well as by section scores. Lin et al. (2013) converted the results to Z-scores for analysis. Ermer and

Dunn (1998) analysed their results by factor scores. Shimizu et al. (2014) and Yochman et al. (2004) both analysed their results by factor and section scores. Iyer and colleagues (2020) report scores for each sensory quadrant (sensitivity, avoiding, registration, and seeking). Despite the varied nature of scoring, all seven studies observed significant differences between children with ADHD and typically developing children, with children from the ADHD group displaying lower scores (i.e. a higher frequency of issues) of sensory processing in some or all subscales. Lin et al. (2013), Shimizu et al. (2014), and Yochman et al. (2004) observed no significant difference between the ADHD and control groups on the factor of sensory sensitivity. Ermer and Dunn's (1998) discriminant analysis found that children with ADHD were best discriminated from controls by a high incidence of sensory seeking and inattention/distractibility and a low incidence of oral sensitivity and fine motor/perception. Thus, suggesting there was no discriminant difference between groups on sensory sensitivity, similar to the aforementioned studies. Lin et al. (2013) and Shimizu et al. (2014) also found no significant difference between the ADHD and control groups in terms of oral sensitivity. Similarly, Iyer et al. (2020) found that the ADHD group scored significantly lower than children with no ADHD symptoms on the sensory seeking quadrant only.

The Sensory Profile has also been condensed into a Short Sensory Profile (McIntosh et al., 1999b), consisting of 38 items. The Short Sensory Profile was used by five studies in this review (Manegot et al., 2001; Miller et al., 2012; Engel-Yeger & Ziv-On, 2011; Mimouni-Bloch et al. 2018; Yochman et al., 2013), two of which used the Hebrew version of the scale (Engel-Yeger & Ziv-On, 2011; Yochman et al., 2013). The Short Sensory Profile consists of seven subscales: tactile sensitivity, movement sensitivity, taste/smell sensitivity, visual/auditory sensitivity, seeking sensation, auditory filtering, and low energy/weak. Internal consistency of the subscales ranges from .70-.90 (McIntosh et al., 1999b). All four studies observed significant differences between children in the ADHD group and those in the control group for at least five of the seven subscales. Engel-Yeger and Ziv-On (2011), Mangeot et al. (2001), Miller et al. (2012), and Mimouni-Bloch et al. (2018) found that the ADHD group scored significantly lower than controls in the subscales of tactile sensitivity and low energy/weak (with effect sizes ranging from $d = 0.25\ to\ 0.88$ for tactile sensitivity and $d = 0.14\ to\ 1.43$ for low energy/weak). Miller et al. (2012) divided the ADHD group into individuals with ADHD and SMD and those with ADHD only (see below for differences). Children with ADHD alone still scored significantly lower than controls on five of seven subscales (excluding auditory filtering and seeking sensation). On the other hand, Mimouni-Bloch et al. (2018) reports a significantly lower score for the ADHD group relative to controls for all subscales (effect sizes range from $d = 0.05\ to\ 0.64$). The largest effect sizes in Mimouni-Bloch's study were the auditory filtering and seeking sensation subscales ($d = 0.64$ and $d = 0.45$ respectively), in direct contrast to the results of Miller et al. (2012). Yochman and colleagues (2013) compared children with SMD to those with ADHD only, without a control group. Yochman et al. (2013) found that the SMD group had significantly lower scores than the ADHD group for all subscales.

The Sensory Profile 2 (Dunn, 2014) is an updated version of the Sensory Profile. It contains 86 items, with internal consistency scores ranging from 0.6 to 0.92 (Dunn, 2014). Unlike the Sensory Profile, higher scores indicate greater difficulties. Two studies in this review employed the Sensory Profile 2 (Little et al., 2017; Little et al., 2018). Little et al. (2017) found that children with ADHD had higher scores (i.e. greater difficulties) on all nine subscales of the Sensory Profile 2 than typically developing children. The other study classified children with ADHD into sensory processing patterns (Little et al., 2017). Little and colleagues observed that of 96 children with ADHD, 13.5% showed increased sensory seeking, 10.4% showed an intense, aversive pattern, 10.4% showed increased scores in avoidance and registration of sensory stimuli, and 12.5% showed increased sensitivity and avoidance. The remaining participants with ADHD (51.3%), showed a balanced profile with low frequency of sensory behaviours. Using the Spanish version of the Short Sensory Profile 2, Delgado-Lobete and colleagues (2020) found increased incidence of atypical sensory processing scores for children with ADHD across all sensory processing quadrants and patterns (bystander, seeker, sensor, avoider).

Sensory Overresponsivity Scale (SensOR). Three studies assessed sensory processing using the Sensory Overresponsivity Scale (SensOR), developed by Schoen and colleagues (2008), (Ben-Sasson et al., 2017; Reynolds et al., 2010; Lane et al., 2010). The SensOR is a caregiver report containing 76 items, all focusing on the overresponsive pattern of sensory processing. It encompasses all seven sensory domains: tactile, auditory, visual, olfactory, gustatory, and vestibular–proprioceptive. Reliability for the total scaled ranged from a Cronbach's alpha of .74 to .94. The internal reliability within each domain ranged from a Cronbach's alpha of .65 to .88. Higher scores on the SensOR are associated with more difficulty in terms of sensory processing. The cut-off for the presence of SOR is based on the presence of four or more tactile or auditory items (Schoen et al., 2008; Ben-Sasson et al., 2017). Ben-Sasson et al. (2017) used items from the auditory and tactile scales of the SensOR only to examine clusters of ADHD and sensory overresponsivity (SOR) symptomatology. Children with high levels of ADHD symptomatology had significantly higher sensitivity scores (SOR) than those with low levels of or an absence of ADHD symptoms. This study also found that 48% of participants with elevated ADHD scores on the Child Behaviour Checklist also met criteria for SOR. Similarly, Reynolds et al. (2010) found that thirteen participants (54.17%) from their ADHD group met the criteria for sensory overresponsivity, based on their SensOR scores. Lane et al. (2010) observed that 46% of participants from the ADHD group met criteria for SOR.

Sensory Processing Measure. The Sensory Processing Measure – Home Form was developed by Parham et al. (2007) and employed by one study in this review (Pfeiffer et al., 2015). The Sensory Processing Measure is a norm-referenced caregiver report. It consists of 8 subscales: social participation, vision, hearing, touch, taste and smell, body awareness, balance and motion, and planning and ideas. The subscales of vision, hearing, touch, taste and smell, body awareness, and balance and motion are combined to represent a total sensory systems score (Lai et al., 2011). It has good internal consistency with Cronbach's alpha ranging from .77 to .95 and strong test–retest reliability, with estimates ranging from .94 to .98 (Pfeiffer et al., 2015). Pfeiffer et al. (2015) found that for each subscale of SPM, children with ADHD had a higher mean score (i.e. more problems) than controls. Pfeiffer and colleagues also reported that 64% of those in the ADHD group scored in the range of "some problems" or "definite dysfunction", compared to less than 5% of controls who scored in range of "some problems". No controls scored in the range of "definite dysfunction".

Evaluation of Sensory Processing Questionnaire. The Evaluation of Sensory Processing Questionnaire was used by one study (Yochman et al., 2013). There are six subscales related to specific sensory systems: visual, auditory, tactile, olfactory/gustatory, proprioceptive, and vestibular sensory systems. Higher scores indicate fewer sensory problems. Yochman et al. (2013) observed that children with SMD scored lower than children with ADHD on three of the six subscales (taste and smell, tactile, motion/vestibular).

Touch Inventory for Preschoolers. The Touch Inventory for Preschoolers is a parent-report scale based on children's typical responses to tactical stimuli and was used by one study in this review (Parush et al., 2007). Internal consistency of .89 has been reported (Royeen, 1987). Parush and colleagues calculated tactile defensiveness (TD) as one standard deviation above the mean score of a sample of 60 typical children (2007). Out of 67 children with ADHD, 49 children met the criteria for TD (Parush et al., 2007). Mean scores on the Touch

Inventory for Preschoolers was 112.30 for the ADHD group, compared to 61.51 for typically developing controls.

OTA The Koomar Centre Development/Sensory History. OTA The Koomar Centre Development/Sensory History questionnaire is a parent-report measure concerning sensory processing and motor skills in children aged 4-12 years which was used by one study in this review (May Benson et al., 2020). Each item is scored on a 3-point scale where higher scores indicate greater functional problems. May Benson and colleagues (2020) focused on the gravitational insecurity subscale in their study. Gravitational insecurity is a type of movement-related overresponsivity dysfunction (May Benson et al., 2020). Results showed that children with SPD+ADHD did not differ from those with SPD only in terms of gravitational insecurity scores.

Non-standardized measures. It should be noted that three studies included in this review did not use standardized measures to assess sensory processing abilities (Ghanizadeh, 2008; Ghanizadeh, 2009; Ghanizadeh, 2013). However, all of these new measures were assessed for face validity by a team of three psychiatrists and subjected to a pilot study. One study found that ADHD subtypes were not associated with scores on the hyposensitivity or hypersensitivity subscales of the Tactile Sensory Dysfunction Checklist (Ghanizadeh, 2008). Another study reported that ADHD subtypes were not associated with total scores on the Auditory Dysfunction Checklist (Ghanizadeh, 2009). Ghanizadeh reported that children with ADHD who display ODD symptoms were more likely to have oral sensitivity and oral over-responsivity on the Oral Over- and Under-responsivity Behaviours Inventory (2013). In interpreting the results of these three studies of non-standardized measures, it should be noted that all of these studies were single group designs, with no matched control group.

Self-report measures

Touch Inventory for Elementary School-Aged Children. The Touch Inventory for Elementary School-Aged Children (TIE) is a self-report screening questionnaire for children aged 6-12, measuring tactile defensiveness to tactile stimuli. It contains 26 items and has good internal reliability, with a Cronbach's alpha of 0.79. One study in this review used the Dutch version of the Touch Inventory for Elementary School-Aged Children (Broring et al., 2008). Broring and colleagues (2008) observed children with ADHD scored higher (i.e. a greater incidence of tactile defensiveness) than controls.

Behavioural measures

Sensory Reactivity Score. The Sensory Reactivity Score is a rating scale developed to quantify both verbal and non-verbal behaviours of touch-related discomfort and agitation (Parush et al., 2007). It was used by one study in this review (Parush et al., 2007). Test-retest and interrater reliability was examined by coding videos, while construct validity was established by six experts from occupational therapy, neuroscience, and psychology backgrounds. Ratings of reactivity or discomfort were made by the experimenter while four scalp-electrodes were attached for electrophysiological recordings (see below for discussion on physiological data). Ratings were on a scale from 0 (no discomfort) to 4 (intense discomfort). Children with TD had a mean reactivity score of 3.36 compared to .71 for controls.

Fabric Prickliness Test. This behavioural assessment measures the level of pain evoked by the application of prickly fabrics to the skin and was used by one study in this review (Yochman et al., 2013). Three types of woollen fabrics (least prickly, mildly prickly, and very prickly) were applied to the child's non-dominant forearm in 16 applications (Yochman et al., 2013). Children rated their level of pain using the Revised Faces Pain Scale (Hicks et al., 2001). 'Pain after-sensation' was measured 15 seconds after the last fabric application and repeatedly every 1 minute until sensation dissipated. Children with SMD reported higher pain and a longer ‘pain after-sensation’ period than children with ADHD.

Pinprick Pain. Yochman and colleagues (2013) also used a series of Von-Frey filaments to test pinprick pain. Filaments were applied 9 times with increasing levels of punctuate pain. Children were then asked to rate pain intensity using the Revised Faces Pain Scale (Hicks et al., 2001). Children with SMD higher scores in response to punctuate pain than children with ADHD.

Physiological measures

Sensory Challenge Protocol. The Sensory Challenge Protocol (SCP) is a lab paradigm which uses electrodermal response to examine sensory stimulation in olfactory, auditory, visual, tactile, and vestibular domains (McIntosh et al., 1999a). Stimuli presented to the participants include wintergreen oil in a vial (olfactory), a siren at 90 decibels (auditory), a 20-watt strobe light at 10Hz (visual), a feather moved across the face (tactile) and the chair tilted back to a 30-degree angle (vestibular). Electrodermal activity is recorded throughout the procedure (see McIntosh et al., 1999a for a detailed description). Five studies in this review employed the SCP and results are less homogenous than caregiver reports (Mangeot et al., 2001; Miller et al., 2012; Reynolds et al., 2010; Lin et al., 2013; Lane et al., 2010). Three of these studies report no significant differences between the ADHD group and relative controls (Miller et al., 2012; Lin et al., 2013; Lane et al., 2010). However, Lane et al. (2010) did find that children with ADHD+SOR showed higher arousal levels during recovery from the challenge, relative to controls. Mangeot et al. (2001) observed a trend towards a significant difference between children with ADHD and controls ($p = .056$). Reynolds et al. (2010) used salivary cortisol to measure children’s stress responses to the SCP. Reynolds and colleagues (2010) also observed a trend towards a significant difference between children with ADHD+SOR and children with ADHD only in terms of cortisol levels over time ($p = .056$). Although, Reynolds et al. found no significant difference between the children with ADHD+SOR and TD controls in their stress responses to the SCP.

Somatosensory Evoked Potential. One study in this review used somatosensory evoked potential (SEP), electrical activity from the nervous system in response to sensory stimuli, as a measure of somatosensory function (see Parush et al. (2007) for experimental procedure). Parush et al. (2007) observed that children with ADHD who met criteria for tactile defensiveness (as measured by their sensory reactivity score and the Touch Inventory for Preschoolers, n= 46/67) were distinguishable from children with ADHD who did not meet the criteria for tactile defensiveness and typically developing children by larger somatosensory evoked potential amplitudes (N13, N20, P23). There was no difference between children with ADHD only and controls.

Caregiver reports versus experimental measures

Seven studies included both a caregiver report and a physiological assessment. Of these, three studies report that significant differences emerged between groups for the caregiver reports, while no significant difference was found between groups for objective measures (Lin et al., 2013; Mangeot et al., 2001; Miller et al., 2012). Reynolds and colleagues (2010) report significant differences between ADHD+SOR, ADHD, and controls on the SensOR, however the difference between ADHD+SOR and controls, and ADHD+SOR and ADHD only both fail to reach significance in cortisol responses to the Sensory Challenge Protocol. A significant difference does emerge in Reynolds et al. (2010) for the ADHD only and control groups on cortisol responses. Similarly, Lane et al. (2010) observed group differences in SensOR and electrodermal responses during recovery from the Sensory Challenge Protocol. However, no differences emerged between those with ADHD only and the control group

(Lane et al., 2010). On the other hand, Parush et al. (2007) report significant differences between those with ADHD+TD and ADHD only on both parental-report and physiological measures. Likewise, Yochman et al. (2013) did observe differences between SMD and ADHD groups on both caregiver-report and behavioural measures.

Separating SMD from ADHD

Six studies in this review included both children with ADHD only and children with both ADHD and sensory modulation disorder (SMD). One study looked at children with SPD and those with a co-occurring diagnosis of SPD and ADHD. As discussed above, differences between ADHD and SMD behaviours are often difficult to distinguish (Ermer & Dunn, 1998; Koziol & Budding, 2012). In this review, caregiver report questionnaires observed moderate to large effect sizes between groups, whereby participants with SMD or SOR reporting poorer sensory modulation. Ben-Sasson and colleagues (2017) observed a large effect size ($d = 3.1$) between the ADHD+SOR group and ADHD only group on total SensOR scores, in which children with ADHD+SOR reported greater difficulties than those with ADHD only. On the other hand, a large effect size was observed between controls +SOR and ADHD+SOR ($d = -1.3$), whereby children with SOR only had greater difficulties than children with ADHD+SOR. In Lane et al. (2010), the ADHD+SOR group differed significantly from the ADHD group on SensOR scores, with large effect sizes ranging from $d = 0.72$ to $d = 1.94$. The ADHD+SOR and ADHD groups were not distinguishable based on electrodermal responses. Reynolds et al. (2010), observed moderate to large effect sizes when looking at differences between children with ADHD+SOR and those with ADHD on the SensOR, with Cohen’s d ranging from $d = 0.33$ to $d = 2.35$. A trend towards significance ($p = .056$) emerged between the two groups in their cortisol levels during the Sensory Challenge Protocol. Miller and colleagues (2012) report that individuals with ADHD+SMD scored significantly lower than those with a sole diagnosis of ADHD on all subscales of the Short

Sensory Profile, however no effect sizes are available. In Miller et al. (2012), those with ADHD+SMD were excluded from the electrodermal response analysis as too few participants took part in the Sensory Challenge Protocol. Parush et al. (2007) observed that ADHD+TD group was distinguishable from ADHD group by larger SEP amplitudes. Finally, both caregiver reports and behavioural measures were able to distinguish children with SMD from children with ADHD in Yochman et al. (2013). Children with SPD+ADHD could not be distinguished from children with SPD only in terms of parent-reported gravitational insecurity (May Benson et al., 2020).

DISCUSSION

This review had two specific aims: (1) to investigate how SMD is measured in children with ADHD and whether the choice of measure has an influence on the detection of SMD in this population, and (2) to examine whether symptoms of SMD and ADHD could be distinct diagnoses. Results will be discussed below in relation to these aims.

Overall, all studies with a case-control design reported that a proportion of children with ADHD showed atypical sensory modulation. A key finding of this review is that the type of assessment used influenced the detection of these differences. Findings show that caregiver reports and self-reports were more likely to observe differences between children with ADHD and typically developing children, while results from physiological measures were less robust. This is similar to observations reported by Lane and Reynolds (2019). Similar discrepancies between behavioural/parent-report and physiologic measures have been reported in other domains such as sleep (Corkum et al., 1998) and distress in children with cancer (Walco et al., 2005).

This discrepancy between measures calls for further examination of the validity and consistency of assessments. For example, the Sensory Profile does not operationally define 'sensory processing' and includes items which capture behaviours beyond the scope of sensory processing such as emotional and social responses (Koziol & Budding, 2012). Many items also overlap with behaviours included in the diagnostic criteria for ADHD and other DSM disorders (Koziol & Budding, 2012; Lane & Reynolds, 2019). The user manual of the Sensory Profile reports that 43/125 items (34.4%) represent behaviours more commonly seen in ADHD (Dunn, 1999; 2014). A similar overlap issue occurs in the Sensory Processing Measure (SPM) (Parham et al., 2007). One item from the SPM "Fails to gather belongings or otherwise take notice of approaching bus stop" is closely aligned with the DSM criteria of "often has trouble organising tasks and activities". This conceptual overlap may explain more robust differences between ADHD and control groups in caregiver reports over physiological measures. This, however, does not explain why differences emerged in behavioural tests (e.g. pinprick pain test) and not with electrodermal response during the Sensory Challenge Protocol. While Parush and colleagues (2007) did observe a significant difference in physiological response between children with ADHD+TD and a control group, this was a single study with only male participants which warrants replication. Furthermore, parent report measures often combine a complex cluster of behavioural observations over a period of time, while lab assessments assess a child's sensory experiences at a single point in time in a controlled environment (Tavassoli et al., 2018). Perhaps SMD may be better captured over time through caregiver report than a singular lab session. Including additional reports, such as those from a teacher's perspective, may also help to offer a clearer picture of a child's sensory profile. Importantly, the most appropriate measure to use will likely be guided by the specific questions being asked by the researcher.

Seven studies included participants who had ADHD+SMD or ADHD+SOR and those with SMD or SOR only, providing further insight into the differences between these two disorders. Six studies were able to distinguish between those with SOR and those with ADHD only based on caregiver reports. One thing to consider is the way in which SMD or SOR was diagnosed identified within each study. Ben-Sasson et al. (2017), Lane et al. (2010) and Reynolds et al. (2010), used SensOR scores to both differentiate the groups and also to report group differences. Similarly, Parush et al. (2007) divided the ADHD group into ADHD+TD and ADHD only based on their Touch Inventory in Preschoolers score and sensory reactivity score. In the studies by Yochman et al. (2013), Miller et al. (2012), and May Benson et al. (2020), children had been diagnosed with SMD prior to participating in the study and as such had likely undergone further assessment by an occupational therapist regarding sensory processing. It may be useful for future studies examining populations with both ADHD and SMD to include an assessment with an occupational therapist (which may include parent interview and/or skilled observation of child's behaviour), rather than relying solely on the measure used within the study itself. This is also pertinent given the conceptual overlap between common sensory assessments such as the Sensory Profile and ADHD criteria.

Limitations

There are several limitations to be considered in the interpretation of the current findings. This review only included articles published in English, resulting in the exclusion of three studies. The reporting of results from the Sensory Profile was not homogenous. Some studies reported factor scores, while others only reported section scores. Section scores reflect a parent's perception of the child's sensory processing, modulation, and behavioural and emotional responses. Factor scores reflect a parent's perceptions of their child's responsiveness to sensory input. Factor scores have been found to be more reflective of symptoms that characterize ADHD in general (Yochman et al., 2004). Moreover, not all items in the Sensory Profile are included to calculate factor scores (Yochman et al., 2004). This made it difficult to synthesise the results of the review or to perform a meta-analysis.

Thus, the variability observed in this review may be due to the way in which authors report their results.

A further limitation of this area of research is the lack of a universal diagnostic criteria for SMD and sensory processing difficulties. This review employed the nosology of Bundy and Lane (2020), the Interdisciplinary Council on Development and Learning Disorders (2005), and Zero to Three (2016). Although, it cannot be guaranteed that all researchers adopted this framework when examining sensory modulation in their respective studies. Furthermore, this theoretical framework was not always employed in the development of the measures discussed above. Until a cohesive definition and diagnostic criteria are agreed upon for SMD, it is difficult to perform a meta-analysis.

The majority of studies included in this review did not consider DSM subtypes of ADHD. Given the robust finding that a number of children with ADHD experience SMD, it is necessary to investigate whether children with particular subtypes of ADHD are more likely to experience sensory dysfunction. As we move away from a traditional, categorical diagnostic process to a more dimension-based approach, it may be useful to consider SMD as a dimension to ADHD, as proposed by Lane and Reynolds (2019). Furthermore, a small proportion of studies in this review (n=5) did not include a control group of typically developing children. As such, caution is advised in interpreting these studies.

Implications and future research

Sensory processing impairments are important to consider due to the increased incidence of sensory processing problems reported in children with ADHD, particularly given that children with ADHD and sensory difficulties are more likely to present with secondary problems such as clinically significant anxiety (Reynolds & Lane, 2009). The majority of studies excluded participants with co-occurring disorders such as ASD (see Table 2 for further detail), suggesting that SMD is not the result of co-occurring traits from other neurodevelopmental diagnoses. Further research should be mindful of the discrepancies that arise between caregiver reports and experimental measures when investigating sensory processing issues in ADHD. These inconsistencies between questionnaire, behavioural, and physiological assessments raise questions as to their validity: Are caregiver reports too sensitive to sensory processing deficits? Are physiological assessments too conservative? Are these measures evaluating different aspects of the sensory experience? It is important that clinicians and practitioners are aware of the different approaches in measuring sensory processing symptoms in this population, in order to choose the most appropriate tool.

Future research should also aim to further understand potential shared neurobiological underpinnings of ADHD and SMD. There is currently no consistent neuroanatomic understanding of SMD, although studies have suggested that sensory gating paradigms may allow for the dissection of the chain of events involved in sensory processing (Davies et al., 2009). As previously mentioned, SMD is not recognised by the DSM (APA, 2013). Future research could benefit from focussing on disruptions to normal development rather than distinct diagnosis, similar to that of the Research Domain Criteria Framework (RDoC) (Koziol & Budding, 2012). This approach would allow for the consideration of different factors which may underlie SMD, such as poor self-regulating and executive functioning skills (Ahn et al., 2004).

Conclusion

This review reports variability in the prevalence of SMD in children with ADHD that is dependent on the tools used to measure this domain. Studies that employ caregiver-report or behavioural measures tend to report a greater prevalence of difficulties in sensory processing, relative to physiological measures. This has important implications for clinicians in the consideration of tools for sensory processing assessment in children with ADHD. When identifying the most appropriate tool, researchers should be guided by the questions being asked. If daily behaviours are crucial to consider, caregiver reports might be more appropriate to examine. If researchers are focused on understanding the physiological underpinnings of SMD, then physiologic tools are necessary. Finally, this review found differences between SMD and ADHD in studies examining children with dual diagnoses and SMD only or ADHD only suggesting that SMD and ADHD can be considered as distinct, but frequently cooccurring disorders.

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References

Ahn, R.R., Miller, L.J., Milberger, S. & McIntosh, D.N. (2004). Prevalence of parents' perceptions of sensory processing disorders among kindergarten children. *American Journal of Occupational Therapy, 58(3),* 287-293.

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders (DSM-5®)*: American Psychiatric Pub.

Ayres, A. J. (1979). Sensory integration therapy. *Sensory integration and the child.* Western Psychological Services.

Baranek, G. T., Reinhartsen, D., & Wannamaker, S. (2001). Play: Engaging children with autism. In R. Heubner (Ed.), *Sensorimotor interventions in autism*, 311–351. F. A. Davis.

Baranek, G. T. (2018). *Sensory Experiences Questionnaire Manual – Version 2.1.*

Ben-Sasson, A., Soto, T. W., Heberle, A. E., Carter, A. S., & Briggs-Gowan, M. J.. (2017). Early and concurrent features of ADHD and sensory over-responsivity symptom clusters*, Journal of Attention Disorders;21(10):*835-845. DOI: http://dx.doi.org/10.1177/1087054714543495

Bizzell, E., Ross, J., Rosenthal, C., Dumont, R., & Schaaf, R. (2020). Sensory features as a marker of autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *50,* 2240-2246. https://doi.org/10.1007/s10803-019-03948-8

Bröring, T., Rommelse, N., Sergeant, J., & Scherder, E. (2008). Sex differences in tactile defensiveness in children with ADHD and their siblings. *Developmental Medicine & Child Neurology, 50*, 129. https://doi.org/10.1111/j.1469-8749.2007.02024.x

Bundy, A. C. & Lane, S. J. (2020). *Sensory Integration: Theory and Practice (3rd Edition).* F.A Davis.

Cheung, P., & Siu, A. (2009). A comparison of patterns of sensory processing in children with and without developmental disabilities. *Research in Developmental Disabilities, 30*, 1468-1480. http://dx.doi.org/10.1016/j.ridd.2009.07.009

Corkum, P., Tannock, R., & Moldofsky, H. (1998). Sleep disturbances in children with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child & Adolescent Psychiatry, 37*(6), 637-646.

Davies, P.L., Chang, W.P., & Gavin, W.J. (2009). Maturation of sensory gating performance in children with and without sensory processing disorders. *International Journal of Psychophysiology, 72(2),* 187-197.

DeBoth, K. K., & Reynolds, S. (2017). A systematic review of sensory-based autism subtypes. *Research in Autism Spectrum Disorders, 36*, 44-56. https://doi.org/10.1016/j.rasd.2017.01.005

Delgado-Lobete, L., Pértega-Díaz, S., Santos-del-Riego, S., & Montes-Montes, R. (2020). Sensory processing patterns in developmental coordination disorder, attention deficit hyperactivity disorder and typical development. *Research in Developmental Disabilities*, *100*, https://doi.org/10.1016/j.ridd.2020.103608

Dunn, W. (1999). *Sensory Profile.* The Psychological Corporation.

Dunn, W. (2007). Supporting children to participate successfully in everyday life by using sensory processing knowledge. *Infants & Young Children, 20*(2), 84-101.

Dunn, W. (2014). *Child Sensory Profile 2.* Pearson Publishing.

Dunn, W., & Bennett, D. (2002). Patterns of sensory processing in children with attention deficit hyperactivity disorder, *Occupational Therapy Journal of Research,22(1)*:4-15. https://doi.org/10.1177/153944920202200102

Eeles, A., Spittle, A., Anderson, P., Brown, N., Lee, K., Boyd, R., & Doyle, L. (2013). Assessments of sensory processing in infants: A systematic review. *Developmental Medicine & Child Neurology, 55*(4), 314-326. https://doi.org/10.1111/j.1469-8749.2012.04434.x.

Engel-Yeger, B., & Ziv-On, D. (2011). The relationship between sensory processing difficulties and leisure activity preference of children with different types of ADHD. *Research in Developmental Disabilities, 32*, 1154-1162. https://doi.org/10.1016/j.ridd.2011.01.008

Ermer, J., & Dunn, W. (1998). The Sensory Profile: A discriminant analysis of children with and without disabilities, *American Journal of Occupational Therapy, 52(4):*283-290. DOI: http://dx.doi.org/10.5014/ajot.52.4.283

Ghanizadeh, A. (2008). Tactile sensory dysfunction in children with ADHD. *Behavioural Neurology, 20*, 107-112. http://dx.doi.org/10.1155/2008/786905

Ghanizadeh, A. (2009). Screening signs of auditory processing problem: Does it distinguish attention deficit hyperactivity disorder subtypes in a clinical sample of children?, *International Journal of Paediatric Ortohinolaryngology, 73(1):*81-87. https://doi.org/10.1016/j.ijporl.2008.09.020.

Ghanizadeh, A. (2011). Sensory processing problems in children with ADHD, a systematic review. *Psychiatry Investigation, 8*(2), 89-94. https://doi.org/10.4306/pi.2011.8.2.89

Ghanizadeh, A. (2013). Parents reported oral sensory sensitivity processing and food preference in ADHD. *Psychicatric and Mental Health Nursing, 20*(5), 426-432. https://doi.org/10.1111/j.1365-2850.2011.01830.x

Harrison, L. A., Kats, A., Williams, M. E., & Aziz-Zadeh, L. (2019). The importance of sensory processing in mental health: A proposed addition to the Research Domain Criteria (RDoC) and suggestions for RDoC 2.0. *Frontiers in Psychology, 10*, 103. https://doi.org/10.3389/fpsyg.2019.00103

Hicks, C. L., Von-Baeyer, C. L., Spafford, P. A., Korlaar, I. V., and Goodenough, B. (2001). The faces pain scale—revised: toward a common metric in pediatric pain measurement. *Pain,* 93, 173–183. https://doi.org/10.1016/S0304-3959(01)00314-1

Higgins, J., & Green, S. (2011). *Cochrane Handbook for Systematic Reviews of Interventions.* The Cochrane Collaboration.

Interdisciplinary Council on Development and Learning Disorders (ICDL). (2005). Diagnostic manual for infany and early childhood: Mental health, development, regulatory-sensory processing, language, and learning disorders – ICDL-DMIC. *Interdisciplinary Counctil on Developmental and Learning Disorders,* Bethesda, MD.

Iyer, P. R., Chavan, S. R., & Rege, S. (2020). Sensory processing and organisational abilities in children with inattentive-hyperactive behaviours. *International Journal of Therapy and Rehabilitation, 27*(1), 1-10.

Jorquera-Cabrera, S., Romero-Ayusso, D., Rodgriguez-Gil, G., & Trivino-Suaraez, J. M. (2017). Assessment of sensory processing characteristics in children between 3 and 11 years old: A systematic review. *Frontiers in Paediatrics, 30(5),* 57. https://doi.org/10.3389/fped.2017.00057

Koziol, L. F., & Budding, D. (2012). ADHD and sensory processing disorders: Placing the diagnostic issues in context. *Applied Neuropsychology: Child*, *1,* 137-144. https://doi.org/10.1080/21622965.2012.709422

Lai, C.Y.Y., Chung, J.C.C., Chan Chetwyn, C.H. & Li-Tsang, C.W.P. (2011). Sensory Processing Measure – HK Chinese version: Psychometric properties and patterns of response. *Research in Developmental Disabilities, 32(6),* 2626-2643.

Lane, S., Reynolds, S., & Thacker, L. (2010). Sensory over-responsivity and ADHD: differentiating using electrodermal responses, cortisol, and anxiety, *Frontiers in Integrative Neuroscience, 4,* 8. http://doi.org/10.3389/fnint.2010.00008

Lane, S. J., & Reynolds, S. (2019). Sensory over-responsivity as an added dimension in ADHD. *Frontiers in Integrative Neuroscience*, *13,* 40. https://doi.org/10.3389/fnint.2019.00040

Lin, C.-Y., Yang, A.-L., & Su, C.-T. (2013). Objective measurement of weekly physical activity and sensory modulation problems in children with attention deficit hyperactivity disorder, *Research in Developmental Disabilities, 34(10):*3477-86. https://doi.org/10.1016/j.ridd.2013.07.021

Little, L.M., Dean, E., Tomchek, S.D., & Dunn, W. (2017). Classifying sensory profiles of children in the general population. *Child: Care, Health, and Development, 43(1),* 81-88.

Little, L.M., Dean, E., Tomchek, S.D., & Dunn, W. (2018). Sensory processing patterns in autism, attention deficit hyperactivity disorder, and typical development. *Physical and Occupational Therapy in Paediatrics, 38(3),* 243-254.

Mangeot, S. D.; Miller, L. J.; McIntosh, D. N.; McGrath-Clarke, J.; Simon, J.; Hagerman, R. J.; Goldson, E. (2001). Sensory modulation dysfunction in children with attention-deficit-hyperactivity disorder, *Developmental Medicine and Child Neurology, 43(6):*399-406. https://doi.org/10.1111/j.1469-8749.2001.tb00228.x

May-Benson, T. A., de Mello Gentil, J. L., & Teasdale, A. (2020). Characteristics and prevalence of gravitational insecurity in children with sensory processing dysfunction. *Research in Developmental Disabilities, 101*. https://doi.org/10.1016/j.ridd.2020.103640

McIntosh, D., Miller, L., Shyu, V., & Hagerman, R. (1999a). Sensory-modulation disruption, electrodermal responses, and functional behaviors. *Developmental Medicine and Child Neurology, 41*(9), 608-15. https://doi.org/10.1017/S0012162299001267

McIntosh, D. N., Miller, L. J., Shyu, V., and Dunn, W. (1999b). "Overview of the short sensory profile (SSP)," in The Sensory Profile: Examiner's Manual, ed W. Dunn (Psychological Corporation), 59–73.

Miller L.J., Anzalone M.E., Lane S.J., Cermak S.A., Osten E.T. (2007) Concept evolution in sensory integration: a proposed nosology for diagnosis. *American Journal of Occupational Therapy 61 (2),* 135-140. https://doi.org/10.5014/ajot.61.2.135

Miller, L., Nielsen, D., & Schoen, S. (2012). Attention deficit hyperactivity disorder and sensory modulation disorder: A comparison of behavior and physiology, *Research in Developmental Disabilities 33(3)*:804-18. https://doi.org/10.1016/j.ridd.2011.12.005

Mimouni-Bloch, A., Offek, H., Rosenblum, S., Posener, I., Silman, Z., & Engel-Yeger, B. (2018). Association between sensory modulation and daily activity function of children with attention deficit/hyperactivity disorder and children with typical development. *Research in Developmental Disabilities, 83,* 69-76.

Moher, A. Liberati, J. Tetzlaff, D. G. Altman, & The PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA Statement, *PLOS Medicine, 6,* e1000097. http://dx.doi.org/10.1371/journal.pmed.1000097.

Niedźwiecka, A., Domasiewicz, Z., Kawa, R., Tomalski P. & Pisula, E. (2019) Sensory processing in toddlers with autism spectrum disorders, *European Journal of Developmental Psychology,* http://doi.org/0.1080/17405629.2019.1676715

Parham LD & Mailloux Z. (2001) *Sensory integration: Occupational Therapy for Children* (4th ed). Mosby.

Parham, L., Miller-Kuhaneck, H., Ecker, C., & Henry, D. (2007). *SPM Sensory Processing Measure*. Western Psychological Services.

Parush, S., Sohmer, H., Steinberg, A., & Kaitz, M. (2007). Somatosensory function in boys with ADHD and tactile defensiveness, *Physiology & Behaviour, 90(4)*:553-558. DOI: http://dx.doi.org/10.1016/j.physbeh.2006.11.004

Pfeiffer, B., Daly, B.P., Nicholls, E.G., & Gullo, D.F. (2015). Assessing sensory processing problems in children with and without attention deficit hyperactivity disorder. *Physical and Occupational Therapy in Paediatrics, 35(1),* 1-12.

Polanczyk, G., de Lima, M., Horta, B., Biederman, J., & Rohde, L. (2007). The worldwide prevalence of ADHD: A systematic review and metaregression analysis. *American Journal of Psychiatry, 164*(6), 942-948. http://doi.org/10.1176/appi.ajp.164.6.942

Reynolds, S. & Lane, S. (2009). Sensory overresponsivity and anxiety in children with ADHD. *American Journal of Occupational Therapy, 63(4),* 433-440.

Reynolds, S., Lane, S., & Gennings, C. (2010). The moderating role of sensory overresponsivity in HPA activity a pilot study with children diagnosed with ADHD, *Journal of Attention Disorders, 13(5):*468-478. http://dx.doi.org/10.1177/1087054708329906

Royeen C. (1987). TIP — Touch Inventory for Preschoolers: a pilot study. *Physical and Occupational Therapy in Paediatrics, 7,* 29–40.

Schaaf, R. C., Benevides, T. W., Leiby, B. E., & Sendecki, J. A. (2015). Autonomic dysregulation during sensory stimulation in children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 45*(2), 461-472. https://doi.org/10.1007/s10803-013-1924-6

Schoen, S., Miller, L., & Green, K. (2008). Pilot study of the Sensory Over-Responsivity Scales: assessment and inventory. *The American Journal of Occupational Therapy, 62*(4), 393-406. http://doi.org/10.5014/ajot.62.4.393

Schoen, S. A., Miller, L. J., & Sullivan, J. C. (2014). Measurement in sensory modulation: the sensory processing scale assessment. *American Journal of Occupational Therapy, 68*(5), 522-530.

Schupak, B. M., Parasher, R. K., & Zipp, G. P. (2016). Reliability of electrodermal activity: quantifying sensory processing in children with autism. *American Journal of Occupational Therapy, 70*(6), 1-6. https://doi.org/10.5014/ajot.2016.018291

Shimizu, V.T., Bueno, O.F., Miranda, M.C. (2014). Sensory processing abilities of children with ADHD. *Brazilian Journal of Physical Therapy, 18(4)* 343-52.

Soto, T. W., Ciaramitaro, V. M., & Carter, A. S. (2018). Sensory Over Responsivity. In Zeanah, C. H. (Ed.). *Handbook of infant mental health*. Guilford Publications.

Tavassoli, T., Miller, L. J., Schoen, S. A., Jo Brout, J., Sullivan, J., & Baron-Cohen, S. (2018). Sensory reactivity, empathizing and systemizing in autism spectrum conditions and sensory processing disorder. *Developmental Cognitive Neuroscience*, *29*, 72–77. https://doi.org/10.1016/J.DCN.2017.05.005

Thomas, R., Sanders, S., Doust, J., Beller, E., & Glasziou, P. (2015). Prevalence of attention-deficit/hyperactivity disorder: a systematic review and meta-analysis. *Pediatrics, 135*(4), e994-e1001.

Walco, G. A., Conte, P. M., Labay, L. E., Engel, R., & Zeltzer, L. K. (2005). Procedural distress in children with cancer: Self-report, behavioral observations, and physiological parameters. *The Clinical Journal of Pain, 21*(6), 484-490.

Yochman, A., Parush, S., & Ornoy, A. (2004). Responses of preschool children with and without ADHD to sensory events in daily life, *American Journal of Occupational Therapy, 58(3):*294-302. http://doi.org/10.5014/ajot.58.3.294

Yochman, A., Alon-Beery, O., Sribman, A., Parush, S. (2013). Differential diagnosis of sensory modulation disorder (SMD) and attention deficit hyperactivity disorder (ADHD): participation, sensation, and attention. *Frontiers in Human Neuroscience, 7(10).* https://doi.org/10.3389/fnhum.2013.00862

Zero to Three (2016). DC:0-5™ *Diagnostic Classification of mental health and developmental disorders of infancy and early childhood*. Author

Table 1: Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
1. Published in a peer-reviewed journal. 2. Written in English language. 3. Published between January 1980 and June 2020. 4. Sample: Children under the age of 18 who: a. Have a formal diagnosis of ADHD (through screening measure or clinical diagnosis) 5. Phenomenon of interest: Sensory modulation: a. Sensory modulation refers to the ability of the central nervous system to regulate neural messages about sensory stimuli. Sensory modulation can be measured through caregiver reports, behavioural or physiological methods. 6. Design: a. Quantitative study designs included. 7. Evaluation: a. Outcomes of the studies must be reporting, measuring, evaluating or comparing sensory modulation within this sample.	1. If not written in English language. 2. Published before January 1980. 3. Sample: Participants over the age of 18. 4. Phenomenon of interest: Sensory modulation: a. If the results of a sensory modulation measure are not included in the paper. 5. Design: a. Systematic reviews, literature reviews, and qualitative studies will not be included.

Table 2: Details of included studies.

First author	Sample	Recruitment and diagnosis	ADHD subtypes	Exclusion criteria/Presence of co-occurring disorders	Medication
Ben-Sasson et al. (2017)	922 children (aged 7-11)	Longitudinal birth cohort. Participants grouped into ADHD, SOR clusters based on scores on SOR and CBCL	Not considered.	Children excluded due to genetic disorders, developmental delays, low birth weight, prematurity.	Not considered.
Broring et al. (2008)	47 children with ADHD (mean age 9y 8m), 36 non-affected siblings (mean age 8y 10m), and 35 controls (mean age 9y 5m)	Recruited from the International Multicentre ADHD genes study (IMAGE). ADHD diagnosis supported by Conners Parent and Teacher ADHD rating scale, the Parent and Teacher Strengths and Difficulties Questionnaire and the Parental Account of Children's Symptoms.	All combined subtype.	Exclusion criteria were an IQ <70, diagnosis of autism, epilepsy, general learning difficulties (i.e. severe problems in multiple areas of academic learning), brain disorders, or known genetic disorders.	31 children with ADHD took stimulants, 3 took non-stimulants, and 2 took a combination of stimulants and non-stimulants. All children were off medication at least 48 hours before testing.
Cheung & Sui (2014)	1840 controls (aged 3-10), 72 children with ASD (aged 2.7-	Recruited from child and adolescent psychiatric units,	Not considered.	No information on co-occurring disorders.	Not mentioned.

	11.6), and 114 with ADHD (aged 4.8-12)	diagnosed based on DSM-IV criteria.			
Delgado-Lobete et al. (2020)	369 controls, 27 children with ADHD, 46 with DCD, and 10 co-occurring DCD and ADHD (all aged 6-12 years)	Participants categorised as ADHD group based on ADHD-RS-IV scores.	Not considered.	Children with other neurodevelopmental or learning disorders were excluded.	Not mentioned.
Dunn & Bennett (2002)	70 children with ADHD (aged 3-15) and 70 controls (aged 3-15)	Diagnosed at clinic based on DSM-IV criteria.	Not considered.	23 children with ADHD had ODD, 1 had PTSD, 1 had adjustment disorder, 10 had learning disorders	52 children with ADHD were on medication. For 10 children, medication information was unknown.
Engel-Yeger & Ziv-On (2011)	29 children with ADHD (aged 6-10) - 15 hyperactive/impulsive and 14 inattention, 29 controls (aged 6-10)	Diagnosed by neurologists according to DSM-IV criteria and supported by Conners Parent and Teacher Rating Scales. Recruited from clinic.	15 children were hyperactive-impulsive, 14 children were inattentive	Participants were not receiving any medical treatment which impacted their nervous system and did not suffer from any other chronic health condition or uncorrected sensory loss.	No child used medication.
Ermer & Dunn (1998)	671 controls (aged 3-15), 38 children with autism (aged 3-15), and 61 children with ADHD (aged 3-15)	Diagnosed at University of Kansas ADHD clinic.	Not considered.	No information on co-occurring disorders considered.	Not mentioned.
Ghanizadeh (2008)	81 children with ADHD (aged 6-14)	Referred from outpatient clinic.	Subtypes included as variable in analysis.	Children with a diagnosis of autism,	Children were off medication for at

		Underwent Schedule for Affective Disorders and Schizophrenia for School-Aged Children (based on DSM criteria)		epilepsy, brain disorders or known genetic disorders were not included.	least 4 weeks prior to testing.
Ghanizadeh (2009)	104 children with ADHD (aged 6-14)	Referred from Child and Adolescent Psychiatry Clinic. Underwent Schedule for Affective Disorders and Schizophrenia for School-Aged Children (based on DSM criteria)	N=27 inattentive, n= 11 hyperactive/impulsive, n=59 combined.	Children with neurological disorders, seizures, prematurity, history of meningitis, metabolic disorders, or a significant head trauma, and diagnosed hearing problem were not included.	No information provided.
Ghanizadeh (2013)	189 children with ADHD (aged 3.5-15 years)	Diagnosed based on DSM-IV criteria by psychiatrist.	Participants were scored on a hyperactive/impulsive scale and an inattention scale.	ODD and Anxiety symptoms were variables in the analysis. Children with neurological disorders, autism, epilepsy, Down Syndrome, or seizures were excluded.	No information provided.
Iyer et al. (2020)	20 children with inattentive-hyperactive	Categorised as inattentive-hyperactive based on	Inattentive-hyperactive symptoms treated as one group.	Children with a history of neurodevelopmental	Children on medication were excluded.

	symptoms and 56 typically developing children (aged 9-12 years)	Vanderbilt ADHD Diagnostic Parent Rating Scale and Teacher Rating Scale (based on DSM criteria)		diagnosis were excluded.	
Lane et al. (2010)	39 children with ADHD (aged 6-12), 46 controls (aged 6-12)	Underwent clinical evaluation with psychiatrist and/or record review. SensOR scores used to divide groups into ADHD only, typ only, ADHD+SOR and typ+SOR	Not considered.	Children with psychological diagnoses other than ADHD, significant motor impairments such as cerebral palsy, or any known endocrine or metabolic dysfunctions were excluded from this study.	No information provided on number of children taking medication. Parents were asked to withhold their child’s ADHD medication (if applicable) for 24 h before testing.
Lin et al. (2013)	20 children with ADHD (mean age 8.64), 20 controls (mean age 9.1)	Referred from local clinic and diagnosed by child psychiatrist. Confirmed by Conners' Parent Rating Scale and occupational therapist.	Not considered.	Children with fragile X syndrome, autism spectrum disorder, mental retardation, Tourette syndrome, Down syndrome, orthopedic conditions, and mental-disorder-related diseases were excluded.	Use of medication was part of criteria for exclusion from the study.
Little et al. (2017)	788 controls, 77 children with ASD,	Information on diagnosis provided by	Not considered.	Children with autism, learning disabilities,	Information not included.

	96 children with ADHD (all aged 3-14)	parents and verified for 69% of sample using record reviews.		intellectual disabilities, and developmental delay included as separate groups in analysis.	
Little et al. (2018)	77 children with ASD, 78 children with ADHD, 84 controls (all aged 3-14)	Information on diagnosis provided by parents and verified for 70% of sample using record reviews.	Not considered.	Children were excluded if they had a dual diagnosis of ADHD and ASD.	No information provided.
Mangeot et al. (2001)	26 children with ADHD, 30 controls (all aged 5-13)	Referred from local clinics, identified by DSM-IV criteria - confirmed by ACTeRs, and attention, activity level, and impulsivity subscales of Leiter International Performance Scale Revised (parent report).	Not considered.	Possibility of co-occurring disorders not considered systematically.	13 children with ADHD taking medication. Medications were discontinued 24-48 hours before testing.
May Benson et al. (2020)	532 children with SPD, 97 children with SPD+ADHD (aged 4-12 years)	SPD diagnosed by occupational therapist; ADHD diagnosis based on parent disclosing previous diagnosis.	Not considered.	Some children in SPD+ADHD group had an additional diagnosis of ASD, LD, or anxiety (exact number not disclosed).	No information provided.

Miller et al. (2012)	70 children with SMD, 37 children with ADHD, 12 children with ADHD and SMD, 57 controls	Referred from local clinics. Diagnosed by clinicians.	Three subtypes collapsed and analysed as one group due to small sample sizes.	Excluded if diagnosis of fragile X, autism, mental retardation, Tourette's, Down Syndrome, orthopaedic conditions, or psychiatric diagnosis.	8 children with SMD, 17 children with ADHD and 3 children with ADHD+SMD were taking medication. Medications discontinued evening before testing.
Mimouni-Bloch et al. (2018)	38 children with ADHD, 39 controls (all aged 8-11)	Diagnosis given by paediatric neurologist.	Not considered.	Children with autistic spectrum disorders, physical disabilities, or neurological diseases were excluded from the study.	No information provided.
Parush et al. (2007)	67 children with ADHD, 60 controls (all aged 5-11)	Diagnosis of ADHD if met 8 of 14 criteria on DSM-IV and received scores above standardised cut-off for Conner's Rating Scale. Sorted into ADHD+TD or ADHD only based on scores from TIP and sensory reactivity score.	Not considered.	Sample showed no apparent physical or neurological deficits on the standard assessment protocol (Touwen, 1979).	Children must be free of medication for 1 month prior to testing in order to be included.
Pfeiffer et al. (2015)	20 children with ADHD, 27 controls (all aged 5-10)	Diagnosed by a paediatrician/health professional.	Hyperactive/impulsive scale and inattentive scale scores used in	Children with PDD or ASD diagnosis were excluded from study.	12 children with ADHD were taking medication.

			analysis. Children were not grouped based on subtypes.		
Reynolds et al. (2010)	24 children with ADHD, 24 controls (all aged 6-10)	Diagnosis by psychologist or psychiatrist confirmed by parent. Recruitment of children with ADHD was done under the guidance of a licensed child psychiatrist.	Not considered.	Children with psychological diagnoses in addition to or other than ADHD, significant motor impairments such as cerebral palsy, or any known endocrine or metabolic dysfunctions were excluded from this study.	20 of the 24 children in the ADHDs (n=10) and ADHDt (n=10) groups were currently taking daily medication. Parents were asked to withhold their child's ADHD mediation for 24 hr prior to their scheduled laboratory visit.
Shimizu et al. (2014)	37 children with ADHD, 37 controls (all aged 6-11)	Recruited from outpatient clinic, diagnosis confirmed by psychiatric, neurological, and neurophysiological evaluation.	N=8 inattentive, n=7 hyperactive, n=22 combined	N=32 children with ADHD had co-occuring indicators based on CBCL (n=13 affective disorder, n=13 anxiety disorder, n=5 somatic disorder, n=21 ODD, n=22 CD)	Children with ADHD taking medication were excluded from study.
Yochman et al. (2004)	48 children with ADHD, 46 controls (all aged 4-6)	Diagnosed by neuropaediatrician, confirmed by a score of >1.5 SDs above the mean on	Not considered.	Children with any other developmental, physical, sensory, or neurological disorder.	No information provided.

		hyperactive and/or aggressive factors on both teacher and parent Preschool Behaviour Questionnaire			
Yochman et al. (2013)	19 children with ADHD only, 19 children with SMD only (aged 6–9)	ADHD: underwent interview by developmental neurologist, diagnosed according to DSM-IV criteria. SMD: evaluated by occupational therapist.	Not controlled for/considered.	Excluded children with additional physical and/or neurological deficits e.g. cerebral palsy, ASD	Not mentioned whether children taking medication.

Note: SOR= sensory overresponsivity, ACTerS= ADD-H Comprehensive Teachers Rating Scale, PDD= Pervasive Developmental Disorder, ASD= Autism Spectrum Disorder, CBCL= Child Behaviour Checklist.

Table 3: Main results of included studies.

Study	Type of measure	Name of measure	Main result
Ben-Sasson et al. (2017)	Parent report	SensOR	Cluster analysis revealed an ADHD only cluster (n=38), an SOR only cluster (n=35), an ADHD+SOR cluster (n=35). 48% of those with elevated ADHD symptoms had elevated SOR and 50% of those with SOR had ADHD symptoms. The ADHD+SOR cluster could be differentiated from those with SOR only by their lower tactile scores. Both the SOR and ADHD+SOR groups showed high scores for auditory domain.
Broring et al. (2008)	Self-report	Tactile Inventory for Elementary School-Aged Children	Females with ADHD scored higher on TD than males with ADHD ($p<0.002$) and female controls ($p<0.001$). Males with ADHD did not differ from control males ($p<0.91$).

			Overall, children with ADHD had higher TD than control children. 17% of females with ADHD had extreme scores on TIE, only 3% of males with ADHD.
Cheung & Siu (2014)	Parent report	Sensory Profile (Chinese version)	Sensory processing scores (of all 8 subscales on CSP) were significantly higher (i.e. better) for controls than ADHD group. Children with ADHD had lower scores (i.e. higher frequency in behaviour) than controls on 118 of 124 items on CSP. When looking at age, children with ADHD showed a significant increase in auditory processing issues and some increases on all subscales bar movement. Suggests that children with ADHD will likely experience a significant processing issue over childhood.
Delgado-Lobete et al. (2020)	Parent report	Short Sensory Profile-2 (Spanish version)	Children with ADHD showed higher scores (more atypical patterns) for all four sensory quadrants (according to Dunn's model) and sensory patterns than typically developing children.
Dunn & Bennett (2002)	Parent report	Sensory Profile	Statistically significant differences ($p<0.05$) on 118 of 125 items on SP - lower scores (i.e. higher frequency of issues).
Engel-Yeger & Ziv-On (2011)	Parent report	Short Sensory Profile	Differences in sensory processing performance were manifested among children with both ADHD subtypes relative to controls in most SSP scales - tactile, movement, under-responsive/seeking sensation, auditory filtering, low energy/weak - with values under typical performance range.
Ermer & Dunn (1998)	Parent report	Sensory Profile	Children with ADHD were best discriminated by high incidences of behaviours in Factor 1 (sensory seeking) and Factor 5 (inattention/distractability) and low incidences of behaviours in Factor 4 (oral sensitivity) and Factor 9 (fine motor/perceptual). The incidence or frequency of sensory seeking behaviours may be markedly higher in children with ADHD.

Ghanizadeh (2008)	Parent report	Tactile Dysfunction Checklist	ADHD subtypes were not found to be associated with hypersensitivity or hyposensitivity scale scores. No differences found in terms of gender.
Ghanizadeh (2009)	Parent report	Auditory Dysfunction Checklist	HES (hypersensitivity) and HOS (hyposensitivity) was not different between ADHD subtypes. ADHD subtype does not appear to be a predictor of auditory dysfunction. No gender differences were found.
Ghanizadeh (2013)	Parent report	Oral Over- and Underresponsivity Behaviours Inventory	ADHD severity did not predict oral overresponsivity. Impulsivity/hyperactivity score did not predict oral underresponsivity, but inattention score did.
Iyer et al. (2020)	Parent report	Sensory Profile	Inattentive-hyperactive group showed significantly lower scores for sensory seeking quadrant only, compared to typically developing group.
Lane et al. (2010)	Parent report and physiological measure	SensOR, Sensory Challenge Protocol	ADHD only group differed from ADHD+SOR group on all domains of SensOR (tactile, auditory, taste, smell, visual, movement). Children with ADHD+SOR differed from typical controls in their ability to recover from the sensory challenge - showed high arousal levels during recovery. While group differences were not significantly different, ADHD+SOR had higher cortisol levels than other groups at measurement points other than baseline.
Lin et al. (2013)	Parent report and physiological measure	Sensory Profile, Sensory Challenge Protocol	Z-scores on the Sensory Profile were significantly lower (more problems) for the ADHD group on all but three subtests (sensory sensitivity, tactile defensiveness, and oral sensory sensitvity). No signficant differences in EDR mean magnitude between the two groups.
Little et al. (2017)	Parent report	Sensory Profile 2	Divided participants into 5 sensory subtypes - Balanced (53% of ADHD) low frequency of sensory behaviours, Interested (13.5%) increased sensory seeking, Intense (10.4%) may be averse to many experiences but also difficulty registering, Mellow until… (10.4%) increased

			scores in avoidance and registration, Vigilant (12.5%) increased sensitivity and avoidance.
Little et al. (2018)	Parent report	Sensory Profile 2	ADHD group were significantly different on all sensory systems than control group (p<0.001) - with ADHD group showing higher scores (i.e. greater difference).
Mangeot et al. (2001)	Parent report and physiological measure	Short Sensory Profile, Sensory Challenge Protocol	ADHD group showed significantly lower scores on 6 of 7 subscales (bar movement sensitivity) on Short SP. There was a trend for a significant difference by group in EDR, with ADHD group showing greater reactivity for sensory stimuli (p<0.056).
May Benson et al. (2020)	Parent report	The Koomar Center Developmental/Sensory History	Children with SPD only and children with SPD+ADHD did not significantly differ in terms of their gravitational insecurity scores.
Miller et al. (2012)	Parent report and physiological measure	Short Sensory Profile, Sensory Challenge Protocol	Children with a Dual Referral had significantly poorer raw scores compared to ADHD children (p < 0.01) and SMD children (p < 0.02) on the Seeks Sensation subtest. Children with a Dual Referral also had significantly poorer raw scores than ADHD children on Tactile, Visual/Auditory, Low Energy/Weak, and Movement subtests (at least p < 0.05). ADHD+SOR group excluded from analysis of EDR as only n=6 completed SCP. EDR magnitudes greater for SMD children than ADHD children to auditory, visual, and movement stimuli. No differences in EDR magnitude between ADHD and typ. dev. children in any domain.
Mimouni-Bloch et al. (2018)	Parent report	Short Sensory Profile	SSP total score was signficiantly lower than controls (and true for all subtests). The largest effect sizes were observed in auditory filtering and seeks sensation. In the ADHD group, 65.8% of children had atypical SSP performance range, only 2.6% of controls did.

Parush et al. (2007)	Parent report, behavioural, and physiological measure	Touch Inventory for Preschoolers, Sensory reactivity score, Somatosensory Evoked Potential	ADHD group divided into 2 subgroups: TD+ (n=46) and TD- (n=21) based on TIP and Sensory Reactivity scores. 69% of ADHD group met TD criteria based on TIP score. ADHD+TD+ group distinguishable from ADHD+TD- group and control group by larger central SEP amplitudes (N13, N20, P23).
Pfeiffer et al. (2015)	Parent report	Sensory Processing Measure	For each subscale of SPM, children with ADHD had a higher mean score (i.e. more problems) than controls. Subscales are social, visual, hearing, touch, body, balance, and planning. 64% of ADHD group scored in range of "some problems" or "definite dysfunction", compared to less than 5% of controls who scored in range of "some problems". 0 controls scored in range of "definite dysfunction".
Reynolds et al. (2010)	Parent report and physiological measure	SensOR, Sensory Challenge Protocol	13 of ADHD group had SensOR score 2 SDs above mean for at least 1 subscale. 62% of children in ADHDs group had tactile OR and 54% had auditory OR. There was a borderline significant difference between ADHDs and ADHDt groups on SCP (p=0.056), and a significant difference between ADHDt (blunted) and typical groups (p=0.014). No significant difference between ADHDs and typical group (p=0.934). Effect sizes also generally small between ADHDs and typical group.
Shimizu et al. (2014)	Parent report	Sensory Profile	Significant differences found between ADHD and control groups on 11 of 14 SP sections (bar oral processing, modulation of movement affecting activity level, and modulation of visual input affecting emotion/activity level). Also significant differences between groups on 7 of 9 SP factors (bar oral sensitivity and sensory sensitivity). No significant differences found between ADHD subtypes on

			sections or factors expect multisensory - combined scored lower than hyperactive or inattentive.
Yochman et al. (2004)	Parent report	Sensory Profile	ADHD group had significantly lower scores on 6 of 9 factors (not low endurance-tone, poor registration, and sensory sensitivity) and 11 of 14 sections (not vestibular processing, endurance-tone, or emotional responses). Between 6.5-15% of controls had deficits on various factors and 4-11% for sections. In contrast, 12.5-65% of ADHD group had deficits on factors and 8-65% for sections.
Yochman et al. (2013)	Parent report and behavioural measure	Sensory Challenge Protocol, Evaluation of Sensory Processing Questionnaire, Fabric Prickliness Test, von Frey Monofilament Test (Pin prick)	Significant differences were found between the groups on the overall Von-Frey filament test score ($Z = -2.24$; $p = 0.026$). The children with SMD reported higher scores as a response to punctate pain (median = 60) compared to children with ADHD (median = 30). Significant differences were found between the groups in the level of pain elicited by the application of the fabrics ($Z = -2.367$; $p = 0.018$), such that children with SMD reported higher scores (median = 16) compared to children with ADHD (median = 4). In addition, significant group differences were found in the measures of pain "after-sensation" ($Z = -2.803$; $p = 0.005$). After the application of the last fabric of the FPT, the after-pain sensation in children with SMD lingered longer (median = 2 min, 15 s) than the children with ADHD (median = 15 s). The results indicate that the scores for the SMD group were significantly lower than the scores of the ADHD group in three of the six subtests (i.e., taste and smell, tactile and motion /vestibular) on ESP.

Notes: SOR= sensory overresponsivity, TD= tactile defensiveness, EDR= electrodermal response.

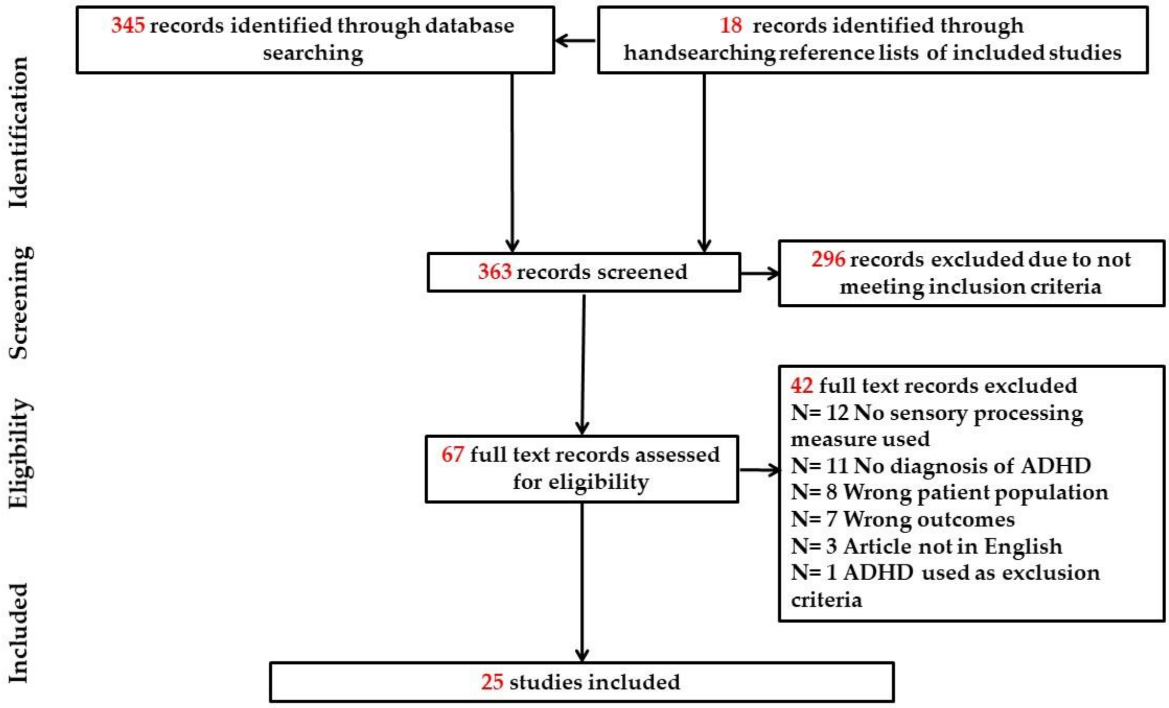

Figure 1: PRISMA flow diagram of study selection.

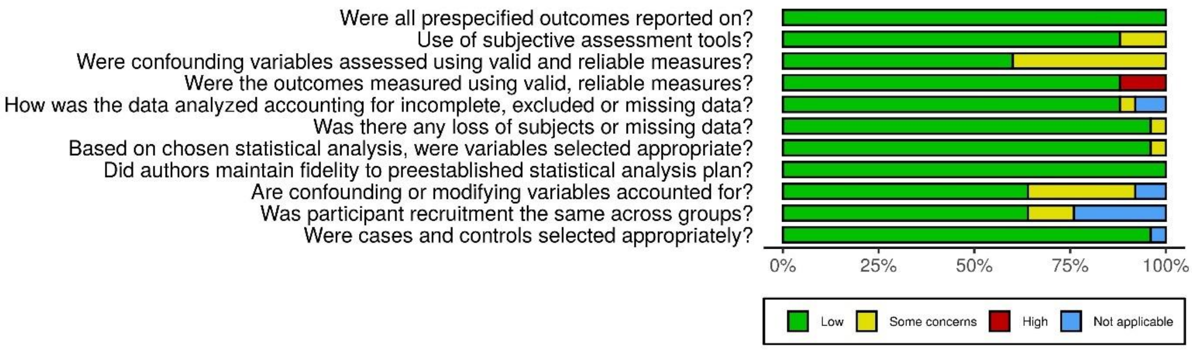

Figure 2: Risk of bias summary.