The original description of what would currently be considered sensory symptoms dates back to Leo Kanner (1943). Kanner observed various atypical reactions to sensory stimuli in 7 of his 11 original cases: for example, fascination with various sensory stimuli such as light reflecting from various surfaces, increased sensitivity and extreme distress due to various sounds, moving objects or covering one’s face. Although Kanner himself (Kanner, 1943) rejected the sensory hypothesis of autism (Rogers & Ozonoff, 2005), several pioneers in autism research did consider the possibility that sensory problems are behind some of the core autism features (Bergman & Escalona, 1949; Hut, Hutt, Lee & Ounsted, 1964; Ornitz, 1974; Ornitz, Guthrie, & Farley, 1977; Zentall & Zentall, 1983; Lovaas, Newsom, & Hickman, 1987). Kanner’s early descriptions were corroborated by subsequent clinical observations, autobiographical accounts and research studies. For example, in one of the earliest studies that systematically looked at the sensory processing in children with autism, Lorna Wing (1969) found responses of children with autism to sound, visual, tactile and olfactory stimuli to be markedly different from reactions of typically developing children, children with Down’s syndrome, receptive and expressive aphasia. Wing noted that responses of children with autism to different sensory stimuli resembled those of deaf-blind children.

Strong, unpleasant reactions to sounds, visual and tactile stimulation and other sensory abnormalities are a prominent and recurring theme running throughout autobiographical accounts of individuals with autism as described here (Williams, 1994; O’Neil, 1999; Grandin, 1992; Jones, Quigney, & Huws, 2003).

“The sharp sounds and bright lights were more than enough to overload my senses. My head would feel tight, my stomach would churn and my pulse would run my heart ragged until I found a safety zone.” (Willey)

“I was also very touch sensitive; scratchy petticoats felt like sandpaper ripping off my skin. There is no way a child is going to function in a classroom if his or her underwear feels like it is full of sandpaper.” (Temple Grandin)
“The sensory overload caused by bright lights, fluorescent lights, colours and patterns makes the body feel like being attacked or bombarded.” (Williams)

It is obvious that these problems present significant obstacles in the lives of people with autism. Despite this, sensory issues are currently not part of the diagnostic criteria for ASD (APA, 2000; WHO, 1944) but they are included in the latest version of the DSM-V criteria (5th ed.; DSM-V; APA, 2013). The inclusion of sensory problems in the latest diagnostic criteria is not at all surprising. As pointed out by Wing, Gould and Gillberg (2011) enough evidence has been accumulated over the years to support such change. Firstly, the majority of studies have demonstrated that more than 90% of autistic individuals exhibit various sensory problems (Rogers & Ozonoff, 2005; Leekam, Nieto, Libby, Wing, & Gould, 2007; Ben-Sasson, Hen, Fluss, Cermak, Engel-Yeger, & Gal, 2009). Secondly, several studies have found that atypical reactions to sensory stimulation in children as young as 12 months predicted later diagnosis of autism (Osterling & Dawson, 1994; Baranek et al., 1999). For example, Baranek and colleagues (Baranek et al., 1999) found that decreased orienting to visual stimuli, increased mouthing of objects and aversion to touch distinguished 9-12 months infants who were later diagnosed with autism from the ones who did not receive diagnosis. Finally, sensory problems have been found to be stable across the life-span of individuals with autism. In a follow-up study with 105 individuals with autism and adults who were diagnosed as children, Billstedt, Gillberg, & Gillberg (2007) found that all individuals showed sensory problems during the original diagnostic assessment and more importantly, that 93% of those individuals continued to have impairing sensory abnormalities as adults. Billstedt and colleagues used the Diagnostic Interview for Social and Communication disorders (DISCO) that provides detailed information on sensory problems during both assessments.

Despite the significant progress in understanding of sensory problems in autism it is still not clear which sensory problems are specific to autism, how sensory problems are associated with the core autism symptomatology and how sensory problems change with age. Here we will review the literature relevant to these topics. Before this, it is important to highlight that the term atypical sensory processing has been used in inconsistent ways throughout the literature. Some authors referred to what is defined as Sensory Discrimination Disorder by the Interdisciplinary Council on Developmental and Learning Disorders (ICDL; 2005; see also Miller, Anzalone, Lane, Cermak, & Osten, 2007), in other words, to the difficulties in interpreting qualities of sensory stimuli and/or inability to perceive similarities.
and differences among stimuli. Other authors have used the term atypical sensory processing to denote the difficulties in responding to sensory input with behaviour that is graded relative to the nature and intensity of the sensory stimuli. These difficulties are termed as Sensory Modulation Disorders (ICDL, 2005) and throughout this document, the term atypical sensory processing will refer to the Sensory Modulation Disorder. However, for the sake of comprehensiveness, a short overview of Sensory Discrimination Disorder will be provided before moving to the issues of prevalence, specificity and phenomenology of Sensory Modulation Disorders in autism.

Sensory Discrimination Disorder

Atypical sensory discrimination is well documented across all modalities in autism. Behavioural and electrophysiological studies showed both enhanced and impaired performance in different areas of visual processing. Higher levels of visual acuity in autism group when compared to typically developing (TD) participants were found by Ashwin, Ashwin, Rhydderch, Howels, & Baron-Cohen (2009). However, several other studies failed to replicate these findings (Bolte et al., 2012; Tavassoli, Latham, Bach, Dakin, & Baron-Cohen, 2011). Results regarding colour discrimination, biological motion perception and visual search seem to be more consistent with several studies reporting impaired colour discrimination in individuals with autism (Franklin, Sowden, Burley, Notman, & Adler, 2008; Heaton, Ludlow, & Roberson, 2008), intact biological motion perception apart from processing emotional expressions (Atkinson, 2009; Murphy, Brady, Fitzgerald, & Troje, 2009; Kaiser, Demolino, Tanaka, & Shiffrar, 2010; Koldewyn, Whitney, & Rivera, 2010) and superior visual search performance (O’Riordan, Plaisted, Driver, & Baron-Cohen, 2001; Jarrold, Gilchrist, & Bender, 2005).

Atypical responses to auditory stimuli are frequently reported in questionnaire studies (Kientz & Dunn, 1997; Talay-Ongan & Wood, 1999; Dunn, Myles, & Orr, 2002; Rogers, Hepburn, & Wehner, 2003; Tomchek & Dunn, 2007, Baker, Lane, Angley, & Young, 2008; Wiggins, Robins, Bakeman, & Adamson, 2009; Hilton, Harper, Kueker, Lang, Abbacchi, Todorov, & LaVesser, 2010, Klintwall et al., 2010). Behavioural studies have consistently found increased pitch perception for both simple and complex tones as well as speech sounds (Bonnel, Mottron, Peretz, Trudel, & Gallun, 2003; Gomot, Belmonte, Bullmore, Bernard, & Baron-Cohen, 2008; Jones et al., 2009). Results regarding intensity discrimination seem less consistent with some studies finding evidence for hyperacusis (Khalfa et al., 2004) and
others finding no differences in intensity discrimination between autism and TD groups (Jones et al., 2009). Lastly, evidence suggest that Individuals with autism are better at local processing of sounds (Mottron, Peretz, & Menard, 2000; Jarvinen-Pasley & Heaton, 2007).

Several experimental studies have shown that individuals with autism have higher thresholds for higher (but not lower) frequency and different placement of tactile stimuli (Blakemore, Tavassoli, Calo, Thomas, Catmur, Frith, & Haggard, 2006; Cascio et al., 2008) as well as lower pain thresholds for thermal tactile stimuli (Cascio McGlone, Folger, Tannan, Baranek, Pelphrey, & Essick, 2008).

Systematic research on the olfactory and taste processing in autism has started only recently. Conflicting results have been found regarding the olfactory detection thresholds with Tavassoli and Baron-Cohen (2012a) finding no differences between autism and TD controls and Dudova, Vodicka, Havlovicova, Sedlacek, Urbanek, and Hrdlicka (2011), reporting impaired olfactory detection thresholds in group with autism. Both Tavassoli and Baron-Cohen (2012a) and Dudova et al. (2011) used the standardized Sniffin’Sticks olfaction task. Mixed results have also been found regarding the odour identification (Suzuki, Critchely, Rowe, Howlin, Murphy, 2003; Dudova et al., 2011; May, Brewer, Rinehart, Enticott, Brereton, & Tonge, 2011). Only two studies have examined taste identification in autism finding that Individuals with autism were impaired at taste identification (Bennetto, Kuschner, & Hyman, 2007; Tavassoli & Baron-Cohen 2012b). Sensitivity to and fascination with smells have been constantly reported in questionnaire studies (Kientz & Dunn, 1997; Dunn et al., 2002; Rogers et al., 2003; Leekam et al., 2007; Tomchek & Dunn, 2007; Schoen, Miller, Brett-Green, & Nielsen, 2009; Wiggins et al., 2009; Hilton et al., 2010; Kintwall et al., 2010).

Sensory Modulation Problems in autism

Sensory modulation disorder (SMD) is defined as the failure to behaviourally respond in a way that is appropriate to the intensity and nature of sensory stimulation. Dunn (1997) proposed four SMD subtypes patterns:

a. sensory hyper-sensitivity-characterized by distress to innocuous stimuli and passive withdrawal from unpleasant situations;

b. sensation avoidingAlso characterized by distress but also active avoidance;

c. low registration (or sensory hypo-responsiveness)-characterized by either complete lack of or delayed response to a stimulus or a higher response threshold (e.g., only responding to a stimuli when it becomes more intense);
d. sensation seeking-behaviours that either perpetuate or intensify a sensory experience.

A very similar classification of SMD has been proposed by the Interdisciplinary Council on Developmental and Learning Disorders (ICDL Work Groups, 2005). ICDL proposed that SMD can be classified into: (a) Sensory Over-responsivity; (b) Sensory Under-responsivity; and (c) Sensory Seeking. As can be seen, the only difference between the two classification systems is that whereas Dunn’s model distinguishes between sensory sensitivity and avoidance as two separate (though related) expressions of sensory over-responsiveness (SOR), ICDL classification considers SOR unitary construct.

1.3.3. Prevalence of Sensory Modulation Disorders in Autism

Over 20 questionnaire studies have compared sensory responses of individuals with autism to both typically developed individuals and individuals with various disorders. In general, studies have consistently shown that Individuals with autism have more SMD problems when compared to TD individuals. Most of the studies used the Sensory Profile questionnaire. The Sensory Profile (SP; Dunn, 1999) is a 125 item, norm-referenced, parent-report questionnaire which measures a child’s/young person’s responses to everyday sensory experiences. Parent rate frequency of each items on a 5-point Likert scale ranging from always to never. SP assesses sensory processing across different modalities and can be also used to obtain four SMD patterns (or sensory quadrants in Dunn’s terminology). In one of the earliest questionnaire studies, Kientz and Dunn (1997) used an original version of the Sensory Profile to examine sensory processing in 38 children with autism, aged 3-13 years and 64 TD children aged 3-10 years. It was found that 85% of the Sensory Profile items differentiated children with autism from TD children. Children with autism had significantly lower scores (indicating poorer performance) across all six modalities and on both sensory hyper- and hypo-sensitivity. Consequent studies that used the Sensory Profile largely replicated results found by Kientz & Dunn in individuals with autism across all ages (Watling, Deitz, & White, 2001; Dunn et al., 2002; Smith Myles et al., 2004; Kern et al., 2007; Ben-Sasson, Cermak, Orsmond, Carter, Kadlec, & Dunn, 2007; Tomchek & Dunn, 2007; Crane, Goddard, & Pring, 2009; Hilton et al., 2010). For example, Crane et al. (2009) found that a group of 18 adults with autism (age range: 18-65 years) had poorer performance in terms of overall Sensory Profile scores as well as on the hypo-sensitivity, sensory sensitivity and sensation avoidance quadrants, but not on the sensation seeking quadrant when compared to 18 age and IQ matched TD controls. In one of the rare studies that
compared sensory responses of autism and TD toddlers, Ben-Sasson et al. (2007) found that autism toddlers (age range: 13-33 months) could be distinguished from both CA and MA matched TD controls in their higher frequency of sensory under-responsiveness and avoidance, and lower frequency of sensory seeking behaviours. Differences between autism and TD individuals in sensory processing found using Sensory Profile were largely replicated in studies that used other questionnaires/interviews, most notably Diagnostic Interview for Social and Communication Disorders (DISCO; Wing et al., 2002), Sensory Sensitivity Questionnaire (Talay-Ongan & Wood, 2000) and Sensory Experiences Questionnaire (Baranek, David, Poe, Stone, & Watson, 2006). For example, Leekam et al. (2007), using the sensory items from DISCO, found that over 90% of children with autism had sensory abnormalities in at least one sensory domain.

Relatively few studies have compared the sensory processing of individuals with autism with other non-typical populations. In a study that compared children with autism and children with Attention Deficit Hyperactivity Disorder (ADHD), Ermer and Dunn (1998) found that children with ADHD had higher incidence of sensory seeking and inattention/distractibility than children with autism. The children with autism had more hyper-sensitive reactions across different modalities and also scored higher on the fine motor/perceptual difficulties factor that is indicative of hypo-sensitivity than the children with ADHD. Rogers et al. (2003) used the Short Sensory Profile to compare young children with autism to children with Fragile X syndrome, other developmental delays (DD), and typical development (TD). They found that while children with autism had more sensory symptoms (especially increased sensitivity to tactile and taste/smell stimuli) compared to both DD and TD groups, they were not significantly different when compared to the children with Fragile X syndrome. Several other studies compared sensory processing of Individuals with autism and DD individuals and in general, individuals with autism were found to have more sensory problems than DD individuals (Baranek, David, Poe, Stone, & Watson, 2006; Leekam et al., 2007; Wiggins et al., 2009; Watson, Patten, Baranek, Poe, Boyd, Freuler, & Lorenzi, 2011). A very important question when comparing sensory problems in autism with both TD and various clinical groups is whether there is a particular type of sensory problems that is specific to the group with autism. The discussion below will consider findings regarding the specificity of sensory hyper-, hypo-sensitivity and sensory seeking separately.
Sensory hyper-sensitivity (ie more sensitive than usual)

The evidence regarding the specificity of sensory hyper-sensitivity in individuals with autism has been somewhat inconsistent but in general, results seem to suggest that hyper-sensitivity is not specific to the population of people with autism. Several studies reported a higher frequency of sensory hyper-sensitivity in children with autism when compared to TD children matched (Baranek et al., 2006; Dunn, Smith-Myles, & Orr, 2002), however, other studies failed to find evidence that sensory hyper-sensitivity distinguished children with autism from either TD children (Ermer & Dunn, 1998; Watling et al., 2001), from children with various developmental delays (Baranek et al., 2006) or individuals with ADHD (Ermer & Dunn, 1998). For example, using the Sensory Experiences Questionnaire, Baranek et al. found that although 56% of children with autism aged 5-80 months showed extreme sensory hyper-sensitive behaviours, these behaviours did not distinguish them from chronological-age (CA) matched DD children. It has been suggested by several authors (e.g. Rogers & Ozonoff, 2005) that sensory hyper-sensitivity is a consequence of lower developmental level rather than specific to autism. However, it is important to point out that hyper-sensitivity is found widely outside of learning disability populations, for example in individuals with anxiety (Hofmann & Bitran, 2007; Farrow & Coulthard, 2012), Schizophrenia (Brown, Cromwell, Filion, Dunn, & Tollefson, 2002) and as pointed out above, ADHD (Ermer & Dunn, 1998).

Sensory hypo-sensitivity (i.e. less sensitive than usual)

Sensory hypo-sensitivity has been suggested to be distinctive of children with autism (Baranek et al., 2006; Rogers & Ozonoff, 2005). Findings from several studies that showed that individuals with autism exhibit a significantly higher frequency of hypo-sensitivity behaviours when compared to both TD individuals matched on CA (Baranek et al., 2006; Dunn et al., 2002; Watling et al., 2001) and either TD or other clinical groups matched on mental age (MA) (Baranek et al., 2006) seem to lend support to the claim that sensory hypo-sensitivity is specific to autism. For example, Baranek, et al., (2006) found that 63% of children with autism showed sensory hypo-sensitivity and that a pattern that differentiated autism from both TD and DD groups was hypo-sensitivity to both social and non-social stimuli. However, several studies failed to find a support for hypo-sensitivity as distinguishing factor between individuals with autism and age-matched TD children, children with ADHD or children with Fragile X syndrome (Ermer & Dunn, 1998; Rogers et al., 2003).
Furthermore, sensory hypo-sensitivity has been also found in clinical disorders without the co-morbid learning disability, for example in Schizophrenia (Brown et al., 2002)

**Sensory Seeking**

Results regarding sensory seeking behaviours seem to be the least consistent. While two studies failed to find the difference in sensory seeking behaviours between autism and TD groups, in both toddlers (Dunn, 2002) and adults (Crane et al., 2009), other studies found increased frequency of sensory seeking in children with autism aged 3-6 years (Watling et al., 2001) and in individuals with autism aged 3-43 years (Kern et al., 2006). All these studies used the Sensory Profile. Studies that compared groups with autism with other clinical groups also reported inconsistent results. For example, Ermer & Dunn (1998) found that the group with autism showed significantly lower frequency of sensory seeking behaviours than children with ADHD. On the other hand, a study by Watson et al. (2011) found that toddlers with autism showed significantly more sensation seeking behaviours than chronologically age-matched DD children.

As can be seen from the brief review of the literature, it is difficult to draw conclusions regarding the question of which, if any, type of sensory problems differentiates individuals with autism from both general population and other clinical groups. Hyper-responsiveness does not seem to be specific to autism as it can be seen in various other disorders and as suggested by Rogers and Ozonoff (2005) it may well be a consequence of lower developmental level rather than any specific pathology. However, as pointed out, sensory hyper-sensitivity can be found in several disorders that are not characterized by low developmental level, for example anxiety. It also seems that hypo-responsiveness might be more prevalent in group with autism although as reviewed above results are inconsistent. It is not possible to draw any conclusion regarding the specificity of sensory seeking behaviours in autism.

At this point it is important to highlight the fact that although studies were very consistent in terms of the measure used, with most studies using either the full or abbreviated Sensory Profile, there was wide variability between the studies in terms of the characteristics of the group with autism. In some studies the group with autism was limited to older, higher functioning individuals and other studies included individuals with a wide age range and abilities. This, together with the fact that in some cases the group with autism were matched with control groups on chronological age and in others on developmental age, necessarily limits generalizability of the findings. Indeed, it has been suggested that sensory problems
can change over time (Rogers & Ozonoff, 2005; Ben-Sasson et al., 2009) and when considering sensory problems, it is necessary to take into account chronological age and developmental level. In the following section we will provide a brief review of the literature examining association between sensory problems and chronological and developmental age as well as small body of literature that looked at the relationship between core autism features and sensory problems.

The relationship between sensory modulation problems, chronological age and developmental level

Results of studies that examined the occurrence of sensory problems across development have been very inconsistent. A cross-sectional study by Kern et al. (2006) reported that in their group with autism (age range 3-56 years), at later ages sensory problems were less frequent and that individuals with autism became more similar to TD controls in the way that they respond to sensory stimuli. The only exception was tactile hyper-sensitivity that did not improve over time. However, other studies did not find evidence for the improvement in sensory problems over time (Talay-Organ & Wood, 2000; Leekam et al., 2007). Using the Sensory Sensitivity Questionnaire with a group of 30 children with autism aged between 4 and 14 years, Talay-Organ and Wood (2000) found that sensory problems were more common in a subgroup of 10 to 14 year olds than in a subgroup of 6 to 9 year olds who in turn had more problems than 4 to 5 year olds. Leekam et al. (2007) found the evidence that, with the exception of visual symptoms, other sensory problems persisted over time supporting numerous autobiographical accounts which pointed out that sensory problems were an on-going problem regardless of the age of an individual (Jones et al., 2003). Results from a relatively recent meta-analysis by Ben-Sasson et al. (2009) which summarized results from 14 studies suggest a non-linear course of sensory problems in autism with an increase in total sensory problems, sensory hyper-sensitivity and sensory seeking up to ages 6-9 and a decreased after the age of 9. Meta-analysis failed to find evidence for a consistent course of sensory hypo-sensitive behaviours.

Although in the typical population, developmental age parallels chronological age, this is not necessarily the case in autism, and differences in the developmental level might have contributed to the mixed findings regarding the relationship between chronological age and sensory problems. However, the results regarding the influence of cognitive level on the expression of sensory problems have been also very inconsistent. Rogers et al. (2003) failed to find an association between developmental level and any of the Sensory Profile scores.
Similar findings were reported by several other studies (Kientz & Dunn, 1997; Baranek et al., 2006; Leekam et al., 2007; Baker et al., 2008; Lane et al., 2010). On the other hand, Crane et al. (2009) found that IQ level was negatively associated with three of four sensory profile quadrants-sensory hypo- and hyper-sensitivity and avoidance but not with sensory seeking behaviours.

**Sensory Problems and Core Autism Symptoms**

The majority of research on sensory patterns among individuals with autism has focused on between-group comparisons of sensory symptom severity in individuals with autism with those with typical development or other developmental disabilities (DD). Relatively few studies have examined the relationship between sensory problems and core autism symptoms. Several studies have reported associations between overall autism severity and the presence of more sensory problems (Adamson, O’Hare, & Graham, 2006; Kern et al., 2006; Ben-Sasson, Cermak, Ormond, Tager-Flusberg, Carter, & Kadlec, 2008). For example, using the CARS (Schopler et al. 1994) as a measure of autism severity, Kern et al. (2006) found that overall sensory processing disturbances as measured by the Sensory Profile correlated with autism severity in children with autism. It is interesting to note that Kern and colleagues did not find correlations between sensory problems and autism severity in adolescents and adults.

However, from looking at the overall autism severity, it is difficult to interpret the relative contribution of individual core symptoms to the significant correlations found in the previously mentioned studies. In this section we will focus on studies that have examined the relationship between sensory problems and other two core autism features. Only four studies have examined the association between social/communicative deficits and sensory problems (Liss et al., 2006; Hilton, Graver, & LaVesser, 2007; Hilton et al., 2010; Watson et al., 2011). Using the Social Responsiveness Scale (SRS; Constantino & Gruber, 2005) to assess social impairments, Hilton et al. (2007) compared the levels of sensory problems assessed by the Sensory profile between a group of individuals with autism with an SRS score in the severe range of functioning and a group of individuals with an SRS score that suggested milder impairments. It was found that Individuals with autism with higher SRS scores had significantly more problems on all 4 Sensory Profile quadrants. It was also found that sensory hyper-sensitivity and avoidance had strong negative correlations with SRS total scores while sensation seeking and hypo-responsiveness were moderately negatively correlated. Similar findings were reported by Watson et al. (2011) apart from the fact that they did not find...
significant correlations between social/communication problems and sensory hypersensitivity. Finally, Liss, Saulnier, Fein, & Kinsbourne (2006) found positive correlations between both hypo-responsiveness and sensory seeking, and social and communication symptom severity in children and adults with autism spectrum disorders. Hyper-responsiveness did not correlate with either social or communication symptoms.

Summary

As can be seen from the short review provided above, the one consistent finding from the literature on sensory problems in autism is that sensory atypicalities are very frequent problem in this population. However, it is still not clear which of these problems is the most pervasive problem in autism, what is the relationship between sensory modulation problems and chronological age, developmental level, and core autism features. Also, previous research has not addressed the question of what is the mutual relationship between different sensory modulation problems in autism.