



Sensory theory in autism makes sense: A brief review of the past and present research

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Abstract

Introduction

Unusual responses to sensory stimuli were noticed from the very beginning of the official history of autism, and the pioneering research started in the 1960s; since then for many decades, sensory hypotheses were not considered important because there were no empirical evidence for this assumption. At present, however, we witness an explosion of interest in sensory perceptual issues, and the sensory perceptual theory of autism is steadily taking shape, incorporating findings from other related fields and producing a framework for studying sensory differences in autism and their impact not only on behaviours but also on language, cognition and social impairments of individuals with autism spectrum disorder.

As a review of all the available literature is beyond the scope of this paper, only a selection of research studies relevant to some methodological and conceptual problems of sensory perception in autism is included. This review challenges the conventional interpretation that gives primacy to social communication problems. The recognition of sensory perceptual differences in autism can assist in improving diagnostic instruments and provide information about appropriate support for each individual.

Conclusion

Current research has aimed to explain sensory perceptual processes

and their mechanisms, but there is no real understanding regarding sensory processing. We call on more research to be done on sensory processing in autism to improve our understanding and to actually be able to help individuals with autism correctly.

Introduction

First sensory hypotheses

Unusual responses to sensory stimuli were noticed from the very beginning of the official history of autism. Both Kanner¹ and Asperger² described bizarre reactions of their patients to sound, touch, sights, taste and smell. Based on their clinical observations, Bergman and Escalona³ put forward a sensory hypothesis to explain the development of autism: autistic children start life with a higher degree of sensory sensitivity, which makes them acquire defensive strategies to protect themselves from overload, which, in turn, results in developmental distortions that are reflected in autistic conditions. Eveloff⁴ described severe perceptual difficulties encountered by children with autism. Creak⁵ included unusual sensory perceptual experiences in the list of core symptoms of autism. Rimland⁶ emphasized the importance of exploring perceptual abilities of autistic children. Lorna Wing⁷ showed that autistic children have significantly more sensory perceptual problems than both typically developing children and children with Down's syndrome and included sensory perceptual features into 'basic impairments in autism'.

Ornitz⁸ researched disorders of perception common in autism and extended the notion of a disorder of sensory processing to the notion of

sensory and information processing. This approach allowed him to clarify and identify separate stages and functions of sensory perception and consider information processing in terms of more discrete functions, such as attention, memory and learning⁹. It was suggested that autism might be identified in young children if we look at very specific and easily described behaviours caused by sensory perceptual differences. For example, before the age of 6, these behaviours were observed with almost the same frequencies as behaviours related to social and communication impairments¹⁰. Delacato¹¹ hypothesized that unusual sensory experiences were a primary characteristic feature of autism, which were able to account for the basic symptoms of the condition considered to be essential in the diagnostic classifications. Thus, abnormal perceptions might give rise to high levels of anxiety; this, in turn, results in obsessive or compulsive behaviours, social and communication problems, making the more commonly accepted criteria, in fact, secondary developmental problems.

Another strand of research has been carried out in the field of occupational therapy (OT). It was started by Ayres¹² who formulated the theory of sensory integration (SI) dysfunction to describe a variety of neurological disorders. This theory attempted to account for the relationship between sensory processing and behavioural deficits in different developmental disorders including autism. Ayres originally limited her investigation to three senses—tactile, vestibular and proprioceptive—and identified the

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problems in them as tactile defensiveness, gravitational insecurity and postural insecurity. Unlike Delacato's concepts of 'hyper/hypo-sensitivities', describing the inner experiences, Ayres defined SI deficits mostly in terms of behavioural reactions; for example, tactile defensiveness is defined as avoiding or negative reactions to non-noxious tactile stimuli, manifested in 'fright, flight or fight' response or reaction.

Recently, OT researchers have suggested the updation of terminology used in SI and proposed 'sensory processing disorder' as a global umbrella term that includes three primary groups (sensory modulation disorder, sensory discrimination disorder and sensory-based motor disorder) and the subtypes found within each¹³. Another model of sensory processing, introduced by Dunn, aims to account for the nervous system's thresholds for acting and the person's propensity for responding to those thresholds (low registration, sensory seeking, sensory sensitivities and sensory avoiding)¹⁴.

Critical assessment of the first hypotheses

In 2005, Rogers and Ozonoff¹⁵ published a critical analysis of controlled experimental laboratory investigations published since 1960 (a total of 48 empirical and 27 theoretical or conceptual papers), with the conclusion that the empirical information available at the time is not supportive of many current theories concerning the specificity of sensory dysfunction in autism, pointing out that empirical work in the areas of cognition and communication provides 'far more definitive information about the nature of autism in those domains than the sensory area'. Their conclusions were based on:

- The lack of good evidence that 'sensory symptoms' differentiate autism from other developmental disorders,

- Some groups of children (with fragile X syndrome and those who are deaf-blind) appear to demonstrate higher rates of sensory-based behaviours than children with autism,
- The analysis of evidence relevant to the theories of sensory dysfunction in autism (over- and under-arousal theory¹⁶⁻¹⁸) provides very little support for hyperarousal and failure of habituation in autism.

The authors also commented on perceptual inconstancy¹⁹ and cross-modal impairment theories²⁰ as not supported by the research findings available at the time. The aim of this review is to discuss the past and present developments in sensory theory in autistic individuals.

Materials and methods

To re-examine some methodological and conceptual problems related to the research of sensory perception in autism, the research studies have been selected on the basis of addressing the limitations of the studies analysed in the review¹⁵, such as a very restricted choice of the phenomena for examination (typically limited to over/hyper-, under/hypo-responsiveness and sensory seeking), while other sensory phenomena common in autism have not been explored. As a result, the fundamental features of sensory processing (common in autism) have been rarely investigated, and many variables have not been taken into account, for example, the person can react to the same stimuli differently in different situations (so the results of the laboratory tests not always provide a full picture). The first-hand account of people with autism is a very important source of our understanding of the problems they experience, and they may have greater validity than our assumptions based on behaviours we observe.

Other theories (often omitted from critical reviews) have been analysed. Limited space means that only a

selection of the research studies relevant to the sensory perceptual issues in autism has been included.

Results

Recent developments and 'new old' hypotheses

Sensory characteristics of autism seem to be primary for many autistic people. Such features as, for example, unusual responses to sensory stimuli, are often seen as the core description of autism. Besides, from the autistic perspective, these responses are 'normal' (not 'unusual' or 'bizarre') because they are caused by different sensory perceptual processing. Many authors consider autism as largely a condition relating to sensory processing²¹⁻²³ and suggest that the true deep-rooted cause of all social and communicative problems is of a sensory perceptual nature^{24,25}. They identify the problems they experience as differences/disturbances in their sensory perception and information processing. Grandin²¹ put forward a hypothesis that there is a continuum of sensory processing problems for most autistic people, which goes from fractured disjointed images at one end to a slight abnormality at the other.

During the last decade, there have been an increased number of research publications on the subject. The scope of the research (both quantitative and qualitative) differs considerably, but the majority of the publications provide robust and validated findings that support the sensory perceptual theory in autism. Some studies produced results that have not been replicated^{26,27} and a few others, having studied certain phenomena in six to eight individuals with Asperger syndrome, over-generalize their findings to cover the whole spectrum.

Many research studies have investigated single sensory modality, for example, auditory discrimination and auditory sensory behaviours were examined by Jones et al.²⁸ and

atypical visual change processing by Clery et al.²⁹; other studies examined multimodal sensory difficulties that are quite common in autism. Foss-Feig et al.³⁰ investigated the differences in multisensory temporal function in autism spectrum disorder (ASD), with the findings suggesting that autistic children have altered multisensory temporal function (for a review of the literature on neuro-physiologic responses to auditory, tactile and visual stimuli in autistic individuals, see ref.³¹). A research report (containing the results of two studies) by Leekam et al.³² was published in 2006, which confirmed that sensory abnormalities are pervasive, multimodal, and persistent across age and ability in children and adults with autism and that individuals with autism have multimodal sensory difficulties. Other findings³³ suggest that the relationship between sensory responsiveness and other autistic traits is very important, and addressing sensory issues in children with autism is critical. The sensory and motor differences found between typical and high-risk infants (infant siblings of autistic children) suggest that early screenings for ASD should include the examination of sensory and motor behaviours³⁴. Robertson and Simmons³⁵ provided the data that indicate a strong link between sensory processing and autistic traits in the general population, which potentially implicates sensory processing problems in social interaction difficulties. Some studies^{36,37} reveal that sensory processing problems differ between clinical subgroups of ASD.

Sensory difficulties have been assessed in people of different ages: for example, in 20- to 54-month-old children, who were subgrouped based on the degree of autistic symptoms and cognitive levels. The most affected modalities in the whole group were pain and hearing³⁶. The researchers report that children in the most typical autism subgroup (nuclear autism without learning disability) had the

highest number of affected modalities; the children with 'autistic features' had the lowest number of affected modalities. However, there were no group differences in the number of affected modalities between groups of different cognitive levels or levels of expressive speech. These findings show that sensory problems are very common in young children with autism.

Ashburner et al.³⁸ investigated the responses to sensations in a group of young people with autism; their research showed that participants experienced a heightened awareness of and difficulty in filtering extraneous sensory input, high level of movement seeking, over-focus on salient sensory input, a preference for predictable and controlled sensory input. Crane et al.³⁹ suggested that unusual sensory processing in autism extended across the lifespan; adults on the autism spectrum can experience very different yet similarly severe sensory processing abnormalities.

Donnellan et al.⁴⁰ challenged the conventional interpretation that gives primacy to social communication and imaginative play and argued that children and adults with autism may have unrecognized and significant sensory and movement differences.

Discussion

The data from the cited studies also raise some very important theoretical questions. Barsalou⁴¹ argues that cognition is inherently perceptual, sharing systems with perception at both the cognitive and neural levels and that a perceptual theory of knowledge can implement a fully functional conceptual system. Thus, the boundaries of neuroscience are changing, and 'the distinction between sensory and cognitive function becomes increasingly unclear. Disorders that were previously considered 'cognitive' may be relabelled'⁴². The differences of sensory processing

may lead to different routes of cognitive and language development, which are eventually reflected in different systems of communication and social interaction⁴³. Bearing in mind the differences in their perceptions, cognitive mechanisms and adaptive strategies they acquire, it is hardly surprising that autistic individuals try to bring predictability and some order in the chaos in which they live. Stereotyped behaviours are seen by many autistic people as their compensatory strategies to regulate their sensory systems and cope with sensory overload. Unlike the most recent trend to interpret stereotypes as attempts to communicate, it is not always necessarily so, and there may be other reasons, different for each individual and for different situations⁴⁴. Self-stimulatory behaviours may serve several purposes, and one and the same behaviour may have different underlying causes. Routines and rituals, typical to the condition, bring some predictability to an otherwise incomprehensible world^{43,45}.

The importance of theoretical and conceptual constructs is undeniable. Gerrard and Rugg⁴⁶ point out theoretical modelling weaknesses (despite abundant data available) and inadequately tested hypotheses. As sensory problems (though widely reported) remain largely unexplained by existing models, the authors suggest a re-examination of causal modelling. Their analysis supports a heterogeneous causal model for autistic characteristics. They proposed that the development of a standardized framework for analysing autistic features would facilitate the identification of subgroups and the location of biological markers for genetic variation. This approach supports a neuroconstructivist model, indicating that sensory abnormalities disrupt compilation of complex skills; impact on synaptogenesis, synaptic pruning and myelination; and subsequently manifest themselves as autistic behaviours⁴⁶. The authors believe that

such a model explains some structural and functional brain abnormalities and many of the perceptual, cognitive and attentional features of autism. They disagree with the conclusion¹⁵ that sensory impairments are not a distinguished characteristic of autism and cite a body of research that indicates that a possible cause of autistic characteristics by sensory abnormalities cannot be ruled out⁴⁷⁻⁴⁹. Gerrard and Rugg persuasively argue (supporting their views with the empirical research evidence) that 'a deficit in one submodality might make only a small contribution to overall primary processing in this mode, but could play a more significant role in certain aspects of higher-level processing', concluding that certain sensory abnormalities can produce behaviours that meet clinical criteria for diagnosis of autism, and whether sensory deficits arise peripherally or centrally, they not only significantly affect cognitive and social functioning but also can be experienced as far more debilitating than social interaction and communication⁴⁶.

There are some theoretical models that can account for the sensory development in autism. For example, Rubenstein and Merzenich⁵⁰ devised a model for autism that could explain the symptoms, specific features of emotional, cognitive and language development, and suggest their underlying cause. They propose that efforts to understand autism origin should be on the development of neural circuits and systems that underlie language processing (i.e. audition, language comprehension, speech production and verbal memory and cognition), along with development of social behaviours. Some other studies confirm that autistic individuals appear to have a range of perceptual processing abnormalities/differences, expressed especially strikingly by a hypersensitivity to auditory and tactile stimuli^{48,51}. Such studies indicate that the auditory environment has a paramount impact

on the progression of the fundamental maturation and specialization of the primary auditory cortex and implicate a number of specific sensory factors that could potentially amplify or otherwise modulate developmental progressions⁵⁰.

The comparative research of minicolumns in the brains of nonautistic and autistic individuals has revealed that in nonautistic neocortex, information is transmitted through the core of the minicolumn and is prevented from activating neighbouring units by surrounding inhibitory fibres. Minicolumns in autism, however, are smaller, more numerous and have abnormal structure⁵², so stimuli are no longer contained within them but rather overflow to adjacent units, thus creating an amplifier effect. Inhibitory fibres just do not cope with this flow⁵³.

Markram and colleagues⁴⁹ propose a unifying hypothesis of autism (which they call 'the intense world syndrome'), where the core neurological pathology is excessive neuronal information processing and storage in local circuits of the brain, which gives rise to hyperfunctioning of the most affected brain regions. According to the authors, the vast autism spectrum could be explained by the specific degree to which this hyperfunctional molecular syndrome is active in different areas of the brain, which could depend on the precise stage of development that the brain is exposed to a triggering insult, the type of toxic insult and the presence of any predisposing genes⁴⁹. Thus, *all* features of autism (social interaction impairments, communication and language problems, cognitive functioning, repetitive behaviours, etc.) can be seen as rooted in sensory overload experienced by individuals with autism. Autistic people perceive, feel and remember too much. Faced with bombarding, confusing, baffling and often painful environment, autistic infants withdraw into their own world by shutting down

their sensory systems. It brings unfavourable consequences for their social and linguistic development. Repetitive behaviours such as rocking the body, flapping hands and head-banging are seen as an attempt to bring order and predictability to their environment.

The Swiss researchers have provided a strong neurological evidence of the presence of overload in individuals with autism. Contrary to most neurological studies that describe underconnectivity/hypoactivity/deficits of connectivity of the autistic brains, the Markram's research has established that the autistic brain is, in fact, overperforming. They cite reduced activation reported in attention tasks⁵⁴, in speech recognition and generation⁵⁵, but normal to increased activation – during motor tasks^{54,56}. In general, functional imaging studies seem to suggest that higher-order brain areas are not fully activated, being disconnected from lower-order sensory areas, while these lower-order sensory areas may be even hyperactivated⁴⁹.

Hyperreactivity and hyperplasticity mean that minicolumns have a higher than normal capacity for processing information. Excessive processing of the sensory input in the microcircuits leads, in turn, to exaggerated perception, producing extremely intense images, sounds, smells, etc. This sensory overload, combined with inability to filter information, causes autistic children to withdraw and miss the opportunity to develop shared conceptual understanding of the world. In this view, ASDs are disorders of hyperfunctionality as opposed to disorders of hypofunctionality, as is often assumed. Excessive neuronal processing may make the world painfully intense when the neocortex is affected and even aversive when the amygdala is affected⁴⁶. This research confirms the findings and theories of sensory perceptual cause(s) of autism that were introduced in the last century.

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The criteria of core features can be applied to sensory perceptual issues in autism:

- **Specificity:** Characteristics specific only to autism, but not to other disorders. Research has shown that sensory perceptual profiles of autistic people differ from those with other disabilities^{57,58}.
- **Universality:** Features present in *all* individuals. It may be seen in their 'autistic thinking' and behavioural responses, especially *if* we include not only hypersensitivities as indicators of 'sensory characteristics' but other quite common in autism phenomena⁴³.
- **Primacy:** Early in development. 'Sensory symptoms' can be detected in early development – much earlier than social and communication impairments – *if* we know what to look for and overcome the traditional 'hypersensitivity/defensiveness approach'. For example, 'seeming deafness' or 'fascination with sensory stimuli' is 'visible' at the age of 9–12 months⁵⁹ or even earlier. There is research evidence that does indicate that sensory perceptual differences may be among the first signs of autism in young children. However, these early signs, especially those occurring in the first year of life, are often missed and become apparent only retrospectively⁴. These autistic 'sensory symptoms' observed during the first years seem to persist into the second year of life⁶⁰. Autistic toddlers and preschool children display atypical sensorimotor behaviours (including both heightened sensitivities or reduced responsiveness across sensory modalities, and motility disturbances such as stereotypies) at some point of their development⁶¹. Numerous individual differences, indicating possible subtypes based on different patterns of sensory perceptual problems have been reported.
- **Account for other characteristics:** Should connect and explain

biological/genetic, cognitive/psychological and behavioural manifestations; and the diversity of manifestation of autism in different individuals^{49,50,52}.

Conclusion

Sensory theories of autism have been discussed from the first description of the condition. However, the available empirical information did not support them because of the lack of appropriate theoretical and clinical construct that instructed the research investigation in the past (e.g. limiting autism to very few phenomena). The research studies aiming to explain the role of sensory perception will generate more specific hypotheses about the sensory perceptual processes and their mechanisms in autism. Better understanding of sensory processing in autism will assist in improving diagnostic instruments and distinguishing sensory perceptual subtypes of autistic individuals and provide appropriate choices of help needed by each particular individual. As sensory perceptual profiles of autistic individuals differ considerably, it is no wonder that certain sensory-based approaches will work for some individuals while making no difference to others.

The recognition of sensory perceptual differences (both strengths and weaknesses) is a new (but old) field and, unfortunately, many professionals are unaware or unknowledgeable about these issues, how to recognize them and what to do about them. Isn't it time at last to listen to those who live with autism and consider the problems they identify as the primary ones instead of going in the opposite direction?

Abbreviations list

ASD, autism spectrum disorder; OT, occupational therapy; SI, sensory integration

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