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REVIEW ARTICLE

How auditory processing influences the autistic profile: A review

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Abstract

We need to combine sensory data from various sources to make sense of the world around us. This sensory data helps us understand our surroundings, influencing our experiences and interactions within our everyday environments. Recent interest in sensory-focused approaches to supporting autistic people has fixed on auditory processing—the sense of hearing and the act of listening—and its crucial role in language, communications, and social domains, as well as non-social autism-specific attributes, to understand better how sensory processing might differ in autistic people. In this narrative review, we synthesize published research into auditory processing in autistic people and the relationship between auditory processing and autistic attributes in a contextually novel way. The purpose is to understand the relationship between these domains more fully, drawing on evidence gleaned from experiential perspectives through to neurological investigations. We also examine the relationship between auditory processing and diagnosable auditory conditions, such as hyperacusis, misophonia, phonophobia, and intolerance to loud sounds, as well as its relation to sleep, anxiety, and sensory overload. Through reviewing experiential, behavioral and neurological literature, we demonstrate that auditory processes interact with and shape the broader autistic profile—something not previously considered. Through a better understanding of the potential impact of auditory experiences, our review aims to inform future research on investigating the relationship between auditory processing and autistic traits through quantitative measures or using qualitative experiential inquiry to examine this relationship more holistically.

Lay Summary

Autistic people often have increased sensitivity to certain noises or trouble ignoring background noise, which can affect people's wellbeing and how they go about their daily lives. This review looks at how the published research on this topic helps us understand how autistic people experience sound, and to explore the impact on autistic traits and everyday experiences like anxiety and sleep. The findings highlight the influence of sound sensitivities for autistic people and suggest that future research could look at this more specifically.

KEYWORDS
auditory processing, autism, autistic traits, decreased sound tolerance

INTRODUCTION

Auditory processing—the neurological process of perceiving and interpreting sound—has emerged as a significant issue in understanding the experiences of autistic people. Early theories of autism, such as the "sensory-focused" theory posited by Bergman and Escalona (1947), emphasized atypical sensory processing as a factor driving other autistic behaviors (Ornitz, 1969). While these theories were overlooked for many years, recent investigations have rekindled interest in the importance of sensory processing in autistic people (Baranek et al., 2018; Bradshaw et al., 2022; Hazen et al., 2014; Kashefimehr et al., 2021; McCormick et al., 2016; Mottron, 2017; Pellicano, 2013; Robertson & Baron-Cohen, 2017; Sibeoni et al., 2022; Thye et al., 2018). Consequently, sensory differences have become a widely recognized phenomenon that potentially impact daily life for many autistic people (Kirby et al., 2021). They have received increasing attention in recent years as a part of autistic divergence, including their potential for influencing other "core" characteristics (Glod, Riby, Honey & Rogers, 2015).

Here, we focus exclusively on sensory processing in the auditory domain. Evidence suggests auditory stimuli can overly influence sensory and information processing as a single modality and in multisensory contexts (Ben-Sason, Katz-Zetler & Cermak, 2019; Bonneh et al., 2008; Ronconi et al., 2016). Strong, often adverse, reactions to sound may distinguish autistic from non-autistic people early in life (Dahlgren & Gillberg, 1989), and a recent study reported that the most distressing sensory experiences for autistic and other neurodivergent people were in the auditory modality (Wada et al., 2023). Williams, Campi, et al. (2021), Williams, He, et al. (2021), and Williams, Suzman, et al. (2021) also discuss how the processes of receiving, analyzing, and interpreting auditory information all seem altered for autistic compared to neurotypical people, as prominently manifested in reduced tolerance to sound per se.

In this narrative review, we therefore examined the current literature regarding auditory processing and the experiences of autistic people. We sought to understand how auditory processing interacts with autistic traits and attributes. We begin by discussing how autistic people perceive sound based on existing reports, including reported hypersensitivity, decreased sound tolerance, adaptation, and sensory overload. Next, we turn to the neurological aspects of auditory processing in autism and the relationship to auditory conditions, sleep, and anxiety. We then review the published data that examine specific autistic traits and auditory experiences. Finally, we extend prior discussions around how variations in auditory processing might broadly influence other cognitive functions contributing to the overall profile of autistic traits.

SPECIFICITIES OF THE AUTISTIC AUDITORY PROFILE

Hypersensitivity

Autism has long been associated with a heightened reactivity to loud sounds, as described in the DSM-5 criteria for an autism diagnosis (APA, 2013). Several studies have shown that many autistic people exhibit hyper-reactivity to sounds throughout the lifespan, with loud and unexpected sounds being particularly distressing (Carson et al., 2021; Gomes et al., 2008; Khalfa et al., 2004; Rosenhall et al., 1999; Williams, Suzman, et al., 2021). Autistic people may also exhibit stronger startle responses, which could be considered "over responsiveness," to sounds, including sounds of low intensity, although this finding is not consistently reported across studies (Cheng et al., 2018; Hannant, Tavassoli & Cassidy, 2016, Takahashi et al., 2016, 2017).

As well as a heightened sensitivity to sounds, some autistic people may find busy auditory scenes challenging, such as isolating a single speech source in a noisy environment (Hernandez et al., 2020), and may have difficulty filtering out interfering sounds that capture their attention (Brinkert & Remington, 2020; Remington & Fairnie, 2017; Schafer et al., 2014; Schwartz et al., 2020; Stefanelli et al., 2020). Difficulties with detecting speech in noise has been reported across the lifespan, from children (e.g., Foxe et al., 2020; Kanakri, Shepley, Varni & Tassinary, 2017; Schafer et al., 2014) to adults (e.g., Landon et al., 2016) as well as in subgroups of the autistic population (e.g., non-speaking adolescents and young adults; Stefanelli et al., 2020). Indeed, several studies report that autistic people struggle more than non-autistic people to filter speech sounds amidst noise (reviewed by Ruiz Callejo & Boets, 2023). Some lines of evidence suggest the difficulties that some autistic people have recognizing target words amidst distracting speech are evident relatively early in development —2–5 years of age, (Newman et al., 2021). Similar reports of difficulties understanding or attending to speech-in-background noise have been identified in people diagnosed with ADHD (Lewandowski et al., 2021; Honisch, Mane, Golan & Chakrabarti, 2021; Michalek et al., 2014; Riccig & Hynd, 1996). Overall, such altered auditory processing—including difficulties attending to relevant speech sounds, or difficulties ignoring interfering sounds—are likely to impact significantly on autistic people's daily lives, whether at home, school or in the workplace (Anderson, Carter & Stephenson, 2018; Davies, 2019; Gelbar, Smith & Reichow, 2014; Landon et al., 2016; Madriaga, 2010; Robertson & Simmons, 2015; Scheef et al., 2019).

Decreased sound tolerance and sensory overload

A recent autistic-led review explored the published evidence regarding reduced sound tolerance in autistic people, including its phenomenology, contributing factors, and potential mechanisms (Williams, He, et al., 2021). Reduced tolerance to sounds is often conceptualized, at least in autism research, as the single construct of "sound sensitivity" or "auditory over-responsivity". Still, it may more accurately be represented in terms of many different (and sometimes overlapping) experiences, all of which relate to the difficulties autistic people experience tolerating everyday sounds that are otherwise largely innocuous for non-autistic people (Marco, Hinkley, Hill & Nagarajan, 2011). The reasons why sounds might be perceived as intrusive, bothersome, or even aversive varies between autistic people but can typically be grouped based on whether psychoacoustic characteristics such as loudness or pitch are the source of discomfort (Ocak, Eshraghi, Danesh, Mittal & Eshraghi, 2018).

The distress experienced by autistic people in response to loud sounds has been described as "sensory overload" (Belek, 2019; Charlton et al., 2021; Elwin et al., 2013; Goddard & Cook, 2022; Strömberg et al., 2022); when exposed to excessively intense stimuli, or too many stimuli simultaneously, autistic people—especially if already experiencing a high cognitive load—report a perceived overload of sensory information. This can lead to intense feelings of distress or panic (Kuiper et al., 2019; Pellicano, 2013), culminating in "shutdown" or "meltdown" (Ben-Sason, Katz-Zetler & Cermak, 2019; Belek, 2019), in which autistic people can feel a loss of volitional control over their behavior (Phung et al., 2021; Welch et al., 2020). Consistent with this interpretation, autistic young people show heightened physiological and neural responses to "mildly aversive" auditory stimulation, as well as tactile and joint auditory-tactile stimulation (Jung et al., 2021; Keith et al., 2019a; Keith et al., 2019b), assessed using physiological (e.g., heart and rate) and neurological (functional MRI) metrics. Indeed, when of sufficient severity, autistic sensory distress has been described as traumatic, although this perspective has yet to be evaluated using standardized trauma measures (Kerns et al., 2016, 2022).

Autistic experiences of sensory distress and overload also appear to be linked to anxiety, vigilance, and attention (Livingston, Shah & Happé, 2019). Not only do autistic people describe stress as a factor that exacerbates sensory distress, but they also indicate that experiences of sensory distress can lead to increased stress and hypervigilance, exacerbating sensory distress in a feedback loop (Neil et al., 2016; Smith & Sharp, 2013). Many autistic people report sounds to be a specific cause of anxiety (Kerns et al., 2016; Lau et al., 2020a,b; Muskett et al., 2019; Verhulst et al., 2022), and chronic and existing anxiety may themselves exacerbate auditory, and broader sensory, sensitivities (Amos et al., 2019), lowering tolerance to sound and generating sensory overload (MacLennan, O'Brien, & Tavassoli, 2021; MacLennan, Rossow, et al., 2021; Williams, Campi, et al., 2021).

Adaptation and habituation

In addition to hyper-reactivity to loud sounds, differences in auditory adaptation—a reduction in the magnitude of response to a repeated stimulation over time—have been reported between autistic people and neurotypical people (Cary et al., 2023; Gandhi et al., 2020; Green et al., 2018; Hudac et al., 2018; Jamal et al., 2020; Kleinhans et al., 2009; Ruiz-Martínez et al., 2020). In the auditory domain, autistic people exhibit reduced habituation and recovery following a brief respite from stimulation and the addition of a dishabituating (novel) stimulus of a different modality (Gandhi et al., 2020; Green et al., 2019; Hudac et al., 2018; Kuiper et al., 2019; Lawson et al., 2015; Ruiz-Martínez et al., 2020). Additionally, some evidence suggests that autistic people experience reduced cortical adaptation to repetitive sound stimulation, with stronger cortical responses (assessed using functional MRI) to stimuli positively correlated with autistic attributes (Millin et al., 2018).

A reduction in the ability to adapt to sounds may lead to an increase in the perceived loudness of sound sources or the acoustic environment in general, and this may be related to the difficulties that autistic people experience when attempting to filter out and ignore interfering or background sources of noise. Differences in homeostatic plasticity in the central nervous system, which contributes to the ability to adapt to stimuli in humans (Desai et al., 1999; Dellapiazza et al., 2018; Mamashli et al., 2017), can also contribute to difficulties ignoring a persistent stimulus, such as moderately intense background noise (Tyler et al., 2014; Wilson et al., 2017). Atypical homeostatic plasticity in autism is consistent with the hypothesis that autism can be characterized by a higher level of neural excitation relative to inhibition (Rubenstein & Merzenich, 2003; Sohal & Rubenstein, 2019). Interestingly, in a study by Whitehouse and Bishop (2008), autistic children effectively shifted their attention to novel speech sounds when required but displayed reduced involuntary responses to repetitive speech sounds. This phenomenon may rely on the activity of efferent pathways in the auditory brain—pathways that ultimately terminate within the inner ear—and a reliance on 'top-down' inhibition when processing of speech in autistic children (Kanakri, Shepley, Varni & Tassinary, 2017; Whitehouse & Bishop, 2008).

Neural and psychoacoustic underpinnings

The processing of auditory information in the brain involves multiple regions and networks. Following the transduction of sound energy into electrical signals by sensory cells in the inner ear, synaptic transmission of this information to auditory nerve fibers propagates trains of action potentials unilaterally to cochlear nuclei and bilaterally to the nuclei of the superior olivary complex of the brainstem, before inputs from both sides of the brain converge through the almost obligatory midbrain nucleus of the inferior colliculus and from there to the thalamus and primary and secondary auditory cortices. Subsequent projections to the limbic system allow for emotional regulation and long-term memory processing associated with sound. Heightened responses to auditory stimuli, reduced filtering of sensory inputs, and differences in temporal processing are some of the most reported neurological findings of auditory processing in autistic people (Chen, Sideris, Watson, Crais & Baranek, 2022; Font-Alaminos et al., 2020; Gomes et al., 2008; Haesen et al., 2011; Kargas et al., 2015; Kuiper et al., 2019; Lucker, 2013; Park et al., 2017; Williams, 2022).

While peripheral hearing function in autistic people appears similar to the general, neurotypical population (Beers et al., 2014; Kuiper et al., 2019; Mishaal et al., 2022), autistic people may exhibit an increased ability to detect subtle nuances in auditory scenes (Davies, 2019); evidence suggests frequency discrimination and musical memory may be enhanced in at least a subset of autistic people (Aguirre et al., 2019; Bonneh et al., 2008; Germain et al., 2019; Jones et al., 2009; Stewart et al., 2018). In a study of basic psychoacoustic abilities, Jones et al. (2009) reported a subset (20%) of autistic people to possess "excellent" abilities to distinguish different sound frequencies from each other, and that these abilities were unrelated to overall sensitivity to sound (i.e., hearing thresholds), whilst those who performed poorly on an intensity-discrimination task reported more behaviors reflective of discomfort to sound stimulation. In contrast, autistic people who performed well on distinguishing between different durations of sounds reported greater auditory sensory behaviors (Ruiz Callejo & Boets, 2023). The authors suggested that the range of auditory discrimination skills evident in autism may impact auditory sensory behaviors by altering the degree to which environmental noises are detected or overlooked (Jones et al., 2009; Murray, Lesser & Lawson, 2005). This hypothesized role for allocating attention or, at least, sensory resources to salient stimuli appears consistent with findings from more recent studies (Cary et al., 2023; Karhson & Golob, 2016; Keehn, Kadlaskar, et al., 2019, Keehn, Westerfield, & Townsend, 2019). For example, Karhson and Golob (2016) used an event-related paradigm (ERP) paradigm to demonstrate that although performance in auditory target detection is similar across autistic and non-autistic listeners as a function of increasing perceptual load, electrophysiological correlates of top-down processing appear altered in non-autistic individuals as perceptual load increases, but this is not necessarily so in autistic people. This result is consistent with load theory, suggesting that perceptual load can influence attentional processes (Khalfa et al., 2004; Tillmann et al., 2021).

Currently, assessment of sensory discomfort in autistic people in community settings is largely through self- or parent-report questionnaires that gauge behavioral and affective responses to sensory stimuli (Schauder & Bennetto, 2016)—using the Short Sensory Profile (Tomchek & Dunn, 2007), for example—, with sensory phenotyping beyond these measures rare in clinical practice (Schaaf & Lane, 2015; Schauder & Bennetto, 2016). There is a notable lack of evidence demonstrating the clinical utility of sensory measures to support an autism diagnosis or monitor outcomes relevant to effective service interventions. However, it is crucial to incorporate lived experiences, including evidence from autistic-led research (Davies, 2019; MacLennan, O'Brien, et al., 2021, Talcer, Duffy & Pedlow, 2021) and in-depth autistic self-accounts of auditory experience (Charlton et al., 2021; Keith et al., 2019a; MacLennan, O'Brien, et al., 2021), into the broader process of autism research, not least to better understand the auditory experience of autistic people and the underlying factors contributing to atypical auditory profiles.

Neurobiological mechanisms of autistic auditory processing

Rather than hearing loss per se—which is quantified in terms of hearing thresholds—potential mechanisms/sources for hyperacusis and altered central gain in autism might be evident in the magnitude or form of auditory brainstem responses (ABRs)—sound-evoked potentials generated by neurons in the auditory nerve and brainstem auditory pathways (Miron et al., 2017; Pillion et al., 2018; Talge et al., 2018). Using ABRs to assess nerve and lower brainstem evoked activity to sounds, Rosenhall et al. (2003) reported longer latencies in ABR waves in autistic people than non-autistic participants. Altered brain activity in early brainstem pathways is suggested to lead to elevated central gain in midbrain, thalamic, and cortical centers (as reviewed in Pillion et al., 2018; and Talge et al., 2018), potentially the result of an imbalance in the ratio of excitatory and inhibitory activity (Sohal & Rubenstein, 2019). However, any straightforward understanding of this perspective is difficult to ascertain, particularly as the magnitude of many auditory cortical responses assessed electrophysiologically span similar ranges in autistic and non-autistic people (Fujihiri, Itoi, Furukawa, Kato & Kashino, 2021; Williams et al., 2020); notably, this includes the latencies of evoked cortical potential in the subgroup of autistic children displaying enhanced responses to high-intensity sounds reported by Dwyer et al. (2021) and Williams et al. (2020). Whilst this appears inconsistent with the notion that cortical auditory gain is enhanced in autistic people, understanding precisely what would constitute evidence of elevated neural gain, including the sound-stimulation parameters to which it might be sensitive, remains to be determined.

Studies exploring possible neurobiological mechanisms underlying the various auditory processing differences in autism suggest heterogeneity, potentially reflecting the lack of a single "autism-specific" auditory profile. Considering neurological studies alone, functional connectivity—coordinated activity and communication between auditory brain regions—appears altered in at least some autistic people, with changes relative to neurotypical control subjects manifesting as disrupted connectivity when processing environmental background noise, as well as reduced local and increased long-range functional connectivity in the thalamus (Hull et a., 2017; Tomasi & Volkow, 2019). However, whilst earlier studies investigating connectivity reported brain-wide hypo-connectivity in autistic people (Just et al., 2007; Rubenstein & Sohal, 2013; Tran et al., 2021), others suggest that connectivity may be heightened only in localized regions (Belmonte, 2004; Lui et al., 2020). Generally, recent explorations of brain connectivity in autism suggest a more complex perspective than simple brain-wide hypo- or hyper-connectivity, with a consider degree of variability in reported findings (Picci et al., 2016; Rubenstein & Sohal, 2013). This heterogeneity may simply reflect heterogeneity in the population; individual autistic people often appear to exhibit idiosyncratic patterns of atypical connectivity, including in sensory and attentional networks (Benkarim et al., 2021; Mamashli et al., 2017). Connectivity might be altered in many autistic people, but perhaps in a diverse range of ways. Autism research lacks any overarching framework that might explain the high degree of variability between studies, notwithstanding the possibility that methodological differences in assessment might also account for some of the reported variance.

The consideration of diagnosable auditory conditions

Williams, He, et al. (2021) concluded that the autistic auditory profile most likely, but not exclusively, includes a variety of auditory patterns previously described in the general population (Henry et al., 2022; Jastreboff & Jastreboff, 2015), with each pattern reflecting distinct varieties of reduced tolerance to sound. Hyperacusis, for example, refers to distress or pain caused by exposure to certain frequency and intensity (volume) ranges of sound, whilst misophonia refers to emotional reactions such as anger, rage, or disgust to specific sounds, and phonophobia to fears of specific sounds. The pattern of auditory profiles is discussed further below, but in both research and practice, assessments reducing these patterns to categorical diagnostic classifications may be helpful (see Williams, 2022, for operational diagnostic criteria). Williams, He, et al. (2021) further suggest that these ranges of reduced sound tolerance seen in autism might not be solely physiological or psychological, but likely a combination of both. Differences in lower-level perceptual processes might contribute to hyperacusis, while higher-level cognitive processes likely contribute to misophonia and phonophobia. However, these relationships have yet to be tested empirically and remain speculative. Moreover, it is also possible that higher-level cognitive processes related to experiences of sensory overwhelm may account for some observations of hyperacusis.

One specific condition that has been largely overlooked in autism research is misophonia, an affective pattern of sound intolerance characterized by intensely negative emotional reactions (typically extreme irritation, anger, or disgust) in response to specific "trigger" sounds (e.g., chewing, tapping, and sniffling). This auditory trigger can generate significant distress, avoidance behaviors, and reduced quality of life (Swedo et al., 2022). It is likely that the elevated prevalence of misophonia in autistic people (e.g., Williams et al., 2022) reflects difficulties in "attentional filtering" of these sounds, attributing salience to specific sounds, and/or regulating emotional reactions to distressing sounds (Neacsiu et al., 2022; Williams, He, et al., 2021). Notably, though exploration of misophonia (and its overlap with autism) remains in its infancy, specific behavioral and pharmacological interventions are under investigation in both autistic and non-autistic people who experience misophonia (e.g., Ferrer-Torres & Giménez-Llort, 2022; Haq et al., 2021; Naguy et al., 2022; Webb, 2022). In addition to standard management of misophonia as a behavioral/psychiatric condition (i.e., using cognitive-behavioral and psychopharmacological treatment modalities), interventions targeting lower-level sensory processes such as auditory filtering (e.g. Feldman et al., 2022; Harper-Hill et al., 2021; Schafer et al., 2019) may also demonstrate collateral effects on misophonia symptoms, although these putative benefits remain speculative.

Hyperacusis is another distinct form of reduced tolerance to sounds commonly reported by autistic people (as reviewed in Salvi et al., 2022; Stefanelli et al., 2020; Tyler et al., 2014). In hyperacusis, moderate-intensity sounds are perceived as excessively loud, and this can lead to "overwhelm"—a term used by autistic people to describe a state caused by excessive sensory or social stimulation—and, in some cases, physically painful, sensory experiences (Bigras et al., 2023; Fackrell et al., 2019; Williams, Suzman, et al., 2021). One potential cause of hyperacusis is elevated central gain (Auerbach et al., 2014), wherein neural activity is amplified, potentially as a compensatory response to some form of impairment within the inner ear, including audiometric hearing loss, though most autistic people's peripheral hearing function appears similar to that of the broader population (Beers et al., 2014; Kuiper et al., 2019). One study has described a subgroup of autistic young children who nevertheless exhibited enhanced cortical electrophysiological responses to higher- relative to lower-intensity sounds (Dwyer et al., 2020), with their caregivers reporting that these children tended to be more distracted by sound or less able to filter out competing sounds, than other autistic children in the study.

Developmental considerations

There are limited longitudinal studies investigating how auditory processing changes over time. Most longitudinal studies are with children and investigate speech and language acquisition (Chen et al., 2019; Lau et al., 2023; Lawrence, Hernandez, Bookheimer & Dapretto, 2019; Port et al., 2016). For example, Lau et al. (2023) investigated the prevalence of hypersensitivity across three timepoints of childhood and reported hypersensitivity, sound aversions and difficulty listening in noisy environments present across all three ages. More research is needed to understand how auditory processing changes throughout development particularly in several critical stages of life—from childhood, through adolescence into adulthood and in older populations. Additionally, research into how to support autistic people across the lifespan regarding auditory processing, is needed.

Having considered the distinctive auditory profile associated with autism, and its prevalence across the lifespan, marked by heightened sensitivities, unique perceptual differences, and potential neural underpinnings, we now turn our attention to the intersection of these auditory features with autistic traits. The existing evidence suggests that these auditory processing differences could have broader implications, extending beyond the sensory processing domain to influence social and communication traits and non-social domains such as cognitive flexibility and repetitive behaviors. We explore in depth this possibility in the following section, where we aim to elucidate the potential reach of auditory processing influences across the diverse aspects of the autistic profile.

AUDITORY PROCESSING AND AUTISTIC TRAITS

Auditory processing, social communication, and language traits

Auditory processing is critical in social and communication skills (Baquerizo Sedano et al., 2017; Bathelt et al., 2017; Chang et al., 2014; Matsuzaki et al., 2019). Moreover, autistic people can have challenges processing, filtering, and ignoring irrelevant background sounds (Davies, 2019; Keehn et al., 2016; Poole et al., 2018), with potential implications for social communication, particularly during dynamic interactions such as conversations. Self-reported accounts from autistic people have described that stress, distraction, and sensory demands can make it more challenging to communicate verbally and to imitate neurotypical social behaviors through masking or suppressing naturalistic autistic responses (Balas-Baconschi et al., 2019; Bellamy et al., 2021; Ai, Cunningham & Lai, 2022; Howard & Sedgewick, 2021; Livingston, Carr, & Shah, 2019). Successful social communication requires awareness of one's behavior, the reactions, and responses of others, and predicting upcoming events in an interaction. Given the rapid pace of many typical social interactions—particularly face-to-face—these already cognitively challenging mental operations can potentially be overwhelming for autistic people in everyday social settings.

An example of how sensory and auditory differences in autistic people might influence communication lies in social contexts that inherently involve the direction of attention among competing stimuli. "Cocktail party listening"—the ability to follow a conversation in an acoustically challenging environment—is reported as being particularly challenging for autistic people, and a reduced ability to ignore background stimuli—for whatever reason—potentially accounts for at least some of the difficulties they experience in social settings (Hernandez et al., 2020; Schwartz et al., 2020). Using fMRI to investigate sensory responsivity and social cognition in autistic adults, Green et al. (2018) demonstrated that activity in brain areas associated with social cognition were reduced when sensory stimuli were presented simultaneously with a tactile distractor stimulus, consistent with the interpretation that cognitive load may increase with more than one modality. Hernandez et al. (2020) also used fMRI to investigate brain responses in autistic and non-autistic youth during conversations in noisy environments. Both groups showed activation in language networks, but autistic youth exhibited greater activation in left-hemisphere speech-processing areas. The degree of increased activation was associated with better social cognition and suggests that these autistic youth recruited additional neural resources to focus on social cues in the presence of distracting stimuli.

How the brain assimilates and processes auditory information such as speech has been shown to influence language development, specifically in terms of receptive language and communication skills (Abbeduto et al., 2016; Chenausky et al., 2016; Donaldson et al., 2017; Filipe et al., 2018; Georgiou, 2020; Haesen et al., 2011; Irwin et al., 2017; Key & Ambrose Slaboch Kathryn, 2021; Petit et al., 2019; Tecoulesco et al., 2020). Difficulties discriminating speech sounds, or following conversations, are likely independent of auditory hypersensitivity (Dunlop et al., 2016). Rather, they appear related to neural correlates of implicit, or statistical, learning of acoustic features and sound-pattern recognition, skills that might be influenced by atypical sensory processing in autistic people (Arnett et al., 2018; Gonzalez-Gadea et al., 2015).

Physiological responses to auditory stimuli suggest that heightened activation of the autonomic nervous system might exacerbate the stress and overload faced by many autistic people in social settings, particularly those in which listeners are challenged with a steady stream of auditory (and other sensory) information from multiple sources simultaneously (Jung et al., 2021; Keith et al., 2019b; Kuiper et al., 2019). With prolonged exposure to such stressors, some autistic people may begin to experience cognitive fatigue and other internalizing symptoms, often described as "autistic burnout" (Arnold et al., 2023; Higgins et al., 2021; Phung et al., 2021; Raymaker et al., 2020). There is, however, no research into specific auditory phenotypes or subgroups of autistic people. Although there has been research into sensory subtypes (Little et al., 2015; MacLennan, O'Brien, et al., 2021; MacLennan, Rossow, et al., 2021), single modality subtypes remain under-researched (Dwyer et al., 2020).

Auditory distress and sensory overload also appear to limit participation, and opportunities for participation, in communal environments such as workplaces, educational settings, and social gatherings (Caniato et al., 2022; de Vries, 2021; Gelbar, Smith & Reinchow, 2014; Madriaga, 2010; Scheerer et al., 2022), with evidence supporting a relationship between self-reported (questionnaire-based) sensory profiles and participation by autistic people in social activities (Chang et al., 2014; Elwin et al., 2013; Lin, 2020; Little et al., 2015). Interestingly, using noise-canceling headphones reportedly increases social participation by some autistic people in home, community, and school environments (Loh, Ee, Marret & Chinna, 2020; Pfeiffer et al., 2019). From this, it seems reasonable to assume that auditory sensory distress reduces opportunities for autistic people to practice social skills and exacerbates their actual and perceived social marginalization. However, the extent to which acoustic environments hinder desired participation by autistic people remains to be determined.

Auditory processing and non-social traits

Auditory processing is often considered when investigating autistic populations regarding social interaction and communication—domains strongly engaged with hearing and listening. However, recent evidence suggests that the autistic auditory profile may also impact the non-social domains of autistic behavior, specifically around "restrictive and repetitive behaviors" (Grove et al., 2021). Autistic children often exhibit difficulties disengaging their attention from an otherwise unimportant sound (Keehn, Kadlaskar, et al., 2019; Keehn, Westerfield, & Townsend, 2019), whilst autistic young children may be less responsive to directed auditory stimuli, including social and speech sounds, as well as less likely to initiate joint attention towards auditory stimuli (Adamson et al., 2021; Estes et al., 2015). Together, enhanced sensitivity or fixation on socially irrelevant sounds, and a reduced tendency to attend to socially important ones such as speech, likely influence communication abilities and social participation, particularly if problems disengaging from irrelevant sounds or attending to socially important ones arise early in development.

Atypical sensory processing, including hyper-responsiveness to sounds and visual objects and scenes, is predictive of repetitive motor behavior in autistic people (Boyd et al., 2010; Glod et al., 2019; Moore et al., 2021; Wigham et al., 2015). Repetitive behaviors are clinically defined as seemingly meaningless, developmentally inappropriate, and functionally impairing (Charlton et al., 2021; Kapp et al., 2019; McLay et al., 2019). However, autistic people often describe these motor stereotypies as having a self-regulatory function (Charlton et al., 2021; Jaffey & Ashwin, 2022;Joyce et al., 2017; Kapp et al., 2019), and vocal stereotypy can be used as a form of communication, such as to express frustration or joy (Min & Fetzner, 2018). Similarly, the insistence on sameness or "rigidity" might reflect autistic people's awareness of dangers posed by distress and overload arising from the challenges of dealing with dynamic acoustic environments (Glod et al., 2019; Kerns et al., 2016; Landon et al., 2016; Williams, He, et al., 2021). Recent evidence suggests associations between sensory sensitivity and a reduced tolerance of uncertainty, the perceived insistence on sameness, anxiety, rituals, and/or compulsions in autistic people (Boyd et al., 2010; Glod et al., 2019; Hwang et al., 2020; MacLennan, Rossow, et al., 2021; Moore et al., 2021; Neil et al., 2016; Normansell-Mossa et al., 2021; Wigham et al., 2015; Williams, Suzman, et al., 2021). It seems reasonable to consider that auditory sensory processing may, at least in part, influence systems and processes responsible for self-regulation, learning, and flexibility. However, understanding the experiential, behavioral, and neurological underpinnings of this influence requires further exploration.

Numerous studies have reported strong associations between sensory reactivity and anxiety in autistic people, although the causal direction of these relationships is unclear (Mazurek & Petroski, 2019; Tavassoli et al., 2014; Uljarević et al., 2020). This association challenges the traditional pathological framing of so-called "insistence on sameness" in autistic people, which assumes they must always conform to neurotypical expectations (Pellicano et al., 2022). If such conformity leads to sensory distress and negative mental health consequences, it may be advantageous to avoid as much as possible distressing stimuli (Fodstad et al., 2021; Rodgers et al., 2023), causing an autistic person might maximize their self-determination and ability to structure their environments and routines. However, in cases where avoidance and intolerance of uncertainty contribute to a self-reinforcing cycle of limiting activity, further accommodation of avoidance may no longer be beneficial. Alternative approaches, such as gradual exposure to situations to which an autistic person might be averse, represents one possible means by which they can participate in desired activities, or foster their autonomy (Fodstad et al., 2021; Ismael, Lawson & Hartwell, 2018; Loh, Ee Marret & Chinna, 2020; Rodgers et al., 2023).

It is worth noting that aversion to sound per se is not an adequate description of the sensory challenges faced by autistic people, with music particularly being reported as pleasurable by many autistic people (Robertson & Simmons, 2015; Smith & Sharp, 2013). Indeed, music is often employed as an "autism intervention" (Marquez-Garcia et al., 2022). Although its effectiveness as a therapeutic method is not empirically validated, it is well-established that many autistic people enjoy music (Bieleninik et al., 2017; Marquez-Garcia et al., 2022; Rickson, 2021). Similarly, at times, pleasure is derived from repetitive behaviors by autistic people as a means of self-expression, self-regulation, or desired sensory feedback (Damiano-Goodwin et al., 2018; Joyce et al., 2017; Kapp et al., 2019), and motor and vocal stereotypy may sometimes reflect a search for positive and pleasurable sensory stimulation (Jones et al., 2003).

Less positively, studies have also reported that autistic people with sensory reactivity are more likely to experience sleep problems (Dwyer et al., 2022; Han et al., 2022; Linke et al., 2021), and hyper-reactivity to sensory input may predict sleep difficulties later in life (Hohn, de Veld, Mataw, can Someren & Begeer, 2019; Manelis-Baram et al., 2022; Mazurek et al., 2019). Although prior studies have yielded inconsistent outcomes with respect to those sensory modalities most critical for exacerbating sleep problems (Linke et al., 2021; Manelis-Baram et al., 2022; Tzischinsky et al., 2018), it appears that auditory filtering is a contributing factor (Hollway et al., 2013; Wang et al., 2019). Sleep problems can, in turn, negatively impact autistic people's ability to navigate the world, leading to diminished quality of life (Deserno et al., 2019; Lin & Huang, 2019; McLean et al., 2021).

BEYOND THE AUDITORY DOMAIN: CONSIDERING OTHER SENSES

Here, we have posited that processing differences in a single sensory modality, namely audition, in autistic people might be a critical and fruitful avenue to explore the broader range of sensory challenges many autistic people experience. It is widely acknowledged that autistic people show a unique profile of sensory reactivity spanning multiple modalities, and person-to-person variance in any of these sensory domains can compound and further influence social, language, and communication differences, as well as "restricted and repetitive behaviors" (He et al., 2023; Trevisan et al., 2021). Even if these initial differences are slight, they can influence how a person perceives, interprets, and responds to their environment. Hyperacusis and difficulties filtering out sound, combined with light and olfactory sensitivities, for example, may lead to an autistic person avoiding an environment full of loud sounds, bright lights, and strong smells, such as a food court in a shopping center (Ben-Sason, Katz-Zetler & Cermak, 2019; Trevisan et al., 2021).

Sensory experience plays a crucial role in forming neural circuitry (Henschke et al., 2018; Jiao et al., 2011; Kersbergen et al., 2022; Penn & Shatz, 1999). Presuming sensory encoding is altered in a unique combination of ways, this combination will likely influence neurodevelopmental outcomes and present phenotypically as a neurodivergent group such as autism. This influence has potential upstream implications on developmental trajectories within the sensory domain, and the cognitive, perceptual, regulatory, and social domains (Bradshaw et al., 2022; Bravo et al., 2017; Cotter et al., 2022; Glod et al., 2019; Green et al., 2018; Maloney et al., 2013; Samson et al., 2011; Thye et al., 2018; Williams, Campi, et al., 2021). In recent decades, growing evidence suggests that atypical sensory neural processing is an important aspect of the autistic phenotype (Baum et al., 2015; Belmonte, 2004; Brandwein et al., 2015; Cotter et al., 2022; Dinstein et al., 2012; Haigh et al., 2015; Pellicano et al., 2014).

LIMITATIONS

This narrative review has several limitations. First, it is important to acknowledge that it is conceptual, rather than systematic, in nature. Narrative reviews play a crucial role in research by synthesizing a broad range of studies and perspectives into a cohesive understanding of a topic, offering insights, and identifying trends or concepts that might not be apparent from individual studies or systematic reviews (e.g., Pruccoli et al., 2021). They provide an accessible overview for academics and practitioners, helping to establish a foundation for future research and practice (Greenhalgh et al., 2018). This narrative review is therefore not intended to replace, or be a substitute for, original research or systematic reviews but, rather, serves as a synthesis of existing knowledge from which a framework for future discovery might be developed.

Whilst we have endeavored to report accurately the published data by exploring the interface between autistic attributes and auditory processing for autistic people, we risk subjectivity bias, a common concern with narrative reviews. We sought to circumvent this bias by following narrative review protocol employing comprehensive literature searches and using our combined professional and lived expertise in autism, auditory neuroscience, and sensory processing (Greenhalgh et al., 2018). Our research team, composed of autistic and non-autistic researchers, brings diverse expertise in auditory neuroscience, audiology, psychology, psychoacoustics, education, and autism studies, enriched by personal lived experiences as autistic people and their allies. This blend of academic and experiential knowledge facilitated a comprehensive analysis that bridges theoretical research with the practical realities of the autistic experience.

FUTURE DIRECTIONS

Future investigations into the auditory profile of autistic people should work towards understanding the nature of autism and diagnosable auditory conditions. For example, studies of auditory processing in autistic populations might include assessments of different combinations of auditory profiles, and this will likely require the development of a diagnostic "toolbox" of sufficient utility to encompass the complex spectrum of hearing and listening function. Not doing so will fail to capture a sufficient understanding of auditory processing in autistic people (Williams, 2022), limiting the potential for technological or other interventions to support effective listening and communication.

Another important avenue for future research is the investigation of potential auditory subtypes within the autistic population. Examining whether the auditory profile of autistic people presents as distinct phenotypes could lead to a more nuanced understanding of the heterogeneity in auditory processing. Identifying these subtypes and their relationship to other co-occurring conditions or sensory processing differences in autism could provide valuable insights into the underlying mechanisms driving these unique auditory experiences (Kirby et al., 2021; Dwyer et al., 2020). Additionally, longitudinal examinations of traits, conditions and subtypes would be useful to identify patterns of change of auditory processing throughout the lifespan that may lie outside of normal hearing loss.

As technological advances enable more sophisticated exploration of the neural underpinnings of auditory processing, future research should also delve into the roles and interplay of subcortical and cortical mechanisms in auditory processing in autistic people (Matsuba et al., 2022). By examining the unique contributions of the subcortex and cortex and their relationship with each other, researchers should gain a more comprehensive understanding of the complex pathways involved in assimilating auditory information in autistic people. Further research is needed into the largely under-researched relationship between auditory processing and non-social autistic traits such as repetitive behaviors, particularly from a neurological perspective, including underlying mechanisms. Additionally, future investigations could include the relationship between auditory processing and repetitive self-regulation behaviors such as stimming.

CONCLUSION

Focused on the auditory modality, this review examined the autistic auditory profile and how it relates to broader autistic attributes. Data derived from empirical research and personal accounts demonstrated how sensory differences in the auditory domain impact autistic people's daily lives positively and negatively. These impacts include hyper-sensitivity, decreased sound tolerance, difficulties with speech-in-noise, misophonia, phonophobia, decreased filtering of noise, reduced adaptation to background acoustic environments, and temporal or other neurological differences in auditory information processing (He et al., 2023; Williams, He, et al., 2021). These characteristics, which can be complex and often present heterogeneously, warrant further investigation to ensure a fuller understanding of the autistic experience.

Although "hyper- and hypo-responsivity" and "sensory seeking" describe autistic behaviors defined in diagnostic manuals, the neural, behavioral, and experiential studies we reviewed demonstrated that autistic auditory processing is more intricate and complex than such descriptions warrant (Damiano-Goodwin et al., 2018; Muskett et al., 2019). Moreover, a growing body of published research suggests that auditory attributes in autistic people can influence broader behavioral and cognitive domains, including language, social communication, stimming or stereotypies and focused interests.

Understanding the neural bases of sensory processing in all modalities is crucial to understanding brain mechanisms that might account for reported autistic sensory experiences and related phenomena. This knowledge can inform other research and practice and contribute to the effective support of autistic people's sensory needs. Further fundamental research on autistic people's auditory processing is important and may bring translational and applied benefits. Yet, researchers must also be guided by questions that align with the research priorities identified by autistic people themselves (Cascio et al., 2020; Den Houting, Higgins, Isaacs, Mahony & Pellicano, 2020; Poulsen et al., 2022, Pukki et al., 2022). Adopting a co-designed approach to discovery research can inform allies of the autistic community on how to better support people with sensory processing differences who are not currently accommodated and enable autistic people to participate in the world in ways they prefer (Jagosh et al., 2015; Jaswal & Akhtar, 2019; Milton & Bracher, 2013). Furthermore, such research should address how we might maximize the autonomy of people with sensory processing differences and how certain sensory differences contribute positively to flourishing autistic lives (Frazier et al., 2018; Gillespie-Lynch, Kapp, Brooks, Pickens & Schwartzman, 2017; Pellicano et al., 2022).

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CONFLICT OF INTEREST STATEMENT

RP, PD & ZJW are members of the INSAR Autistic Researchers Committee. RP is the co-chair of the Australian Autism Research Council and a member of the Australian Society for Autism Research executive committee. RP has previously received consulting fees from Autism CRC. ZJW has received consulting fees from Roche, and ZJW and PD have received consulting fees from Autism Speaks. PD and ZJW are members of the Autistic & Neurodivergent Scholars Working for Equity in Research (ANSWER) committee of the Autism Intervention Network on Physical Health (AIR-P). The other authors report no potential conflicts of interest. The other authors have no financial relationships or potential conflicts of interest relevant to this review.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

ETHICS STATEMENT

This review is not an original research project and is not overseen by any institutional review board or ethics board. No original data were generated, analyzed, or presented in this manuscript.

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