Neuroscience and Biobehavioral Reviews 188 (2026) 106796

Contents lists available at ScienceDirect

Neuroscience and Biobehavioral Reviews

journal homepage: www.elsevier.com/locate/neubiorev

Sound hypersensitivity phenotypes and sound hypersensitivity disorder

Jose Antonio Lopez-Escamez [a,b,c,d,*], Dirk De Ridder [e], Kelly N. Jahn [f,g], Berthold Langguth [h], William Sedley [i], Jae-Jin Song [j,k], Sven Vanneste [l]

[a] Meniere's Disease Neuroscience Research Program, Faculty of Medicine & Health, School of Medical Sciences, The Kolling Institute, University of Sydney, Sydney, NSW, Australia
[b] Otology & Neurotology Group CTS495, Instituto de Investigación Biosanitaria, ibs.GRANADA, Universidad de Granada, Granada, Spain
[c] Sensorineural Pathology Programme, Centro de Investigación Biomédica en Red en Enfermedades Raras, CIBERER, Madrid 28029, Spain
[d] Ear Science Institute Australia, Nedlands, WA, Australia
[e] Departament of Neurosurgery – University of Otago, New Zealand
[f] Department of Speech, Language, and Hearing, The University of Texas at Dallas, USA
[g] Callier Center for Communication Disorders, The University of Texas at Dallas, USA
[h] Department of Psychiatry and Psychotherapy, University of Regensburg, Regensburg, Germany
[i] Translational and Clinical Research Institute - Newcastle University, United Kingdom
[j] Sensory Organ Research Institute, Seoul National University Medical Research Center, Seoul, Republic of Korea
[k] Department of Otorhinolaryngology-Head and Neck Surgery, Seoul National University Hospital, Seoul National University College of Medicine, Seoul, Republic of Korea
[l] Lab for Clinical & Integrative Neuroscience, Trinity College Institute for Neuroscience, Trinity College, Dublin, Ireland

ARTICLE INFO

Keywords:
Hyperacusis
Tinnitus
Auditory neuroscience
Noxacusis
Misophonia
Phonophobia

ABSTRACT

This paper proposes an overarching definition for *sound hypersensitivity*, a common symptom frequently observed in patients with hearing loss, tinnitus and other neurological and psychiatric disorders. This multifaceted condition includes several phenotypes, which may exist in isolation or combination in the same individual: loudness hypersensitivity (hyperacusis), noxacusis, misophonia, phonophobia and noise-induced cognitive symptoms. Some individuals with sound hypersensitivity may develop a resultant *sound hypersensitivity disorder*, a clinically heterogeneous syndrome defined by recurrent episodes of sound-induced symptoms that are associated with a negative emotional response and/or avoidance behavior leading to suffering and/or limitation of social, leisure or occupational activities. We have assembled an international, multidisciplinary working group to develop this theoretical foundation and propose objective operational diagnostic criteria for sound hypersensitivity and sound hypersensitivity disorder. Given the large co-occurrence between tinnitus and sound hypersensitivity phenotypes, it is essential to establish a common ground to differentiate sound hypersensitivity as a symptom from sound hypersensitivity disorder and distinguish between phenotypes. The distinction will facilitate pathophysiological, translational and clinical research differentiating various forms of sound hypersensitivity and separating them from tinnitus, and represent a paradigm shift in auditory and behavioral sciences. Adopting a global and multidisciplinary lens, we aim to spark a debate fostering collaboration and innovation in addressing this pervasive yet underappreciated condition involving auditory, behavioral and cognitive neurosciences.

1. Introduction

Sound amplitude modulation is a critical feature for hearing. Auditory perception relies not only on frequency discrimination, but also on loudness fluctuation, and it is essential for recognizing natural sounds and speech (Joris et al., 2004;Koumura et al., 2023).

Hyperacusis or decrease sound tolerance is an auditory sensory symptom characterized by an increased sensitivity to everyday sounds that are typically well tolerated by others (Baguley, 2003). It is reported to impact between 0.2% and 17% of the general population (Ren et al., 2021). The large variation in the reported prevalence of hyperacusis is due to the different ways in which the condition is defined, the methods used to assess it, and the populations studied (Adams et al., 2021). People with hyperacusis may find typical environmental sounds—like

* Correspondence to: Faculty of Medicine & Health, School of Medical Sciences, University of Sydney, The Kolling Institute, 10 Westbourne St, St Leonards, Sydney, NSW 2064, Australia
E-mail address: jose.lopezescamez@sydney.edu.au (J.A. Lopez-Escamez).

https://doi.org/10.1016/j.neubiorev.2026.106796
Received 12 March 2026; Received in revised form 2 June 2026; Accepted 4 June 2026
Available online 10 June 2026

Box 1
Sound, sound intensity and sound loudness.

Sound in air is a pressure wave. The ear directly senses sound pressure, which is the power carried by sound waves per unit area (W/m^2).

Sound intensity is the amount of sound energy flowing per unit time through a unit area perpendicular to the direction of wave propagation. It is proportional to pressure squared, in other words × 2 pressure = ×4 intensity, or × 10 pressure = ×100 intensity.

Sound loudness is the psychoacoustic correlate of intensity and is related to the sound pressure level (SPL). Whereas sound pressure is the raw physical pressure fluctuation below and above atmospheric pressure measured in pascals, SPL is its logarithmic expression in decibels (dB) relative to the hearing threshold (20 μPa).

Humans can encode loudness over an enormous intensity range from roughly 1×10^{-12} W/m^2 = 0 dB SPL at the threshold of hearing to approximately 1 W/m^2 = 120 dB SPL near the auditory threshold of pain (Ades et al., 1959;Salvi et al., 2022a). This logarithmic compression allows the auditory system to optimize information efficiency and permits preservation of sensitivity at low levels while preventing saturation at high levels, thereby preventing sensory overload and pain (Salvi et al., 2022a). "Dynamic range" is a term used to refer to the difference, in dB SPL, between the threshold of hearing and the loudest tolerable sound.

running water, clinking dishes, or even conversations—uncomfortable, painful, or distressing. There are distinct types of reactions to bothersome sounds such as loudness discomfort, pain, annoyance, and fear (Tyler et al., 2014).

Even referring specifically to symptoms of loudness intolerance, there is limited correlation between symptoms reported by individuals, e.g. scores on commonly-used symptom scales, and tolerance of sound intensity on formal psychoacoustic tests, for example, with loudness discomfort levels (LDLs;Sheldrake et al., 2015; Zaugg et al., 2016; Vidal et al., 2022).

A decrease of central loudness sound compression may lead to a reduced dynamic range between minimum audible and maximum tolerable sound intensity. Such cases of hyperacusis are therefore best understood as a pathological loss of logarithmic loudness compression associated with excessive central gain (Auerbach et al., 2014), increased loudness growth steepness, and/or lowered pain thresholds including pain responses to ordinary sounds. Moreover, peripheral mechanisms such as the cochlear efferent system might be involved (Liang et al., 2025). In fact, sound hypersensitivity can also occur with normal audiometric thresholds, suggesting that peripheral factors such as cochlear synaptopathy (Jahn et al., 2022) or subclinical outer hair cell dysfunction may contribute independently of central gain changes, or that they may facilitate elevated central gain.

Hyperacusis is often associated with tinnitus (Cederroth et al., 2020), which is defined as the conscious awareness of a sound in the absence of external sound (De Ridder et al., 2021;Vanneste et al., 2026). Other frequent hyperacusis co-morbidities include autism spectrum disorder (ASD;Williams et al., 2021) and migraine (Qi et al., 2024). The frequent co-occurrence of hyperacusis and tinnitus makes it difficult to investigate the differential cellular and molecular bases of sound hypersensitivity and tinnitus, respectively. This is further complicated by the lack of sensitive biomarkers for either tinnitus or hyperacusis.

Different sound hypersensitivity phenotypes have been proposed, for example:

a. Loudness hyperacusis, pain hyperacusis, annoyance hyperacusis, fear hyperacusis (Tyler et al., 2014).
b. Loudness hyperacusis, pain hyperacusis, misophonia, noise sensitivity, phonophobia (Henry et al., 2022).

Loudness hyperacusis accompanies pain hyperacusis in up to 90% of cases, whereas pain hyperacusis is present in more than half of people with loudness hyperacusis (Williams et al., 2021;Jahn et al., 2025).

Phonophobia refers to a fear of sounds, specifically requiring negative emotional or autonomic symptoms to occur in the absence of the sounds themselves, but prompted by anticipation or association (Henry et al., 2022). It is unlikely to occur in isolation but can occur as an additional symptom dimension to another form of sound hypersensitivity. In neurological practice, the term 'phonophobia' is used more broadly to refer to negative experiences of, and/or aversion to sounds, and is used to describe a symptom of certain neurological conditions such as migraine; we avoid this usage and consider that phonophobia is a specific endophenotype under the umbrella term 'sound hypersensitivity'.

Misophonia refers to the experience of anger, anxiety and/or sympathetic arousal provoked by certain sounds, independent of their loudness. Such sounds are often human-generated and typically relate to eating, drinking, speaking or breathing, but can include other sounds such as repetitive tapping or rustling packets. Misophonia is not currently recognized as a disorder in major medical or psychiatric classification systems (Edelstein et al., 2013;Rosenthal et al., 2026).

Noise sensitivity refers to a more general reactivity to, or poor tolerance of, sound, particularly being in environments with ongoing background noise, but lacks a precise definition. Symptoms of being in noisy environments can include negative emotional or autonomic consequences, as well as cognitive difficulty and fatigue. (Shepherd et al., 2019;Henry et al., 2022). Symptoms do not require the causative noise to be loud, but they could be worse with louder sounds. Noise sensitivity is common in the context of traumatic brain injury or anxiety (Shepherd et al., 2019), but can occur as an isolated state or trait, overlapping in some cases with personality type and neurodiversity conditions. However, these definitions are not consistently applied across clinical practice or research studies, nor do they offer specific diagnostic criteria that would enable accurate diagnosis and symptom surveillance (Jahn and Koach, 2023).

In the International Classification of Diseases (ICD−10), hyperacusis is defined as "an abnormally disproportionate increase in the sensation of loudness in response to auditory stimuli of normal volume." and classified in the chapter "other abnormal auditory perceptions (H93.2)" with the code H93.23. In ICD−11, hyperacusis is defined as "experiencing sounds as excessively loud, often with discomfort, despite most people tolerating them" and classified within the ear diseases chapter (Chapter 10) in the subchapter "Other specified disorders of ear, not elsewhere classified".

The extent of functional impairment caused by hyperacusis is not considered in any of these diagnostic classifications, although it varies greatly among those affected and is clinically highly relevant.

The goal of this perspective is to precisely define sound hypersensitivity phenotypes and propose diagnostic criteria for sound hypersensitivity disorder (SHD). Through this, we expect to establish a conceptual framework for clinical research to generate robust epidemiological and clinical data given the large co-occurrence between tinnitus and sound hypersensitivity phenotypes. It is essential to establish a common ground to differentiate sound hypersensitivity as a

Table 1
Sound hypersensitivity symptom definition.

Criteria A-D must be met
A. External sound elicits signs and/or symptoms in at least one of the following categories, experienced at greater-than-minimal severity[1]:
1. Increase in sound loudness perception[2]
2. Alterations in sympathetic arousal[3]
3. Difficulty performing cognitive tasks[4]
4. Ear pain, headache and/or facial muscle tension[5].
B. Signs and/or symptoms appear during sound exposure and build or persist as exposure is prolonged[6].
C. Signs and/or symptoms decrease significantly and eventually stop after cessation of sound exposure[7]
D. Sign(s) and/or symptom(s) are not better accounted for by another disease or disorder[8].

Notes
1. Signs and/or symptom severity should be quantified by a visual analog scale (0−10). A score ≥ 4 should be considered as greater-than-minimal sensitivity (Raj-Koziak et al., 2018). Each episode is temporally bounded by the onset and cessation of the triggering sound exposure, as defined by Criteria B and C in Table 1.
2. Loudness hypersensitivity is the subjective sensation of increased loudness when an external sound is occurring. Normal conversation loudness typically measures ~60 dB SPL at 1 m distance in quiet environment; tolerable loudness is 65–75 dB in environments with moderate background noise (cocktail party;Pearsons, 1977). In the absence of an external sound, loudness hypersensitivity cannot be defined.
3. Autonomic arousal refers to the activation of the autonomic nervous system which occurs in response to emotional or stressful stimuli and is not under conscious control (increased heart rate and blood pressure, rapid or shallow breathing, sweating, dilated pupils).
4. May include transient working memory impairment (holding information temporarily, performing simple calculations), reduced attention or concentration, reduced flexibility (difficulty switching between tasks), slower thinking or decision-making and task completion.
5. Sound hypersensitivity can trigger ear or facial pain, tension-type headache or migraine headache; conversely, if the headache develops in the absence of external sound, and sound hypersensitivity occurs later, the diagnosis of migraine or tension-type headache should be preferred. Headache or facial pain that continues to build and peaks after sound exposure has ended is likely to be a primary headache disorder (such as migraine or tension headache) triggered by sound, rather than being considered a primary sound hypersensitivity condition.
6. The exception is the 'phonophobia' phenotype, which often features anticipatory symptoms and thus does not have to exclusively occur during sound exposure. Otherwise, signs and/or symptoms occurring before sound exposure should be considered anticipatory and may be better explained by anxiety.
7. Signs and/or symptoms persisting with similar intensity after cessation of sound exposure are not considered and may be better explained by another behavioral disorder. Some individuals with pain hyperacusis may experience persistent pain after cessation of sound exposure.
8. The differential diagnosis should include migraine, tension-type headache, trigeminal neuralgia, generalized anxiety disorder, depression or any other neuropsychiatric condition that can better explain the symptoms. Symptoms of sound hypersensitivity occurring in the presence of one or more of these conditions should be classified as 'secondary' sound hypersensitivity, but not a primary sound hypersensitivity condition.

symptom from SHD. Clear and widely accepted definitions are essential for improving study design in basic and translational research, facilitating clinical diagnosis, reducing selection bias in clinical studies and producing reliable results in epidemiological, socio-economic and burden-of-disease studies. In addition to their importance for therapeutic progress, these definitions are also relevant for insurance, social and legal evaluations, since diagnostic labeling influences coverage, disability assessment and liability considerations.

1.1. Approach

Members of the Tinnitus Research Initiative (TRI) met in Seoul, South Korea in May 2025 and discussed the challenges in distinguishing tinnitus and hyperacusis research outcomes, given the clinical and experimental overlap between the conditions. J.A.L.E. proposed the creation of a Sound Hypersensitivity/Hyperacusis Working Group to choose TRI members who represented a broad range of subspeciality expertise and who came from four different continents. A formal Delphi process was felt by the committee to not be optimal for the condition under study, and a nominal expert group was preferred; consensus was reached through iterative rounds of videoconferencing meetings, email exchanges and revisions of the manuscript text. This process continued until all authors confirmed they agreed with all statements.

1.2. Sound hypersensitivity and sound hypersensitivity disorder

Some individuals report discomfort to moderate intensity sounds or to certain types of sounds without this phenomenon significantly affecting their lifestyle and without any relevant impairment of their quality of life. Others are severely impaired by their sound hypersensitivity complaining about anticipatory avoidance, social withdrawal, phobic episodes or panic attacks. The transition from Sound Hypersensitivity as a symptom to SHD can be gradual and may be caused or associated with the emotional and behavioral response to isolated episodes of discomfort leading to a recurrent or persistent syndromic disorder.

1.3. Sound hypersensitivity

Based on the available literature and on clinical experience, the workgroup proposes the following criteria to define the symptom of sound hypersensitivity. Table 1

2. Comments

2.1. Prevalence of sound hypersensitivity

A scoping review of 42 studies reported hyperacusis prevalence in the general population ranging from 0.2% to 17.2%, reflecting heterogeneity in its definition (Ren et al., 2021). Systematic reviews in pediatric populations reveal between 3.2% and 17.1% in children and adolescents aged 5–19 years (Rosing et al., 2016).

2.2. High-risk groups

In people with auditory disorders (i.e., chronic tinnitus or hearing loss), or neuropsychiatric disorders such as autism spectrum disorders (Williams et al., 2021), Williams syndrome (Van Borsel et al., 1997), or schizophrenia, sound hypersensitivity is much more common. Individuals with occupational sound exposure or listening demands (e.g., musicians, music students, teacher) also show elevated prevalence with studies reporting ranges roughly 3.8–67% for self-reported sound intolerance (Ren et al., 2021).

2.3. Overlap with tinnitus

Sound hypersensitivity is frequently associated with tinnitus (Cederroth et al., 2020), the subjective perception of sound in the

Table 2
Sound hypersensitivity phenotypes.

Phenotype	Loudness-dependent	Pattern-dependent	Pain	Fear	Dominant proposed system
Loudness hypersensitivity (hyperacusis)	✓✓✓	×		✓	Auditory gain
Noxacusis	✓✓	×	✓✓✓	✓	Pain coupling
Misophonia	×	✓✓✓	×	✓	Salience/autonomic /motor network
Phonophobia	✓	✓	×	✓✓✓	Fear/autonomic
Noise-induced cognitive symptoms	✓✓	✓	×	×	Frontoparietal/anterior cingulate network

absence of an external stimulus that is estimated to affect 10–15% of the population (Jarach et al., 2022). While tinnitus is often considered as a symptom rather than a disease, chronic tinnitus can evolve into a debilitating disorder, significantly impacting an individual's quality of life. Tinnitus is considered as a disorder when it is associated with suffering, related to negative behavioral, cognitive, or emotional symptoms (De Ridder et al., 2021). The prevalence of hyperacusis in individuals with any tinnitus is 3.51 times higher than in individuals without tinnitus. Moreover, the association of severe tinnitus, defined as THI score $\geq$ 58, was greater with increasing severity of hyperacusis, with the odd ratio (ORs) ranging from 8.15 to 77.4 for moderate and severe hyperacusis, respectively (Cederroth et al., 2020). Tinnitus patients with co-morbid hyperacusis typically experience higher tinnitus severity compared to those without comorbid hyperacusis (Schecklmann et al., 2014;Cederroth et al., 2020).

2.4. Sound hypersensitivity phenotypes

There are several sound hypersensitivity phenotypes, depending on the sound loudness, the nature of the sound intolerance, and the type of emotional response. These phenotypes may also overlap (Andermane et al., 2023). These phenotypes include (a) Loudness hypersensitivity (hyperacusis): Sounds of moderate intensity are perceived as uncomfortably loud; (b) Noxacusis: Sounds of moderate intensity cause physical pain in the ears (e.g., burning, stabbing, or pinching sensations); (c) Misophonia: Specific sounds not usually associated with threat provoke negative emotional and/or autonomic responses (where anxiety or fear are not the main focus); (d) Phonophobia: Sounds, and/or the anticipation of sounds, trigger anxiety or fear, sometimes leading to avoidance behaviors, and (e) Noise-induced cognitive symptoms: Environmental noise such as background chatter or traffic sounds interfere with cognitive tasks (difficulty to concentrate to perform simple calculations or hold temporary information), affective symptoms or fatigue (Table 2).

Loudness hypersensitivity is a common sensory phenotype in auditory (SNHL, tinnitus and presbycusis) and non-auditory disorders, such as autism spectrum disorder, schizophrenia, migraine and fibromyalgia (Salvi et al., 2022).

2.5. Loudness hypersensitivity (hyperacusis)

Perception of moderate intensity sounds as excessively loud, leading to discomfort on account of the loudness of the sounds.[1]

2.6. Noxacusis

Sound-evoked pain in or near the ears.[2]

2.7. Misophonia

A feeling of anger or irritation due to sound that is independent of its intensity. These sounds are often repetitive and human-generated.[3,4]

2.8. Phonophobia

A learned aversion or avoidance behavior towards sounds or environments likely to contain those sounds.[5, 6]

2.9. Noise-induced cognitive symptoms

Transient or recurrent experience of fatigue or cognitive difficulty in environments featuring a significant level of background sound (i.e., background chatter, traffic noise).[7]

2.10. Notes

1. Hyperacusis is a sensorial hypersensitivity to sound that leads to suffering and/or disability.
2. Noxacusis is a painful sound hypersensitivity with suffering and + /- disability often associated with loudness hyperacusis and may be considered an extreme hypersensitivity phenotype.
3. Certain types of sound can be perceived as painful independent of the intensity.
4. Sound annoyance or misophonia is defined as an emotional and behavioral response to specific sounds, regardless of their intensity. It is often triggered by oral/buccal movements or related to breathing, but it can include other repetitive sounds such as tapping or pen clicking. Symptoms typically include autonomic arousal. Symptoms can be specific to certain sounds and/or to certain individuals who are generating the sounds.
5. Misophonia and phonophobia both include an emotional component, that may lead to behavioral changes.
6. Phonophobia should be considered as a fear or avoidance behavior to any kind of sound and usually occurs secondary to another sound hypersensitivity phenotype, which can be of any type. Note that the term 'phonophobia' is often used in migraine to mean sound hypersensitivity (typically hyperacusis, or noxacusis), which is distinct from our proposed usage. Since phonophobia can be an anticipatory symptom, based on previous experiences, it can occur in the absence of sound exposure. We propose a biobehavioural definition that integrates both the neurological and psychiatric perspectives: phonophobia is a pathological lowering of the threshold at which sound becomes aversive, generating responses disproportionate to the objective acoustic stimulus. In other words, there is a mismatch between the auditory stimulus and the response. In the psychiatric sense, the mismatch is affective/cognitive, in the neurological sense it is sensory.
7. Noise-induced cognitive symptoms are distinct from discomfort caused by any individual sound, and also from cognitive difficulties arising from struggling to hear on account of background noise (which is the speech-in-noise or 'background chatter associated with cocktail party' problem). It is characterized by abnormally high negative impact of background sounds on cognition and/or emotional state.

2.11. Diagnostic criteria for sound hypersensitivity disorder (SHD)

Some individuals who experience sound hypersensitivity develop recurrent signs and/or symptoms that may persist beyond sound exposure and lead to an ongoing functional impairment and suffering. The

Table 3
Diagnostic criteria for sound hypersensitivity disorder (SHD).

Criteria A through E are met:

A. At least 5 episodes of sound hypersensitivity triggered by the same or similar sound stimuli[1,2,3].
B. Signs and/or symptoms are reliably triggered by the same or similar sound stimuli[4].
C. Signs and/or symptom severity do not significantly decrease after repeated exposure to the same or similar sound stimuli[5].
D. Signs and/or symptoms lead to one or more of the following behavioral or emotional responses[6].
   1. Modification of social activities to reduce sound hypersensitivity signs/symptoms[7].
   2. Avoidance of the sound stimulus that triggers symptoms[8].
   3. Aversive anticipatory emotions prior to exposure to the sound stimulus[9]
E. Signs and/or symptoms are not better accounted for by another disease or disorder.

Notes
1. Probable SHD can be diagnosed if two to four episodes have occurred. The temporal boundary of each episode is inherently defined by the duration of sound exposure rather than a fixed time window.
2. Sound hypersensitivity can be experienced with the following phenotypes: a) Loudness hypersensitivity (hyperacusis), b) Noxacusis (sound-induced ear pain), c) Misophonia, d) Phonophobia, e) Noise-induced cognitive symptoms to perform simple tasks. One or more sound-induced phenotypes can co-occur in the same patient.
3. Susceptibility to SHD from one type of stimulus may not predict reactions to other disparate types of stimuli.
4. Signs and/or symptoms triggered may include a) autonomic arousal, b) difficulties to performing cognitive tasks, c) headache and/or muscle tension.
5. An individual may be diagnosed with one or more sound hypersensitivity phenotypes.
6. Behavioral or emotional response usually occurs during sound exposure, but it may be observed before sound exposure as an anticipatory behavior. This anticipatory behavior is commonly observed in phonophobia associated with migraine.
7. Can be observed with any SH phenotype.
8. Usually observed in misophonia.
9. Can be observed in any phenotype.

behavioral change may range from anticipatory avoidance of sounds over phobic episodes or panic attacks to social withdrawal, inability to work and even to suicidal ideation.

Sound hypersensitivity disorder can be defined as a pathological reduction in the sound tolerance threshold at which sound becomes aversive, manifesting as hyperacusis, noxacusis, phonophobia, misophonia and/or cognitive symptoms, associated with suffering, defined as an unpleasant experience with negative cognitive, emotional, and autonomic impact leading to changes in behavior and functional disability (Table 3).

2.12. Comments

Epidemiological studies do not distinguish sound hypersensitivity as a symptom from SHD, and population-based studies are needed to determine SHD prevalence and its relationship with tinnitus disorder (De Ridder et al., 2021). Moreover, the prevalence of the SHD phenotypes and their associated co-morbidities deserves further research, since we can expect one or several phenotypes in the same individual.

Scientific evidence confirms that loudness hypersensitivity is strongly associated with other sensorial hypersensitivities such as photophobia through a mechanism known as central sensitization (Yunus, 2007). Individuals with hyperacusis may have significantly lower thresholds for visual (light) and tactile (pressure) stimuli (Landgrebe et al., 2009).

Furthermore, noxacusis may be associated with a generalized lowered pain threshold throughout the body and experimental data support that noise-induced hearing loss increases pain sensitivity (Manohar et al., 2020). The underlying biological explanation is central sensitization (or nociplastic pain), a mechanism where the central nervous system becomes hyper-responsive and amplifies neural signals, leading to pain hypersensitivity from both auditory and non-auditory sources (Latremoliere and Woolf, 2009). This makes the individual more sensitive to any incoming sensorial stimulus, whether it's loud sound, bright light, or physical pressure.

Concomitant sound-induced phenotypes are common in SHD (De Ridder et al., 2021; Jastreboff and Jastreboff, 2015; Salvi et al., 2022), suggesting a low threshold for sound-evoked emotional responses.

2.13. Neurophysiology of sound sensitivity

Both peripheral and central mechanisms contribute to sound hypersensitivity. Loudness perception is proportional to the overall level of sound-evoked activity in the auditory cortex (AC;Clayton et al., 2025). Accordingly, in cases of loudness hypersensitivity, increased activity in central auditory pathways is expected. Clinical and experimental evidence support that SNHL reduces cochlear neural activity and paradoxically enhances central auditory activity, indicating an increase in central gain (Auerbach et al., 2014). Determining the origin of central gain enhancement is challenging due to the complex interconnected nature of the auditory system, but animal models indicate that central gain enhancement is generally largest at the inferior colliculus (IC) and at the AC at suprathreshold intensities (Popelář et al., 1987). These changes in central gain levels are dynamic, and the magnitude and the cell types displaying central gain enhancement vary over time. The AC generally displays a fast gain increase after noise-exposure whereas the increase manifests later in the IC (Sun et al., 2008). These temporal changes in sound sensitivity are also observed in individuals with acute and chronic tinnitus (Umashankar et al., 2025).

Peripheral and central neural mechanisms contribute to loudness sensitivity and noise protection. Type II auditory nerves that innervate outer hair cells in the organ of Corti provide an input to the cochlear efferent system (Zhao et al., 2022). Mouse models lacking ATP-gated P2x7 receptors can impair type II spiral ganglion neuron efferent suppression leading to increase of active cochlear amplification and hearing hypersensitivity (Liang et al., 2025). Moreover, parvalbumin-expressing inhibitory neurons (PVNs) in the mouse AC regulate sound level and loudness perception. A mouse model of high-frequency noise exposure used to induce hyperacusis showed AC hyperactivity, PVN hypofunction and loudness hypersensitivity. Interestingly, a 40-Hz optogenetic PVN stimulation was able to enhance inhibition and desensitize loudness perception in the rodents (Clayton et al., 2025).

Noxacusis may be mediated by type II afferent fibers that are activated by tissue-damaging noise and does not require glutamate release from inner hair cells. The detection of noise-induced tissue damage is termed auditory nociception (Flores et al., 2015; Liu et al., 2015). Other theories suggest that noxacusis may be related to dysfunction of the tensor tympani muscle and/or irritation of the trigeminal nerve (Noreña et al., 2018). To date, no human functional imaging studies have been performed to test these hypotheses, and these mechanisms have not been linked to the perception of sound-evoked pain in animals or humans. Similarly, no human functional imaging data are available for phonophobia.

In humans, functional MRI studies (Gao et al., 2015) and

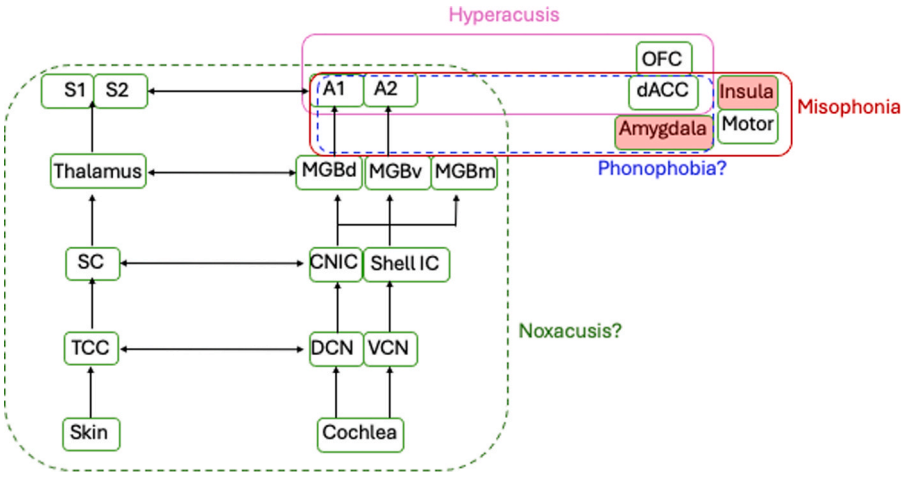

Fig. 1. Proposed brain networks associated with the central auditory pathways linked to sound hypersensitivity phenotypes, with color-coded boxes for hyperacusis (loudness hypersensitivity, purple), misophonia (red), phonophobia (blue dotted) and noxacusis (green dotted). Abbreviations: A1, A2: auditory cortex areas; CNIC: central nucleus inferior colliculus; Shell IC: shell inferior colliculus; DCN: dorsal cochlear nucleus; MGBd, dorsal division medial geniculate body; MGBm, medial division medial genicular body; dACC: dorsal anterior cingulate cortex; MGBv, ventral division medial genicular body; OFC: orbitofrontal cortex; S1, S2: somatosensory cortex; SC, superior colliculus; TCC: trigeminocervical complex; VCN, ventral cochlear nucleus. Dotted lines represent hypothesized networks, full lines represent literature-based networks. The color-filled boxes represent sound unpleasantness (Aldhafeeri, 2025).

electrophysiologic studies (Smith et al., 2025) demonstrate increased sound-evoked activity in the central auditory system of individuals with sound hypersensitivity. However, most available studies are confounded by co-morbid tinnitus (Sedley, 2019). Conceptually, one would expect that tinnitus results from the addition of central noise in the auditory system, whereas loudness hypersensitivity results from multiplicative central gain (Zeng, 2020). However, experimental evidence for this model is still lacking. Instead, available human studies suggest that non-auditory areas such as the dorsal anterior cingulate cortex, amygdala and orbitofrontal cortex are involved in loudness hypersensitivity (Song et al., 2014;Gao et al., 2015;Fig. 1).

For misophonia, the neural signature overlaps with hyperacusis, but it adds the insula (Hansen et al., 2026; Kumar et al., 2017) and motor components (Kumar et al., 2021) to the picture. The amygdala and insula in combination with nucleus accumbens reflect the unpleasantness of a sound (Aldhafeeri, 2025).

In certain tinnitus patients, frequent or constant pain, often triggered or aggravated by everyday sound has been linked to tonic tensor tympani syndrome (Westcott, 2016), associated with hyper-reactive tensor tympani muscle with reduced contraction threshold (Fournier et al., 2022).

2.14. Genetic contribution to sound sensitivity

Tinnitus has a significant heritability, according to twin, adoptee, and familial aggregation studies, particularly in individuals with European ancestry (Maas et al., 2017;Cederroth et al., 2019;Perez-Carpena et al., 2024). Genome-wide association studies have found several common variants with pleiotropic effects on tinnitus and hearing loss, but also distinct genetic variants not shared with hearing loss (Clifford et al., 2024). Conversely, severe tinnitus is associated with rare variants in coding regions with a large effect size that support a different genetic structure (Amanat et al., 2021;Escalera-Balsera et al., 2023).

Although evidence to support sound hypersensitivity heritability in humans is limited, evidence from genetically modified animal models indicate that allelic variations in several hearing loss genes, leading to a partial loss of gene function, could be involved in hyperacusis susceptibility (L.-M. Liu et al., 2023;Gagliardini et al., 2025). Several monogenic syndromes are commonly present with sound hypersensitivity, although the peripheral or central mechanisms have not been clearly defined. Sound hypersensitivity is a prominent symptom in Fragile X syndrome (FXS), the most prevalent monogenic cause of autism and intellectual disability. FXS arises through the loss of the protein encoded by the *FMR1* (Fragile X Messenger Ribonucleoprotein 1) gene, FMRP, required for normal neural circuit excitability, and its loss is associated with audiogenic seizures (Möhrle et al., 2026). Williams-Beuren syndrome is a severe multisystemic disorder caused by a large deletion on chromosome 7q11.23, which contains ~28 genes (ref). The condition shows a moderate to severe loudness hypersensitivity beninning in infancy in 35–84% of cases, and it is associated with the absence of contralateral acoustic reflexes (Silva et al., 2021).

On the other hand, common and rare variations have been associated with noise-induced hearing loss and tinnitus (Perez-Carpena et al., 2024), and these genetic factors could also contribute to reduced LDLs and sound hypersensitivity.

2.15. Psychometric assessment

Several assessment tools have been used for sound hypersensitivity and misophonia (Scheerer et al., 2026), but none of them have been psychometrically validated and none are widely accepted. Both tinnitus and sound hypersensitivity phenotypes are continuous traits, and researchers have designed psychometric tools to quantify the health-related quality of life associated with tinnitus (Jin and Tyler, 2022) or hyperacusis (Jahn, 2022a), such as the Tinnitus Handicap Inventory (Newman et al., 1996), the Hyperacusis Questionnaire (Khalfa et al., 2002) or the GUF Noise Hypersensitivity Questionnaire (Nelting et al., 2002). With these tools, individuals located at both extremes of the phenotype distribution can be identified, including patients with severe tinnitus, a proxy of tinnitus disorder. Of note, tinnitus and hyperacusis are co-morbid in many cases, and further research will need to address shared and distinct features between severe tinnitus/tinnitus disorder and SHD.

2.16. Physiological assessment

Several objective methods have been proposed to assess loudness sensitivity such as auditory brainstem response (ABR), otoacoustic emissions (OAE) suppression, middle ear muscle reflex (MEMR), functional magnetic resonance imaging (fMRI) or functional near-infrared spectroscopy (fNIRS). Individuals with sound hypersensitivity often display a reduced wave I amplitude in the ABR (indicating cochlear

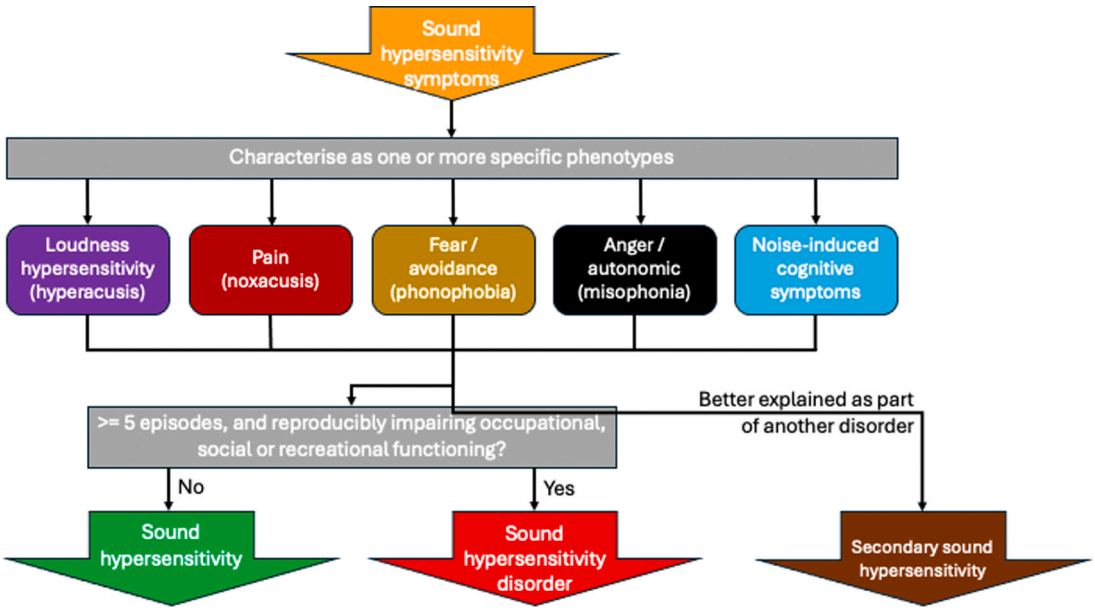

Fig. 2. Clinical workflow to define sound hypersensitivity phenotypes and sound hypersensitivity disorder.

synaptopathy) associated with an enhanced wave V amplitude, illustrating the increase in the central gain (Jahn, 2022b). The OAE suppression measure outer hair cell function while a noise is presented to the contralateral ear and assess the medial olivocochlear efferent response (Jahn, 2022b). These tests cannot be considered biomarkers since SNHL itself can produce similar findings and the concurrent of hearing loss and hyperacusis in most individuals make difficult its interpretation.

The strength of MEMR has been proposed as a subrogate of cochlear synaptopathy in individuals with noise-induced tinnitus and normal hearing (Wojtczak et al., 2017). The stapes reflex is triggered by loud sound increasing the stiffness of the ossicular chain and damping the transmission of low-frequency sound to the inner ear; however, MEMR testing in individuals with loudness or pain hypersensitivity should be used with caution since it may exacerbate symptoms, particularly in autistic spectrum disorders (Jahn, 2022b).

Among neuroimaging techniques, fMRI has a promising but still limited role in hyperacusis assessment; it can detect abnormal sound-evoked activity and connectivity in auditory and related brain networks, but it is expensive, time-consuming and studies are still few in number (Wong et al., 2020)

The fNIRS is an emerging neuroimaging technique that uses infrared light to map metabolic and blood-flow changes within the auditory cortex in real time, capturing central hyperactivity. The test has been performed using auditory stimulation in individuals with tinnitus (Shoushtarian et al., 2020), (Shoushtarian et al., 2025), but its applicability in individuals with sound hypersensitivity has not been established.

2.17. Implications for diagnostic management and treatment

Despite research efforts, objective assessments of central auditory activity fail to distinguish between tinnitus and sound hypersensitivity phenotypes in humans (Smith et al., 2025), and diagnosis currently relies on reported symptoms alone. “Objective” measures of sound hypersensitivity also fail to distinguish between SHD phenotypes. Even within a single phenotype, psychoacoustic methods of hyperacusis assessment (e.g., LDLs) are neither reliable, nor sensitive or specific enough for diagnosis since they only show limited correlation between symptoms of hyperacusis, or scores on severity questionnaires (Meeus et al., 2010;Sheldrake et al., 2015). Moreover, available experimental paradigms in animal models cannot effectively separate tinnitus and sound hypersensitivity, making it challenging to identify associations between these subjective symptoms and underlying pathophysiology.

We argue that sound hypersensitivity and SHD should be recognized as distinct neurobehavioral conditions, not merely symptoms of tinnitus or auditory dysfunction, requiring their own diagnostic criteria, mechanistic models, and treatment strategies. Given the large co-occurrence between tinnitus and sound hypersensitivity phenotypes, it is essential to develop precise criteria for sound hypersensitivity and SHD. Fig. 2 present a clinical workflow to identify sound hypersentivity symptoms, define the phenotypes and eventually SHD. This distinction will facilitate clinical and translational research in auditory and brain sciences. Adopting a global and multidisciplinary lens, we aim to spark a debate fostering collaboration and innovation in addressing this pervasive yet underappreciated condition.

With rising awareness of noise sensitivity and sensory processing disorders in both neurotypical and neurodivergent populations, clearer diagnostic boundaries could influence public health strategies, workplace accommodations, and access to treatment.

2.18. Future directions

We hope that by adopting and validating these proposed definitions of sound hypersensitivity and SHD in clinical and research practices in epidemiologic, neuroimaging, genetic and clinical research, we can facilitate progress in the following ways:

- Establishing objective measures of sound hypersensitivity and tinnitus that can differentiate between both conditions and that can be used for sensitive diagnosis and monitoring.
- Determining the prevalence and the global burden of specific sound hypersensitivity phenotypes (i.e., loudness, pain, misophonia, phonophobia, noise-induced cognitive symptoms).
- Identifying widely effective, evidence-based treatments for each phenotype.
- Developing clinical protocols and guidelines for diagnosis and management of SHD.

Acknowledgments

Jose A Lopez-Escamez has received funds from the American

Tinnitus Association (Grant #1329287) and the University of Sydney. William Sedley's salary is funded by the Wellcome Trust, as part of Clinical Career Development Fellowship. Sven Vanneste received funding from the Rainwater foundation, Royal Insitute for Deafness, EU Horizon.

References

Adams, B., Sereda, M., Casey, A., Byrom, P., Stockdale, D., Hoare, D.J., 2021. A Delphi survey to determine a definition and description of hyperacusis by clinician consensus. Int. J. Audiol. 60 (8), 607–613. https://doi.org/10.1080/14992027.2020.1855370.

ADES, H.W., MORRILL, S.N., GRAYBIEL, A., TOLHURST, G.C., 1959. Threshold of aural pain to high intensity sound. Aerosp Med. PMID: 13791879,Sep;30:678-84.

Aldhafeeri, F.M., 2025. Distinct neural circuits processing pleasant and unpleasant sounds: an fMRI-based approach. BMC Neurosci. 26 (1), 52. https://doi.org/10.1186/s12868-025-00975-3.

Amanat, S., Gallego-Martinez, A., Sollini, J., Perez-Carpena, P., Espinosa-Sanchez, J.M., Aran, I., Soto-Varela, A., Batuecas-Caletrio, A., Canlon, B., May, P., Cederroth, C.R., Lopez-Escamez, J.A., 2021. Burden of rare variants in synaptic genes in patients with severe tinnitus: An exome based extreme phenotype study. EBioMedicine 66, 103309. https://doi.org/10.1016/j.ebiom.2021.103309.

Andermane, N., Bauer, M., Sohoglu, E., Simner, J., Ward, J., 2023. A phenomenological cartography of misophonia and other forms of sound intolerance. iScience 26 (4), 106299. https://doi.org/10.1016/j.isci.2023.106299.

Auerbach, B.D., Rodrigues, P.V., Salvi, R.J., 2014. Central gain control in tinnitus and hyperacusis. Front. Neurol. 5, 206. https://doi.org/10.3389/fneur.2014.00206.

Baguley, D.M., 2003. Hyperacusis. J. R. Soc. Med. 96 (12), 582–585. https://doi.org/10.1177/014107680309601203.

Cederroth, C.R., Lugo, A., Edvall, N.K., Lazar, A., Lopez-Escamez, J.-A., Bulla, J., Uhlen, I., Hoare, D.J., Baguley, D.M., Canlon, B., Gallus, S., 2020. Association between hyperacusis and tinnitus. J. Clin. Med. 9 (8), 2412. https://doi.org/10.3390/jcm9082412.

Cederroth, C.R., PirouziFard, M., Trpchevska, N., Idrizbegovic, E., Canlon, B., Sundquist, J., Sundquist, K., Zöller, B., 2019. Association of genetic vs environmental factors in Swedish adoptees with clinically significant tinnitus. JAMA Otolaryngol. – Head. & Neck Surg. 145 (3), 222–229. https://doi.org/10.1001/jamaoto.2018.3852.

Clayton, K.K., Awwad, B., McGill, M., Stecyk, K.S., Kremer, C., Sudana, K., Skerleva, D., Narayanan, D.P., Zhu, J., Hancock, K.E., Kujawa, S.G., Kozin, E.D., Polley, D.B., 2025. Cortical PV interneurons regulate loudness perception and sustainably reverse loudness hypersensitivity. Neuron, S0896627325007986. https://doi.org/10.1016/j.neuron.2025.10.017.

Clifford, R.E., Maihofer, A.X., Chatzinakos, C., Coleman, J.R.I., Daskalakis, N.P., Gasperi, M., Hogan, K., Mikita, E.A., Stein, M.B., Tcheandjieu, C., Telese, F., Zuo, Y., Ryan, A.F., Nievergelt, C.M., 2024. Genetic architecture distinguishes tinnitus from hearing loss. Nat. Commun. 15 (1), 614. https://doi.org/10.1038/s41467-024-44842-x.

De Ridder, D., Schlee, W., Vanneste, S., Londero, A., Weisz, N., Kleinjung, T., Shekhawat, G.S., Elgoyhen, A.B., Song, J.-J., Andersson, G., Adhia, D., de Azevedo, A.A., Baguley, D.M., Biesinger, E., Binetti, A.C., Del Bo, L., Cederroth, C.R., Cima, R., Eggermont, J.J., Langguth, B., 2021. Tinnitus and tinnitus disorder: theoretical and operational definitions (an international multidisciplinary proposal). Progress. Brain Res. 260, 1–25. https://doi.org/10.1016/bs.pbr.2020.12.002.

Edelstein, M., Brang, D., Rouw, R., Ramachandran, V.S., 2013. Misophonia: physiological investigations and case descriptions. Front. Human. Neurosci. 7. https://doi.org/10.3389/fnhum.2013.00296.

Escalera-Balsera, A., Parra-Perez, A.M., Gallego-Martinez, A., Frejo, L., Martin-Lagos, J., Rivero de Jesus, V., Pérez-Vázquez, P., Perez-Carpena, P., Lopez-Escamez, J.A., 2023. Rare deletions or large duplications contribute to genetic variation in patients with severe tinnitus and meniere disease. Genes 15 (1). https://doi.org/10.3390/genes15010022.

Flores, E.N., Duggan, A., Madathany, T., Hogan, A.K., Márquez, F.G., Kumar, G., Seal, R. P., Edwards, R.H., Liberman, M.C., García-Añoveros, J., 2015. A non-canonical pathway from cochlea to brain signals tissue-damaging noise. Curr. Biol. 25 (5), 606–612. https://doi.org/10.1016/j.cub.2015.01.009.

Fournier, P., Paleressompoulle, D., Esteve Fraysse, M.-J., Paolino, F., Devèze, A., Venail, F., Noreña, A., 2022. Exploring the middle ear function in patients with a cluster of symptoms including tinnitus, hyperacusis, ear fullness and/or pain. Hear. Res. 422, 108519. https://doi.org/10.1016/j.heares.2022.108519.

Gagliardini, M., Mechaussier, S., Campos Pina, C., Morais, M., Postal, O., Jean, P., Dupont, T., Singh-Estivalet, A., Udugampolage, S., Scandola, C., Verpy, E., Libé-Philippot, B., Inbar, T.C., Schwenkgrub, J., Spinola, C.M.B., Etournay, R., El-Amraoui, A., Bathellier, B., Mallet, A., Michalski, N., 2025. Deciphering auditory hyperexcitability in *Otogl* mutant mice unravels an auditory neuropathy mechanism. Adv. Sci. 12 (19), 2410776. https://doi.org/10.1002/advs.202410776.

Gao, P.P., Zhang, J.W., Fan, S.-J., Sanes, D.H., Wu, E.X., 2015. Auditory midbrain processing is differentially modulated by auditory and visual cortices: An auditory fMRI study. NeuroImage 123, 22–32. https://doi.org/10.1016/j.neuroimage.2015.08.040.

Hansen, H.A., Norris, J.E., Bain, C.M., Ethridge, L.E., Tardif, C.L., 2026. Selective disruption of salience-network anterior insula connectivity in misophonia: a disorder-specific neural signature. Human. Brain Mapp. 47 (3), e70468. https://doi.org/10.1002/hbm.70468.

Henry, J.A., Theodoroff, S.M., Edmonds, C., Martinez, I., Myers, P.J., Zaugg, T.L., Goodworth, M.-C., 2022. Sound tolerance conditions (Hyperacusis, Misophonia, Noise Sensitivity, and Phonophobia): definitions and clinical management. Am. J. Audiol. 31 (3), 513–527. https://doi.org/10.1044/2022_AJA-22-00035.

Jahn, K.N., 2022a. Clinical and investigational tools for monitoring noise-induced hyperacusis. J. Acoust. Soc. Am. 152 (1), 553–566. https://doi.org/10.1121/10.0012684.

Jahn, K.N., 2022b. Clinical and investigational tools for monitoring noise-induced hyperacusis. J. Acoust. Soc. Am. 152 (1), 553–566. https://doi.org/10.1121/10.0012684.

Jahn, K.N., Hancock, K.E., Maison, S.F., Polley, D.B., 2022. Estimated cochlear neural degeneration is associated with loudness hypersensitivity in individuals with normal audiograms. JASA Express Lett. 2 (6), 064403. https://doi.org/10.1121/10.0011694.

Jahn, K.N., Kashiwagura, S.T., Yousuf, M.S., 2025. Clinical phenotype and management of sound-induced pain: Insights from adults with pain hyperacusis. J. Pain. 27, 104741. https://doi.org/10.1016/j.jpain.2024.104741.

Jahn, K.N., Koach, C.E., 2023. Hyperacusis diagnosis and management in the united states: clinical audiology practice patterns. Am. J. Audiol. 32 (4), 950–961. https://doi.org/10.1044/2023_AJA-23-00118.

Jarach, C.M., Lugo, A., Scala, M., van den Brandt, P.A., Cederroth, C.R., Odone, A., Garavello, W., Schlee, W., Langguth, B., Gallus, S., 2022. Global prevalence and incidence of tinnitus: a systematic review and meta-analysis. JAMA Neurol. 79 (9), 888–900. https://doi.org/10.1001/jamaneurol.2022.2189.

Jastreboff, P.J., Jastreboff, M.M., 2015. Decreased sound tolerance: hyperacusis, misophonia, diplacousis, and polyacousis. Handb. Clin. Neurol. 129, 375–387. https://doi.org/10.1016/B978-0-444-62630-1.00021-4.

Jin, I.-K., Tyler, R.S., 2022. Measuring tinnitus in pharmaceutical clinical trials. J. Acoust. Soc. Am. 152 (6), 3843–3849. https://doi.org/10.1121/10.0014699.

Joris, P.X., Schreiner, C.E., Rees, A., 2004. Neural processing of amplitude-modulated sounds. Physiol. Rev. 84 (2), 541–577. https://doi.org/10.1152/physrev.00029.2003.

Khalfa, S., Dubal, S., Veuillet, E., Perez-Diaz, F., Jouvent, R., Collet, L., 2002. Psychometric normalization of a hyperacusis questionnaire. ORL J. Oto-Rhino-Laryngol. Relat. Spec. 64 (6), 436–442. https://doi.org/10.1159/000067570.

Koumura, T., Terashima, H., Furukawa, S., 2023. Human-like modulation sensitivity emerging through optimization to natural sound recognition. J. Neurosci. 43 (21), 3876–3894. https://doi.org/10.1523/JNEUROSCI.2002-22.2023.

Kumar, S., Dheerendra, P., Erfanian, M., Benzaquén, E., Sedley, W., Gander, P.E., Lad, M., Bamiou, D.E., Griffiths, T.D., 2021. The motor basis for misophonia. J. Neurosci. Off. J. Soc. Neurosci. 41 (26), 5762–5770. https://doi.org/10.1523/JNEUROSCI.0261-21.2021.

Kumar, S., Tansley-Hancock, O., Sedley, W., Winston, J.S., Callaghan, M.F., Allen, M., Cope, T.E., Gander, P.E., Bamiou, D.-E., Griffiths, T.D., 2017. The brain basis for misophonia. Curr. Biol. CB 27 (4), 527–533. https://doi.org/10.1016/j.cub.2016.12.048.

Landgrebe, M., Frick, U., Hauser, S., Hajak, G., Langguth, B., 2009. Association of tinnitus and electromagnetic hypersensitivity: Hints for a shared pathophysiology? PLOS One 4 (3), e5026. https://doi.org/10.1371/journal.pone.0005026.

Latremoliere, A., Woolf, C.J., 2009. Central sensitization: a generator of pain hypersensitivity by central neural plasticity. J. Pain. 10 (9), 895–926. https://doi.org/10.1016/j.jpain.2009.06.012.

Liang, C., Zhai, T.-Y., Chen, J., Fang, S., Zhu, Y., Liu, L.-M., Yu, N., Zhao, H.-B., 2025. ATP-gated P2x7 receptors express at type II auditory nerves and required for efferent hearing control and noise protection. Proc. Natl. Acad. Sci. USA 122 (25), e2421995122. https://doi.org/10.1073/pnas.2421995122.

Liu, C., Glowatzki, E., Fuchs, P.A., 2015. Unmyelinated type II afferent neurons report cochlear damage. Proc. Natl. Acad. Sci. USA 112 (47), 14723–14727.

Liu, L.-M., Liang, C., Chen, J., Fang, S., Zhao, H.-B., 2023. Cx26 heterozygous mutations cause hyperacusis-like hearing oversensitivity and increase susceptibility to noise. Sci. Adv. 9 (6), eadf4144. https://doi.org/10.1126/sciadv.adf4144.

Maas, I.L., Brüggemann, P., Requena, T., Bulla, J., Edvall, N.K., Hjelmborg, J.V.B., Szczepek, A.J., Canlon, B., Mazurek, B., Lopez-Escamez, J.A., Cederroth, C.R., 2017. Genetic susceptibility to bilateral tinnitus in a Swedish twin cohort. Genet. Med. Off. J. Am. Coll. Med. Genet. 19 (9), 1007–1012. https://doi.org/10.1038/gim.2017.4.

Manohar, S., Adler, H.J., Radziwon, K., Salvi, R., 2020. Interaction of auditory and pain pathways: Effects of stimulus intensity, hearing loss and opioid signaling. Hear. Res. 393, 108012. https://doi.org/10.1016/j.heares.2020.108012.

Meeus, O.M., Spaepen, M., Ridder, D.D., Heyning, P.H.V. de, 2010. Correlation between hyperacusis measurements in daily ENT practice. Int. J. Audiol. 49 (1), 7–13. https://doi.org/10.3109/14992020903160868.

Möhrle, D., Ma, D., Xue, W., Yan, J., Cheng, N., 2026. Altered auditory maturation in fragile X syndrome and its involvement in audiogenic seizure susceptibility. Autism Res. Off. J. Int. Soc. Autism Res. 19 (1), e70152. https://doi.org/10.1002/aur.70152.

Nelting, M., Rienhoff, N.K., Hesse, G., Lamparter, U., 2002. The assessment of subjective distress related to hyperacusis with a self-rating questionnaire on hypersensitivity to sound]. *Laryngo- Rhino- Otologie*, 81 (5), 327–334. https://doi.org/10.1055/s-2002-28342.

Newman, C.W., Jacobson, G.P., Spitzer, J.B., 1996. Development of the tinnitus handicap inventory. Arch. Otolaryngol. Head. & Neck Surg. 122 (2), 143–148. https://doi.org/10.1001/archotol.1996.01890140029007.

Noreña, A.J., Fournier, P., Londero, A., Ponsot, D., Charpentier, N., 2018. An integrative model accounting for the symptom cluster triggered after an acoustic shock. Trends Hear. 22, 2331216518801725. https://doi.org/10.1177/2331216518801725.

Pearsons, K.S., 1977. Effect of tone/noise combination on speech intelligibility. J. Acoust. Soc. Am. 61 (3), 884–886. https://doi.org/10.1121/1.381343.
Perez-Carpena, P., Lopez-Escamez, J.A., Gallego-Martinez, Á., 2024. A systematic review on the genetic contribution to tinnitus. J. Assoc. Res. Otolaryngol. JARO 25 (1), 13–33. https://doi.org/10.1007/s10162-024-00925-6.
Popelář, J., Syka, J., Berndt, H., 1987. Effect of noise on auditory evoked responses in awake guina pigs. Hear. Res. 26 (3), 239–247. https://doi.org/10.1016/0378-5955(87)90060-8.
Qi, L., Jilei, Z., Lisheng, Y., Yuanyuan, J., 2024. Hyperacusis questionnaire and event-related potential correlation in migraine patients. Sci. Rep. 14 (1), 14117. https://doi.org/10.1038/s41598-024-65014-3.
Raj-Koziak, D., Gos, E., Swierniak, W., Rajchel, J.J., Karpiesz, L., Niedzialek, I., Wlodarczyk, E., Skarzynski, H., Skarzynski, P.H., 2018. Visual analogue scales as a tool for initial assessment of tinnitus severity: psychometric evaluation in a clinical population. Audiol. & Neuro-Otol. 23 (4), 229–237. https://doi.org/10.1159/000494021.
Ren, J., Xu, T., Xiang, T., Pu, J.-M., Liu, L., Xiao, Y., Lai, D., 2021. Prevalence of hyperacusis in the general and special populations: a scoping review. Front. Neurol. 12, 706555. https://doi.org/10.3389/fneur.2021.706555.
Rosenthal, M.Z., Shan, Y., Hanna, M., 2026. Misophonia is a newly defined disorder, but is it an anxiety disorder? Annu. Rev. Clin. Psychol. https://doi.org/10.1146/annurev-clinpsy-061324-071140.
Rosing, S.N., Schmidt, J.H., Wedderkopp, N., Baguley, D.M., 2016. Prevalence of tinnitus and hyperacusis in children and adolescents: a systematic review. BMJ Open. 6 (6), e010596. https://doi.org/10.1136/bmjopen-2015-010596.
Salvi, R., Chen, G.-D., Manohar, S., 2022. Hyperacusis: loudness intolerance, fear, annoyance and pain. Hear. Res. 426, 108648. https://doi.org/10.1016/j.heares.2022.108648.
Schecklmann, M., Landgrebe, M., Langguth, B., 2014. TRI Database Study Group. Phenotypic characteristics of hyperacusis in tinnitus. PLoS One. 9 (1), e86944. https://doi.org/10.1371/journal.pone.0086944.
Scheerer, N.E., Rosenthal, M.Z., Birmingham, E., Carson, T.B., Van Esch, N., Williams, Z., Iarocci, G., Jahn, K.N., 2026. Transdiagnostic mechanisms of decreased sound tolerance. Nat. Rev. Psychol. https://doi.org/10.1038/s44159-026-00565-y.
Sedley, W., 2019. Tinnitus: does gain explain? Neuroscience 407, 213–228. https://doi.org/10.1016/j.neuroscience.2019.01.027.
Sheldrake, J., Diehl, P.U., Schaette, R., 2015. Audiometric characteristics of hyperacusis patients. Front. Neurol. 6. https://doi.org/10.3389/fneur.2015.00105.
Shepherd, D., Landon, J., Kalloor, M., Theadom, A., 2019. Clinical correlates of noise sensitivity in patients with acute TBI. Brain Inj. 33 (8), 1050–1058. https://doi.org/10.1080/02699052.2019.1606443.
Shoushtarian, M., Alizadehsani, R., Khosravi, A., Acevedo, N., McKay, C.M., Nahavandi, S., Fallon, J.B., 2020. Objective measurement of tinnitus using functional near-infrared spectroscopy and machine learning. PLOS One 15 (11), e0241695. https://doi.org/10.1371/journal.pone.0241695.
Shoushtarian, M., Bravo, M.M.G., Datta, S., Fallon, J.B., 2025. Multimodal assessment of tinnitus using functional near-infrared spectroscopy and psychophysiological measures. Int. J. Audiol. 64 (5), 437–449. https://doi.org/10.1080/14992027.2023.2296866.
Silva, L.A.F., Kawahira, R.S.H., Kim, C.A., Matas, C.G., 2021. Auditory hypersensitivity in Williams syndrome. Int. J. Pediatr. Otorhinolaryngol. 146, 110740. https://doi.org/10.1016/j.ijporl.2021.110740.
Smith, S.S., Jahn, K.N., Sugai, J.A., Hancock, K.E., Polley, D.B., 2025. Objective autonomic signatures of tinnitus and sound sensitivity disorders. Sci. Transl. Med. 17 (796), eadp1934. https://doi.org/10.1126/scitranslmed.adp1934.
Song, J.-J., De Ridder, D., Weisz, N., Schlee, W., Van de Heyning, P., Vanneste, S., 2014. Hyperacusis-associated pathological resting-state brain oscillations in the tinnitus brain: a hyperresponsiveness network with paradoxically inactive auditory cortex. Brain Struct. & Funct. 219 (3), 1113–1128. https://doi.org/10.1007/s00429-013-0555-1.
Sun, W., Zhang, L., Lu, J., Yang, G., Laundrie, E., Salvi, R., 2008. Noise exposure–induced enhancement of auditory cortex response and changes in gene expression. Neuroscience 156 (2), 374–380. https://doi.org/10.1016/j.neuroscience.2008.07.040.
Tyler, R.S., Pienkowski, M., Roncancio, E.R., Jun, H.J., Brozoski, T., Dauman, N., Dauman, N., Andersson, G., Keiner, A.J., Cacace, A.T., Martin, N., Moore, B.C.J., 2014. A review of hyperacusis and future directions: Part I. Definitions and manifestations. Am. J. Audiol. 23 (4), 402–419. https://doi.org/10.1044/2014_AJA-14-0010.
Umashankar, A., Gander, P., Alter, K., Sedley, W., 2025. Short- and long-term changes in auditory sensitivity and tinnitus distress between acute and chronic tinnitus: longitudinal observation in a community-based sample. Hear. Res. 463, 109299. https://doi.org/10.1016/j.heares.2025.109299.
Van Borsel, J., Curfs, L.M., Fryns, J.P., 1997. Hyperacusis in Williams syndrome: a sample survey study. Genet. Couns. 8 (2), 121–126.
Vanneste, S., De Ridder, D., Gallus, S., Husain, F.T., Kleinjung, T., Langguth, B., Lopez-Escamez, J.A., Schlee, W., Yasoda-Mohan, A., Elgoyhen, A.B., 2026. Tinnitus. Nat. Rev. Dis. Prim. 12 (1), 29. https://doi.org/10.1038/s41572-026-00702-0.
Vidal, J.L., Park, J.M., Han, J.S., Alshaikh, H., Park, S.N., 2022. Measurement of loudness discomfort levels as a test for hyperacusis: test-retest reliability and its clinical value. Clin. Exp. Otorhinolaryngol. 15 (1), 84–90. https://doi.org/10.21053/ceo.2021.00318.
Westcott, M., 2016. Hyperacusis-induced pain: understanding and management of tonic tensor tympani syndrome (TTTS) symptoms. J. Pain. & Relief 05 (02). https://doi.org/10.4172/2167-0846.1000234.
Williams, Z.J., Suzman, E., Woynaroski, T.G., 2021. Prevalence of decreased sound tolerance (hyperacusis) in individuals with autism spectrum disorder: a meta-analysis. Ear & Hear. 42 (5), 1137–1150. https://doi.org/10.1097/AUD.0000000000001005.
Wojtczak, M., Beim, J.A., Oxenham, A.J., 2017. Weak middle-ear-muscle reflex in humans with noise-induced tinnitus and normal hearing may reflect cochlear synaptopathy. Eneuro 4 (6), ENEURO.0363-17.2017. https://doi.org/10.1523/ENEURO.0363-17.2017.
Wong, E., Radziwon, K., Chen, G.-D., Liu, X., Manno, F.Am, Manno, S.Hc, Auerbach, B., Wu, E.X., Salvi, R., Lau, C., 2020. Functional magnetic resonance imaging of enhanced central auditory gain and electrophysiological correlates in a behavioral model of hyperacusis. Hear. Res. 389, 107908. https://doi.org/10.1016/j.heares.2020.107908.
Yunus, M.B., 2007. Fibromyalgia and overlapping disorders: the unifying concept of central sensitivity syndromes. Semin. Arthritis Rheum. 36 (6), 339–356. https://doi.org/10.1016/j.semarthrit.2006.12.009.
Zaugg, T.L., Thielman, E.J., Griest, S., Henry, J.A., 2016. Subjective reports of trouble tolerating sound in daily life versus loudness discomfort levels. Am. J. Audiol. 25 (4), 359–363. https://doi.org/10.1044/2016_AJA-15-0034.
Zeng, F.-G., 2020. Tinnitus and hyperacusis: central noise, gain and variance. Curr. Opin. Physiol. 18, 123–129. https://doi.org/10.1016/j.cophys.2020.10.009.
Zhao, H.-B., Liu, L.-M., Yu, N., Zhu, Y., Mei, L., Chen, J., Liang, C., 2022. Efferent neurons control hearing sensitivity and protect hearing from noise through the regulation of gap junctions between cochlear supporting cells. J. Neurophysiol. 127 (1), 313–327. https://doi.org/10.1152/jn.00468.2021.