Central auditory processing and perception of sound

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ABSTRACT: Perception of sound without the presence of an external source, although not fully understood pathophysiologically, is known to be linked to lesions in either the peripheral or the central auditory nervous system. Functionality of the central auditory nervous system permits the processing of auditory information which is mediated in real time both as a bottom-up (from the peripheral auditory nervous system to auditory cortex) and a top-down (from the auditory cortex to subcortical structures) process. Examples of symptoms researched are auditory hallucinations and tinnitus. Auditory processing deficits, as well as, central auditory nervous pathology may partly explain patients perceiving sound in the absence of an external source. Based on current published research, an optimal clinical assessment of either psychiatric patients with auditory hallucinations or patients with tinnitus, may include central auditory processing evaluation. This evaluation may primarily include temporal processing, speech in bubble and frequency discrimination abilities of the patient to better assess everyday difficulties in listening and communication.

INTRODUCTION
Perception of sound without the presence of an external source, although not fully understood pathophysiologically, is known to be linked to lesions in either the peripheral or the central auditory nervous system. Functionality of the central auditory nervous system permits the processing of auditory information which is mediated in real time both as a bottom-up (from the peripheral auditory nervous system to auditory cortex) and a top-down (from the auditory cortex to subcortical structures) process. This short review focuses on deficits in the central auditory nervous system, which may explain the perception of sound in the absence of an external auditory source. Examples used are auditory hallucinations and tinnitus. These two clearly distinct symptoms at everyday clinical practice may provide insights into the general pathophysiology of “hearing a sound that is not there”.

PRESENTATION OF TINNITUS AND AUDITORY HALLUCINATIONS
Tinnitus is a common symptom of ENT-Audiological patients. It is described as the perception of sound in the absence of an external auditory source. The degree of everyday functionality alteration differs and is linked with personality type indicating cognitive involvement in its clinical presentation\(^2\). Numerous classification systems exist with no one prevailing as a gold standard. The most clinically useful classification distinguishes tinnitus into peripheral or central, on the basis of identified lesion; into subjective or objective and into pulsatile and non-pulsatile. A musical tinnitus is a rare phenomenon and is practically indistinguishable from a musical auditory hallucination. Peripheral tinnitus has its pathophysiological aetiology associated with disorders of the inner ear or vestibulocochlear nerve (cranial nerve VIII). Central tinnitus is associated with Central Auditory Nervous System deficits or disorders. Hyperacusis, a hypersensitivity to certain frequency and volume ranges of sound, is often reported (40\%) by patients experiencing tinnitus. Tinnitus may be a symptom of hearing loss but it may present with normal hearing sensitivity as measured by the pure tone audiogram.

Auditory hallucinations may present in psychiatric patients as the most prevalent type of hallucination.
The degree of annoyance in everyday life may vary from mild to total disruption. Auditory hallucinations may be referred to as aural hallucinations, “voices”, acoustic hallucinations or hallucinations of hearing. They are defined as auditory percepts with no appropriate source in the extracorporeal world and are conceptualised as perceptual phenomena. They may be divided on the basis of perceived content as verbal auditory hallucinations (VAHs) and nonverbal auditory hallucinations (NVAHs) and may change over time (non-stable hallucinations) or appear as a repetition of prior auditory hallucinations. Musical hallucinations are classified as NVAHs. Debate exists for the classification of musical hallucinations including verbal content in the form of lyrics. The term subvocalisation is used to denote subtle instances of motor activity within the larynx that may or may not be accompanied by VAHs. Voices perceived may be in a regular tone of voice, or whisper or shout, and they may be intelligible or unintelligible. They may be an individual’s thoughts commentary. Hallucinated speech is more often encountered in auditory hallucinations leading researchers to hypothesise that this may either reflect the language importance in human consciousness and communication or a deficit in language perception of psychiatric patients, especially those predisposed to schizophrenia. It should be mentioned that a minority of researchers refer to auditory hallucinations as cognitive phenomena. However, on the perceptual basis perceived by the majority of researchers, they are distinguished from cognitive phenomena such as auditory imagery and obsessive thoughts. Further, auditory hallucinations happen in the waking mind and are distinguished from dream-related auditory phenomena. By definition they are not the result of misinterpretation of an auditory source in the extracorporeal world and are distinguished from auditory illusions. Auditory hallucinations may be the result of pathology in the Central Auditory Nervous System and this may present similarities with central tinnitus at a neurobiological and neurophysiological level.

DEFICITS THROUGHOUT THE AUDITORY SYSTEM

The common element of both tinnitus and auditory hallucinations is that in cases where morphological changes exist, these are present in the auditory system. Tinnitus may be the result of a cochlear lesion at the level of the outer hair cells; selective hearing loss at specific frequency regions may be present or remain subclinical at the beginning of the tinnitus appearance. One of the leading hypotheses of subjective tinnitus is the perception of specific frequency sounds in the sensory absence of hearing them. Interestingly the presence of auditory hallucinations in individuals (with no psychiatric history) due to sensory deprivation is documented. This is further substantiated by the experience of musical hallucinations in individuals with severe sensorineural hearing loss. Deficits in the processing of auditory information may be present as measured by electrophysiological and psychoacoustical methodologies, when a patient is experiencing auditory hallucinations. A temporal deficit observed in auditory hallucinations during schizophrenia is associated with information coordination and auditory processing leading to timing dysfunctions together with perceptual and cognitive ones. The timing deficit is widespread from sounds of milliseconds to those of several seconds. A reduction in the gray matter volume in the left planum temporale and Heschl’s gyrus is found in first episode psychosis patients. This reduction is responsible for the disappearance of the normal asymmetry of the temporal lobes which is normally favouring the left one. This morphological asymmetry reflects the left hemisphere specialisation for language processing. Its disappearance or even reversal leads to abnormal language processing and possible verbal auditory hallucinations. Debate considering the exact site of lesion (sensory or prefrontal) exists as central auditory processing deficits may be found in hallucinating patients. Auditory information processing is known to affect schizophrenic patients (where auditory hallucinations are commonly observed) both at the level of complex stimuli and at the level of simple stimuli during routine tasks. A characteristic example is the reduced ability observed in schizophrenia to match two similar tones when separated by a brief delay. Distraction, medication or overall symptoms severity is not accounted as a contributing factor. Speech in noise perception is pathologically reduced in schizophrenia. Auditory processing starts at the level of the cochlea and extends to the level of the cortex. Auditory representation as a sensory one, is hierarchically structured with representations becoming increasingly complex in higher level auditory areas. The primary auditory cortex has a tonotopic organisation with neighbouring neurons.
responding to very similar frequencies. This representation becomes increasingly sophisticated in higher order auditory regions. Phonological word forms are represented in the middle portion of the superior temporal sulcus, semantic and prosodic language aspects are represented in the posterior temporal sulcus (Wernicke’s area) and the inferior parietal region. Both auditory hallucinations and tinnitus may be the result of a deficit (structural or functional) within the auditory nervous human network (peripheral and central auditory system). Tinnitus starting at an earlier sensory level and auditory hallucinations starting at a later sensory or higher cognitive level of the auditory system. The experience of tinnitus (hearing a “phantom” sound) is often the result of peripheral hearing loss and is related to the representation found in the central auditory nervous system. The initial neurophysiological phenomenon related to tinnitus is the following. The presence of hearing loss leads to reduced neuronal inhibition of the neurons that were tuned to the frequency that is affected (lost). This causes an increased activity of the neurons representing the affected frequency. This increased excitability is the source of the tinnitus as the pitch of tinnitus is in the hearing loss frequency range. A second neurophysiological phenomenon is the reorganisation with larger territory and increased responsiveness for the neurons that are specialised for unaffected frequencies that a subject is able to hear. Moreover, neurons corresponding to affected frequencies in the periphery are taken over by adjacent frequencies or even by other sensory systems, such as the visual system. Treatment of tinnitus may be achieved through tinnitus retraining therapy, which is a type of cognitive therapy. Musical hallucinations are associated with activation of higher order auditory cortex in the posterior temporal lobes, basal ganglia, cerebellum, inferior frontal cortex, Broca’s and Wernicke’s areas and insula. Based on current published research an optimal clinical assessment of either psychiatric patients with auditory hallucinations or patients with tinnitus, may include central auditory processing evaluation. This evaluation may primarily include temporal processing, speech in babble and frequency discrimination abilities of the patient to better assess everyday difficulties in listening and communication.
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