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 babble 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[1,2]. 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.

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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[1]. 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[2], 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[3] 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[4].

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[5]. A temporal deficit[6] 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[7]. A reduction in the gray matter volume in the left planum temporale and Heschl's gyrus is found in first episode psychosis patients[8,9]. 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[10] reflects the left hemisphere specialisation for language processing. Its disappearance or even reversal leads to abnormal language processing and possible verbal auditory hallucinations[11]. Debate considering the exact site of lesion (sensory or prefrontal) exists as central auditory processing deficits may be found in hallucinating patients[12,13,14,15]. 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[16,17,18]. 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[19]. 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[20]. 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[21] (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.

Κεντρική ακουστική επεξεργασία και αντίληψη του ήχου

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ΠΕΡΙΛΗΨΗ: Η αντίληψη ύπαρξης ήχου σε απουσία εξωτερικής ηχητικής πηγής, αν και δεν είναι πλήρως κατανοητή ως προς την παθοφυσιολογία της, συνδέεται με βλάβες, είτε στο περιφερικό, είτε στο κεντρικό ακουστικό νευρικό σύστημα. Η λειτουργία του κεντρικού ακουστικού νευρικού συστήματος επιτρέπει την επεξεργασία της ακουστικής πληροφορίας, η οποία μεταφέρεται σε πραγματικό χρόνο, τόσο από την περιφέρεια του ακουστικού συστήματος προς το κέντρο της ακοής στον εγκεφαλικό φλοιό, όσο και από τον εγκεφαλικό φλοιό προς τα υποφλοιικά κέντρα της ακοής. Παραδείγματα που έχουν ερευνηθεί είναι οι ακουστικές ψευδαισθήσεις και οι εμβοές. Τα ελλείμματα ακουστικής επεξεργασίας, καθώς και η παθολογία του κεντρικού ακουστικού νευρικού συστήματος μπορούν μερικώς να εξηγήσουν την κλινική εικόνα ασθενών που αντιλαμβάνονται ήχο, όταν αυτός δεν υπάρχει. Με βάση σύγχρονα δημοσιευμένα ερευνητικά δεδομένα η βέλτιστη κλινική προσέγγιση, είτε ψυχιατρικών ασθενών με ακουστικές ψευδαισθήσεις, είτε ασθενών με εμβοές μπορεί να περιλαμβάνει εκτίμηση ακουστικής επεξεργασίας. Η εξέταση ακουστικής επεξεργασίας, μπορεί πρωτίστως να περιλαμβάνει χρονική ανάλυση, ομιλητική ακουομετρία σε θόρυβο και διάκριση συχνοτήτων και με τον τρόπο αυτό να εκτιμά καλύτερα τα καθημερινά προβλήματα του ασθενούς αναφορικά με την ακουστική αντίληψη και την επικοινωνία του.

REFERENCES

Araneda R, De Volder AG, Deggouj N, Renier L. Altered inhibitory control and increased sensitivity to cross-modal interference in tinnitus during auditory and visual tasks. PloS One 2015;10(3)

Araneda R, De Volder AG, Deggouj N, Philippot P, Heeren A, Lacroix E, Decat M, Rombaux P, Renier L. Altered top-down cognitive control and auditory processing in tinnitus: evidences from auditory and visual spatial stroop. Restor Neurol Neurosci 2015; 33(1):67-80

Northoff G. Are auditory hallucinations related to the brain's resting state activity? A 'neurophenomenal resting state hypothesis'. Clinical Psychopharmacology and Neuroscience 2014; 12(3):189-195.

Krishnan RR, Fivaz M, Kraus MS, Keefe RSE. Hierarchical temporal processing deficit model of reality distortion and psychoses. Mol Psychiatry 2011; 16(2):129-144.

Leavitt VM, Molholm S, Foxe J. "What" versus "where" in patients with schizophrenia: An electrophysiological investigation of explicit tasks of dorsal and ventral pathway auditory processing. Biol Psychiatry 2008; 63(7):869.

Kang JI, Kim JJ, Seok JH, Chun JW, Lee SK, Park HJ. Abnormal brain response during the auditory emotional processing in schizophrenic patients with chronic auditory hallucinations. Schizophr Res 2009;107(1):83-91.

Fisher DJ, Labelle A, Knott VJ. Auditory hallucinations and the mismatch negativity: Processing speech and non-speech sounds in schizophrenia. Int J Psychophysiol 2008; 70(1):3-15.

Elvevag B, McCormack T, Brown GDA, Vousden JI, Goldberg TE. Identification of tone duration, line length, and letter position: An experimental approach to timing and working memory deficits in schizophrenia. J Abnorm Psychol 2004; 113(4):509-521.

Carroll CA, O'Donnell BF, Shekhar A, Hetrick WP. Timing dysfunctions in schizophrenia span from millisecond to several-second durations. Brain Cogn 2009; 70(2):181-190.

Collinson SL, Mackay CEOJ, James ACD, Crow TJ. Dichotic listening impairments in early onset schizophrenia are associated with reduced left temporal lobe volume. Schizophr Res 2009; 112(1-3):24-31.

Hirayasu Y, McCarley RW, Salisbury DF, Tanaka S, Kwon JS, Frumin M, et al. Planum temporale and heschl gyrus volume reduction in schizophrenia: A magnetic resonance imaging study of first-episode patients. Arch Gen Psychiatry 2000; 57(7):692-699.

L berg E, J rgensen HA, Hugdahl K. Functional brain asymmetry and attentional modulation in young and stabilised schizophrenic patients: A dichotic listening study. Psychiatry Res 2002; 109(3):281-287.

Hugdahl K, L berg E, J rgensen HA, Lundervold A, Lund A, Green MF, et al. Left hemisphere lateralisation of auditory hallucinations in schizophrenia: A dichotic listening study. Cognitive Neuropsychiatry 2008; 13(2):166-179.

Iliadou V, Iakovides S. Contribution of psychoacoustics and neuroaudiology in revealing correlation of mental disorders with central auditory processing disorders. Annals of General Psychiatry 2003; 2(1):5.

Javitt DC. Sensory processing in schizophrenia: Neither simple nor intact. Schizophr Bull 2009; 35(6):1059-1064.

Cromwell HC, Mears RP, Wan L, Boutros NN. Sensory gating: A translational effort from basic to clinical science. Clinical EEG and Neuroscience 2008; 39(2):69-72.

Cromwell HC, Panksepp J. Rethinking the cognitive revolution from a neural perspective: How overuse/misuse of the term 'cognition' and the neglect of affective controls in behavioral neuroscience could be delaying progress in understanding the BrainMind. Neurosci Biobehav Rev 2011; 35(9):2026-2035.

Holcomb HH. Tone discrimination performance in schizophrenic patients and normal volunteers: Impact of stimulus presentation levels and frequency differences. Psychiatry Res 1995; 57(1):75-82.

Iliadou VV, Apalla K, Kaprinis S, Nimatoudis I, Kaprinis G, Iacovides A. Is central auditory processing disorder present in psychosis? Am J Audiol 2013; 22(2):201-208. Retrieved from www.scopus.com

Iliadou V, Bamiou DE, Chermak GD, Nimatoudis I. Comparison of two tests of auditory temporal resolution in children with central auditory processing disorder, adults with psychosis, and adult professional musicians. Int J Audiol 2014; 53(8):507-513.

Rabinowicz EF, Silipo G, Goldman R, Javitt DC. Auditory sensory dysfunction in schizophrenia: Imprecision or distractibility? Arch Gen Psychiatry 2000; 57(12):1149-1155.

Ffytche DH, Wible CG. From tones in tinnitus to sensed social interaction in schizophrenia: How understanding cortical organization can inform the study of hallucinations and psychosis. Schizophr Bull 2014; 40(SUPPL. 4):S305-S316.

Klosterkötter J, Hellmich M, Steinmeyer EM, Schultze-Lutter F. Diagnosing schizophrenia in the initial prodromal phase. Arch Gen Psychiatry 2001; 58(2):158-164.