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Tinnitus as a Fragment of Consciousness

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Abstract

Subjective, chronic tinnitus that is tonal is a human condition that results in the perception of a continuous sound of a particular frequency, in the absence of that sound, by activation of deafferented portions of the auditory cortex. During ongoing behavior, the brain assumes various states as exemplified by the neural activity at the level of the neocortex and hippocampal formation. For the hippocampus, theta oscillations (6-10 Hz) have been associated with behaviors such as walking, running, and swimming, whereas non-theta oscillations have been associated with eating, drinking, and alert immobility. It was found that during walking, running, and swimming one's awareness of tinnitus is reduced; during eating, drinking, and alert immobility, however, one's awareness of tinnitus is enhanced. Tinnitus can be thought of as electrically stimulating one site in a conscious brain which yields the sensation of buzzing. Once the tinnitus is diminished during ongoing behavior other regions of the brain are now accessed by the hippocampus to transmit information (stored as well as sensory) that is expressed as a stream of consciousness and that assists in the execution of motor responses. This idea concurs with the views of William James established over 100 years ago.

Keywords

Theta rhythms, Traveling wave, Hippocampus, Awareness, Behavior, Humans

Introduction

Mammals assume many different states as they transition from waking to sleep. During waking, the brain exhibits low-voltage fast EEG (electroencephalographic) activity at the level of the neocortex; during sleep, spindles and large amplitude EEG activity are exhibited [1-4]. Low-voltage fast activity can also occur during sleep, but this activity is accompanied by skeletomotor atonia plus rapid eye movements. The reduction in muscle tone has been associated with the postsynaptic inhibition of alpha and gamma spinal cord neurons as well as with the presynaptic inhibition of 1a sensory afferents [5,6], and the eye movements are typically disjunctive with looped and torsional trajectories [7-9]. The eye movements during sleep lose their volitional component for the execution of saccades, smooth pursuit, and vergence [10]. Wakefulness therefore is a neocortex anchored to the sensorimotor system and receptive to feedback from the environment as the neocortex exhibits low-voltage fast activity. This activity is pronounced during walking, running, and swimming [1].

Penfield [11] believed that the cadence of consciousness during wakefulness is dependent on an intact hippocampus, which when damaged prevents against the creation of long-term memories [12]. Consciousness as envisaged by James [13] is a linear process or a stream. This is well illustrated when one walks into an office in pursuit of an item and upon forgetting what the item is one must leave the office and retrace the 'stream' to recall the item. Current evidence suggests that the hippocampus of humans and rodents exhibits similar EEG patterns for transferring information about past, present, and future events by way of a theta (6-10 Hz) travelling wave [14,15]. Focal electrical stimulation of neurons in the neocortex evokes fragments of perceptual events rather than a stream of consciousness [16]. Accordingly, the hippocampus may establish a linkage between events as spaced over one's lifetime and as stored in various locations in the central nervous system [17-19].

The hippocampal formation as well as the thalamus and amygdala has been found to be activated in humans with

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the onset of 480 nm, blue light [20], which is the wavelength of light that best induces waking state [21]. Two patterns of electrical activity in the hippocampus have been correlated with the ongoing behavior of animals [1]. In rats, hippocampal EEG is dominated by theta oscillations during walking, running, swimming, rearing, exploratory head turning, and sniffing. These behaviors have been called Type 1 and they represent volitional movements [22], or arousing conditions [23,24]. In contrast, during eating, drinking, grooming, face washing, and awake-immobility, theta is replaced by 'large amplitude irregular activity'. The behaviors associated with this activity have been called Type 2 and they represent non-volitional acts [22], or non-arousing conditions [23,24].

Tinnitus as related to wakefulness

Some 48 million people in the United States suffer from hearing loss [25], which can culminate in subjective, chronic tinnitus that is tonal [26]. In May of 2016, I woke up to find that there was ringing in my left ear. The ringing can best be described as a high-frequency hissing sound that is continuous. This tinnitus has prevailed unabated for almost one year. The cause is unknown suffice it to say that I have had a history of being on extensive medications during treatment for Burkitt's lymphoma that included the chemo-agent vincristine, which has been associated with inducing tinnitus by damaging the cochlear hair cells [27,28].

Tinnitus has been described as being similar to phantom-limb pain whereby the auditory cortex contralateral to the affected ear contains a representation of a sound in the absence of any internal or external sound source [26,29,30]. Damaged frequency bands in the cochlea are filled in by plastic changes at the level of the auditory cortex as evidenced by the enhancement of neural activity at the cortical sites coding the damaged bands [27,31,32,33,34]. The frequency bands damaged in my case were between 4 and 6 KHz as established by audiometry (Figure 1). It has been shown that activation of the auditory cortex can ameliorate the symptoms of tinnitus by reconfiguring the plastic changes in the cortex [35,36]. As well, training with appropriate frequency bands delivered through music can reduce the loudness of tinnitus [37].

My awareness of the tinnitus varied as a function of behavioral state and this awareness mapped onto Vanderwolf's [1], categorization of Type 1 and Type 2 behavior. Table 1 summarizes the various behaviors and the subjective levels of tinnitus. What is clear from the table is that during Type 1 behavior it was common for the

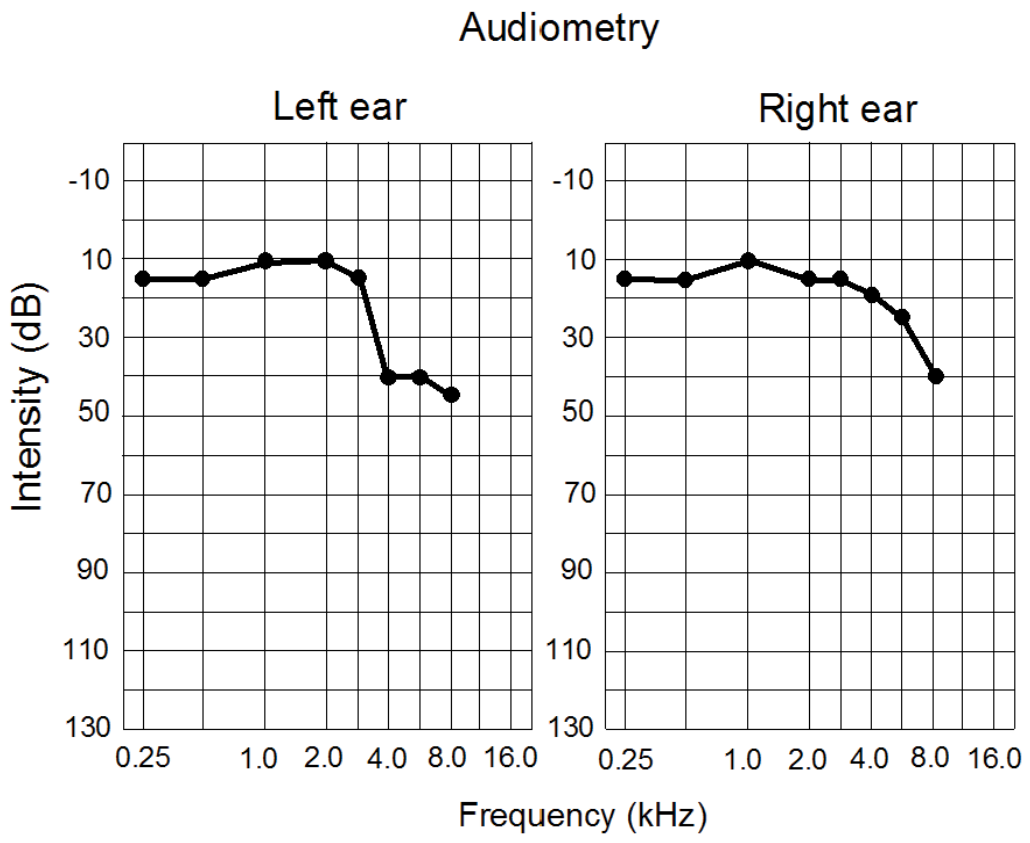

Figure 1: Audiometric data are shown for the left and right ears. Sound intensity (dB) is plotted as a function of sound frequency (kHz). Data were collected by Dr. Iamma Radace at the Clínica Pedro Cavalcanti Ltd in Parnamirim, Rio Grande do Norte, Brazil on January 24, 2017 for the patient, Edward J Tehovnik.

Table 1: Tinnitus as reported during different behavioral states for Edward J Tehovnik. The onset of the tinnitus was May 26, 2016. The observations were made over a 60 day period during the months of January and February 2017. The observations for walking, running, and swimming were based on 24 trials with each trial lasting at least 20 minutes. The observations for driving, talking, attentive writing, attentive reading, attentive listening, watching TV, lying down awake, drinking, eating, defecating, urinating, sleeping, and dreaming were based on at least 59 trials (i.e. one trial per day) with a variable trial-duration. The intensity and quality of the tinnitus remained constant from its start (May 26, 2016) to the completion of this manuscript (March 12, 2017). The tinnitus can best be described as a high-pitched hissing sound that is continuous and originating from the left side.

Behavioral state and tinnitus	
Type 1	Type 2
Walking (reduced)	Lying down awake (pronounced)
Running (eliminated)	Drinking (pronounced)
Swimming (eliminated)	Eating (pronounced)
Driving (eliminated)	Defecating (pronounced)
Talking (eliminated)	Urinating (pronounced)
Attentive writing (eliminated)	
Attentive reading (reduced)	
Attentive listening (eliminated)	
Watching TV (reduced)	
Other behaviors	
Sleeping (eliminated)	
Dreaming (eliminated)	

awareness of tinnitus to be either eliminated or reduced whereas during Type 2 behavior the awareness of tinnitus was pronounced. When viewing a television program non-attentively, however, the tinnitus was potentiated and was no different from that experienced during Type 2 behavior. Indeed the more engaged one was in the execution of a volitional act the more suppressed was the tinnitus. It is well established that during Type 1 behavior the auditory system is suppressed [38,39]. During sleep or dreaming there was never any experience of tinnitus. In the case of dreaming never did I awake from a dream to recall the prevalence of tinnitus. Finally, it was quite apparent that the tinnitus was most evident when engaged in the present rather than when contemplating past or future events.

Overall the intensity of the tinnitus was less robust in the morning hours than late at night. This may have been due to the road traffic being more conspicuous at my home and in my city in the early morning hours as compared to late at night. Road traffic has a peak sound frequency of 1 kHz with a broad distribution ranging from 0.125 to 8 kHz [40], which may have caused some masking of the tinnitus. As well, wind of high velocity (> 11 km/hr) that generated noise [41], matching the sound frequency of the tinnitus (i.e. > 4 KHz), was effective at masking the tinnitus.

Tinnitus can be thought of as the continuous activation of one site within the cerebral cortex [27,33,34], which according to Penfield's electrical stimulation experiments would produce a fragment of perception [16]. A subject is aware that tinnitus is separate from one's perceptual schema much like the perceptual effects of cortex stimulation [11], and tinnitus has characteristics similar to the percept elicited by electrical activation of cortical neurons thereby causing interference of the percept if produced externally [42,43]. This is why tinnitus can be masked using auditory stimuli. Finally, tinnitus can be overridden by behavioral state just as the effect of stimulating the cerebral cortex can be overridden by behavioral state [44].

If the hippocampus is indeed the organ that links the various regions of the brain to have a continuous stream of consciousness [11], then the disengagement of the auditory neurons mediating tinnitus might indicate that the hippocampus is now conveying and sequencing information from other regions of the brain to drive behaviors such as language, music, and locomotion. These behaviors are often accompanied by the need to link the past, present, and future in a continuous stream. Just how hippocampal theta and cortical oscillations correlate with one's awareness of tinnitus is open to exploration in humans as well as animals [45].

In conclusion, the hippocampus may enable the execution of a 'next' command to maintain a stream of consciousness going from the past to the future via its theta travelling wave [14]. One's awareness of tinnitus keeps the wave stationary by locking the hippocampus into a steady state (just a metaphor) causing one to dwell on a single input from the brain, i.e. as induced by the hyperactive cells of the auditory system coding for a single tone thereby bringing the tinnitus into consciousness.

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