

Tinnitus: An Evolutionary Symptom?

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Abstract

Introduction: The mechanism contributing to the causation of tinnitus continues to evade us. It is unlikely that our current thinking is progressing in the right direction. The literature on the subject is mounting but with no real insights into causation.

Objectives: To introduce, if possible, a paradigm shift that may produce a different trend in thinking and hopefully change our direction and lines of research.

Materials and methods: Herein is presented a hypothesis employing logical inductive reasoning aided by modern computer logic and also incorporating neuroscience, artificial intelligence, evolution and philosophy. This hypothesis attempts to employ a forensic methodology ("crime scene analysis" technique) and utilising the available evidence to build an aetiology, as other methods have not contributed significantly in deciphering causation. A pragmatic model incorporating the known features of tinnitus is thus available.

Results: A plausible explanation for the causation of tinnitus is offered with a possible link to its evasive nature, in our search for a cause.

Conclusion: The functional value of tinnitus may be provided by our evolutionary history. It is possible that tinnitus was a protective adaptive phenomenon in earlier forms but in our current environment merely contributes to nuisance value.

Keywords: Subjective tinnitus; Tinnitus mechanisms; Evolutionary symptoms

Introduction

Tinnitus is the perception of sound in the absence of an external source. It is described as 'subjective' when perceived by the patient and 'objective' when perceived in addition, by others. The vast majority of tinnitus is subjective. While the majority perceive tinnitus only as a mild symptom, many struggle with severe tinnitus that significantly impairs their quality of life. In such cases tinnitus can be a debilitating condition, that negatively impacts a patient's overall health and social well-being. Sometimes even moderate cases can interfere with the ability to work and socialize.

The U.S. Centers for Disease Control estimates that nearly 15% of the general public (over 45 million Americans) experience some form of tinnitus. Roughly 20 million people struggle with burdensome chronic tinnitus, while 2 million have extreme and debilitating problems [1]. Tinnitus is the leading service-related disability among U.S. veterans, with 9.7% of all veterans receiving service-related disability compensation [2]. An estimated one in five high schoolers suffer from tinnitus [3].

Thus tinnitus has huge negative costs, both in terms of human and economic impact. Apart from the suffering at the individual and his/her relationship level, these costs are also felt by the population at-large by way of compensation damages in associated industrial noise

induced hearing loss and in war veterans. Sums are also invested in research to find a proximate cause and thus a cure.

The mechanism contributing to the causation of tinnitus continues to evade us to date and perhaps this may be related to the insistence of neuroscience on the search for proximate explanations based on mechanisms, but a full biological explanation may require an evolutionary explanation for the origin and function of tinnitus.

There is no known effective treatment for tinnitus. Relief most often comes through various methods of "managing" the condition [4].

This hypothesis proposes:

- Tinnitus may have an evolutionary basis.
- and instantiates at a "nagging center" with a "halting problem" possibly in the thalamic regions.
- Tinnitus and hearing have separate paths. Hearing initiates peripherally and tinnitus initiates centrally.
- that compete for attention at the consciousness level.

Materials and Methods

In the best quest of testing this hypothesis, and as tinnitus is presumed to be a "vigilance" signal for danger (see below), it was felt that it might be more plausible if we could find a subset of the human population who lacked tinnitus and were at greater risk, say, of injuring in bicycle accidents when hit from behind or the side by cars that they

could not detect, as well as another with tinnitus, who were less at risk due to the persistent “cautionary signal” from tinnitus. There is no shortage of the former [5] and although the absolute absence of tinnitus was not confirmed, it is more likely than not, that they did not suffer from tinnitus. This may tentatively serve as the first arm of the quest. As expected, attempts to document the latter arm in the literature or on social media were futile.

However cycling accidents do increase as individuals grow older, with 10 to 15 year old riders being more at risk than other age groups up to about the age of 60 years, when the incidence falls [5]. This is more likely to indicate riskier behaviour by younger groups and a switch to motorised transport in the later years rather than an absolute relation to tinnitus, although such cannot be ruled out with certainty.

Faced with such circumstances, we undertook an open, self report study on 37 patients aged between 11 and 73 years and a significantly male predominance (29 males and 8 females) who were referred for the management of bothersome bilateral tinnitus, who were questioned directly about what effect tinnitus itself has on them when crossing a busy road. All of them said, that the presence of tinnitus causes them to be more “cautious/wary/tense/apprehensive/alert” and they have a tendency to check and recheck visually before crossing. Even after closer questioning, none of them admitted that it does not cause any concern on a busy road. They explained that the distraction caused by the tinnitus increases their wariness as they are aware of this distraction tendency and the disability it provokes in these and similar circumstances. When specifically propositioned that it may be their hearing loss rather than tinnitus that may be causing them concern, 34 insisted that they had considered hearing loss but felt that it was the tinnitus that caused the anxiety and the added vigilance under the circumstances. In other words, an undeniable “anxious vigilance” is maintained.

Results

None of them had an accident or any near misses supposedly due to the innate caution. Available statistics show that there were 174 pedestrian fatalities on Australian roads in 2012 [6]. The casualties were possibly much more.

Discussion

This study demonstrates:

1. A high level of alertness/vigilance in tinnitus. Such has also been reported by other authors [7]. No case of “untroubled by tinnitus” was noted.
2. The absences of any casualties. This denotes effective vigilance. (evolutionary type 1 error response. See below)

These findings lend significant weight to the validity of an evolutionary basis for tinnitus as explained above in Materials and Methods.

Nevertheless, it is accepted that one cannot convincingly test an ultimate adaptationist hypothesis only with proximate, mechanistic data. And it is also not convincing to imagine a past environment and endow it with features that support the hypothesis but that cannot be observed or measured. However it is not at all unreasonable to accept a predator/prey environment with evolutionary pressure for survival.

That tinnitus does occur in the absence of disease clearly implies that pathological causes are not absolutely necessary for its occurrence and when such do occur, they may only really be correlations and may imply that a proximate pathological cause may not be necessary and an adaptive or evolutionary mismatch hypotheses as indicated below, is probable.

Mechanics

In attempting the mechanics, it may benefit to visualize a three stage model:

1. Input
2. Mechanism
3. Output

Knowledge of any two of the above allows a pre/retro-diction or an explanation of the remnant component. However, when only one is known we need a hypothesis, which when confirmed by experimentation leads to a theory.

Thus, in the elucidation of tinnitus, it may benefit to visualize a three stage model thus:

1. Input (cause or stimulus) - a “halting problem” in the brain’s connectome parallel processor (possibly the medial and dorsal parts of the thalamus).
2. Mechanism - separate paths for hearing and tinnitus conveying perception to conscious attention.
3. Output (effect) - tinnitus percept in consciousness.

Sensation along the hearing path is initiated by sound at the ear and finally perceived consciously by the brain. Tinnitus may initiate at a “iterative (nagging) center” (the site with the “halting problem”, see below) and finally be perceived consciously, attention allowing, by the brain.

The facts [8,9] about tinnitus are:

- Tinnitus is a conscious central percept [10-13] and is not perceived during sleep or anesthesia.
- Tinnitus has several similarities with pain and the neuroses and possibly addiction [14-19].
- The qualia (subjective qualitative experience) of the tinnitus are private and privileged only to the sufferer. The point is made at this stage that tinnitus, like thoughts, feelings etc occupies the *phenomenal* consciousness domain, being private and individual.
- Functional MRIs tend to localize areas of activation in tinnitus [20-23].
- Tinnitus is best masked by incorporating the “dead” frequencies [24,25].

The following serve to elucidate the proposed hypothesis further:

Evolution

In the Heller and Bergman study [26], 94% of 80 normal individuals experienced tinnitus in quiet surroundings. Considering such a high proportion which is also available in other similar studies [27,28] including one with a placebo suggestion [28], the possibility that tinnitus may lie in our evolved cognitive architecture cannot be ruled out. Tinnitus possibly initiated as “siren” hearing, to warn the organism to be on guard constantly for predators. The “siren” sound creates an

atmosphere of present-centeredness which may have adaptive value for the organism by forcing the recruitment of a broad network of task-related neural resources. The triggered limbic and autonomic events may be such (“fight or flight”) responses. The oft-noted association of tinnitus with the limbic/autonomic response is thus easily explained.

Such a natural “siren” may be comparable in computer terms to the “halting problem” of the Turing machine (see below). As evolution proceeded, and possibly to reduce energy consumption, a higher expenditure of cognitive resources and related energetics, ‘normal hearing’ evolved with cortical representation. With the evolution of ‘normal hearing’ the evolutionary alertness advantage of tinnitus was not required and was hence subjugated to the subcortex, with access to conscious attention. This inference also helps to support the concept of separate paths for hearing and tinnitus, having evolved at different times for different needs.

As per our hypothesis, tinnitus initiated at the time when ‘normal hearing’ was not available. It is quite possible that this situation reverts back to that initial stage with the advance of a hearing loss causing a pre-normal hearing scenario again.

The experimental animal models support that tinnitus exists in our common ancestor species, at least as far back as rodents [29,30].

Another path that may point to the ancient and primal aspect of tinnitus and its evolution is its rhythmic quality. Rhythm is the systematic patterning of events in terms of timing accent and grouping. “Systematic patterning” distinguishes rhythmic patterns from random patterns of events in time. Rhythm can be periodic, like the beat of music or it may be non-periodic, like the sound of a morse code message (which manifests temporal structure without periodicity). In other words, all periodic patterns are rhythmic, but not all rhythmic patterns are periodic.

Rhythm is fundamental to the nervous system which abounds in rhythms, including the heartbeat and the rhythmic oscillations of electrical potentials in the brain (also found in numerous species of mammals including rodents, rabbits, dogs, cats, bats, and marsupials). These latter brain wave oscillations manifest different patterns.

Pulsatile tinnitus manifests a periodic rhythmic pattern and non-pulsatile tinnitus manifests a non-periodic rhythmic pattern which involves grouping or phrasing, which is the (perceptual) segmentation of events into chunks. Rhythm may thus suggest a link to the evolutionary status of tinnitus.

The acoustic element of tinnitus is tonally very basic, again suggesting an early appearance in evolution. Even birdsong is more complex suggesting a later evolution and the possibility that tinnitus emerged prior to the emergence of vocalisation is thus a distinct possibility.

Due to the eons of time involved, this a priori evolution cannot be subjected to falsifiability. Such may not matter in this case as this is a historical hypothesis about the causes of traits in current populations.

It thus appears that animals can experience tinnitus but the human characteristics of language and narrative; the tendency to attribute causes to events in the world; and perhaps the ability to experience emotions like awe make tinnitus a concern for some individuals.

Halting problem

As neurons have threshold firing only, tinnitus is most likely to be a “halting problem”, where the input of the causative signal/code is subject to an infinite loop of causation and effect.

The senses employ a form of multi-layer nets subcortically in perception which are also good at pattern recognition. In tinnitus such a layer of neurons may be subject to the above “halting problem”.

As the brain is a massively parallel processor, the term is used here in comparison to the “halting problem” of the Turing machine which in computer language is a program that will not halt on a particular contributing input. Computer scientists are able to build such machines that can mimic human abilities and still not understand the mechanism of those abilities.

As such, the exact mechanism of the “halting problem” of the Turing machine (a mathematical concept) still remains an enigma. Nevertheless it is useful to incorporate the concept into our argument as it allows us an explanation of the repetitive nature of the phenomenon of tinnitus at a computational level by the brain (thalamus).

Separate paths

At this stage of our knowledge, it is admitted that this is subject to confirmational empiricism. The following pointers however may suffice to suggest the plausibility that the hearing and tinnitus pathways may be separate:

1. Tinnitus can occur in the presence of normal hearing [26], indicating that separate pathways are highly probable.
2. Only some patients with hearing loss develop tinnitus.
3. Absence of both hearing as well as tinnitus is plausible with separate paths.
4. Somatosensory tinnitus occurs in the absence of a hearing loss.
5. If ototoxic drugs and excessive noise damage the hearing pathway then it is unlikely that tinnitus will travel the same functionally damaged path to produce a sensation of sound.
6. Cochlear implants (may) work in some cases [31] of tinnitus as they possibly repopulate the hearing pathway.
7. Support for such dual pathways is also provided by the existing concepts of a classical (lemniscal) and non-classical (extralemniscal) auditory pathway.

Consciousness

The absolute attention workspace may be occupied by one of several options to include sense data, thoughts, tinnitus etc. and the competition for this workspace is like radio channels competing for a narrow frequency band with a “winner take all” equilibrium [32].

Counselling aids the patient to take control of this space and oust the negative intruders by introducing positive thoughts (“voluntary” top-down attention) and as this space is limited, this can work. Sound therapy (masking) also works (“reflexive” bottom-up attention) by attempting to occupy this space.

The cognitive component of tinnitus is essentially the remnant of the type 1 error (false positive) response which was the more reliable interpretation necessary for the survival of our ancestors when a

predator clue emerged. Imagine an ancestor interpreting an unfamiliar sound as nonthreatening (false negative or type 2 response). Not many such interpreters would survive and reproduce. The type 1 error (false positive) response is thus etched into our constitution.

Extinction of this basic response is the aim of Cognitive Behavioural Therapy (CBT).

Evolutionary (Ultimate) Substantiation

Tinnitus is a uniform trait in mammals and possibly pre-mammals, possibly emanating from the need for predator vigilance in the need for survival [33]. This concept may also bear an evolutionary similarity to saccadic vision (employed for tracking moving prey or predators by our ancestors). Prior to the long period of evolution of the basic tasks required of an auditory system, to include acoustic feature discrimination, sound source localization, frequency analysis, and auditory scene analysis, this “siren” sound may have had survival value. Subsequently, with the evolution of the ear and normal hearing, and possibly to conserve energy this trait is suppressed but re-accessible with the loss of serviceable hearing. Another way of looking at this would be that tinnitus is genetic and hearing loss provides an epigenetic footing.

Essentially heuristic behaviours, which were quite adaptive during the earlier parts of human evolutionary history are no longer adaptive, given the current environments in which we find ourselves (mismatch) and are hence now considered (medical) neuroses. Neuroses also occur over a continuum spectrum, and like emotions are not easily subject to voluntary cortical control and are therefore available only to therapy which lies in the domain of the psychiatrist/psychologist (e.g. cognitive behavioural therapy).

Proximate Substantiation

To date fMRI is the only non invasive investigation available for the investigation of tinnitus. These studies have provided inconsistent and contradictory results and “a vague picture of the neuronal correlates of tinnitus” [34].

What is the function of tinnitus?

Tinnitus is a repetitive sound. All physical and emotional signals like pain, hunger, anxiety, etc. have a repetitive nature, thus attempting to gain attention and keep it, and thus serving a survival need. Repetitive stimuli, like flickering lights, smoke alarms create an urgency of response but once the absence of danger is realised, only serve to create an annoyance. The fact that sufficient neural machinery has evolved to create this attention seeking and a response mechanism, may denote its importance as a “warning alarm” in survival.

Perception of tinnitus in a very quiet environment may be related to the fact that tinnitus acquires a non-competitive access to consciousness in this situation and also such an environment may promote anxiety which may facilitate access [35].

Why a “siren” sound?

Ultimately survival and reproduction is the objective of every organism. To this end every (evolutionary) adaptive mechanism is dedicated. In a predator coexisting environment, a method of surveillance is essential. These methods essentially only depend on the basic available perceptory armamentarium i.e. the senses, for an immediate response as opposed to the ‘learned’ response.

Some evolutionary pressure considerations may provide a clue:

1. The visual sensation is actually the most reliable for survival and only a 360 degree vision in all axes, at all times, would be helpful but this is a physical unreality under available anatomical constraints and any other misinterference with vision would itself threaten survival. Some organisms may have followed this path with extinction consequences.

2. The olfactory sensation is the most unreliable for survival and hence the most likely to be ignored by the organism. The smell sense is more primitive in evolution, with individual (not species) specific preferential links (and related only to specific odorants) to the limbic/autonomic systems [36]. Thus it is unlikely to create an atmosphere of urgency. Also, in the competition for attention, hearing trumps olfaction. In falling to sleep (losing consciousness) hearing is the last sensation to disappear. Also, because of the paucity of spatial localisation, olfaction cannot be concerned with precise environmental details. Chemical sensitivity is the oldest response of animals to the environment and with the development of the neopallium, it appears that auditory and visual sensations gained prominence [37]. It is a common experience of pet owners that unfamiliar smells provoke curiosity and unfamiliar sounds provoke caution. Nevertheless, in earlier times, some organisms may have followed this path to extinction.

3. The touch and taste sensations are “too close for comfort” under predator supervision. Again, this path may have been followed by some organisms with guaranteed extinction.

A further consideration

Working memory (and “attention”) were initially explored by Alan Baddeley with the concept of the “Central Executive (CE)” [38]. With the plethora of information available, entry into “attention” occurs after filtration by the CE conglomerate of the prefrontal cortex (PFC) and the basal ganglia (BG). Essentially PFC allows prioritisation of current task goals (maintaining focus) and BG provide the mental muscle to block out information that does not match these goals. Emotional stimuli dependent on Darwinian hierarchy for survival gain most priority. In other words, evolutionarily, the brain is always on high alert for perceived threats. The emotional salience of tinnitus is undoubted.

There is a time delay between conscious awareness and the emotion. Similar delays between spontaneous voluntary acts and “readiness potentials” are available elsewhere in cognitive neurophysiology [39].

It is plausible that there is a persistent pre-tinnitus activity (innate evolutionary) that is filtered into awareness as tinnitus when there is malfunction of the central executive blocking mechanism (BG). Such occurrences have been documented [40,41].

Predictions

1. Due to the proximity/commonality (cf. also quantum computation possibility) of the prefrontal – limbic path in these afflictions, it is likely that tinnitus may be co-morbid with anxiety, depression, chronic pain, sleep disorders and perhaps addiction including gambling [42]. A genetic linkage may also contribute.

2. Being an evolutionary phenomenon, it is more likely that tinnitus may only succumb to psychotherapy in some cases [4].

3. The most effective curative (as opposed to management) therapy is Cognitive Behavioural Therapy (CBT) [43-45].

Tinnitus is annoying and unmanageable only when the limbic and autonomic systems are recruited. The measured loudness of tinnitus is maximally within 30 to 40 dB of threshold, which by itself is not significantly loud but the associated limbic and autonomic system recruitment provoke anxiety and depression at a subcortical level. CBT is helpful as it attempts to alter the subcortical response but does not affect the acoustic component of tinnitus thereby rendering it impotent and nonreactive [46].

4. The probability of success of any CBT may be made available by prior assessment of prefrontal (control) testing by using the Stroop Color-Word Interference Task or similar tasks.

5. Drug therapy must aim at cognition-altering or attention-altering medication without affecting reason/consciousness. It may also be possible in future to provide BG neuroreceptor exo-agonists to mount an effective blockage to innate tinnitus/anxiety/depression/chronic pain/addiction and deny entry to limbic and consciousness paths. Such endo-neurotransmitters (cf. endomorphins provoked by belief) may possibly be contributing to the minor reported successes, and are essentially a “placebo effect”.

Conclusion

A credible mechanism for tinnitus must conclusively explain how tinnitus occurs in the absence of a hearing loss. It must also explain why tinnitus only occurs in some but not all cases of hearing loss.

It is proposed here that tinnitus is a maladaptive evolutionary trait that in humans resulted from phylogenetic inertia [47], and in the modern human constitutes a mismatch between a slow-evolving organism and a changing environment [33].

It is also proposed that hearing and tinnitus occupy separate proximate paths competing for conscious ‘attention’.

Further discussion including challenges to current concepts is available elsewhere [48]. Similar to the pragmatic solar model of the atom and the double helix structure of the DNA molecule, this hypothesis awaits empiric confirmation which in this case may be available with advances in technology, to detect the tiny sequential changes that occurred over millions of generations that have resulted in partially differentiated components, that may serve many functions in parallel [33,42].

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