340 Somatic Modulation of Tinnitus III: Prevalence and Properties in Profoundly Deaf Subjects. A Functional Cochlea Is Not Necessary for Somatic Modulation of Tinnitus

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Two lines of evidence imply a close relationship between tinnitus and non-auditory inputs to the central nervous system.

I. Somatic Tinnitus Syndrome

- **Non-auditory sensory input from the head or neck can precipitate tinnitus**
- **The syndrome can occur in people with no hearing loss**
- **The occurrence of tinnitus is temporally associated with an insult to the head or upper cervical region**
- **Tinnitus occurs in the ear ipsilateral to the insult.**

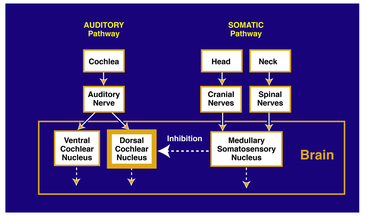
Example 1: Somatic Tinnitus Syndrome

As a 50 year old man was swallowing some sleeping pills, he sneezed and developed acute right ear pain. After a night's sleep, he developed **right ear tinnitus**.

An ENT evaluation detected an **abrasion of his right nasopharynx**, which resolved uneventfully. His **audiogram was normal**. He matched his tinnitus to a 10 kHz tone.

His right ear tinnitus has persisted for more than a year

Dorsal Cochlear Nucleus Disinhibition Hypothesis



The Dorsal Cochlear Nucleus Disinhibition Hypothesis can account for (a) the cardinal features of the somatic tinnitus syndrome and (b) tinnitus related to a disorder of the peripheral auditory system.

It is well established that disorders of the auditory periphery, which are associated with decreased spontaneous activity of the primary auditory nerve fibers, lead to an increased level of spontaneous activity of the dorsal cochlear nucleus (Kaltenbach et al., 1996). It is also well established that somatosensory input from the head and neck can modulate the activity of the dorsal cochlear nucleus through the pathway diagrammed at the left (Kanold et al., 2001).

The Dorsal Cochlear Nucleus Disinhibition Hypothesis, diagrammed at the near left, describes a mechanism by which the auditory and non-auditory systems interact at the level of the dorsal cochlear nucleus to influence the level of spontaneous activity of the dorsal cochlear nucleus. The development of tinnitus depends on the interplay between the input from the auditory system and the input from the somatosensory system on the dorsal cochlear nucleus.

Not only can the somatic tinnitus syndrome occur in a "pure" form as in the example at the far left, but also the input of the somatosensory system in the presence of a hearing loss can play a major role in determining whether or not tinnitus occurs due to a hearing loss.

II. Somatic Modulation of Tinnitus (forceful head-, neck-, or jaw-contractions can induce tinnitus or change ongoing tinnitus)

Previous Results:

Twenty percent of patients in our Tinnitus Clinic report that they can modulate their tinnitus with either a head and neck contraction or a change of head position. Møller et al. (1992) have shown that median nerve stimulation modulates tinnitus in nearly 40% of subjects. Rubinstein et al. (1993) have reported that about 30% of subjects can modulate their tinnitus with jaw movements. Our previous studies have shown that about 75% of all subjects in our Tinnitus Clinic can modulate their tinnitus with intense head and neck contractions (A). Their tinnitus can become louder, softer, change pitch or change location. Likewise, if non-clinical subjects have tinnitus in the quiet, even if very faint, 75% of them likewise can modulate their tinnitus (B). Furthermore, of those who have no tinnitus whatsoever in the quiet, 50% develop a transient auditory perception (tinnitus) with forceful head, neck, or jaw contractions (C).

The question then arises whether somatic modulation of tinnitus is related to generation of a sound by some of these muscle contractions that is then heard by the ear and thereby influences the ongoing tinnitus perception. The report by Bento, et al., (1998) makes this question more than a hypothetical possibility. They reported that a patient's chronic, life-long, monaural, high-pitched, tonal tinnitus could be temporarily abolished by paralysis of all muscles (curare) and then permanently abolished by transection of the middle ear muscle tendons.

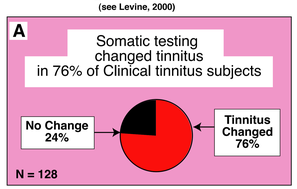
Hearing Subjects, Clinical

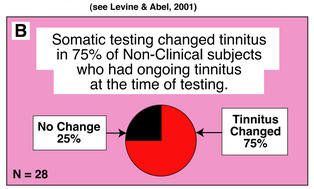
(see Levine, 2000)

Hearing Subjects, Non-Clinical

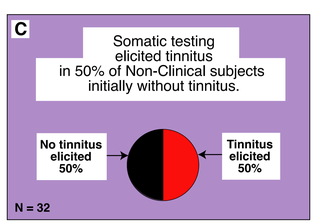
(see Levine & Abel, 2001)

Subjects With Tinnitus





Subjects Without Tinnitus

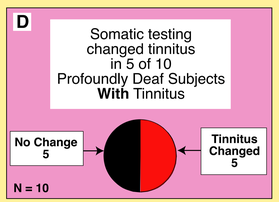


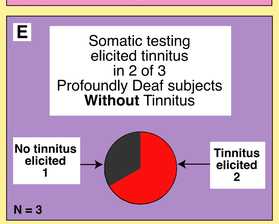
New Results:

To answer the question whether somatic modulation of tinnitus is mediated through sounds produced by the subjects, we studied somatic modulation in 13 profoundly deaf subjects*.

- **10 subjects had ongoing tinnitus. 5 of these 10 subjects could modulate their tinnitus with head, neck, or jaw contractions. (D)** Tinnitus loudness increased for 3 subjects and decreased for 2 subjects (one subject's tinnitus could not be heard).
- **3 subjects had no ongoing tinnitus at the time of testing. 2 of the 3 subjects could induce an auditory perception with forceful head, neck or jaw contractions. (E)**

Non-Hearing Subjects





Example 2. Somatic testing modulated tinnitus of a profoundly deaf subject who had ongoing tinnitus.

This 52 year old man had received a right cochlear implant 16 years earlier. He had no tinnitus with his processor connected but heard "wind" in his right ear with the processor disconnected.

Condition*	**Right** Ear Tinnitus	Left Ear Tinnitus
Baseline (0 - 10 Scale)	**4**	**0**
3. Open Jaw Agains Resistance	5	0
5. Protrude Jaw Against Resistance	5	0
12. Forehead Pressure	5	0
15. Right Temple Pressure	6	0
18. Left Turn (see Methods)	5	0
19. Left Sternocleidomastoid	5	0

*Only maneuvers that modulated his tinnitus are shown.

His tinnitus persisted louder for up to 2 minutes with forehead pressure and 1 minute with right temple pressure

Example 3. Somatic testing elicited tinnitus in a profoundly deaf subject who had no ongoing tinnitus

This 52 year old woman had received a left cochlear implant 12 years earlier. She had no tinnitus with her processor connected or disconnected. Three months prior to testing, she had experienced 45 minutes of left ear tinnitus which reoccurred three times that week, but not subsequently.

Condition*	Right Ear Tinnitus	**Left** Ear Tinnitus
Baseline (0 - 10 Scale)	**0**	**0**
2. Open jaw	0	1
5. Protrude Jaw Against Resistance	0	0.5
10. Retract Jaw	0	1

*Only maneuvers that modulated her tinnitus are shown.

Methods

Somatic Testing

25 brief, forceful contractions were made by each subject in a low-noise room.

Duration of the contractions was only a few seconds -- just enough time for the subject to judge his/her auditory perceptions.

10 contractions involved **jaw**
10 contractions involved **head and neck**
5 contractions involved **extremities**

Jaw contractions

1) clench the teeth together forcefully
2,3) maximally open mouth, with and without restorative pressure
4,5) maximally protrude jaw, with and without restorative pressure
6,7) maximally slide jaw to left, with and without restorative pressure
8,9) maximally slide jaw to right, with and without restorative pressure
10) maximally retract jaw

Head and Neck contractions

With the head in the neutral position, contractions were made to resist maximal pressure applied by the examiner to:

11) occiput
12) forehead
13) vertex
14) mandible (upward)
15) right temple
16) left temple
17) with the head turned to the right, maximally resist the tortional force on the right zygoma
18) with the head turned to the left, maximally resist the tortional force on the left zygoma
19) with the head turned to the right and tilted to the left, maximally resist force applied to the left temple (left sternocleidomastoid)
20) with the head turned to the left and tilted to the right, maximally resist force applied to the right temple (right sternocleidomastoid)

Extremity contractions

21) locking the fingers of the 2 hands together and pulling as hard as possible

Resisting maximal pressure to:
22) right shoulder abduction
23) left shoulder abduction
24) right hip flexion
25) left hip flexion

***Testing of profoundly deaf subjects:**

Subjects were 13 postlingually deaf adults (7 males, 6 females, ages 37 to 69, mean age 51)

Each subject had received a cochlear implant for profound bilateral deafness

Duration of implantation ranged from 9 months to 16 years (mean = 8 years)

Subjects were tested with their cochlear implant processors **disconnected**

Subjects were recruited from the Massachusetts Eye and Ear Infirmary Cochlear Implant Laboratory's research subjects

Discussion

1. In profoundly deaf subjects, somatic-auditory neural interactions within the central nervous system cause somatic modulation of tinnitus.

In two of the deaf subjects without tinnitus, somatic manipulations elicited tinnitus and in half of the deaf subjects with tinnitus, somatic manipulations changed their tinnitus percept [somatic modulation]. Because these subjects are deaf, their somatic modulation of tinnitus must occur within the central nervous system.

2. In hearing subjects, somatic-auditory neural interactions within the central nervous system probably cause somatic modulation of tinnitus.

The similarities in the characteristics of the changes in auditory perception that occur in deaf people and hearing people suggest that the same mechanism operating in the profoundly deaf is operating in most, if not all, of the other groups. Thus we conclude that somatosensory-auditory neural interactions within the central nervous system account for (a) most, if not all, somatic modulation of ongoing auditory perception and (b) the development of auditory percepts from somatic testing in subjects without tinnitus.

3. What neural system is responsible for somatic modulation of auditory perception (somatic modulation of tinnitus)?

The cutaneous sensory system is unlikely. Never in our clinical experience or from clinical reports have intact patients reported that light touch can modify auditory perception. The only report of cutaneous stimulation causing modulation of auditory perception is in two patients who had been deafened by posterior fossa surgery (Cacace et al. (1999)).

The motor system is likely. It is almost exclusively non-noxious but **forceful** muscle contractions that elicit modulations of auditory perception. Such contractions involve (a) the entire voluntary efferent motor system [motor cortex, corticospinal and corticobulbar tracts, and primary motor neurons], and (b) the motor afferent system, which begins with the deep muscle receptors such as the muscle spindles and tendon organs.

Muscle fatigue abolishes somatic modulation of auditory perception. Serendipidously we made the following observations.

Example 4. A 57 year old man with lifelong non-lateralized tinnitus could increase the loudness of his tinnitus with jaw protrusion. After being a subject of an fMRI experiment in which he repeatedly modulated his tinnitus with jaw protrusion for about an hour, for the next 3-4 days he could not modulate his tinnitus, after which the ability to modulate with jaw protrusion gradually returned.

Muscle fatigue is principally due to fatigue (weakening) of the muscle fibers. Unlike the the motor efferent system, the motor afferent system requires contraction of the muscle fibers to be activated. Therefore, muscle fatigue inactivates the motor afferent system. Hence, the **motor afferent system [from muscle spindles and Golgi tendon organs] is responsible for somatic modulation of auditory perception.**

This conclusion is consistent with Kanold and Young's findings (2001), which implicate the pinna's muscle spindles and/or Golgi tendon organs as the likely source of neural activity which ultimately affects the cat's dorsal cochlear nucleus.

The Golgi tendon organ senses muscle tension and the spindle muscle length. Because somatic testing is done principally with **isometric** muscle contractions [i.e. no change in muscle length], we favor the Golgi tendon organ as the source for somatic modulation of auditory perception.

4. Where in the Central Nervous System do the somatosensory and auditory systems interact to modify auditory perception?

A possible site of neural somatosensory-auditory interactions is the inferior colliculus, since it is known to exhibit tinnitus-related abnormalities and it receives somatosensory inputs (Melcher et al., 2000). Experimentally, the firing of all units in the cat central nucleus of the inferior colliculus can be somatically modulated (Davis, 1999).

The dorsal cochlear nucleus appears to be critical when tinnitus is due to ear disorders (Kaltenbach & McCaslin, 1996). We have previously described the somatic tinnitus syndrome and, based on its clinical features, proposed a model with dorsal cochlear nucleus playing a pivotal role (Levine, 1999a). If the change in auditory perception is unilateral, then the cochlear nucleus becomes a highly likely locus for the site of somatic-auditory interaction, as we have proposed previously to explain the unilateral tinnitus of the somatic tinnitus syndrome. Non-lateralized tinnitus suggests either bilateral cochlear nuclei or some higher center such as the inferior colliculus.

Conclusions

1. **Somatic modulation of tinnitus demonstrates the interaction of the central auditory nervous system with the central somatosensory system.**
2. **An auditory sensation can be created by somatosensory stimulation alone.**
3. **Somatosentory modulation of auditory perception probably originates peripherally from muscle spindles and/or Golgi tendon organs.**
4. **Because somatic testing can suppress some subjects' tinnitus, understanding somatosensory-auditory interactions could lead to more effective tinnitus treatments.**
   - for example, electrical stimulation of the Golgi tendon organs could diminish or abolish tinnitus in some cases.

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Website where papers are available:
www.LEVINEtinnitus.org