

All that rings is not from the ear: somatic tinnitus in non-clinical subjects and the profoundly deaf

Levine RA^{*}, Abel M and Cheng H

Massachusetts Eye and Ear Infirmary; Massachusetts General Hospital; Harvard Medical School; Harvard Dental School; Massachusetts Institute of Technology, Boston

Evidence has been accumulating linking clinical tinnitus to the somatosensory system. Most clinical tinnitus patients can change the acoustic properties of their tinnitus with forceful head and neck contractions. The significance of such somatic modulation of tinnitus was assessed by testing non-clinical subjects. Like clinical tinnitus patients, about 80% of non-clinical subjects, who had ongoing tinnitus at the time of testing (whether or not they had been previously aware of it), could modulate their tinnitus with head and neck contractions. Half of those with no tinnitus at the time of testing could elicit a tinnitus-like auditory percept with head and neck contractions. Because similar results were found in the profoundly deaf, we conclude that neural somatosensory-auditory interactions within the central nervous system are accounting for most, if not all, somatic modulation of tinnitus as well as the development of auditory percepts with somatic testing. Somatic influences upon auditory perception are not limited to tinnitus subjects but are a fundamental property of the auditory system.

Introduction

Tinnitus is a many faceted symptom. It may be due to a sound generated by an acoustic source within the body (objective tinnitus) or it may have no acoustic source (subjective tinnitus), in which case it is a purely neural phenomenon. Subjective tinnitus has been characterized by (1) assessing its acoustic features such as with pitch and loudness matching, as well as with the effect of external sounds upon its perception (masking properties) or (2) its affective features through psychological profiles of the patient.

Another aspect of tinnitus that has received much less attention is the somatic component. It has long been known, almost as a curiosity, that some people can modulate their tinnitus somatically. Møller et al. showed that median nerve stimulation could modulate tinnitus in close to 40% of subjects (Møller et al 1992). Rubinstein et al. found that about a third of their subjects could influence their tinnitus with jaw movements or pressure on the temporomandibular joint (Rubinstein 1993). When interviewed, about 20% of our tinnitus clinic patients report they can somatically modulate the acoustic properties of their tinnitus

by head and neck movements or muscle contractions such as clenching the teeth together (Levine & Kiang 1995). For the past two years we have systematically examined all patients seen in our tinnitus clinic and found that more than two-thirds can somatically modulate their tinnitus (Levine 1999b). However, the significance of this finding is uncertain, since there have been no reports of the effects of muscle contraction upon auditory perception in non-clinical subjects.

To understand the significance of somatic modulation in our tinnitus clinic patients, we studied the effect of somatic contractions upon spontaneous auditory perceptions in (1) a non-clinical population and (2) the profoundly deaf. Our results support the view that somatic modulation is more than a curiosity restricted to tinnitus patients, but is a fundamental property of the human auditory system. Further they suggest that it is somatosensory-auditory interactions within the central nervous system which account for both somatic modulation of tinnitus and the somatic tinnitus syndrome (Levine 1999a).

Methods

Subjects: 60 adults recruited from our personal contacts comprised the non-clinical population of this study (38 males, 22 females, ages 18 to 74, mean age = 41), while 13 adults recruited from the Massachusetts Eye and Ear Infirmary cochlear implant research laboratory comprised the profoundly deaf group (7 males, 6 females, ages 37 to 69, mean age = 51). The cochlear implant subjects were postlingually profoundly deaf bilaterally. All had received a unilateral cochlear implant between 9 months and 16 years earlier [mean= 8 years].

Prior to somatic testing, the following questions were asked of each subject:

1. Do you have normal hearing?
2. Do you ever have a brief ring in one ear, lasting about a minute or less?
3. Do your ears ever ring after a loud sound?
4. Do you have tinnitus?

Procedure: Subjects were asked to report any changes in their auditory perception, including changes in loudness (louder or softer), pitch or location. They were instructed to rate the loudness of their ongoing or elicited tinnitus on a numerical scale where zero corresponds to no tinnitus and ten corresponds to a sound at the loudest level they could tolerate.

Twenty-five brief, forceful contractions were made by each subject in a room with low-level ambient noise. Duration of contractions was only a few seconds -- just enough time for the subject to judge whether any change occurred in his/her auditory perceptions.

Ten involved jaw contractions as follows:

- 1) clench the teeth together as forcefully as possible,
- 2,3) maximally open the mouth, with and without maximal restorative pressure applied by the heel of the subject or examiner's hand,
- 4,5) maximally protrude forward the jaw, with and without maximal restorative pressure,
- 6,7) maximally slide the jaw to the left, with and without maximal restorative pressure,
- 8,9) maximally slide jaw to right, with and without maximal restorative pressure, and
- 10) maximally retract jaw.

Ten involved head and neck contractions as follows:

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

- 11) occiput,
- 12) forehead,
- 13) vertex,

- 14) mandible (upward),
- 15) right temple, or
- 16) left temple.

17) With the head turned to the right, resist maximal torsional force applied by the examiner to the right zygoma.

18) With the head turned to the left, resist maximal torsional force applied by the examiner to the left zygoma.

19) With the head turned to the right and tilted to the left, maximally resist full force applied by the examiner to the left temple (left sternocleidomastoid)

20) With the head turned to the left and tilted to the right, maximally resist full force applied by the examiner to the right temple (right sternocleidomastoid)

Five involved extremity contractions as follows:

21) locking the subject's flexed fingers of the two hands together and pulling them apart as forcefully as possible

Contractions were made to resist maximal pressure applied by the examiner to the subject's

22) abducted right shoulder,

23) abducted left shoulder,

24) flexed right hip, or

25) flexed left hip.

Results

A. Non-clinical subjects

Nine subjects (15%) were aware of a mild hearing loss. Forty-six subjects (77%) had recalled experiencing a tonal ring in one ear lasting less than a minute. Thirty-one subjects (52%) reported that they had experienced tinnitus after a loud sound.

Eleven of the sixty subjects (18%) reported prior to testing that they had been aware of ongoing tinnitus (Table 1). The ratings of their tinnitus loudness ranged between 0.5 to seven. Almost half of these subjects (5) perceived their tinnitus as lateralized to one ear; the tinnitus loudness ratings of these five spanned the entire range.

Another seventeen subjects (28%) were unaware of any ongoing tinnitus, but, when taken into a quiet room prior to somatic testing, they heard something that no one else in the room heard. The ratings of their tinnitus loudness ranged between less than one to five with more than 80% at one or less. Only two of these subjects perceived their tinnitus as lateralized to one ear but these two subjects had the largest tinnitus loudness ratings of this group.

| Subject Type | Number |
|----------------------------------|----------|
| Previously aware of tinnitus | 11 (18%) |
| Not previously aware of tinnitus | 17 (28%) |
| Without tinnitus | 32 (53%) |
| Total | 60 |

Table 1. Subtypes of non-clinical subjects

From combining these two groups together, overall nearly half (47%) of all the non-clinical subjects had tinnitus in the quiet test room at the time of testing.

Somatic Modulation

A variety of descriptions were used to describe the change in the hearing percept that occurred with somatic testing. These included "ring, high-pitched ring, or tone." We did not consider descriptions of clicking as tinnitus, since this probably represented joint or muscle generated sounds such as coming from the temporomandibular joint or Eustachian tube. Descriptions such as "wind" or "snowstorm" were also not considered tinnitus since these likely represent tensor tympani contraction as has been described for tinnitus associated with forced eye closure (Rock 1995).

Overall twenty-two of the twenty-eight subjects (79%) who had ongoing tinnitus in the quiet test room modulated their tinnitus with somatic testing (Table 2). Whether or not the subjects had been previously aware of their tinnitus, the incidence of somatic modulation was essentially no different (82% and 76% respectively). In contrast, of the thirty-two subjects who had no ongoing tinnitus in the quiet, only eighteen (56%) developed an acoustic perception (tinnitus) with somatic testing.

Alterations in tinnitus perception that occurred with somatic testing included changes in loudness, pitch or location. By far most common were changes in tinnitus loudness that could be either louder or softer, or louder for some maneuvers and quieter for others in the same subject. Of these increased loudness alone was the most frequent.

| Subject Type | Somatic modulation | | Totals |
|-----------------------|--------------------|-------------|--------|
| | Present | Not Present | |
| With Ongoing Tinnitus | 22 (79%) | 6 (21%) | 28 |
| Without tinnitus | 18 (56%) | 14 (44%) | 32 |
| Totals | 40 (67%) | 20 (33%) | 60 |

Table 2. Somatic modulation and whether or not non-

clinical subjects were experiencing tinnitus at the time of testing.

Sometimes the effects of somatic testing were prolonged. In twenty-two percent of subjects who could change or induce tinnitus with a somatic manipulation, the effect persisted after the contraction was released. This effect could be for a few seconds or up to 10 minutes. The two longest ones (5 and 10 minutes) occurred in subjects who had had no tinnitus at the time of testing.

Which maneuvers altered a subject's tinnitus varied from subject to subject. On average seven different maneuvers altered a subject's auditory perception (range 1 to 16). This average and range was about the same whether or not a subject had tinnitus at the time of testing.

Head and neck contractions changed tinnitus more effectively than extremity contractions. Without exception whenever extremity maneuvers modulated or elicited tinnitus, head and neck maneuvers also did in the same manner, but the reverse was not always true. In fact, twice as many subjects could modify or elicit tinnitus with head and neck contractions as with extremity contractions. Whichever the direction of the loudness changes, those elicited by head and neck maneuvers in any subject were always equal to or larger than those from extremity maneuvers of the same subject.

B. Profoundly deaf subjects

The thirteen profoundly deaf subjects were tested with their cochlear implant processor disconnected from the patient. At the time of testing ten subjects had ongoing tinnitus and three did not. Five of the ten (50%) with ongoing tinnitus could modulate their tinnitus with somatic testing, while two of the three (67%) without tinnitus could elicit an auditory percept with somatic testing. As with hearing subjects, loudness changes were the most common type of somatic modulation. Three of the five increased their tinnitus loudness, while for the other two it decreased with somatic testing. No subjects of this group did both. Likewise the effects of somatic testing could persist; the longest was for a subject whose tinnitus disappeared for four minutes. Pitch changes also occurred. In all cases head and neck alterations in auditory perception were more effective than those induced by extremity maneuvers.

Discussion

This two part study demonstrates that somatic modulation of tinnitus is widespread and is not restricted to clinical patients. Our previous study in our clinic population found that 68% of seventy consecutive tinnitus patients could modulate their tinnitus with somatic testing (Levine 1999b). The present study is not exactly comparable because it included more types of maneuvers, particularly involving the jaw. When these additional maneuvers are included in testing our clinic patients [unpublished results], we have found virtually identical incidence of somatic modulation as in the non-clinical group. In both groups about 80% of subjects with ongoing tinnitus at the time of testing could modulate their tinnitus with somatic testing. Other characteristics were likewise similar in the two groups. Thus, somatic modulation is as common in the non-clinical tinnitus subjects as in clinical tinnitus patients. The ability to somatically modulate is therefore not what makes tinnitus a clinical problem.

Furthermore in the present report we have demonstrated that a tinnitus-like auditory percept could be elicited in 56% of non-clinical subjects who in the quiet were hearing nothing at the time of somatic testing. This result suggests that it is likely that some cases of clinical tinnitus may be due to activation of latent somatic-auditory interactions. Such activations could account for some cases of clinical tinnitus including the somatic tinnitus syndrome (including the tinnitus associated with the temporomandibular joint syndrome or whiplash) (Levine 1999a). One such example is as follows.

A 29 year old woman with normal audiometry had for seven months highly distressing right ear tinnitus, which had resolved about two months prior to her visit to our tinnitus clinic. On physical examination there was increased muscle tension and tenderness in her right sternocleidomastoid as compared to the left. At the time of somatic testing she was hearing slight constant ringing of both ears (1/10), which was much fainter than her prior right ear tinnitus. With somatic testing each time her right sternocleidomastoid muscle was forcefully contracted she reported hearing right ear tinnitus identical to her prior distressing tinnitus (table 3). The right ear tinnitus did not persist after her somatic testing.

| | | |
|---------------------------|---|---|
| Forehead Pressure | 4 | 1 |
| Mandibular Pressure | 4 | 1 |
| Right Sternocleidomastoid | 4 | 1 |

Table 3. Somatic testing of 29 year old woman with prior right ear tinnitus. Only maneuvers that modulated her tinnitus are shown.

Our findings can account for the fact that the incidence of change in auditory perception with somatic testing is significantly lower in subjects with no tinnitus than in subjects with tinnitus. From our observations of clinical and non-clinical tinnitus subjects, it is clear that somatic testing can increase and/or decrease tinnitus loudness and pitch. If such changes in auditory perception are happening equally for all groups of subjects, then one would expect the incidence of a change in auditory perception to be less in people without tinnitus than in those who have an ongoing auditory perception (tinnitus) for at least two reasons. (1) If somatic modulation decreases the loudness of auditory perception, then this would not be detected in the non-tinnitus subjects; similarly for any change of pitch. (2) If somatic testing causes only a small degree of change in the level of activity in the auditory system, such as might be perceived in tinnitus subjects as a small change in their tinnitus loudness, then subjects without tinnitus might raise the overall activity in their auditory pathways, but not enough to cross the threshold of auditory perception. Thus, for these two reasons the incidence of change in auditory perception will be lower in the non-tinnitus groups than the tinnitus groups.

Several possible underlying mechanisms for changes in auditory perception with somatic testing can be considered. One is that the changes in auditory perception are due to changes in otoacoustic emissions (OAEs). We cannot totally exclude this possibility, but some subjects with known spontaneous OAEs heard nothing in the quiet and it is well established that the vast majority of subjects with spontaneous OAEs never hear them.

Since somatic testing consists of forceful muscle contractions, the generation by a muscle of an acoustic sound that is heard by the ear is an obvious possibility. This study has excluded from consideration elicited sounds that have been described with such terms as "wind" or "snow storm" since these are highly likely to be generated by tensor tympani and/or pharyngeal muscle contractions (Rock 1995). Nonetheless, a case has been described of "continuous high-frequency unilateral [objective] tinnitus" that disappeared with sectioning of the stapedius and tensor tympani tendons (Bento et al 1998). If a

| Condition | RIGHT Ear Tinnitus | Left Ear Tinnitus |
|------------------------------|--------------------------|----------------------|
| Baseline (0-10 Scale) | 1 | 1 |

similar phenomenon occurs with somatic testing, then this could account for many of our findings. However, in none of our subjects was the modulation "objective," since a high pitched sound coming from the ear has never been heard by nearby observers during somatic testing. Moreover we have made ear canal microphone recordings in some subjects during somatic modulation of their tinnitus and detected no signal corresponding to the change in auditory perception described by the subject. Also, subjects who can decrease the loudness of their tinnitus with somatic testing are highly unlikely to be doing so with muscular generation of an acoustic sound.

Our findings in the cochlear implant subjects with and without tinnitus, who describe changes in their auditory perceptions with somatic testing, clearly indicate that acoustic sounds are not responsible for their results, since these subjects are profoundly deaf and their implant was not activated at the time of somatic testing. Furthermore the similarities in the characteristics of the changes in auditory perception that occur for all groups suggests that the mechanism operating in the profoundly deaf is likewise operating for most, if not all, of the other groups. Thus we conclude that somatosensory-auditory neural interactions within the central nervous system are accounting for most, if not all, somatic modulation of tinnitus and the development of auditory percepts with somatic testing.

Possible sites of neural somatosensory-auditory interactions include 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).

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 site 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 nucleus or some higher center such as the inferior colliculus.

We conclude that (a) somatic modulation of

tinnitus is as common in non-clinical subjects as in clinical tinnitus subjects, (b) somatic influences upon auditory perception are not limited to tinnitus subjects but are a fundamental property of the auditory system, and (c) somatosensory - auditory neural interactions are critical not only for understanding clinical tinnitus, but also for understanding auditory perception in general.

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