

## Characteristics of Patients with Gaze-evoked Tinnitus

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**Objective:** The authors describe symptoms and population characteristics in subjects who can modulate the loudness and/or pitch of their tinnitus by eye movements.

**Study Design:** Data were obtained by questionnaire.

**Setting:** The study was conducted at a university center and a tertiary care center.

**Patients:** Respondents had the self-reported ability to modulate their tinnitus with eye movements.

**Results:** Ninety-one subjects reported having gaze-evoked tinnitus after posterior fossa surgery involving the eighth nerve. Eighty-seven of them underwent removal of a vestibular schwannoma (acoustic neuroma), two had bilateral eighth nerve tumors (one underwent bilateral tumor removal; the other unilateral tumor removal), one underwent removal of a cholesteatoma, and one underwent removal of a glomus jugulare tumor. Seventeen subjects who had never had posterior fossa surgery reported gaze-evoked tinnitus. Of those with vestibular schwannomas, tumor size ranged from small (<2 cm) to large (>4 cm). The gender distribution was 48.3% male and 51.7% female. In 77% of patients, the gaze-evoked tinnitus was localized to the surgical ear or side of head; 21.8% had bilateral tinnitus that was louder in the surgical ear or side of head. In 86 of 87 subjects, loudness of tinnitus changed with eye move-

ment. Eye movement away from the central (eyes centered) position increased the loudness of tinnitus in all 86 subjects who responded to this question. Seventy-three of 85 (85.9%) patients indicated that pitch changed with eye movement, with pitch increasing in 64/72 (88.9%) of them. Eighty-three of 87 (95.4%) patients reported total loss of hearing in the surgical ear. Seventy of 83 (84.3%) patients reported facial nerve problems immediately after surgery, 52 of 87 (60%) reported persistent facial weakness, and 16 of 87 (18.4%) patients reported persistent double vision. In those 17 subjects with gaze-evoked tinnitus and no posterior fossa surgery, the majority of respondents (14/17, 82.4%) were male.

**Conclusions:** Gaze-evoked tinnitus after cerebellar pontine angle surgery is more common than was previously believed. In addition, posterior fossa surgery is not a prerequisite for the development of gaze-evoked tinnitus. It is likely that gaze-evoked tinnitus is a manifestation of functional reorganization. Gaze-evoked tinnitus could result from an unmasking of brain regions that respond to multiple stimulus/response modalities, and/or from anomalous cross-modality interactions, perhaps caused by collateral sprouting. **Key Words:** Gaze-evoked tinnitus—Eye movements—Acoustic neuroma—Tinnitus.

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As part of an ongoing project involving the functional imaging of tinnitus, we have sought groups of patients who can modify their tinnitus by a voluntary motor act. This allows a statistical comparison of functional activity (cerebral blood flow) by positron emission tomography (PET) when tinnitus is “softer” versus when it is “louder.” For example, Lockwood et al. (1) investigated changes in cerebral blood flow in patients who could modulate their tinnitus by an oral-facial maneuver. In a survey of subjects with that same ability, Pinchoff et al. (2) reported that the tinnitus attributes of these subjects

were largely indistinguishable from those with generic tinnitus as reported by Stouffer and Tyler (3), except for gender distribution. Specifically, Stouffer and Tyler (3) reported that 55% of their tinnitus patients were male and 45% were female. By contrast, Pinchoff et al. (2) reported that 83% of subjects whose tinnitus was modified by an oral-facial maneuver were male and only 17% were female.

Several authors have described patients who could modulate their tinnitus by eye movements after section of the eighth nerve (4–10). This gaze-evoked tinnitus seemed ideal for PET evaluation because the tinnitus is reportedly absent, or softest, when eyes are in the central position (looking straight ahead), and the tinnitus becomes louder with vertical and/or horizontal eye movements. Because subjects with gaze-evoked tinnitus seemed extremely rare, we placed a notice in the Acoustic Neuroma Association (ANA) newsletter requesting

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that readers who could modulate their tinnitus by eye movement contact the authors. A notice was also placed in *Tinnitus Today*, which more generally requested contact from readers who could modulate their tinnitus by a motor act such as an oral-facial movement, including eye movement. A questionnaire similar to that used by Pinchoff et al. (2), which was adapted from Stouffer and Tyler (3), was sent to these respondents. The present report summarizes the responses of 87 patients who reported gaze-evoked tinnitus after surgical removal of an eighth nerve tumor, as well as a group of 17 patients who reported gaze-evoked tinnitus but had never had posterior fossa surgery.

## MATERIALS AND METHODS

The following notice was placed in the ANA newsletter in December 1997 and again in May 1998:

Researchers at the University at Buffalo are using a powerful brain imaging technique, PET, to investigate how the central auditory system changes after acoustic neuroma surgery. After surgery, some individuals develop a unilateral hearing loss and an unusual form of "ringing or buzzing" in their ear known as gaze-evoked tinnitus. Patients with gaze-evoked tinnitus report hearing a ringing or rushing sensation when their eyes are directed to the left, right, up, or down.

When their eyes are straight ahead, the tinnitus disappears or decreases. Eye movements can also change the pitch of the tinnitus. Some patients can also modify the pitch or loudness of their tinnitus by touching or moving other parts of the body such as the jaw, face, or arm. This research project uses the PET imaging technique to determine the regions of the brain that are activated when the tinnitus sensation is modified.

The aim of the study is to understand how the brain functions after unilateral hearing loss. This research is supported by grants from the American Tinnitus Association and the National Institutes of Health, and is approved by the Institutional Review Board at the University at Buffalo and the VA Medical Center.

Researchers are interested in identifying individuals who have developed gaze-evoked tinnitus or other forms of tinnitus that can be modified by touching or moving some part of the body. This study will require a comprehensive hearing test and PET scan at our facility. Persons interested in participating or learning more about this medically important research project should contact.... [The remainder of the notice is not reproduced here.]

Several similar notices were placed in *Tinnitus Today* in September and December 1996 and again in December 1998. The *Tinnitus Today* notices sought subjects who could modulate their tinnitus by any oral-facial movement, including eye movements. Once contacted, we mailed each respondent a tinnitus questionnaire used by Pinchoff et al. (2) in a study investigating the population characteristics of patients who could reportedly modulate their tinnitus by some sort of facial motor act. Additional questions specifically related to gaze-evoked tinnitus, as well as the Beck Depression Inventory, were added to the questionnaire. Responses to the questionnaire were coded and entered into a database management program (Microsoft Access; Microsoft Corp., Redmond, WA, U.S.A.).

## RESULTS

We mailed 159 questionnaires, and 113 completed questionnaires were returned. Of those 113 returned questionnaires, 5 subjects reported not having gaze-

evoked tinnitus, and another 17 subjects reported gaze-evoked tinnitus but did not report posterior fossa surgery. A total of 91 persons reported having gaze-evoked tinnitus after posterior fossa surgery. Eight patients came to the Center for Hearing and Deafness and the Center for Positron Emission Tomography for audiometric evaluation and to undergo PET scans. The results of clinical, audiometric, and PET investigations are reported elsewhere (11).

### Subjects with gaze-evoked tinnitus after posterior fossa surgery

#### *Patient characteristics*

Eighty-seven of the 91 subjects with gaze-evoked tinnitus after posterior fossa surgery had undergone removal of a vestibular schwannoma (often referred to as an acoustic neuroma). Two subjects had bilateral eighth nerve tumors; it is likely that they had neurofibromatosis type 2 (NF-2). One subject had a glomus jugulare tumor removed, and one subject had a cholesteatoma removed. To maintain a homogeneous patient population, these analyses focused on the 87 patients who had undergone removal of unilateral eighth nerve tumors (excluding the one subject with bilateral auditory nerve tumors, with only one removed) and gaze-evoked tinnitus. Of these 87 subjects, 45 (51.7%) were women and 42 (48.3%) were men. The mean age was 51.8 years (range 24–73 years). The time after surgery ranged from 1 month to 27 years, (mean 7.6 years, SD 6.5 years). Of the 69 patients who reported the size of their tumor, 19 (27.5%) had tumors that were 2 cm or smaller (the smallest reported was 0.64 cm), 32 (46.4%) had tumors between 2 and 4 cm, and 18 (26.1%) had tumors larger than 4 cm (the largest reported was 10 cm). Of 87 responses, 45 (51.7%) tumors were on the left and 42 (48.3%) tumors were on the right.

#### *Tinnitus characteristics*

Table 1 summarizes the subjective localization of the tinnitus. Subjects could respond that they heard the tinnitus in the right or left ear or side of the head, that they heard the tinnitus in both ears equally, or in both ears, with the tinnitus in one ear louder than in the other. Sixty-seven (77%) of 87 patients heard the tinnitus solely in the ear or side of head ipsilateral to the tumor. None of the subjects heard their tinnitus solely in the ear or side of head contralateral to the tumor. No patients heard the tinnitus equally in both ears or in the head. Nineteen

**TABLE 1.** Sites where subjects with gaze-evoked tinnitus reported hearing their tinnitus

Tinnitus	Left-ear tumor	Right-ear tumor
Both ears equal	0	0
Both ears, right louder	0	8
Both ears, left louder	11	1
Right side of head	0	3
Left side of head	2	0
Right ear	0	30
Left ear	32	0

(21.8%) of 87 heard the tinnitus bilaterally, but predominantly on the side ipsilateral to the tumor.

Eighty-six of 87 (98.9%) patients in this data set reported that loudness changed with eye movement. When asked about the direction of loudness change, 86 respondents all said that loudness increased with eye movement away from the central position. When asked how much the loudness changed with eye movement, 36 of 82 (43.9%) indicated that loudness doubled, and 30 (36.6%) indicated that loudness tripled. Of 85 respondents, 73 (85.9%) reported that pitch changed during eye movements. When asked if pitch increased or decreased with eye movements, of 72 responses, 64 (88.9%) indicated pitch increased, 5 (6.9%) indicated pitch decreased, and 3 (4.2%) indicated that pitch both increased and decreased during eye movement. When asked to quantify the magnitude of the pitch change, 32 of 69 (46.7%) indicated that pitch doubled, and 23 (33.3%) indicated that pitch tripled.

When asked if jaw movements modified the loudness of their tinnitus, 19 (21.8%) of 87 respondents reported a loudness change. Of these 19, 17 (89.5%) reported a loudness increase with jaw movement. Thirteen of 19 reported that jaw movement produced a doubling in loudness, one of 19 reported a 50% increase in loudness, and 2 reported "slight" or "subtle" changes in loudness. Of 80 responses, 19 (23.8%) indicated that tinnitus pitch changed with jaw movement. Eighteen of 19 (94.7%) indicated pitch increased with jaw movement, and 1 of 19 (5.3%) indicated that pitch decreased. Of those reporting pitch changes, 13 of 18 (72.2%) respondents indicated pitch doubled with jaw movement, with 1 indicating that pitch only changed "slightly."

Because of some ambiguity in the wording of our question concerning the time course of gaze-evoked tinnitus after surgery, we sent out an additional questionnaire to the subjects. Of 73 respondents, 20 (27.4%) did not know whether they had gaze-evoked tinnitus before surgery, 1 (1.4%) reported having gaze-evoked tinnitus before surgery, and 52 (71.2%) reported not having gaze-evoked tinnitus before surgery. When asked how long after surgery it took for them to notice the onset of gaze-evoked tinnitus after surgery, 3 (4.1%) reported tinnitus onset within 24 hours, 8 (11.0%) reported onset from 1 to 7 days, 12 (16.4%) reported onset from 1 week to 1 month after surgery, 13 (17.8%) reported tinnitus onset from 1 to 6 months, and 27 (37.0%) reported that it took longer than 6 months. It is instructive to note that several respondents were not aware that they had gaze-evoked tinnitus until they read the notice, and that 8 (11.0%) did not know when the gaze-evoked tinnitus had started.

#### *Other surgical consequences*

When asked if they experienced hearing loss after surgery, all 87 respondents indicated "yes." When asked if their hearing loss was total in the involved ear after surgery, 83 of 87 (95.4%) stated "yes," and 69 (73.9%) of 83 stated that they had experienced hearing loss before

surgery. Fifty-five (63.2%) of 83 subjects reported tinnitus before surgery.

Seventy (84.3%) of 83 respondents reported facial nerve problems immediately after surgery, and 35 (42.2%) of 83 subjects reported double vision immediately after surgery. At the time of questionnaire completion, 52 (60.0%) of 87 subjects reported persistent facial weakness, 16 (18.4%) of 87 reported double vision, 33 (37.9%) of 87 reported having headaches, 35 (40.2%) of 87 reported dizziness, and 20 (23.0%) of 87 reported a feeling of disorientation.

### **Patients with gaze-evoked tinnitus with no posterior fossa surgery**

#### *Patient characteristics*

For those patients who reported gaze-evoked tinnitus but had no history of cerebellar pontine angle surgery, 14 (82.4%) of 17 respondents were men and 3 (17.6%) of 17 were women. The mean subject age was 50.8 years (range, 34–72 yr).

#### *Tinnitus characteristics*

When asked where they perceived their gaze-evoked tinnitus, 5 (29.4%) of 17 subjects heard the tinnitus predominantly on the left, 9 (52.9%) of 17 heard their tinnitus predominantly on the right, and 3 (17.6%) of 17 heard their tinnitus in the head or equally in both ears. Sixteen (94.1%) of 17 subjects reported a loudness change in their tinnitus with eye movements, with 15 (93.7%) of 16 reporting loudness increases and 1 (6.3%) of 16 reporting loudness decreases. Eight (53.3%) of 15 respondents reported that the loudness of their tinnitus doubled with eye movement. Ten (62.5%) of 16 respondents reported pitch changes with eye movement. Eight (80%) of 10 reported that the pitch of their tinnitus increased with eye movements, and 2 (20%) of 10 reported that pitch decreased. Six (66.7%) of 9 respondents reported a doubling of the pitch of their tinnitus with eye movements.

In 14 (82.4%) of 17 respondents jaw movements changed the loudness of their tinnitus, in 12 (85.7%) of 14 the tinnitus became louder with jaw movements, and in 2 (14.3%) of 14 the tinnitus became softer with jaw movements. Nine (69.2%) of 13 respondents reported that their tinnitus loudness doubled with jaw movements. Thirteen (76.5%) of 17 subjects reported that the pitch of their tinnitus changed with jaw movements; in 10 (76.9%) of 13 the pitch increased, and in 3 (23.1%) of 13 the pitch decreased. Ten (76.9%) of 13 subjects reported that their tinnitus doubled in pitch with jaw movements.

## **DISCUSSION**

The presence of gaze-evoked tinnitus after surgical section of the eighth cranial nerve can be traced back to several letters to the editor in the early 1980s (4–6). Whitaker (5,6) reported observing three such patients after eighth nerve tumor removal, and House (4) reported

seeing this phenomenon four or five times, as referenced in Wall (7) and Cacace (8). Wall et al. (7) provided two detailed case studies of gaze-evoked tinnitus after eighth cranial nerve resection. Cacace et al. (8) reported two cases of gaze-evoked tinnitus, providing detailed pitch and loudness matching data in these patients. Cacace et al. (9) reported on two patients with cutaneous-evoked tinnitus, one of whom also had gaze-evoked tinnitus after eighth nerve section. Finally, Giraud et al. (10) reported on PET studies of four subjects with gaze-evoked tinnitus. Thus, our literature search located reports of fewer than 18 subjects with gaze-evoked tinnitus. On the basis of the few cases reported in the literature, we believed gaze-evoked tinnitus to be a rare sequela of posterior fossa surgery. To our surprise, our notice in the ANA and *Tinnitus Today* newsletters drew numerous contacts from patients reporting gaze-evoked tinnitus.

Let us assume that most of our respondents were from the notice in the ANA newsletter, and that all members of ANA with gaze-evoked tinnitus responded to our notice. The ANA newsletter has a circulation of roughly 5000. If all of these had a vestibular schwannoma removed, then the prevalence of gaze-evoked tinnitus would be 1.7% (87/5000). We believe this estimated prevalence to be conservative. A prospective study is needed to obtain a more accurate estimate of the prevalence of gaze-evoked tinnitus after posterior fossa surgery.

Of a total of 108 questionnaires returned by those reporting gaze-evoked tinnitus, 17 reportedly had never undergone posterior fossa surgery. Of 91 patients reporting gaze-evoked tinnitus after posterior fossa surgery, 87 reported gaze-evoked tinnitus after removal of unilateral eighth nerve tumors, which were presumably vestibular schwannomas. Two patients reported having bilateral eighth nerve tumors; one had only one tumor removed, and the other had both tumors removed. Vestibular schwannomas are typically unilateral, whereas NF-2 often presents with bilateral eighth nerve tumors (12). Thus, it is likely that these two patients had NF-2, and they appear to be the first NF-2 patients with gaze-evoked tinnitus reported in the literature. In our database, one subject with gaze-evoked tinnitus had the eighth nerve sectioned during removal of a glomus jugulare tumor. Cacace et al. (9) reported a patient with a paraganglioma near the jugular bulb in a patient with both gaze-evoked and cutaneous-evoked tinnitus after eighth nerve section. Finally, one of our subjects reported gaze-evoked tinnitus after removal of a cholesteatoma. Our literature search did not locate previous reports of gaze-evoked tinnitus after surgical removal of a cholesteatoma, although several reports indicate that surgical removal of a meningioma can lead to gaze-evoked tinnitus (7,8). It appears that surgical removal of any space-occupying growth affecting the eighth nerve can lead to gaze-evoked tinnitus.

We have no explanation for the gaze-evoked tinnitus without posterior fossa surgery reported by 17 subjects. The majority of these subjects (16/17: 94.1%) reported a

loudness change in their tinnitus when moving the eyes from the central position. As with gaze-evoked tinnitus after posterior fossa surgery, most of these subjects (15/16: 93.8%) reported that the loudness of their tinnitus increased when the eyes were moved from the central position. Of those reporting pitch changes with eye movement (10/16: 62.5%), 8 of 10 (80%) reported a loudness increase. These numbers agree favorably with the loudness and pitch increases reported by those in whom gaze-evoked tinnitus developed after posterior fossa surgery.

Pinchoff et al. (2) found that 83% of the patients who could modulate their tinnitus by jaw movements were male. By contrast, Stouffer and Tyler (3) reported that in a large data set of unselected tinnitus patients seen in four clinics that 55% were male and 45% were female. In our gaze-evoked tinnitus subjects with vestibular schwannomas, 51.7% were female and 48.3% were male. However, in our subjects with gaze-evoked tinnitus without any posterior fossa surgery, 81.3% of respondents (13/16) were male. Furthermore, in this same nonsurgical group, 14 (82.4%) of 17 reported changes in the loudness of their tinnitus with jaw movement, whereas 13 (76.5%) of 17 reported pitch changes. In a series of 1667 patients who had undergone removal of eighth nerve tumors, House and Hitselberger (13) found that 51% were male and 49% were female, in good agreement with our roughly 52% female and 48% male subjects with gaze-evoked tinnitus. It appears that gaze-evoked tinnitus after posterior fossa surgery is equally represented in male and female subjects but that gaze-evoked tinnitus in those without a history of posterior fossa surgery is more prevalent in male subjects. Interestingly, in the vast majority of those with gaze-evoked tinnitus without posterior fossa surgery, their tinnitus could be modified by jaw movement.

We were interested in the time course of onset of gaze-evoked tinnitus, given that a rapid onset might support a mechanism such as disinhibition or unmasking of existing pathways, whereas a long time course could support a collateral-sprouting hypothesis (14). Wall et al. (7) reported that their two patients noticed their gaze-evoked tinnitus in the year after removal of their tumors. Cacace et al. (8) reported that the onset of gaze-evoked tinnitus was 4 to 6 weeks after surgery in both patients they studied. We found a wide range of time between surgery and the onset of gaze-evoked tinnitus. A few patients (4.1%) noted gaze-evoked tinnitus within 24 hours of surgery, whereas 37.0% reported gaze-evoked tinnitus 6 months or more after surgery. Several patients commented that they didn't even know they had gaze-evoked tinnitus until they read our notice. We are unable to determine whether those reports are accurate, or whether the variability in time of reported onset of gaze-evoked tinnitus was the result of inattention to a phenomenon that is not particularly bothersome. An accurate description of the time of onset of gaze-evoked tinnitus must await a prospective study.

A few patients had some residual hearing in the

surgical ear after removal of the vestibular schwannoma. Thus, gaze-evoked tinnitus does not require complete surgical transection of the eighth nerve. It is likely that all patients with removal of the vestibular schwannoma had complete section of the inferior and superior vestibular nerves, and thus their surgical intervention led to disorders of at least two modalities (auditory and vestibular) in the majority of subjects. In addition, double vision was commonly reported, both immediately after surgery and as a long-term surgical consequence. Thus, the visual system appears to be affected quite often in patients who experience gaze-evoked tinnitus. Furthermore, facial nerve disorders were reported both immediately after surgery and as long-term consequences of surgery.

It appears that multiple sensory (auditory, vestibular, visual) and motor (facial nerve) systems are transiently or permanently affected in patients who experience gaze-evoked tinnitus. Wall et al. (7) suggested that gaze-evoked tinnitus involves the neural integrator. This neural system integrates (in the mathematical sense) velocity-coded signals into position signals (15). Our data do not speak directly to the thesis that gaze-evoked tinnitus involves the neural integrator, but they are consistent with this hypothesis. Thus, it seems reasonable to interpret gaze-evoked tinnitus as a consequence of aberrant cross-modality plasticity, as has been suggested by others (1,2,7,14,16,17). On the other hand, the mechanisms responsible for gaze-evoked tinnitus may not necessarily involve surgical trauma, given that 17 subjects in our survey who had not undergone posterior fossa surgery nevertheless reported gaze-evoked tinnitus.

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