Association Between Childhood Hearing Disorders and Tinnitus in Adulthood

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**IMPORTANCE** The association between childhood hearing disorders and adult tinnitus has not been examined in longitudinal cohort studies.

**OBJECTIVES** To determine the association between different types of childhood hearing loss and tinnitus in adulthood and evaluate whether tinnitus risk is mediated by adult hearing loss.

**DESIGN, SETTING, AND PARTICIPANTS** Population-based cohort study of 32 430 adults (aged 20-56 years) who underwent pure-tone audiometry and completed a tinnitus questionnaire in the Nord-Trøndelag Hearing Loss Study, which was a part of the Nord-Trøndelag Health Study 2 (HUNT2). The study was conducted from January 1, 2014, to April 1, 2015. Data analysis was performed from April 1, 2014, to April 1, 2015. As children, the same individuals had undergone screening audiometry in a longitudinal primary school hearing investigation, including ear, nose, and throat examinations when indicated.

**INTERVENTIONS** Pure-tone audiometry, questionnaires, and ear, nose, and throat examinations.

**MAIN OUTCOMES AND MEASURES** Self-reported tinnitus (yes or no) in adulthood measured by questionnaires.

**RESULTS** Adults who had hearing loss at the time of the school investigation (n = 3026) reported more tinnitus, measured as odds ratio (95% CI), than did adults with normal childhood hearing (n = 29 404) (1.4 [1.3-1.6]). Childhood hearing disorders associated with tinnitus in adulthood included sensorineural hearing loss, chronic supplicative otitis media, and hearing loss associated with a history of recurrent acute otitis media (2.4 [1.9-3.0], 2.4 [1.5-3.9], and 1.6 [1.3-2.0], respectively). These estimates were adjusted for age, sex, and noise exposure in adulthood. After further analyses that included adjustment for adult hearing threshold, none of these childhood hearing disorders remained positively associated with tinnitus.

**CONCLUSIONS AND RELEVANCE** Childhood hearing disorders associated with tinnitus in adulthood include sensorineural hearing loss, chronic supplicative otitis media, and hearing loss associated with a history of recurrent acute otitis media. After adjustment for the adult hearing threshold, none of the childhood hearing disorders was positively associated with tinnitus. Hence, it appears that these significant associations are mediated or transmitted through adult hearing loss.

Published online November 5, 2015.

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Tinnitus, a ringing, roaring, or buzzing in the ears or head, is a common symptom that can be debilitating. Prevalence estimates are mixed, but most studies\(^1\) show prevalences of bothersome tinnitus (episodes lasting ≥5 minutes during the past year) between 10% and 15% in the adult population.

Hearing loss is presumably the most important risk factor for tinnitus, but the association is complex. Tinnitus is reported in individuals with apparently normal hearing, and only some hearing-impaired persons report tinnitus. One current, prominent causal theory of tinnitus states that hearing loss is often the initial source of tinnitus but that subsequent neural changes in the central auditory system maintain the condition.\(^3\)

Although the association between hearing loss and tinnitus is well established in children\(^4\) and adults,\(^1,2,10-12\) to our knowledge, the association between childhood hearing disorders and the prevalence of adult tinnitus has not been examined previously in longitudinal cohort studies. A history of recurrent childhood otitis media has been associated with tinnitus in adulthood.\(^2,10,11,13\) The association may be transmitted or mediated through subsequent permanent hearing loss (childhood otitis media influences adult hearing loss, which in turn influences the occurrence of tinnitus). However, it has also been suggested\(^14\) that temporary conductive hearing loss in childhood is associated with permanent sound-processing deficits in the central auditory system, increasing the risk of later tinnitus. To our knowledge, no previous cohort study has included information on childhood hearing disorders and both tinnitus and hearing thresholds in adulthood. The aims of this study were to examine the association between different types of hearing loss in childhood and tinnitus in adulthood and evaluate whether tinnitus risk is mediated by adult hearing loss.

Methods

The study was approved by the Norwegian Regional Committee of Medical Ethics and by the Norwegian Data Inspectorate and is in agreement with the established Public Health Code of Ethics of the American Health Association. Participants provided written informed consent. There was no financial compensation. The study was conducted from January 1, 2014, to April 1, 2015. Data were deidentified.

Sample

This study used baseline data from the School Hearing Investigation in Nord-Trøndelag (SHINT), a long-term study (1954-1986) of the hearing of primary school pupils, and follow-up data from the more recent Nord-Trøndelag Hearing Loss Study (NTHLS). Both studies are described elsewhere.\(^15,16\) A related study\(^17\) from the same database, using similar methods and analyses to the extent to which childhood otitis media is associated with adult hearing thresholds, has been conducted. The study reported that childhood chronic suppurative otitis media and childhood hearing loss after recurrent acute otitis media were associated with a significant hearing loss in adulthood: 17, 17, and 20 dB and 7, 7, and 10 dB in the low-, middle-, and high-frequency ranges, respectively.

Another study\(^18\) from the same database (the linkage between the SHINT and NTHLS) reported a super-additive effect of childhood high-frequency sensorineural hearing loss (SNHL) and aging on adult hearing.

Baseline Childhood Study

The late Norwegian ear, nose, and throat (ENT) specialist Hans Fredrik Fabritius, MD, and his colleagues conducted an audiometric screening of almost all 7-, 10-, and 13-year-old school children in Nord-Trøndelag County, Norway, from 1954 to 1986. The study did not record information confirming the participation of children with normal hearing, so the exact number of participants is unknown. The number of children born between 1941 and 1977 in Nord-Trøndelag County (78 524) may serve as a crude approximation. The children with hearing loss identified at screening were invited to a later ENT specialist examination. Between 1954 and 1962, average attendance at the ENT examinations was 97%, and we believe this high level of attendance did not change later.\(^15\) A total of 10 269 children participated in the specialist examination.

Follow-up Adult Study

The NTHLS (1996-1998) was part of the Nord-Trøndelag Health Study 2 (HUNT2), a large, general health screening study.\(^19\) The NTHLS included a pure-tone audiometry examination and hearing questionnaires. The present study used questionnaire 1, which contained items about tinnitus. The total adult population (aged ≥20 years) from 17 of the 23 municipalities in Nord-Trøndelag County was invited, and valid audiometric data were collected from 50 723 participants. The participation rate was 67% except in one municipality where the population was invited to the hearing examination after HUNT2 was finished (participation rate, 41%). Among individuals born between 1941 and 1977 (the population cohort for the present study), 87% of the county’s population was invited, with an overall participation rate of 59%.

After Linkage

Among the 10 269 children with different types of hearing loss in the SHINT, 3066 attended the NTHLS. Among these, 40 children did not have a valid questionnaire 1 (which contained the tinnitus items) and were excluded. Accordingly, the present study included 3026 cases.

As previously described, the SHINT did not register children with normal hearing. Thus, as a reference group we included all participants of the NTHLS who were at primary school age during the SHINT (born between 1941 and 1977) and who were not registered with hearing loss in the SHINT (n = 29 720). Individuals without a valid questionnaire 1 (n = 316) were excluded. Accordingly, this study included 29 404 noncases.

Measures

Childhood Hearing Loss

A trained hearing assistant or district health nurse performed the audiometric screening in the SHINT in a quiet location within the school. Air-conduction thresholds were obtained by pure-tone audiometry at 0.25, 0.5, 1.0, 2.0, 4.0, and 8.0 kHz.
Hearing loss for the screening was defined by thresholds of a 20-dB hearing level (HL) or greater at 3 or more frequencies or a 30-dB HL or greater threshold at 1 or more frequencies. All children with hearing loss at screening were invited to a later ENT specialist examination, which took place at 1 of 14 different outpatient clinics in Nord-Trøndelag County. In addition, at the time of the specialist examination, the parents completed a questionnaire about their child’s ear problems. The medical examination included family and medical history, complete ENT examination for the child, and pure-tone audiometry with air- and bone-conduction thresholds. Depending on the underlying hearing disorder, the children had 1 or more examinations. The specialist recorded the history, findings, presumed diagnoses, and treatment.

Some children had more than 1 diagnosis (eg, SNHL and excessive cerumen). In the present study, only the diagnosis considered most severe was registered according to the following hierarchy (definitions by Fabritius15) and as reported elsewhere21: (1) SNHL (air-conduction thresholds in agreement with the bone-conduction thresholds); (2) anomalies of the outer and/or middle ear; (3) otosclerosis; (4) chronic suppurative otitis media (chronic infection of the middle ear with eardrum perforation and intermittent secretion, as well as conductive or mixed hearing loss; (5) hearing loss associated with a history of recurrent acute otitis media (no middle ear effusion at the examination but a history of recurrent preschool ear infections, sometimes also occurring during school years, mostly including impairment of the eardrum and conductive or mixed hearing loss); (6) otitis media with effusion (chronic middle ear effusion and reduced mobility of the eardrum tested by Brüning’s magnifying glass, without signs or symptoms of acute infection); (7) acute otitis media (middle ear effusion with signs and symptoms of acute infection); (8) otitis externa; (9) foreign body; (10) cerumen; and (11) other (intellectual disability, unknown or no registered etiology, and other).

Hearing thresholds less than 20-dB HL usually were not registered in the childhood audiograms performed during the ENT clinic examination; therefore, the thresholds for many single frequencies were missing. This replacement is described in detail in a related study.17

Adult Hearing Thresholds
The NTHLS included pure-tone audiometry; air-conduction thresholds from 0.25 to 8.0 kHz were determined in sound-attenuation booths by audiologists or trained assistants in accordance with ISO 8253-1.20 We considered hearing thresholds greater than 100-dB HL as equal to 100-dB HL. Adult hearing threshold levels were defined as the pure-tone average of 0.5, 1.0, 2.0, and 4.0 kHz in the worse-hearing ear.

Noise Exposure
We used questionnaire data from the NTHLS for the assessment of occupational and nonoccupational adult noise exposure, as reported elsewhere.17 A general index based on all of the noise scores was computed to estimate the overall effect of noise, similar to the one described by Tambs et al.21 The scores for each item were weighted by the respective regression coefficients in an initial regression analysis predicting pure-tone average at 0.5 to 4.0 kHz and summed. The final composite variable was dichotomized at a level corresponding to the upper 10% of the distribution.

Outcome Measure
On a questionnaire in the NTHLS, respondents answered yes, no, or don’t know–maybe to the question, “Are you bothered by ringing in the ears?” Missing values and don’t know–maybe were treated as no tinnitus.

Statistical Analysis

Analysis of Main Effects
Data analysis was conducted from April 1, 2014, to April 1, 2015. We used logistic regression analysis (SPSS, Version 20; IBM), specifying the statistical significance level at $P = .05$, to estimate the odds ratios with 95% CI for each type of childhood hearing disorder and adult tinnitus. The predictors were diagnostic groups (with normal childhood hearing as the reference category), age (at the follow-up adult study, in years), sex, and adult noise exposure (dichotomous; no or medium vs high levels of reported noise exposure). To investigate whether the risk of adult tinnitus was mediated by adult hearing loss, the analyses were performed both with and without adjustment for adult hearing threshold.

Interaction Analysis
We tested whether the previously described associations (the effect of each childhood hearing disorder on adult tinnitus, with and without adjustment for adult hearing threshold) were moderated by sex or noise exposure by using interaction terms. The logistic regression analysis was repeated, testing one interaction term at a time (diagnostic group × sex or diagnostic group × noise exposure level). Because of the high number of interaction terms, the statistical significance level used was $P < .01$.

Results

Descriptive Statistics
The present sample included 32 430 adult participants: 29 404 with normal childhood hearing at the school investigation (46.7% males) and 3026 with various types of childhood hearing disorders diagnosed (51.1% males). Descriptive statistics of the sample are presented in Table 1. Mean age at the NTHLS was 40 years (range, 20-56 years) for both cases (95% CI, 39-40) and noncases (95% CI, 40-40). Tinnitus prevalence was 11% in noncases and 15% in cases. In cases, the mean childhood hearing threshold was 22-dB HL (95% CI, 20-23) in cases, 11% in noncases and 15% in cases. In cases, the mean childhood hearing threshold was 22-dB HL (95% CI, 20-23) in noncases (95% CI, 18-19) in those not reporting adult tinnitus.

Main Results
We examined the association between different types of hearing loss in childhood and tinnitus in adulthood, adjusted for age, sex, and noise exposure in adulthood (model 1) (Table 2). Childhood hearing disorders associated with tinnitus in adulthood included SNHL, hearing loss in combination with chronic...
suppurative otitis media, and hearing loss associated with a history of recurrent acute otitis media. After additional analyses with adjustment for adult hearing threshold, only childhood SNHL was significantly associated with tinnitus; however, the direction of association was reversed such that childhood hearing loss after adjusting for adult hearing loss had a reduced risk of adult tinnitus (model 2) (Table 2).

We also tested whether the previously described associations were moderated by participants’ sex or noise exposure. There were no significant interaction terms.

### Discussion

#### Main Findings

Adults with hearing loss at the school screening audiometry (with follow-up ENT clinic visit for hearing threshold determination) reported more tinnitus than did adults with negative school screening results. Childhood hearing disorders associated with tinnitus in adulthood included SNHL, hearing loss in combination with chronic suppurative otitis media, and hearing loss associated with a history of recurrent acute otitis media. This study found no significant association between adult tinnitus and childhood hearing loss in combination with excessive cerumen, an unknown diagnosis, or an “other” diagnosis. Associations were estimated after adjusting for age, sex, and noise exposure in adulthood. After additional adjustment for the adult hearing threshold, the positive association with SNHL was reversed such that children with SNHL had lower risk of adult tinnitus than did children with normal hearing screening examinations. For other types of hearing disorders, the significant association disappeared.

#### Strengths and Limitations of the Study

**Selection Bias**

All schools in Nord-Trøndelag County were included in the SHINT, so we do not suspect a serious selection bias at this stage. However, there was a loss to follow-up since only 3066 of 10 269 childhood hearing loss cases (29.9%) participated in the NTHLS. A related study explained and examined the general loss to follow-up from the SHINT to the NTHLS. In short, many participants in the SHINT were not invited to enroll in the NTHLS; 13% lived in a municipality not included in the NTHLS, and some were not old enough to be included. A few individuals were lost owing to missing identification numbers. The participation rate at the NTHLS among individuals aged 56 years or younger (the population of this study) was 59%. The remaining loss to follow-up (approximately 3300) is difficult to explain, but emigration from Nord-Trøndelag County after the SHINT or death (approximately 3300) are parts of the explanation. However, we have no reason to suspect a selective loss to follow-up. Aarhus et al reported no important differences in the distribution of risk factors (etiology, childhood hearing threshold, and sex) between childhood hearing loss cases (total of 10 269 in the original cohort) who did (n = 3066) or did not (n = 7203) participate in the NTHLS. Finally, the NTHLS was part of a large, general health study (HUNT2), so we do not suspect that possible occurrence of tinnitus affected the likelihood of participation.

#### Abbreviations

OM, otitis media; OR, odds ratio.

* This population is the same as that used in a previous related study.

* Pure-tone average at 0.5 to 4.0 kHz in the worse-hearing ear at the last audiometric test in the baseline childhood school investigation.

* Normal hearing threshold at the baseline childhood school investigation.

* Of the 105 participants, 4 individuals underwent surgery for radical cholesteatoma removal, 13 for myringoplasty, and 7 for a nonspecified ear operation. Nine participants had dry eardrum perforations.

* Other diagnostic groups included middle or outer ear anomaly, otosclerosis, otitis externa, foreign body, intellectual disability, and other disorders (all groups with <13 individuals).
Information Bias

Misclassification | For the reference group, we lacked information confirming participation in the SHINT. We assumed that all persons born between 1941 and 1977 and living in Nord-Trøndelag County as adults attended the SHINT—this is an approximation. Some participants categorized as noncases probably had undetected childhood hearing loss because they did not participate in the SHINT, for example, owing to immigration to Nord-Trøndelag County after primary school age. This bias cannot exceed an almost trivial value, however, since the false-negative to true-negative ratio will remain low. From the part of the reference group who went to primary school during the SHINT, nearly all long-standing or permanent hearing loss was probably detected since there were 3 separate hearing screening examinations (at ages 7, 10, and 13 years).

We suspect high diagnostic accuracy since the diagnoses were determined by an ENT specialist after repeated, complete examinations with both air- and bone-conduction audiometry. Considering the course and treatment of otitis media at that time, antibiotics were prescribed and middle ear surgery (eg, tympanostomy, adenotomy, tympanoplastics, and cholesteatoma removal) was performed at the Namsos Hospital. The classifications of various types of otitis media at that time correspond well with the classifications used today.23 Most of the children with diagnosed otitis media showed a conductive hearing loss (ie, normal bone-conduction thresholds indicating a normal inner ear or sensorineural function). However, some of these children also had impaired bone-conduction thresholds (mixed hearing loss), indicating some degree of SNHL. This SNHL component is probably due to inner ear damage associated with otitis media,24,25 but other sources (eg, noise exposure) cannot be excluded.

Outcome Variable | The tinnitus measure used in this study is based on a single questionnaire item. Approximately half of the sample completed a second follow-up hearing questionnaire with a similar question about tinnitus a few weeks after they participated in the NTHLS hearing examination. The retest-retest polychoric correlation was 0.65 (95% CI, 0.63-0.67),26 which indicates that the reliability is satisfactory.

Potential differences in tinnitus prevalence might result from variations in how the question is phrased. Whereas a restrictive definition of tinnitus results in a lower tinnitus prevalence, a more liberal definition results in a higher prevalence. Hence, the association between adult hearing loss and tinnitus might have been weaker for a more liberal tinnitus definition (eg, experienced tinnitus rather than bothered by tinnitus). However, the use of the term bothered may imply that the content of the item is conflated with tolerance to tinnitus, that is, with a psychological component. The consequence of this wording might then have been an attenuated association between reported tinnitus and hearing.

Comparison With Other Studies

To our knowledge, the association between childhood hearing disorders and tinnitus in adulthood has not been examined previously in longitudinal cohort studies. Our investigation suggests that the effect of childhood hearing disorders on tinnitus in adulthood is transmitted through adult hearing loss (thus, adult hearing loss underlies the observed association). This correlational study cannot establish cause and effect. However, because this is a longitudinal study, it seems unlikely that tinnitus in adulthood could affect childhood ear diseases; therefore, we think it is reasonable to assume this directionality.

Childhood Otitis Media

A history of recurrent childhood otitis media has been associated with adult tinnitus in previous studies.2,10,31,43 However, no cohort study has included information on different types of childhood otitis media and both tinnitus and hearing thresholds in adulthood. The present study found that children with hearing loss in combination with chronic suppurative otitis media and hearing loss associated with a history of recurrent acute otitis media had an increased risk of tinnitus as adults. There was no evidence indicating that hearing loss together with the common conditions of otitis media with effusion and acute otitis media was associated with adult tinnitus. However, studies24,25 indicate that otitis media can be associated with SNHL. Furthermore, recurrent and chronic suppurative otitis media have been associated with hearing loss in adulthood. This association could explain the increased risk of adult tinnitus associated with these conditions. The lack of evidence of a significant association between childhood otitis media and adult tinnitus after adjustment for adult hearing suggests that the positive association between some types of otitis media and tinnitus is mediated by adult hearing loss. This conclusion is not
in accord with animal studies\textsuperscript{34,27} that have shown that temporary conductive hearing loss in early life can alter the functional properties of the auditory cortex on a permanent basis, which could increase the risk of later tinnitus. However, our study only included otitis media with hearing loss occurring between ages 7 and 13 years, and it is unclear to what extent our results can be generalized to otitis media in younger children whose auditory pathways probably show greater plasticity and may not lead to similar outcomes.

Childhood SNHL

Compared with normal childhood hearing, childhood SNHL was, as hypothesized, associated with an increased risk of tinnitus in adulthood. However, after including adjustment for adult hearing thresholds, childhood SNHL appeared to protect against adult tinnitus. To our knowledge, the association between the time of onset of hearing loss (childhood vs adulthood) and tinnitus in adulthood has not been examined previously. There are several possible explanations as to why adults with childhood-onset hearing loss could have a lower risk of tinnitus than adults with later-onset hearing loss. Children who have more cognitive flexibility than adults, may cope better with their hearing loss-associated tinnitus and maintain this capacity throughout life. Eventually, they could learn to cope better with tinnitus, resulting in a lower prevalence of reported tinnitus in adulthood compared with those with later-onset hearing loss (who may have had less time for tinnitus habituation).

Another explanation as to why adults with childhood-onset hearing loss could have a lower risk of tinnitus than adults with later-onset hearing loss could be that individuals with childhood-onset hearing loss are less likely to develop tinnitus, for example, if the causes of childhood SNHL (eg, genetic and infectious) are less frequently associated with tinnitus than the causes of adult-onset hearing loss, such as excessive noise exposure. Because this study did not provide data on tinnitus in childhood, safe conclusions on the interpretation of the finding cannot be drawn.

Conclusions

Childhood hearing disorders associated with tinnitus in adulthood include SNHL, chronic supplicative otitis media, and hearing loss associated with a history of recurrent acute otitis media. After adjustment for the adult hearing threshold, none of the childhood hearing disorders was positively associated with tinnitus. Hence, it appears that adult hearing loss plays an important role in governing this association.

ARTICLE INFORMATION

Submitted for Publication: November 9, 2014; final revision received July 9, 2015; accepted July 15, 2015.


Author Contributions: Dr Engdahl had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Aarhus, Engdahl, Tambs.

Acquisition, analysis, or interpretation of data: All authors.

Drafting of the manuscript: Aarhus, Engdahl.

Critical revision of the manuscript for important intellectual content: All authors.

Statistical analysis: Aarhus, Engdahl, Hoffman.

Obtained funding: Engdahl, Tambs.

Administrative, technical, or material support: Engdahl, Hoffman.

Study supervision: Engdahl, Tambs, Kvestad.

Conflict of Interest Disclosures: None reported.

Funding/Support: The Nord-Trøndelag Hearing Loss Study, which is a part of the Nord-Trøndelag Health Study, was funded by the National Institute on Deafness and Other Communication Disorders, National Institutes of Health research contract N01-DC-6-2104. This study was supported by research contract 2012/FOFM9336 to the National Institute of Public Health from the Extra Foundation: Health and Rehabilitation through the member organization, the National Association of Hard of Hearing.

Role of the Funder/Sponsor: The funding organizations had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Disclaimer: The views expressed in this article are those of the authors; they do not represent official policies of the Norwegian and US government agencies.

Previous Presentation: This study was presented at the 12th Congress of the European Federation of Audiological Societies, May 28, 2015, Istanbul, Turkey.

Additional Contributions: We are grateful to the late Hans Fredrik Fabritius, MD, and to Namos Hospital and Eskil Bjergan, MD (Namos Hospital), for making the School Hearing Investigation in Nord-Trøndelag data available to us. They received no financial compensation. The Nord-Trøndelag Health Study (the HUNT Study) is a collaboration between the HUNT Research Center, Faculty of Medicine, Norwegian University of Science and Technology, Norwegian Institute of Public Health, and Nord-Trøndelag County Council. The Nord-Trøndelag County health office and the community health officers in Levanger and other municipalities provided organizational and other practical support. We also thank the Nord-Trøndelag Hearing Loss Study team for their diligence.

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