Contributing Determinants to Hearing Loss in Elderly Men and Women: Results from the Population-Based Rotterdam Study

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Key Words

Presbycusis · Age-related hearing loss · Determinants of hearing loss · Body mass index · Smoking · Alcohol

Abstract

To contribute to a better understanding of the etiology in age-related hearing loss, we carried out a cross-sectional study of 3,315 participants (aged 52–99 years) in the Rotterdam Study, to analyze both low- and high-frequency hearing loss in men and women. Hearing thresholds with pure-tone audiometry were obtained, and other detailed information on a large number of possible determinants was collected. Hearing loss was associated with age, education, systolic blood pressure, diabetes mellitus, body mass index, smoking and alcohol consumption (inverse correlation). Remarkably, different associations were found for low- and high-frequency loss, as well as between men and women, suggesting that different mechanisms are involved in the etiology of age-related hearing loss.

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Introduction

Age-related hearing loss (ARHL) is highly prevalent [Gates and Mills, 2005] and contributes substantially to the global burden of disease [Pascolini and Smith, 2009]. ARHL is a disease with a complex etiology [Gates and Mills, 2005]. Schuknecht and Gacek [1993] described several audiological threshold patterns belonging to different pathological types, possibly with several etiologies and determinants. Since multiple determinants may interact in ARHL, it is essential to identify the individual and independent contribution of each of the determinants.

To date, several cross-sectional cohort studies have identified multiple contributing determinants to ARHL such as hypertension [Gates et al., 1993; Helzner et al., 2005; Rosenhall and Sundh, 2006], diabetes mellitus [Helzner et al., 2005], body mass index (BMI) [Fransen et al., 2008], smoking [Fransen et al., 2008; Gopinath et al., 2010; Dawes et al., 2014a, b], an inverse correlation of alcohol consumption [Fransen et al., 2008; Gopinath et al., 2010; Dawes et al., 2014a, b], occupational noise [Agra-

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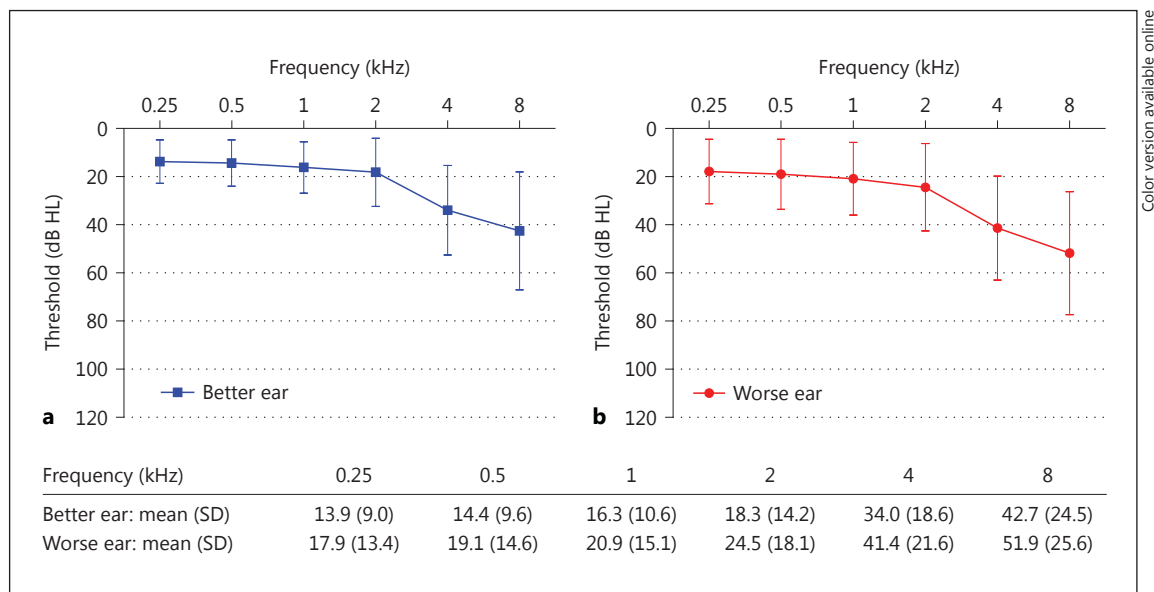E-Mail s.rigters@erasmusmc.nl

Fig. 1. Mean thresholds and standard deviations per frequency shown in pure-tone audiogram and table. **a** Better ear. **b** Worse ear.

Frequency (kHz)	0.25	0.5	1	2	4	8
Better ear: mean (SD)	13.9 (9.0)	14.4 (9.6)	16.3 (10.6)	18.3 (14.2)	34.0 (18.6)	42.7 (24.5)
Worse ear: mean (SD)	17.9 (13.4)	19.1 (14.6)	20.9 (15.1)	24.5 (18.1)	41.4 (21.6)	51.9 (25.6)

wal et al., 2008; Fransen et al., 2008], education [Agrawal et al., 2008], and race [Helzner et al., 2005; Agrawal et al., 2008]. Although consensus has been established about the associations with age, sex and occupational noise, less consistent results were found for determinants related to systemic diseases and lifestyle factors.

Methodological differences or insufficiencies in study design and data quality may be the reason for inconsistent results. Firstly, some studies rely on self-reported hearing loss instead of audiometric measurements. Secondly, many studies approach hearing loss as a categorical instead of a continuous variable, introducing loss of statistical power. Thirdly, most studies do not distinguish between low- and high-frequency hearing loss. Fourthly, some studies describe or select a specific cohort, rather than the general elderly population at large. And lastly, in some cases of research, only one or two determinants are examined while determinants will have a potential to influence one another and should thus be studied simultaneously.

With this study, we aimed to contribute to a better understanding of ARHL alongside the existing literature by studying the effects of known lifestyle factors and cardiovascular factors, on both low- and high-frequency hearing loss, among healthy elderly men and women within a large study cohort.

Material and Methods

Study Design and Subjects

This cross-sectional study was embedded in the Rotterdam Study [Hofman et al., 2015], an open-ended prospective cohort study, which focusses on factors associated with healthy aging. We included participants from cohorts RS-I-1, RS-II-3, and RS-III-2, who underwent pure-tone audiometry between 2011 and 2013. We excluded subjects with an air-bone gap of 15 decibel (dB) or more in the best hearing ear, to eliminate conductive hearing loss, leaving 3,315 participants.

The Rotterdam Study was approved by the medical ethics committee according to the Population Study Act Rotterdam Study, executed by the Ministry of Health, Welfare and Sports of the Netherlands. A written informed consent was obtained from all participants.

Pure-Tone Audiometry

Pure-tone thresholds (air conduction: 0.25, 0.5, 1, 2, 4, and 8 kHz; bone conduction: 0.5 and 4 kHz) were measured in dB HL by pure-tone audiometry performed by a trained person according to the ISO standard 8253-1 [International Organization for Standardization, 2010]. All measurements were performed in a soundproof booth. A computer-based clinical audiometry system (Decos Technology Group, version 210.2.6 with AudioNigma interface) and TDH-39 headphones were used.

Outcome variables were the overall hearing loss (average threshold of all measured frequencies), low-frequency hearing loss (average thresholds at 0.25, 0.5, and 1 kHz), and high-frequency hearing loss (average thresholds at 2, 4, and 8 kHz). We calculated the averages for the best-hearing ear (i.e. lowest averaged thresholds of all measured frequencies), to exclude the con-

Table 1. Characteristics of study population (n = 3,135)

Characteristic	Value for men	Value for women
Sample size, n	1,376 (43.9%)	1,759 (56.1%)
Age, years	65.5±7.4	65.6±7.8
Low-frequency hearing loss, dB HL	13.2±7.9	15.0±9.1
High-frequency hearing loss, dB HL	34.7±17.3	28.5±15.8
Education level		
Secondary	659 (48.7%)	845 (48.7%)
Higher	456 (33.7%)	321 (18.5%)
Systolic blood pressure, mm Hg	141.4±20.4	139.3±21.5
Diastolic blood pressure, mm Hg	84.5±11.0	82.4±11.2
Diabetes mellitus yes, n	182 (13.4%)	155 (8.9%)
Cholesterol ratio	4.3±1.3	3.7±1.1
BMI	27.7±3.8	27.5±4.8
Smoking		
Former	826 (60.4%)	830 (47.7%)
Current	188 (13.8%)	247 (14.2%)
Alcohol consumption		
Light	1,145 (83.5%)	1,242 (71.1%)
Above average	102 (7.4%)	207 (11.8%)

Values are means (and standard deviation) for continuous variables or numbers (and percentage) for categorical variables. Alcohol consumption calculated in average grams a day. Light consumption for women is 0–10 g a day, for men 0–20 g a day. Above-average consumption for women is more than 10 g a day, for men more than 20 g a day [Dawson and Room, 2000].

founding effects of asymmetrical hearing loss and focus on bilateral hearing loss. If both ears were equal, we alternately chose right and left.

Determinants

Several lifestyle and cardiovascular factors were investigated as possible determinants for ARHL. Age, sex, educational level, smoking status and alcohol consumption were determined at enrollment to the study through a questionnaire that was administered by a researcher at a home visit. Both smoking status and alcohol consumption were reassessed every 5 years at follow-up visits in the cohort study. Smoking status was categorized as never, former, or current smoker. Alcohol consumption was categorized as nondrinker, light drinker (1 unit per day for women and 1–2 units per day for men), or above-average drinker (more than 1 unit per day for women and more than 1–2 units per day for men) [Dawson and Room, 2000]. Educational level was categorized as completed primary level, secondary level, or higher education.

As well as audiometry, a set of examinations was done. Blood pressure was measured and the BMI was calculated. The cholesterol level was measured in serum, and the cholesterol ratio (the quotient of the total and high-density lipoprotein cholesterol) was calculated. Diabetic status was either confirmed at the home interview, tested by measuring glucose (fasting 7 mmol/l or more, nonfasting 11 mmol/l or more), or registered when a participant was prescribed diabetic medication.

Statistics

Data was checked for outliers and quadratic terms, which appeared not to be present. Missing data on covariates in 211 subjects (6.7%) were entered via multiple imputation. Missing values were present for educational level (1.5%), blood pressure (1.1%), diabetes mellitus (1.4%), cholesterol ratio (2.9%), BMI (1.2%), smoking (0.9%), and alcohol consumption (0.5%). Allowing for a 5% risk of type I error, significance was set at $p < 0.05$. A linear regression analysis was performed to assess the contribution of all determinants simultaneously. Data analysis was done using IBM SPSS Statistics version 21.

Results

Characteristics of the study population are summarized in table 1. Male participants had more hearing loss at high frequencies, while women had more hearing loss at low frequencies. Mean hearing thresholds for worse and better ears are shown in figure 1. A classic sloping audiogram can be seen.

Results of the multivariable linear analyses are shown in table 2. In men, low-frequency hearing loss was significantly associated with age (0.44 dB loss per year of age) and systolic blood pressure (0.03 dB loss per increase in 1 mm Hg of blood pressure). High-frequency hearing loss in men was significantly associated with age (1.34 dB loss per year of age), lower educational level and being a current smoker.

Table 2. Multivariable model for low- and high-frequency hearing loss in men and women

Determinants	Low frequency		High frequency	
	men β	women β	men β	women β
Age				
Per year ↑	*0.44 (0.38; 0.50)***	*0.56 (0.50; 0.61)***	*1.34 (1.22; 1.46)***	*1.25 (1.17; 1.34)***
Education				
Secondary vs. higher	0.67 (−0.19; 1.54)	0.45 (−0.58; 1.48)	0.88 (−0.85; 2.60)	0.42 (−1.23; 2.06)
Primary vs. higher	1.00 (−0.13; 2.12)	*1.87 (0.75; 2.99)***	*3.87 (1.62; 6.12)***	1.52 (−0.27; 3.31)
Systolic blood pressure				
Per mm Hg	*0.03 (0.00; 0.06)**	−0.02 (−0.04; 0.01)	0.03 (−0.03; 0.09)	−0.04 (−0.09; 0.00)
Diastolic blood pressure				
Per mm Hg	−0.03 (−0.08; 0.03)	0.01 (−0.04; 0.06)	−0.03 (−0.14; 0.08)	0.03 (−0.05; 0.11)
Diabetes mellitus				
Yes vs. no	0.48 (−0.68; 1.64)	0.87 (−0.45; 2.20)	0.12 (−2.13; 2.38)	*2.21 (0.08; 4.34)**
BMI				
Per point ↑	0.10 (−0.01; 0.20)	*0.09 (0.00; 0.17)**	0.06 (−0.15; 0.27)	*0.18 (0.05; 0.31)***
Cholesterol ratio				
Per unit ↑	0.04 (−0.26; 0.33)	−0.12 (−0.45; 0.22)	0.32 (−0.27; 0.91)	0.08 (−0.46; 0.63)
Smoking				
Former vs. never	−0.15 (−1.04; 0.74)	0.22 (−0.60; 1.04)	1.57 (−0.19; 3.32)	0.61 (−0.72; 1.93)
Current vs. never	0.98 (−0.29; 2.25)	*1.69 (0.50; 2.88)***	*3.01 (0.51; 5.52)**	*2.49 (0.60; 4.38)***
Alcohol				
Light vs. never	0.22 (−1.09; 1.53)	*−1.51 (−2.52; −0.50)***	1.85 (−0.76; 4.45)	−0.59 (−2.20; 1.02)
Above average vs. never	0.57 (−1.29; 2.42)	*−2.02 (−3.46; −0.58)***	1.10 (−2.58; 4.77)	−0.08 (−2.37; 2.22)

Effect sizes (β) are shown and 95% confidence limits are given in parentheses. Data in italics are significant findings. ** p < 0.01, * p < 0.05. Alcohol consumption calculated in average grams a day. Light consumption for women is 0–10 g a day, for men 0–20 g a day. Above-average consumption for women is more than 10 g a day, for men more than 20 g a day [Dawson and Room, 2000].

In women, low-frequency hearing loss was significantly associated with age (0.56 dB loss per year), lower educational level, BMI (0.09 dB loss per increase in 1 BMI point) and being a current smoker. Alcohol consumption was significantly associated with less low-frequency hearing loss (1.51 dB better hearing for light drinkers, 2.02 dB better hearing for above-average drinkers) when compared to nondrinkers. High-frequency hearing loss in women was significantly associated with age (1.25 dB loss per year), diabetes mellitus, BMI (0.18 dB loss per increase in 1 BMI point), and being a current smoker.

Discussion

Since ARHL is a growing problem in our increasing elderly population, it is important to gain a better understanding about its exact etiology. Obviously, ARHL is the cumulative effect of aging on hearing; however, multifactorial determinants are likely to contribute to the large variance observed in hearing loss among people of the same age.

In this study, we found a large number of determinants to be associated with ARHL including: age, smoking habits, consumption of alcohol, BMI, systolic blood pressure, diabetes mellitus, and educational level. Interestingly, these associations substantially differed between low- and high-frequency hearing loss, and also between men and women.

The largest effect on ARHL was found in age, as expected. For every decennium increase in age, hearing thresholds increase around 5 and 13 dB for low- and high-frequency hearing loss, respectively, in both men and women.

Furthermore, we found a substantial effect of smoking in both low- and high-frequency hearing loss in women and in high-frequency hearing loss in men. Associations with smoking were found in other studies [Gopinath et al., 2010; Dawes et al., 2014], but those studies did not stratify on gender, nor did they differentiate between high- and low-frequency hearing loss [Fransen et al.,

2008]. Hypothetically, smoking can cause alterations in the cochlear blood flow, thereby leading to different effects on the base and apex of the cochlea. However, such alterations are hard to investigate because of the cochlea's location [Nakashima et al., 2003]. The consistent associations found for high-frequency loss suggest that at least the basal part of the cochlea is involved. The contrary seems true for the effect of alcohol consumption, as associations are only found with low-frequency loss, suggesting an influence upon the apical part of the cochlea. Dawes et al. [2014] also found an inverse effect of alcohol on hearing loss suggesting alcohol has a protective function on hearing due to complex cardiovascular pathways [Matsumoto et al., 2014]. Concerning other cardiovascular risk factors, we found an effect of systolic blood pressure in low-frequency hearing loss in men, an effect of BMI in low- and high-frequency hearing loss in women and an effect of diabetes mellitus in high-frequency hearing loss in men. The more pronounced effects of determinants upon low-frequency hearing loss in women serve as support for the hypothesis of a cardiovascular disease-related cause. However, we did not find significant associations with all cardiovascular determinants in our model as possibly our determinants were not sufficiently accurate to detect a vascular origin of hearing loss.

The strength of this study includes the fact that we measured pure-tone thresholds for individual frequencies, treating the average threshold as a continuous variable as opposed to using self-reported hearing loss estimations as categorical variables, thus permitting for greater power in analysis in our study design. Race was not considered as a variable since the cohort represented almost 100% Caucasians. A limitation of this study is the lack of information on noise exposure, as this was not included in the questionnaire for participants. Noise exposure is an obvious determinant as it causes direct mechanical damage to the cochlea [Ciorba et al., 2011]. The only implication about noise exposure as a possible determinate in this study is in considering the association between educational level and the amount of noise exposure. We found a significant association between lower educational attainment and hearing loss, while in other studies there was controversy on this issue [Helzner et al., 2005; Agrawal et al., 2008; Cruickshanks et al., 2015]. Indirectly, we could assume people with a higher education to be less exposed to occupational noise and, if exposed, they might be more inclined to use hearing protection. Previous studies that did take noise exposure into account, still found an independent effect of smoking and alcohol on hearing loss [Fransen et al., 2008; Dawes et al., 2014].

The results of the current study confirm that ARHL is highly prevalent and influenced by many factors. Extending the knowledge about these contributing factors is essential for the prevention and future treatment of ARHL. This can be achieved by comprehensive population-based studies, taking into account relevant environmental and medical aspects.

Conclusion

In conclusion, hearing loss was associated with age, education, systolic blood pressure, diabetes mellitus, BMI, smoking, and alcohol consumption (inverse correlation). Results were different for low- and high-frequency loss among men and women, suggesting that different mechanisms are involved in the etiology of ARHL. Overall, a healthy lifestyle, e.g. without smoking or being overweight, may contribute to less hearing loss at an older age.

Disclosure Statement

The authors have no conflicts of interest to disclose.

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