Prevalence of Hearing Impairment by Gender and Audiometric Configuration: Results from the National Health and Nutrition Examination Survey (1999–2004) and the Keokuk County Rural Health Study (1994–1998)

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Abstract

**Purpose:** This study describes the most common audiometric configurations and the prevalence of these configurations among adults (ages 20 to 69) in the noninstitutionalized population of the United States and in a sample of residents of a rural county in Iowa.

**Research Design:** This was a cross-sectional population-based study.

**Study Sample:** Estimates generalizing to the noninstitutionalized population of the United States were based on National Health and Nutrition Examination Survey (NHANES) data collected from 2819 women and 2525 men between 1999 and 2004. Estimates from the rural county were based on Keokuk County Rural Health Study (KCRHS) data collected from 892 women and 750 men between 1994 and 1998.

**Data Collection and Analysis:** Cluster analyses (k-means) were used to divide participants into groups including maximally similar bilateral air conduction audiograms. Separate cluster analyses were conducted for each gender. For NHANES data, prevalence and error estimates were obtained using sample weights intended to provide data generalizing to the noninstitutionalized population of the United States within this age range.

**Results:** The hierarchical structure of audiometric configurations revealed that approximately 25% of women and 50% of men aged 20 to 69 in the noninstitutionalized population of the United States were best described by a configuration consistent with a marked hearing impairment in at least one frequency. Hearing impairments were more common among participants in the KCRHS. Gently sloping configurations of hearing impairment were dominant among women, while configurations featuring a greater slope were dominant among men. There was a greater variety of audiometric configurations in men than women.

**Conclusions:** In addition to their descriptive value, these data can be used to inform future studies of risk factors and progression of hearing loss, and to improve the generalizability of studies involving rehabilitative options for people with hearing impairment.

**Key Words:** Hearing impairment classification, epidemiology, NHANES, prevalence, public health statistics, pure tone audiometry, rural health, sex distribution

**Abbreviations:** BD = bulge depth; HTL = hearing threshold level; KCRHS = Keokuk County Rural Health Study; NHANES = National Health and Nutrition Examination Survey

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Prevalence of Audiometric Configurations/Ciletti and Flamme

**Sumario**

**Propósito:** Este estudio describe las configuraciones audiométricas más comunes y la prevalencia de estas configuraciones entre adultos (edades de 20 a 69 años) en la población no institucionalizada de los Estados Unidos y en una muestra de residentes del área rural de Iowa.

**Diseño de la Investigación:** Este fue un estudio de corte transversal basado en la población.

**Muestra del Estudio:** Los resultados que establecen generalización en relación con la población no institucionalizada de los Estados Unidos se basaron en los datos de la Encuesta Nacional para Examinar Salud y Nutrición (NHANES), colectadas de 2819 mujeres y 2525 hombres entre 1999 y el 2004. Los estímulos de la comunidad rural se obtuvieron de los datos del Estudio de Salud Rural del Condado de Keokuk (KCRHS), colectadas de 892 mujeres y 750 hombres entre 1994 y 1998.

**Recogida y Análisis de los Datos:** Se usó análisis de agrupaciones (medianas k) para dividir a las poblaciones en grupos, incluyendo los audiogramas de conducción aérea más similares bilateralmente. Se condujo un estudio separado para cada área geográfica, incluyendo los audiogramas de conducción de una misma área. Para los datos del NHANES, se obtuvieron estimados de prevalencia y error usando ponderaciones de muestra con la intención de generalizarlo a la población no institucionalizada de los Estados Unidos en este rango de edades.

**Resultados:** La estructura jerárquica de las configuraciones audiométricas reveló que aproximadamente 25% de las mujeres y 50% de los hombres en edades entre los 20 y los 69, en la población no institucionalizada de los Estados Unidos quedó mejor descrita por una configuración consistente con una trastorno auditivo marcado, en al menos una frecuencia. Los trastornos auditivos fueron más comunes entre los participantes en el KCRHS. Las configuraciones audiométricas con pendientes suaves fueron predominantes entre las mujeres, mientras que aquellas configuraciones mostrando caídas con mayor pendiente dominaron entre los hombres. Existió una mayor variedad de configuraciones audiométricas entre los hombres en las mujeres.

**Conclusiones:** Además de los valores descriptivos, estos datos pueden ser utilizados para documentar estudios futuros de factores de riesgo y progresión de la hipoaucia, y para mejorar los aspectos de generalización de estudios incluyendo opciones de rehabilitación para personas con trastornos auditivos.

**Palabras Clave:** Clasificación de trastornos auditivos, epidemiología, NHANES, prevalencia, estadísticas de salud pública, audiometría de tonos puros, salud rural, distribución por sexo

**Abreviaturas:** BD = profundidad del bulto; HTL = nivel umbrales de audición; KCRHS = Estudio de Salud Rural del Condado de Keokuk; NHANES = Encuesta Nacional para Examinar Salud y Nutrición

This study was motivated by a desire to better know the hearing status of the general population in terms of audiometric configuration. Clinicians and researchers are aware that a listener’s audiometric configuration influences the real-life consequences and the availability of rehabilitative options. But there is little or no research describing the configurations present in unscreened populations. Most research on the epidemiology of hearing loss involves the use of pure tone threshold distributions at individual frequencies or averaged pure tone thresholds. Despite their usefulness in the identification of hearing impairment trends over time, threshold data at individual frequencies and average thresholds can obscure differences among listeners that have important implications pertaining to etiology and rehabilitation.

Two approaches have been used to classify individuals based on audiometric configuration. In one approach, the investigators identify the classes of configurations expected to describe the population and assign data from each case to a configuration based on their similarity to the nearest class (Brockett and Schow, 2001; Pittman and Stelmachowicz, 2003; Hederstierna et al, 2007). Studies using this approach have tended to limit the number of configurations to eight or fewer, and any reported configuration prevalence data have not been based on samples of unscreened populations. The largest such study (Pittman and Stelmachowicz, 2003) classified the audiograms of six-year-old children and 60-year-old adults into sloping, rising, flat, U-shaped, tent-shaped, and one additional category, to which participants were assigned in the case that their audiometric configuration did not fit any other class. The operational definitions of the sloping and rising configurations were based on a 20 dB difference between the thresholds at 0.25 and 8 kHz. A configuration was defined as flat when all thresholds were present within a 20 dB range. U-shaped and tent-shaped were identified by the presence of at least one threshold between 0.5 and 4 kHz that was 20 dB different from the worse or better threshold, respectively, at 0.25 or 8 kHz. Results from the Pittman and Stelmachowicz...
(2003) study revealed that 73% of the adult participants in that study were best described as having either sloping or U-shaped configurations.

The approach of applying configuration definitions developed a priori yields results with an appealing simplicity. However, this approach may not be the most productive if one's intent is to describe the characteristics of an unscreened population. For example, adults in the Pittman and Stelmachowicz study were predominantly assigned to the sloping configuration (50%), but many hearing losses differing in audiometric shape and degree would fit within this classification even though the causes, needs, and problems in daily life faced by these individuals would likely be different. In addition, subclasses of audiometric configurations must be identified manually via the addition of new definitions post hoc.

An alternative approach to the identification of the principal audiometric configurations in a population involves examining audiometric patterns and grouping similar configurations without first specifying the audiometric configurations of interest. This analytic strategy, which uses a family of techniques called cluster analysis, is particularly useful when the existing literature provides little information about the variety of patterns present in the data (Waller, et al, 1998). In order to identify the typical amplification needs of children with hearing impairment enrolled in special education schools in Hong Kong, Yuen and McPherson (2002) used a k-means cluster analysis technique to divide a group of over 200 schoolchildren into five groups, each having different amplification needs.

Cluster analysis is an iterative method by which each case in a sample is assigned membership in the group that most closely matches the data profile of that case. The k-means approach to cluster analysis can be used to organize audiometric data into groups, or clusters. Each resulting cluster is represented by the audiometric configuration that best represents the subsample.

The purpose of the current study was to describe and estimate the prevalence of the predominant audiometric configurations present in unscreened adult populations and to examine the extent to which the prevalence of each configuration differed between the two sources of data used in this study. Analyses were stratified by gender to account for differences in results between men and women. Gender differences in the severity and prevalence of hearing loss have been identified in prior research (e.g., Borchgrevink et al, 2005), and prior research on gender-related differences in audiometric slope among the elderly revealed a trend toward more gently sloping audiometric shapes among women (Jerger et al, 1993). We felt it was important that systematic gender-based differences were not obscured by analyses of data collapsed across gender.

The two sources of data for the present study were the National Health and Nutrition Examination Survey (NHANES) and the Keokuk County Rural Health Study (KCRHS). The NHANES dataset was selected because it produced results that generalize to the noninstitutionalized U.S. population, after relevant aspects of the NHANES study design have been taken into account (National Center for Health Statistics, 2006). NHANES is an ongoing national survey conducted in two-year cycles to determine the health status of noninstitutionalized U.S. residents. Individuals invited to participate in the NHANES were selected based on a complex multistage probability sample involving multiple levels of stratification and sampling groups. The sampling frame used in NHANES divided the United States into communities and then further divided the communities into neighborhoods based on most recent census information. Households were randomly selected from the selected neighborhoods and participants were chosen from randomly selected households. All household members were interviewed, but not all were selected to participate. The NHANES data include sampling weights, which relate to the degree of influence each participant has on resulting estimates of health status in the population. Many health domains are assessed in the NHANES, but comprehensive data are not obtained from all participants. For example, audiometry data were obtained on only a subset of NHANES participants.

The KCRHS is an ongoing 20-year prospective cohort study designed to examine the health and consequences of injuries in a rural population. The KCRHS dataset was chosen because it is a large-scale study wherein comprehensive data are obtained on all participants. Approximately 25% of the U.S. population resides in a rural area (Hewitt, 1989). The rates of hearing impairment among residents of rural areas may not be well represented by the national estimates produced using the NHANES data because greater exposure to noise and other potential risk factors for hearing impairment can be expected in rural populations, where most participants engage in farming at some point in their lives (Merchant et al, 2002). The differences between prevalence estimates from NHANES and KCRHS data help identify the types of audiometric configurations that are more or less affected by the risk factor profiles that are more commonly found among residents of rural areas.

Participants in the KCRHS came from a rural Iowa county with a total population of approximately 11,000 (U.S. Census Bureau, 2007) where no town population exceeded 2,500 at the time the study began in the early 1990s. The KCRHS included participants (aged 8 to 92

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674
years) from whom data are collected every five years. Data were collected via interviews, medical tests, and environmental assessments of homes and farms. The majority of the participants in the KCRHS have engaged in farming at some point in life (Merchant et al, 2002). There is a high prevalence of hearing loss among KCRHS participants (Flamme et al, 2005). Households were the primary sampling unit in the KCRHS, and farm households were sampled at a greater probability than town and rural nonfarm households to provide better estimates of farm-related health issues. Further details regarding the KCRHS can be found in Merchant et al (2002).

METHOD

Participants

Data from 3711 women and 3275 men participating in the National Health and Nutrition Examination Survey (NHANES) and the Keokuk County Rural Health Study (KCRHS) were used in this retrospective study. NHANES data from three two-year cycles (1999–2004) were used in the current study. These de-identified data are available to the public via the National Center for Health Statistics Data Warehouse Web site (http://www.cdc.gov/nchs/datawh.htm). Audiometric thresholds were collected from a subsample of participants (2819 women and 2525 men), aged 20–69, during medical examinations that included blood chemistry, blood pressure, vision exam, cardiovascular fitness, and questionnaires about diet, depression, and work history (National Center for Health Statistics, 2001).

KCRHS data from participants aged 18 years and older (892 women and 750 men) were included in these analyses. De-identified data were obtained from the Keokuk County Rural Health Study group at the University of Iowa College of Public Health. Relative to NHANES, there were fewer young adults and more middle-aged and elderly adults in the KCRHS sample. This demographic trend is consistent with other rural areas in the United States (U.S. Census Bureau, 2007). In addition, participants in the KCRHS had greater high school graduation rates than participants in NHANES.

Instrumentation

Review of the operations manuals provided by the National Center for Health Statistics revealed that audiometric testing in NHANES was conducted at 0.5, 1, 2, 3, 4, 6, and 8 kHz using an Interacoustics Model AD226 audiometer with TDH 39 supra-aural earphones or Etymotic EarTone 3A insert earphones, which were used with participants judged by the tester to have a high likelihood of ear canal collapse if tested with supra-aural earphones. Testing was conducted inside a sound booth in a Mobile Examination Center. Ambient noise levels in the sound suite were sufficiently low to permit testing to 0 dB hearing threshold level (HTL) (re: ANSI S3.1-1991 [American National Standards Institute (ANSI), 1991]). Threshold testing was conducted down to −10 dB HTL. Calibration was conducted using reference values designed for NHANES that deviated −1 dB from the ANSI S3.6 (ANSI, 1996) standards at 3 and 6 kHz. Audiometric testing in KCRHS was conducted at the same frequencies in a single-walled sound suite using the Maico Model 800 audiometer and TDH 39 supra-aural earphones. Ambient noise levels in the sound suite were sufficiently low to permit testing to 0 dB HTL (re: ANSI S3.1-1991 [ANSI, 1991]). Stimulus calibration was completed in accordance with ANSI S3.6 (ANSI, 1989).

Data Analyses

Derivation of Audiometric Configurations

If responses to audiometric stimuli could not be obtained at the maximum output of the audiometer, a proxy threshold one audiometric step greater than the upper limit of the audiometer was substituted for the missing value. Gender-stratified iterative $k$-means cluster analyses were conducted using SPSS 14.0. Data from both ears were included within each analysis so that asymmetries could be identified. Root mean square error between the cluster centers and participant thresholds across frequencies were used to indicate the accuracy with which each cluster center matched the participants’ configurations. Plots of each participant’s audiogram relative to the associated cluster center were examined by the investigators to determine the nature of any observed inaccuracy.

After participants were assigned to a cluster in each solution, differences between cluster centers were calculated to determine whether all clusters extracted in a solution were substantially different from one another. A substantial difference was operationally defined as a 10 dB or greater difference between each cluster center for at least one frequency in at least one ear. The number of clusters, $k$, was increased incrementally until a pair of nearly identical clusters was identified or until a maximum of 20 clusters was extracted.

Audiometric Configuration Labels

Cluster centers were labeled to describe the location of low to mid frequency thresholds (0.5–2 kHz) and
worst threshold in the frequencies above this range. Low to mid frequency thresholds were labeled using letters A–G where A = 15 dB, B = 16–30 dB, C = 31– 45 dB, D = 46–60 dB, E = 61–75 dB, F = 76–90 dB, and G > 90 dB. In cases where the cluster centers resided in two categories, the category containing two of three cluster centers was used. The threshold at 1 kHz was used if all three cluster centers were in different categories. Each letter was then followed by the worst threshold at frequencies above 2 kHz.

Symmetric audiometric configurations (i.e., configurations wherein bilateral differences between cluster centers were less than 10 dB) were labeled based on the bilateral average while asymmetric cluster centers were labeled separately with the left ear labeled first.

Definitions were used to identify audiometric configurations that contained a bulge or were notched. Bulge was defined using a definition adapted from Dobie (2005). In this study, 8 kHz was included in the definition of bulge depth (BD), BD = PTA2346 – PTA18. (PTA = pure tone average.) Configurations with BD ≥5 dB in the mean values were classified as a bulge. Notched configurations were defined as having a poorer threshold at 3, 4, or 6 kHz with an improvement ≥10 dB at 8 kHz.

**Prevalence Estimates**

For NHANES data, sample weights for the audiometry portion of each two-year cycle of the NHANES were used to derive the prevalence estimate; as a result, prevalence estimates generalize to the noninstitutionalized U.S. population in the age range of 20 to 69 years. No sample weights were used with KCRHS data.

**RESULTS**

Clusters and cluster centers representing typical audiometric configurations were identified for both genders together and for each gender separately. Estimates of the prevalence of each audiometric configuration within each configuration are presented below.

**Audiometric Configurations**

Preliminary analyses revealed that men and women tended toward different audiometric configurations, and this underlying gender-related difference may obscure important differences in subsequent analyses associated with sequelae, risk factors, and progression of hearing impairment. The following analyses were conducted for each gender separately.

**Women**

Nine configurations described audiometric data from women. Six configurations were symmetric (Figure 1) while two were asymmetric (Figure 2). One configuration was identified but not analyzed further due to a small unweighted sample size (n = 3). Tabular representations of the data in these figures and additional technical information are presented in Appendix 1. One (asymmetric) configuration was extracted but not analyzed further due to the small number of participants (n = 3) best described by this configuration. Mean thresholds of 25 dB HTL or better between 0.5 and 4 kHz were present in most symmetric configurations. The prevalence of configurations with mean thresholds ≥25 dB HTL (A11 and A22) was
greater in NHANES (75.4%) than KCRHS (59.6%). Gradually sloping configurations were more prevalent among rural women (29.4%) than in NHANES (13.2%). Rural women were more likely to be represented by configuration A22 (30.9%) than configuration A11 (28.7%), and the prevalence rates for configurations A11 and A22 were higher among participants from NHANES (40.3% and 35.1%, respectively) than women in the KCRHS sample.

Three configurations (A48, B66, and D84) tended to gradually slope across all frequencies but varied in severity. The A48 configuration featured normal thresholds up to 2 kHz and a moderate sloping impairment above 2 kHz. Women best described by configuration B66 tended to have a slight to mild impairment below 2 kHz and a moderately severe impairment at 6 and 8 kHz. Participants described by configuration D84 tended to have a moderate to severe gently sloping impairment. Women were more likely to be represented by configuration A48 (8.7% NHANES, 14.4% KCRHS) than configuration B66 or D84. The prevalence of configuration B66 and D84 in NHANES data was less than five percent, while 15% of participants in KCRHS were members of these configurations.

One configuration (B29) was generally flat. Mean thresholds in configuration B29 were consistent with a slight to mild impairment in all frequencies. The prevalence of configuration B29 was 9 and 8% for NHANES and for KCRHS participants, respectively.

Women were represented by two asymmetric configurations, B40:D82 and C69:B35 (Figure 2). These configurations were bilateral mirrors of one another with respect to magnitude and shape. That is, the audiometric shape for the left ear in the B40:D82 configuration was similar to the shape for the right ear in the C69:B35 configuration, and the right ear in the B40:D82 configuration was similar to the shape for the left ear in the C69:B35 configuration. Thus, configurations B40:D82 and C69:B35 had similar audiometric shapes but differed with respect to the most affected ear. Participants described by these configurations tended to have a moderate to severe impairment for the most affected ear and a slight to mild impairment for the least affected ear. The combined prevalence of these configurations was less than 2%.

To simplify discussion of these results, a hierarchical structure (Figure 3) of configuration shapes and severity was developed by grouping together clusters with similar audiometric shapes. Prevalence defined on these bases revealed that 25% of the U.S. population aged 20 to 69 was best described by a configuration corresponding to a marked hearing impairment in at least one ear at one or more frequency. This rate was greater in the KCRHS sample (40%). In both data sets, the predominant configurations associated with a hearing impairment were characterized by either a gentle slope (13% in US; 29% in KCRHS) or a negligible slope (approximately 9% in both data sets).

Men

The maximum planned number of configurations \( k = 20 \) was needed to describe the data from men. Twelve configurations were bilaterally symmetric (Figure 4) and eight were asymmetric (Figure 5). Appendix 2 includes the associated tabular representations and additional technical information. One configuration was extracted but not examined further due to a small unweighted sample \( n = 1 \). In contrast...
Figure 3. Hierarchical organization of audiometric configurations among women. Audiometric configurations shown in Figures 1 and 2 were grouped according to similarity in shape. Numbers in regular text represent percent prevalence estimates from NHANES data; numbers in parentheses represent percent prevalence estimates from KCRHS data.

Figure 4. Panels A and C represent symmetric configuration cluster centers for men. Panels B and D represent the prevalence of each configuration within the NHANES and KCRHS data sets. Error bars represent the 95% confidence interval for the percentage.
to women, more asymmetric configurations were observed among men, and symmetric configurations were more varied and displayed notched and sharply sloping configurations that were not dominant in data from women. Twenty-five percent of male participants from NHANES were best described by an audiometric configuration with normal thresholds (A11) compared to 10.8% of KCRHS participants.

As observed with women, two configurations (A11 and A19) featured normal thresholds at nearly all frequencies and declined to a worst threshold at 6 kHz. The A19 configuration had normal thresholds up to 4 kHz and

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**Figure 5.** Panels A, C, and E represent asymmetric configurations for men. X = cluster centers for the left ear; circles = cluster centers for the right. A different line style was used for each configuration within a panel. Panels B, D, and F represent the prevalence of each configuration within the NHANES and KCRHS data sets. Error bars represent the 95% confidence interval for the percentage.
was consistent with a slight impairment above 4 kHz. Half of the participants from NHANES were represented by either configuration A11 or A19, but less than 25% of KCRHS participants were represented by those two configurations. Within these configurations, A11 was more likely to include NHANES participants (25.4%), and KCRHS participants were more likely to be represented by configuration A19 (13.8%).

Two notched configurations (A33 and A47) were observed among men. Men best described by configuration A33 tended to have normal thresholds to 2 kHz and a mild notched impairment at 4 kHz. Those described by configuration A47 featured normal thresholds up to 1 kHz and a moderate notched impairment at 4 kHz. Both data sets were more likely to be represented by configuration A33 (8.2% NHANES, 11.1% KCRHS) than configuration A47 (4.4% NHANES, 10.8% KCRHS). Participants described using notched configurations were almost twice as prevalent in the KCRHS sample.

Two configurations (A59 and B82) featured thresholds that sharply declined above 2 kHz. The A59 configuration described participants that tended to have normal thresholds up to 2 kHz and a moderately severe sloping impairment above 2 kHz. The B82 configuration was consistent with a slight impairment below 2 kHz and a profound sloping impairment above 2 kHz. The prevalence of the configuration A59 (5.8% NHANES, 6.5% KCRHS) and configuration B82 (3.3% NHANES, 5.1% KCRHS) was also greater among rural men.

Two configurations (B74 and B91) featured thresholds that sharply declined above 1 kHz. Men represented by configuration B74 tended to have a slight to severe sharply sloping impairment, and those described by configuration B91 had a mild to profound impairment. KCRHS participants were three times more likely than NHANES to be members of configuration B74 (2.1% NHANES, 7.7% KCRHS) or configuration B91 (0.8% NHANES, 3.7% KCRHS).

Two configurations (C55 and D78) featured thresholds that declined gently across frequencies. The C55 configuration was consistent with a mild to moderate impairment where the D78 configuration was consistent with a moderate to severe impairment. Rural men were more likely to demonstrate gently sloping impairments. The combined C55 and D78 configurations represented less than 2% of NHANES participants and less than 7% of KCRHS participants.

One symmetric configuration (E109) had thresholds at more than one frequency greater than 100 dB HTL. Participants described by configuration E109 tended to have a moderate impairment below 2 kHz and a profound impairment above 2 kHz. Less than 1% of participants from both data sets were represented by this configuration.

One configuration (B26) featured a somewhat flat audiometric shape. NHANES and KCRHS participants described by configuration B26 tended to have a slight to mild impairment. Less than 10% of men from both data sets were represented by configuration B26.

Seven configurations were asymmetric. Six of these consisted of three pairs of bilaterally mirrored configurations. Participants best described by the remaining configuration, A45:A35, tended to have a mild to moderate sloping impairment above 3 kHz in the left ear and a mild impairment for frequencies above 3 kHz in right ear. The two configurations, A49:A67 and A67:A53, were mirror images of each other wherein a moderate to moderately severe sloping impairment was typically found above 2 kHz in the most affected ear, while a mild to moderate sloping impairment for frequencies above 2 kHz was typical for the least affected ear. Configuration C68:A27 and A25:C70 represented another mirrored pair wherein a moderate to moderately severe sloping impairment was typically observed in the most affected ear and mild high frequency impairment was observed in the least affected ear. A third mirrored pair was represented by configuration B71:D101 and configuration D104:B65, which typically featured a precipitous mild to profound impairment in the most affected ear and a slight to moderately severe impairment in the least affected ear. Men in the KCRHS sample were more likely to be described by an asymmetric configuration (16.7% NHANES, 20.0% KCRHS).

When examined from within a hierarchical structure (Figure 6), 50% of the U.S. population aged 20 to 69 was best described by an audiometric configuration consistent with a mild impairment or worse in at least one ear at one or more frequencies. The predominant hearing loss configuration is characterized by a substantial slope or bilateral asymmetry. Together, these two configurations have a 42% prevalence rate nationwide (65% in the KCRHS sample). The predominant configurations are bilaterally symmetric with a notched or bulging shape, and the notched configuration with greater impairment on the left side (A45:A35) is the most common asymmetric shape. Bilaterally mirrored pairs of configurations were also common, occurring with varying severity in 9% of the U.S. population (13% in the KCRHS sample). Marked impairments at 500 Hz were observed in less than 1.5% of the U.S. population, and this rate was greater in the KCRHS sample (7%).

**DISCUSSION**

The most common audiometric configurations and estimates of the prevalence of each configuration in the adult population were identified in this study. Although no prior studies of the distribution of
audiometric configurations in the general population were available for comparison, our results confirm and expand upon prior studies that found a high prevalence of hearing impairment in the general population and a higher prevalence of hearing impairment among women (e.g., Davis, 1995; Cruickshanks et al, 1998; Borchgrevink et al, 2005; Flamme et al, 2005; Chia et al, 2007).

Our results are somewhat different from prior studies (e.g., Yuen and McPherson, 2002; Pittman and Stelmachowicz, 2003; Hederstierna et al, 2007). Study designs using audiometric configurations that were defined a priori (e.g., Pittman and Stelmachowicz, 2003; Hederstierna et al, 2007) showed a substantial prevalence of tent-shaped configurations (i.e., configurations wherein a frequency region with better sensitivity in the middle frequencies is surrounded by regions of poorer sensitivity in the high and low frequencies). This kind of configuration was found in approximately 13% of the participants in Pittman and Stelmachowicz (2003) but was not prominent in the current study. The configurations identified by Yuen and McPherson (2002) indicated a much greater prevalence of severe hearing impairments than were identified in the NHANES data from the current study. These differences were expected because neither study employed a sampling strategy likely to represent the general population. For example, the participants in the Pittman and Stelmachowicz study were drawn from the audiological database at the Boys Town National Research Hospital, which is a facility that can be expected to draw uncommon clinical cases, and the Hederstierna et al (2007) study included data from only women near the age of menopause.

**Prevalence Differences across Datasets**

There was a general trend toward increased prevalence of hearing impairment in the KCRHS sample. Among women, the main differences between
prevalence estimates derived from the NHANES and KCRHS data sets were observed in the gently sloping class of configurations, wherein the greatest differences were seen in gently sloping configurations B66 and D84, respectively. Prevalences of these configurations were four to ten times greater within the KCRHS sample.

For men, the prevalence of configurations with a substantial slope was greater in the KCRHS sample (Figure 6). This difference was primarily located in the subclasses of configurations characterized by notched or bulged audiometric shape, wherein the prevalence rates were two to three times higher, respectively. The rate of bilaterally mirrored asymmetric configurations was also about 1.5 times greater in the KCRHS sample. The analyses reported in the current study cannot identify the risk factors associated with these differences. However, notched and bulging configurations are commonly associated with excess noise exposure (Dobie, 2005), so it seems that this difference might be associated with greater lifetime exposure to risk factors for hearing impairment in rural areas (e.g., Holt et al, 1993; Beckett et al, 2000; Depczynski et al, 2005; Solecki, 2006).

**Gender-Related Differences in Audiometric Configurations**

Rates of hearing impairment among men were twice as great as among women. There was also an increase in the variety of configurations among men. Roughly 25% of the U.S. female population aged 20 to 69, and 50% of the corresponding male population, can be expected to have pure tone thresholds most accurately described by a configuration with a marked hearing impairment at more than one frequency (Figures 3 and 6). Notched and sharply sloping configurations were not identified among women but were common among men. The increased variety among men is likely due to the increased number and magnitude of exposures to occupational and nonoccupational risk factors for hearing impairment (e.g., Stewart et al, 2001; Schmuziger et al, 2006; Kurmis and Apps, 2007). It is interesting to note, however, that the prevalence of configurations with negligible slope was similar for women and men (7% and 9%, respectively).

One in four (25%) men in the 20–69 year age group was best described by configurations with notched or bulged shape, and 17% were best described by configurations with substantial asymmetry. Many of these asymmetric configurations could be paired with a complementary configuration with the most affected ear on the opposite side. For example, configurations A25:C70 and C68:A27 feature nearly identical configurations with respect to the least- or most-affected ears, but the right ear was the most affected in the former configuration and the left ear was the most affected in the latter.

**Biases and Limitations**

Weighting of individual NHANES participant data permits generalization to the noninstitutionalized U.S. population aged 20–69 years. However, considerable uncertainty is associated with estimates for more severe hearing loss configurations due to the rarity with which these are observed in the general population. Readers are encouraged to examine carefully the confidence intervals surrounding all prevalence estimates. Configurations having prevalence estimates with excessive confidence intervals (e.g., configuration D84 for women and configuration E109 for men) should be interpreted as provisional indicators of a heterogeneous group that is only grossly represented by the audiometric configuration identified in this study.

In both data sets, audiometric thresholds in the range of normal sensitivity may have been biased toward poorer thresholds. Thresholds better than 0 dB HTL are not uncommon among otologically normal listeners (ANSI S3.44-1996 [ANSI, 1996]), but the methods used in NHANES and the KCRHS were not optimized to detect these cases. Threshold testing in NHANES was conducted down to −10 dB HTL, but ambient noise levels were only known to permit testing down to 0 dB HTL (re: ANSI S3.1 [ANSI, 1991]). Thus it remains possible that thresholds of 0 dB HTL or better included in the NHANES raw data may by overestimated due to the effects of masking from ambient noise. Testing in the KCRHS was not conducted below 0 dB HTL, so reported thresholds of 0 dB HTL may not represent a listener’s best threshold. Based on the typical spectrum of ambient noise and the attenuation characteristics of audiometric earphones, we speculate that the predominant effect of these biases would be limited to configurations with mean low frequency thresholds in the normal range, which includes configurations A11, A22, and A48 for women, and configurations A11, A19, A33, A47, and A59 for men. Low frequency thresholds for the people best described by these configurations may be better than indicated by the mean data presented in this paper.

There is also a possibility that the supra-aural type of earphones used in this study may have caused ear canal collapse in some participants. Within the subpopulation seeking audiometric testing in a hospital in the 1960s, an approximate 3–5% rate of collapsed canals was observed, and this condition lead to a characteristic audiometric configuration with a 5–10 dB notch in air conduction thresholds, typically at 2 kHz (Hildyard and Valentine, 1962). No configuration with a notch centered at 2 kHz was observed in
this study, so we do not regard the possibility of ear canal collapse under supra-aural earphones to be a source of bias for the central tendencies of the audiometric configurations identified here. However, occasional undetected cases of ear canal collapse might have inflated the variance of thresholds within each configuration.

Suggestions for Further Research

Some audiometric configurations identified in the current study may be associated with specific classes of exogenous or endogenous risk factors. For example, notched and bulging configurations can be expected to be associated predominantly with excess noise exposure. It is also plausible that some of the asymmetric configurations may be associated with exposure to nearby sound sources because of the greater magnitude and frequency range of interaural level differences associated with these sound sources (Brungart and Rabinowitz, 1999). Such analyses may also help explain the substantial gender-related difference in typical audiometric configurations observed in this study. Exogenous risk factors recommended for inclusion are exposure to excess noise and toxicants such as organic solvents (e.g., Morata et al, 1997). Potential endogenous factors include otosclerosis, which is more prevalent among women (Sakihara and Parving, 1999), and cardiovascular disease, which is more strongly related to low frequency hearing status among women (Gates et al, 1993).

Some rare audiometric configurations are not described with enough accuracy. Analyses involving larger samples of the general population are required to provide more precise estimates of the variety and prevalence of these configurations.

The identification and estimation of the prevalence of audiometric configurations should be considered an entry point toward arguably more important information. Knowledge of the risk factors, progression, and the determination of the need for and effectiveness of rehabilitative options as a function of audiometric configuration could inform the efforts of clinicians and researchers seeking to find ways to prevent and reduce the negative consequences of hearing impairment.

The prevalence differences between overall U.S. population and the KCRHS sample of the rural population are difficult to interpret. People living in rural areas can be expected to accrue greater exposure to many risk factors for hearing impairment. In addition, there is a demographic trend toward migration out of rural areas, which results in a greater proportion of older people residing in these areas (Larson, 2006). The results of the current study indicate that the prevalence of many audiometric configurations is greater in the KCRHS sample than the U.S. average, but the reasons for this difference remain unclear. Further research is needed to describe the role played by age, excess noise, ototoxic exposures, and other prognostic factors in the prevalence differences between NHANES and the KCRHS.

CONCLUSION

Approximately 25% of noninstitutionalized women in the United States aged 20 to 69 and 50% of corresponding men have audiometric configurations best described as having a marked hearing impairment at one or more frequency. More diversity of configurations was observed among men, and the audiometric slope among men was generally steeper. Approximately 25% of men had audiometric configurations that were best described with a notched or bulging shape. The prevalence of configurations consistent with a marked hearing impairment was greater within the data from the Keokuk County Rural Health Study.

These results have considerable epidemiologic value for clinicians and researchers wishing to determine how common a given configuration is in the general population. The results could also facilitate the optimization of rehabilitative technologies to meet the needs of large numbers of people with hearing impairments who do not currently use hearing aids. In addition, these results are a starting point for epidemiological studies concerning the progression of and risk factors for specific hearing loss configurations.

Acknowledgments. The authors would like to thank Leon F. Burmeister, Beth Henning, Kevin M. Kelly, James A. Merchant, Jill Moore, Wayne T. Sanderson, Diana Sertterh, Ann M. Stromquist, Naomi Tucker, Ann Yeoman, and Craig Zwerling for conducting the Keokuk County Rural Health Study and providing some of the data used in this study. We also thank James M. Hillenbrand and Robert Dobie for their comments on an earlier revision of this manuscript.

NOTE

1. At each frequency, labels for the degree of impairment (re: Clark, 1981) were used. Thus, thresholds in the range of –10–15 dB HTL are labeled normal, 16–25 slight, 26–40 mild, 41–55 moderate, 56–70 moderately severe, 71–90 severe, and >90 profound. Use of these terms was intended to simplify description of the audiometric configurations in terms of the magnitude of impairment rather than the effect of the impairment on the listener.

REFERENCES


### Appendix 1. Cluster Center Means and Standard Deviations for Each Audiometric Configuration among Women

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Note: Configuration G125:D125 was not included due to small unweighted sample size (n = 3).

### Appendix 2. Cluster Center Means and Standard Deviations for Each Audiometric Configuration among Men

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Note: Configuration G105:G75 was not included due to small unweighted sample size (n = 1).