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Asymmetric Hearing Loss: Definition, Validation, and Prevalence

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Hypothesis: An algorithm for identifying asymmetric hearing loss (AHL) can be constructed that performs as well or better than expert judges.
Background: AMCLASS is a method for classifying audiograms based on configuration, severity, site of lesion, and interaural asymmetry. The development and clinician validation for all but asymmetry were reported separately. In this report, an algorithm for identifying AHL is described. Using the clinician-validated algorithm, the prevalence of AHL in a database from an academic health center audiology clinic was analyzed.
Methods: Five expert clinicians classified 199 audiograms as symmetric or asymmetric. Interjudge agreement was analyzed for each pair of judges and between each judge and the consensus of the panel. An algorithm was constructed based on the set of rules that maximized agreement between AMCLASS and judges. Using the clinician-validated algorithm, the prevalence of AHL was analyzed for groups based on quantity of bone conduction testing, hearing loss configuration, severity, and site of lesion.
Results: There was substantial disagreement among judges that was similar to interjudge comparisons for other medical tests. Average agreement between AMCLASS and the judges was higher than agreement between the best judge and the consensus of the judges. Approximately 50% of all patients and 55% of patients with sensorineural hearing loss were classified as AHL by the clinician-validated algorithm.
Conclusion: The algorithm met the goal of equaling or exceeding the performance of expert judges. The prevalence of AHL was higher than expected and suggests that the algorithm is not useful for screening for acoustic neuroma or other conditions. Perhaps, a criterion based on the magnitude of the asymmetry would better serve that purpose. The symmetry category provided by AMCLASS provides a determination of clinically significant AHL that agrees with the consensus of expert judges.
Key Words: AMCLASS—Asymmetric hearing loss—Audiogram—Hearing test.

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Asymmetric hearing loss (AHL) is of interest because it is used diagnostically for the determination of certain causes and because it has implications for rehabilitative strategies such as hearing aids. Although there have been many studies on AHL, there are no standard criteria for defining asymmetry, and there has been no attempt to validate any particular formula. In this study, an algorithm for determination of AHL was derived to maximize agreement with a panel of expert clinicians. The clinician-validated algorithm was used to analyze the prevalence of AHL in a large clinical database of audiograms.

Asymmetric hearing loss is an important risk factor for auditory nerve tumors. Several reports have recommended that further evaluation, especially expensive imaging studies, be conducted to rule out acoustic tumors when AHL is present (1–5).

In separate reports, we described the development and clinician validation of AMCLASS, a system for classification of audiograms based on configuration, severity and site of lesion (6), and the prevalence of hearing loss types in a clinical database (7). AMCLASS was developed to improve communication among clinicians and between clinicians and patients so that audiometric characteristics are described in a standardized, validated manner, provide a clinician-validated method for studying relationships between hearing loss characteristics and ear disease, provide a standardized interpretation of the audiogram to promote a more consistent approach to treatment, and provide a teaching tool for the development of audiogram interpretation skills.

In the first validation study (6), rules for determining audiometric asymmetry were not clinician-validated to

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AMCLASS (patent pending) is the intellectual property of the authors and may become a commercial product.

TABLE 1. *AMCLASS*

AUDIOLOGY INCORPORATED

AMCLASS™ - AUDIOGRAM CLASSIFICATION SYSTEM

Configuration	**Severity**	**Site of lesion**	**Symmetry**
Normal hearing		Conductive	Symmetrical hearing loss
Flat hearing loss	Mild	Sensorineural	AHL
	Moderate	Mixed	
	Severe	Sensorineural or mixed	
	Profound		
Sloping hearing loss	Normal-mild		
	Normal-moderate		
	Normal-severe		
	Mild-moderate		
	Mild-severe		
	Moderate-severe		
	Severe-profound		
	Profound		
Rising hearing loss	Mild-normal		
	Moderate-normal		
	Moderate-mild		
	Severe-normal		
	Severe-mild		
	Severe-moderate		
	Profound-severe		
	Profound		
Trough-shaped hearing loss	Mild		
	Moderate		
	Severe		
Peaked hearing loss	Mild		
	Moderate		
	Severe		
Other	Mild		
	Moderate		
	Severe		

avoid biasing the judges' classifications of the other audiometric features by presenting the audiogram for the other ear. A separate validation study for AHL was conducted and is reported here.

The prevalence of any audiometric feature is dependent on the definition of the feature. In the case of audiometric asymmetry, many formulae have been used, but only one study investigated the variations in prevalence resulting from different formulae. Caldera and Pearson (5) examined 1,490 audiograms of Royal Air Force personnel and analyzed the incidence of asymmetry. Incidence varied from 51 new patients per 100,000 to 7,215 patients per 100,000 per year. This 141-fold variation in prevalence indicates clearly that the prevalence of AHL is inexorably tied to the definition, which should be based on a defensible rationale.

Two defensible rationales come to mind. The definition can be based on test performance for the identification of some condition. This approach was taken by Mangham (8), who analyzed that an average interaural difference of greater than 10 dB at 1, 2, 4, and 8 kHz had the best sensitivity and specificity for detecting acoustic tumors. Another approach is to define AHL according to what expert judges call AHL. That is the approach taken in this report. A definition derived via this method may be best for asking questions regarding the prevalence of AHL in various clinical populations such as those reported by Wilson et al. (9), Caldera and Pearson (5), and Pittman and Stelmachowicz (10).

Standard definitions of audiometric features would facilitate communication between clinicians and between clinicians and patients and avoid the confusion of different

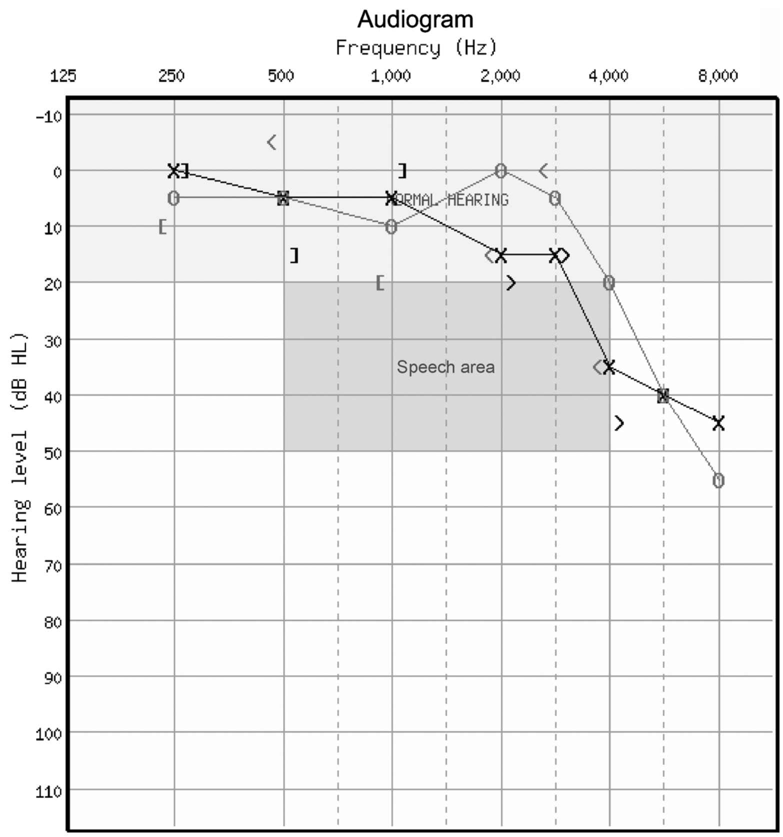

FIG. 1. Audiogram judged to be symmetric by 4 of 5 judges. X indicates left ear air conduction; 0, right ear conduction; >, left ear bone conduction; <, right ear bone conduction.

description of the same hearing loss. In this study, a set of rules for determining audiometric asymmetry was developed and validated.

MATERIALS AND METHODS

AMCLASS (US Patent Pending)

AMCLASS is a set of rules for classification of audiograms based on configuration, severity, site of lesion, and interaural asymmetry. The rules for configuration, severity, and site of lesion were validated in a previous study (6). This study is a validation of the AMCLASS rules for determining audiometric asymmetry and represents the final step in the validation of AMCLASS. AMCLASS categories are shown in Table 1. Audiograms are assigned to categories based on 169 logical rules, including 23 for configuration, 45 for severity, 56 for site of lesion, and 45 for asymmetry.

The initial set of rules for determining asymmetry were the following: 1) ≥10-dB interaural threshold difference at 3-octave frequencies (250–8,000 Hz), 2) ≥15-dB difference at 2-octave frequencies, and 3) >15-dB difference at 1-octave frequency. Although the judges tended to apply these rules, it became apparent that they used a much more complex set of criteria. This is probably due to the wide range of complexities in audiometric patterns. An example is shown in Figure 1. This patient would be judged to be asymmetric based on the previously described rules because there are differences exceeding 10 dB at 2 frequencies (2,000 and 4,000 Hz). However, 4 of 5 judges described it as symmetric.

It is possible that the weights assigned by the judges to asymmetries at some frequencies were influenced by threshold differences at other frequencies. Threshold differences at 250, 1,000, and 8,000 Hz are in the opposite direction (left ear better) from those at 2,000 and 4,000 Hz. Another example is shown in Figure 2. This audiogram would be symmetric by the initial rules, but 4 of 5 judges described it as asymmetric. A new rule would be needed to achieve agreement between AMCLASS and the judges for patients such as the one in Figure 2. Using the judges' responses obtained in the validation study, a set of rules were derived to maximize agreement between AMCLASS and the expert judges.

Clinician Validation Study

To maximize agreement between AMCLASS and expert judges, a set of 199 audiograms were selected from a clinical database. Cases were selected to produce roughly equal numbers of symmetric and asymmetric audiograms. This was accomplished by calculating the interaural pure-tone average difference for a large set of audiograms and randomly selecting cases from the subset for which the interaural pure-tone average differences are between −15 and 15 dB. For this purpose, the pure-tone average was the average threshold at 500, 1,000, 2,000, and 4,000. The constraint on the pure-tone average was necessary to avoid cases that were so asymmetric that agreement between AMCLASS and the judges would be exaggerated.

Five expert judges categorized each audiogram as symmetric or asymmetric. No definition of AHL was provided. The judges were instructed to use the criteria they use in their clinical

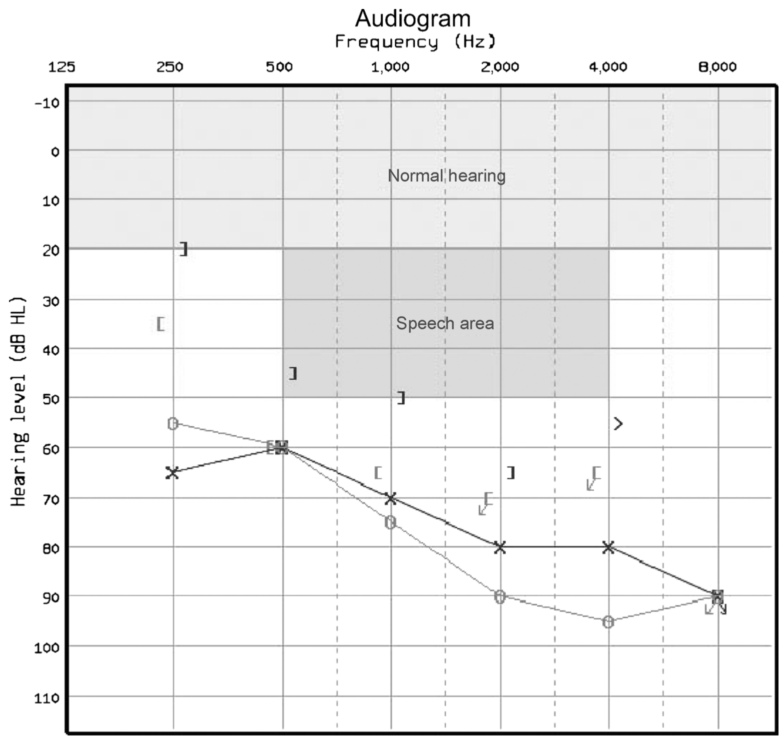

FIG. 2. Audiogram judged to be asymmetric by 4 of 5 judges. X indicates left ear air conduction; 0, right ear conduction; >, left ear bone conduction; <, right ear bone conduction.

practices. The panel included 4 audiologists and an otologist who have practiced for at least 20 years. The first author served as one of the judges. For each case, the consensus of the panel was analyzed. The consensus was the category (symmetric or asymmetric) that was chosen by most judges.

Development of the Final Rule Set

The final rule set was derived by an iterative process in which trends were observed in the cases for which AMCLASS disagreed with the consensus of judges, rule changes were implemented to improve agreement, the influence of the changes was analyzed, and the changes were accepted or rejected depending on whether they improved agreement. This process continued until the agreement between AMCLASS and the consensus exceeded the average interjudge agreement and further changes could not be identified for improving agreement.

The Clinic

The final version of AMCLASS symmetry rules was used to analyze a database of archived records of the University of Minnesota Hospital Audiology Clinic. An electronic archive was mined (with institutional review board approval) to produce a database that included pure-tone thresholds, masking levels, speech thresholds, and speech recognition scores.

The clinic is adjacent to the University of Minnesota Hospital Ear, Nose, and Throat (ENT) Clinic. Patients scheduled for ENT visits were observed in audiology if they had an ear-related complaint. The ENT clinic is a regional referral center

TABLE 2. *Agreement*

	Interjudge agreement, % (κ)				
Judge	1	2	3	4	5
2	72 (0.45)				
3	67 (0.35)	82 (0.64)			
4	78 (0.56)	82 (0.65)	80 (0.61)		
5	85 (0.70)	74 (0.49)	74 (0.49)	77 (0.54)	
Agreement with consensus, % (κ)	83 (0.67)	87 (0.74)	84 (0.68)	90 (0.81)	86 (0.73)
Agreement with AMCLASS, % (κ)	84 (0.68)	81 (0.62)	78 (0.56)	86 (0.73)	86 (0.73)
Mean interjudge agreement, % (κ)	77 (0.55)				
SD	5.5 (0.55)				
Mean agreement with consensus, % (κ)	86 (0.72)				
SD	2.8 (0.06)				
Mean agreement with AMCLASS, % (κ)	83 (0.66)				
SD	3.7 (0.07)				
Mean agreement AMCLASS versus consensus, % (κ)	91 (0.82)				

SD indicates standard deviation.

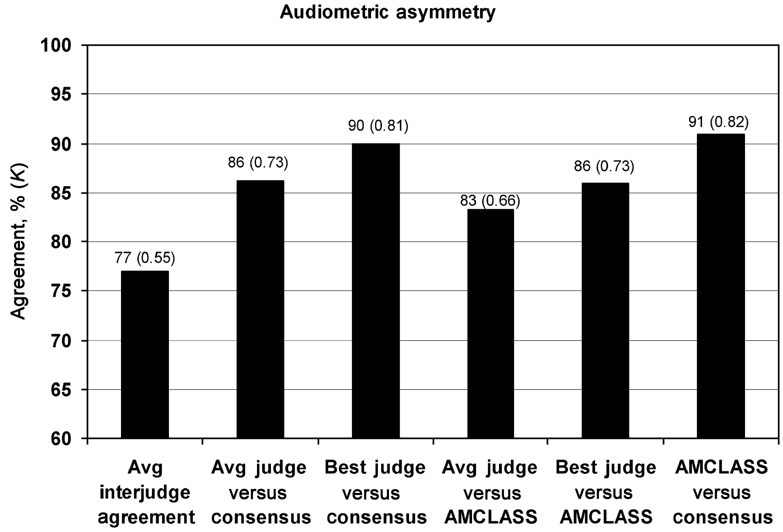

FIG. 3. Interjudge agreement and agreement between judges and AMCLASS.

for neurotology receiving many referrals for dizziness, sudden hearing loss, and other neurotologic issues. In addition, clinic patients were referred by many internal and external healthcare providers or were self-referred. The clinic has a hearing aid dispensing program and a cochlear implant program that produced audiograms associated with initial and follow-up appointments. Because the clinic is part of an academic health center, the database includes some audiograms associated with research visits.

The Database

The database includes all audiometric records that were saved to the electronic archive during the period from June 1989 to January 2003. Most but not all of the patient encounters during that period resulted in a saved record. Some visits for special testing (e.g., play audiometry, auditory brainstem response, otoacoustic emissions, bedside audiograms, and intraoperative testing) did not produce a file saved in the archive. These probably represent less than 10% of the patient visits during that period. There were many incomplete records primarily resulting from aborted evaluations. Some patients were observed more than once. The analyses were conducted on all archived records and on first-visit audiograms, with repeat tests excluded.

A lack of standardization of the pure-tone audiometric assessment complicated the analysis. Audiograms vary with respect to the number of frequencies tested, the number of ears tested, and

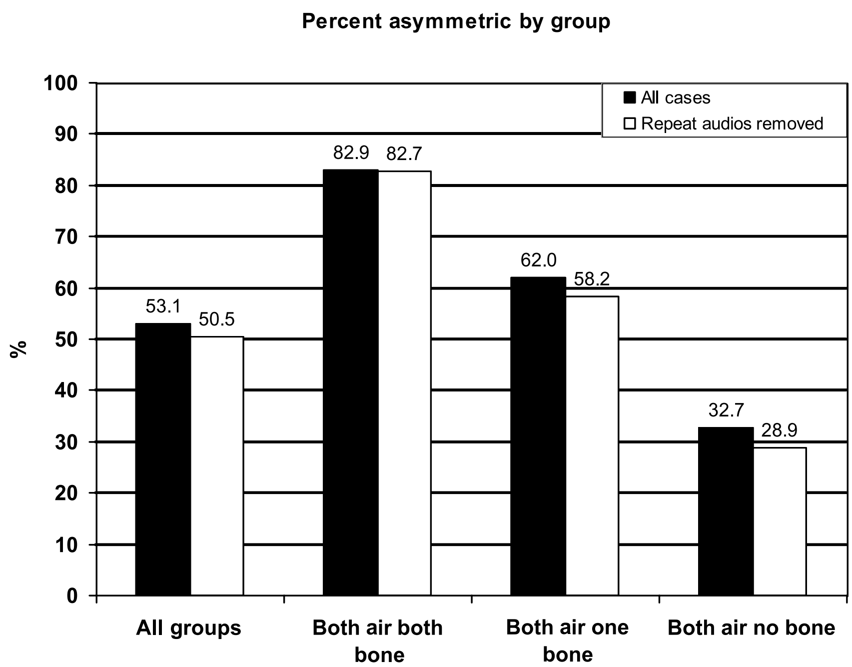

FIG. 4. Prevalence of asymmetric hearing loss in the database.

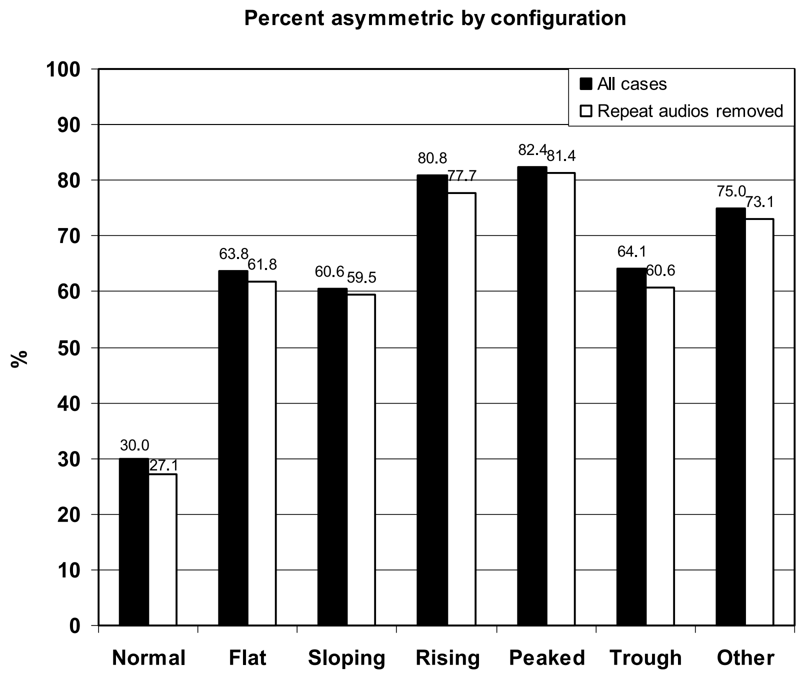

FIG. 5. Prevalence of AHL by audiometric configuration.

whether air and bone conduction were tested on one ear, both ears, or not at all. A minority of records include complete air conduction and bone conduction testing on both ears. From the archive of 31,676 records, 23,798 were selected that were judged to contain complete audiograms. A record was judged to contain a complete audiogram if one of the following conditions was met.

Group 1—complete air and bone conduction testing on both ears (3,891 records, 2,794 patients); Group 2—complete air and bone conduction testing on one ear, complete air conduction testing on the other ear, and no bone conduction or incomplete bone conduction testing (9,886 records, 7,282 patients); and Group 3—complete air conduction testing on both ears and no

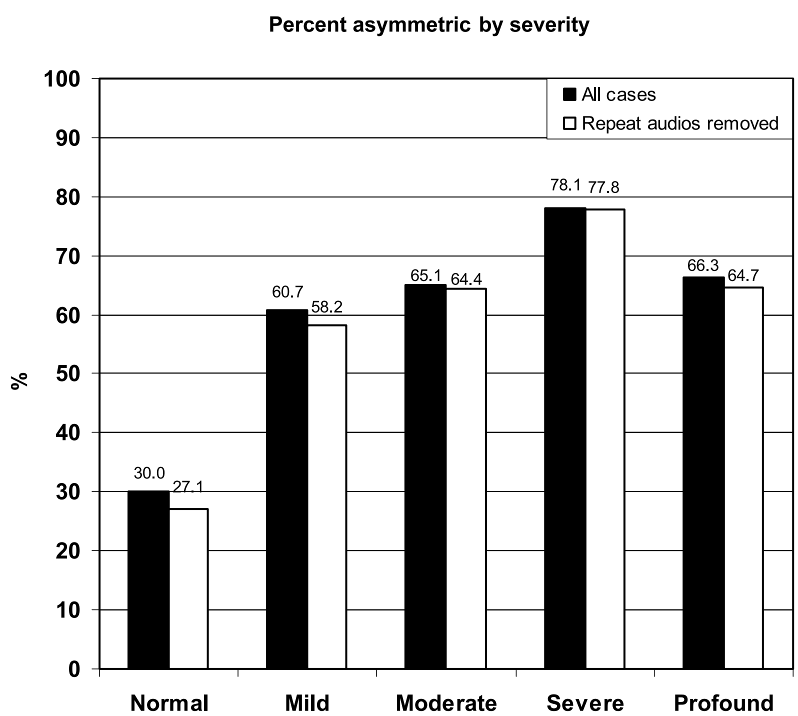

FIG. 6. Prevalence of AHL by severity.

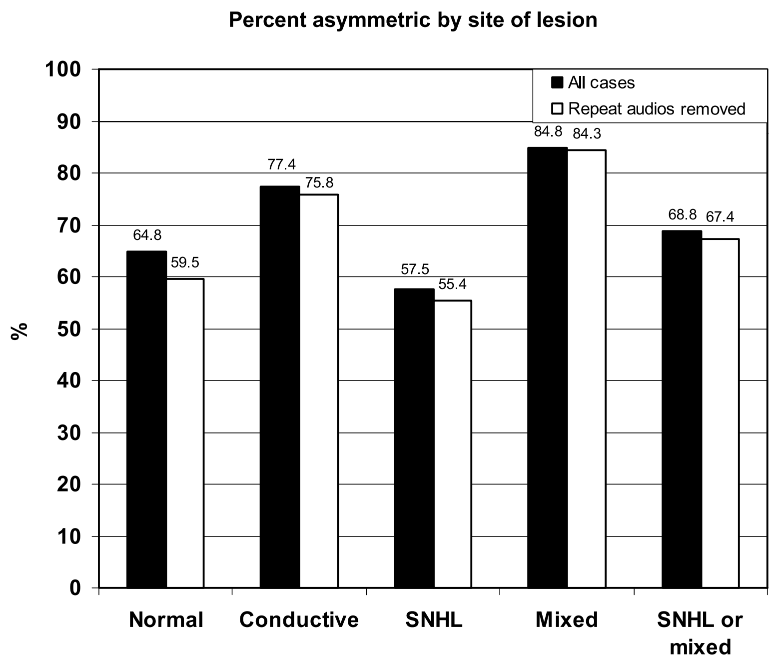

FIG. 7. Prevalence of AHL by site of lesion. SNHL, sensorineural hearing loss.

bone conduction testing or incomplete bone conduction testing on both ears (10,021 records, 6,742 patients).

Complete air conduction testing was defined as thresholds (including no response determinations) at all octave frequencies over the range 250 to 8,000 Hz. Complete bone conduction testing was defined as thresholds (including no response determinations) at all octave frequencies over the range 500 to 4,000 Hz.

Analysis

The analysis was conducted on all records in each group and on first-visit audiograms, with repeat audiograms omitted. A more complete description of the database is available in a previous article (7). Some of the analysis was based on number of patients, and some was based on number of ears. Interjudge agreement and judge-AMCLASS agreement were based on number of patients. To analyze the prevalence of AHL in subgroups based on audiometric configuration, severity, and site of lesion, it is necessary to use “ear” as the unit of analysis because the 2 ears can be different with respect to these characteristics. For these analyses, a separate result was obtained for each of 47,596 ears when all records are included and 33,636 ears when repeat audiograms were excluded.

RESULTS

Interjudge Agreement and Agreement Between Judges and AMCLASS

Agreement was analyzed as the percent of cases and by the κ statistic. The κ statistic (11), is a measure of agreement between categoric data sets that takes into account the probability of agreement due to chance. In the case of 2 symmetry categories, for example, the likelihood of agreement between a pair of observations due to chance is 0.5. With such a small number of categories, the chance-corrected measure of agreement is substantially lower than the percent agreement.

Agreement results are shown in Table 2 and Figure 3. Interjudge agreement ranged from 67 to 85%, with a mean of 77%, indicating that in almost 1 in 4 patients, the judges disagreed on whether an audiogram was symmetric or asymmetric. When corrected for chance agreement using the κ statistic, mean interjudge agreement was only 55%.

Agreement between individual judges and consensus ranged from 83 to 90% and averaged 86% (κ = 0.72). This was adopted as the standard of comparison for determining if AMCLASS agreement with the experts is adequate. If the agreement between AMCLASS and consensus is better than the average agreement between individual judges and consensus, we can say that AMCLASS performs better than the average judge.

Agreement between individual judges and AMCLASS ranged from 78 to 86% and averaged 83% (κ = 0.66). Thus, agreement between individual judges and AMCLASS was generally higher than interjudge agreement.

Agreement between AMCLASS and consensus was 91% (κ = 0.82). This exceeded the average agreement between judges and consensus (86%; κ = 0.72). In fact, the agreement between AMCLASS and consensus was slightly higher than the best agreement between the judges and consensus (90%).

AHL in the Database

The prevalence of AHL in the database is shown in Figure 4. For each group and for all groups combined, prevalence is shown for all patients and for first-visit audiograms with repeat audiograms removed. For all groups combined, approximately one half of the records show AHL.

The prevalence is highest when both ears were tested by air conduction and bone conduction (82%) and lowest when no bone conduction testing was performed (approximately 30%). The effect of removing repeat audiograms was remarkably small, a finding that was similar for configuration, severity, and site of lesion (7).

Figure 5 shows the prevalence of AHL by configuration. Configuration categories were determined by AMCLASS (6). Rising and peaked hearing losses were most likely to be associated with AHL (approximately 80%) and then “Other” (75%). Flat, sloping, and trough-shaped losses were asymmetric 60 to 64% of the time. The surprisingly high prevalence of AHL for normal audiograms (approximately 30%) probably results from patients in which one ear is normal but there is significant hearing loss in the other ear.

Figure 6 shows the prevalence of AHL by hearing loss severity. Severe hearing losses are the most likely to be asymmetric (approximately 80%). Mild, moderate, and profound hearing losses were asymmetric 60 to 65% of the time.

Figure 7 shows the prevalence of AHL by site of lesion. This analysis was restricted to the “Both Air Both Bone” and “Both Air One Bone” groups because determination of site of lesion requires bone conduction thresholds. Because the “Both Air No Bone” group has the lowest prevalence of AHL (Fig. 4), the prevalence of AHL in the “Normal” group had a higher occurrence of asymmetry compared with those shown in Figures 5 and 6.

Mixed hearing losses were highly likely to be asymmetric (approximately 85%), followed closely by conductive, sensorineural or mixed, and normal. Sensorineural hearing losses were asymmetric approximately 55% of the time.

DISCUSSION

Interjudge Agreement for Medical Tests

Disagreement among expert judges in the interpretation of medical tests has been studied in several disciplines, and the levels of disagreement tends to be similar to those reported here for audiometric asymmetry. One study, for example, reported on interjudge agreement on the interpretation of mammograms by radiologists (12). Average agreement between pairs of judges was 78% (κ = 0.47), not unlike the 77% (κ = 0.55) reported here. Another study reported interjudge agreement among radiologists in judging chest x-rays as normal or abnormal (13). Agreement between pairs of judges averaged 80% (range, 70–95%), similar to the average of 77% (range, 67–85%) reported here for audiometric asymmetry. In a study of interpretations of cervical biopsies by pathologists (14), the average agreement between judges and a panel of experts was 87%, similar to the 85% average agreement between individual judges and the consensus of judges reported here for AHL.

Interjudge Agreement and Judge-AMCLASS Agreement

The average interjudge agreement for determining audiometric asymmetry was 77% (Table 2). This level of disagreement may be higher than that encountered in general clinical practice because of the way the patients were selected. Patients with large average interaural threshold differences were not included in the validation sample. Those are the ones for which agreement would be expected to be highest. Nevertheless, the interjudge agreement results indicate that in a large number of patients, expert judges disagree on audiometric asymmetry.

The average agreement between judges and consensus was 86%, and the highest agreement was 90%. Agreement between AMCLASS and consensus was 91%, higher than that for the best judge. Thus, the goal to achieve agreement between AMCLASS and consensus that was as good or better than the average expert judge seems to have been accomplished.

Prevalence of AHL in the Database

The overall prevalence of AHL in the database was approximately 50% (Fig. 4) and differed for groups based on configuration, severity, and site of lesion (Figs. 5–7). The high prevalence of AHL reported here is an indication that in a clinical population, asymmetry may be more the norm than the exception. The remarkably small difference in prevalence in all groups when repeat audiograms were included or excluded is an indication that patients with AHL are not more likely to be observed for multiple visits than patients with AHL.

Substantial differences in prevalence were observed for groups based on the amount of bone conduction testing that was performed (Fig. 4). This results primarily from 1) the widespread practice of testing only one ear by bone conduction when air conduction thresholds are symmetric, and unmasked bone conduction on one ear indicates no air-bone gap, and 2) the practice of not testing bone conduction for either ear when both ears are normal by air conduction. The large variation in the quantity of bone conduction testing that is performed is an indication of a lack of standardization in clinical hearing testing.

The prevalence of AHL will inevitably differ for different populations. The results of Caldera and Pearson (5) for Royal Air Force personnel indicated incidence of AHL ranging from 0.05 to 7% new cases per year. This nonclinical population would be expected to have a lower overall prevalence of hearing loss and a lower prevalence of AHL than a clinical population. Pittman and Stelmachowicz (10) analyzed interaural asymmetries in 2 groups with sensorineural hearing loss, a group of 6-year-old children and a group of 60- to 61-year-old adults. They found interaural asymmetries greater than 20 dB at 1 or more frequencies of 41% for children and 38% for adults. Because of differences in criteria for AHL and in subject selection, it is difficult to compare these results with those reported here. Because of the large number of referrals to our clinic from ENT, including many patients with dizziness, middle ear disease, and other otologic disease, the database may be skewed toward a higher prevalence of AHL compared with other clinical populations.

Screening for Acoustic Tumors

Because acoustic tumors are usually unilateral and hearing loss is often an early sign, AHL is commonly regarded as a risk factor. Some have suggested that referral for further evaluation, especially imaging studies, should be based, at least in part, on audiometric asymmetry. The prevalence of AHL was approximately 50% for the entire database (Fig. 4) and approximately 55% for patients with sensorineural hearing loss (Fig. 7). The exclusion of patients for which the AHL is due to conductive hearing loss will reduce the referral rate. However, the prevalence of AHL that is unrelated to acoustic tumors in the sensorineural group suggests that the specificity of AMCLASS is too low to be a useful screening method for acoustic tumors.

Mangham (8) recommended a screening criterion of 10 dB difference or greater in thresholds averaged over 1 to 8 kHz based on the sensitivity and specificity of various measures of asymmetry. In their nontumor control group, approximately 16% failed this criterion, arguably an acceptable false alarm rate if the sensitivity is adequate. The false alarm rate will differ depending on the composition of the control group. When we applied Mangham's criterion to our Group 1 (complete air and bone conduction tested on both ears) the fail rate was 61%. As shown in Figure 4, the prevalence of AHL is highest in that group. Nevertheless, it is likely that Mangham's rule will produce a higher rate of false positives in some clinical populations than he reported for his control group.

The definition of AHL used by Urben et al. (15) was more similar to that used by AMCLASS. They defined AHL as asymmetries of 10 dB or greater at 2 or more frequencies or 15 dB or greater at 1 frequency. Because these rules are a subset of AMCLASS asymmetry rules, AMCLASS would be expected to produce a higher rate of AHL. They reported a prevalence of AHL of 21% in a sample drawn from a community-based otolaryngology practice. Even with the lower prevalence compared with this study, they reached a similar conclusion that the rate of AHL is high enough to produce an unacceptable false-positive rate. They proposed a protocol similar to the one described by Welling et al. (16) in which a subset of patients with AHL are evaluated for retrocochlear pathologic findings.

Fisher et al. (17) reported a prevalence of 16% of AHL (by self-report) when a sample of otology clinic patients with middle ear or external ear explanations were excluded. They also concluded that the prevalence of AHL results in an unacceptable cost of MRI evaluation for all patients with hearing asymmetry.

Schlauch et al. (18) used a clinical decision theory approach to determining the performance of AHL as a test for retrocochlear pathologic findings. Based on receiver-operating-characteristic curves for hearing loss asymmetry defined two ways, they concluded that AHL does not provide an effective screen for retrocochlear pathologic findings.

It is possible that the definition of AHL that agrees best with expert judges is not the definition that is the most useful for screening for acoustic tumors. However, the consensus of the studies reviewed here is that AHL is not an effective screen for acoustic tumors even when definitions are used that produce much lower prevelences than those reported here. Perhaps a different, more effective definition will emerge. However, it seems likely that AHL has so many causes that no measure of interaural asymmetry will produce a screening test for acoustic tumors that has acceptable sensitivity and specificity. This is not to say that audiometric asymmetry should not be considered in the diagnostic process.

Limitation of the Study

The final rules for identifying audiometric asymmetry perform well in the sense that the agreement with the judges is higher than the average interjudge agreement. It is possible, however, that the agreement will be lower on an independent data set that was not used in the development of the rules. The same principal holds for the other audiometric characteristics categorized by AMCLASS—configuration, severity, and site of lesion—that were reported previously (6). A follow-up study should be undertaken to evaluate the performance of AMCLASS on an independent data set. Ideally, that data set would be sufficiently broad to provide stratification into useful subgroups based on age, cause, and other patient characteristics.

SUMMARY AND CONCLUSION

This study was undertaken to evaluate a system of rules for determining the presence of AHL from a pure-tone audiogram. The rules are part of a larger system that includes the determination of configuration, severity, and site of lesion, which were clinician-validated in a previous study (6). The rules for AHL were compared with the judgments of 5 expert clinicians who judged 199 audiograms as symmetric or asymmetric. The rules were adjusted to maximize agreement between AMCLASS and the judges. The final rules were used to characterize the prevalence of AHL in a large clinical database. The following conclusions are offered regarding AHL in the clinical population that was analyzed.

1. Average interjudge agreement for the sample was 77% indicating that the judges disagreed on whether an audiogram was asymmetric just under a quarter of the time.
2. Average agreement between AMCLASS and the consensus of judges (91%) was higher than the average agreement between pairs of judges.
3. The overall prevalence of AHL in the database was higher than expected—approximately 50% for all patients and 55% for patients with sensorineural hearing loss.
4. Among configuration groups, rising and peaked hearing losses were most likely to be asymmetric—approximately 79% and 82%, respectively.

5. Among severity groups, severe hearing losses were most likely to be asymmetric—78%.
6. The results of this study support the conclusion of several published reports that AHL does not perform well as a screen for tumors of the auditory nerve.

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