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EVALUATION OF DIFFERENT CRITERIA FOR
SIGNIFICANT THRESHOLD SHIFT
IN OCCUPATIONAL HEARING CONSERVATION PROGRAMS

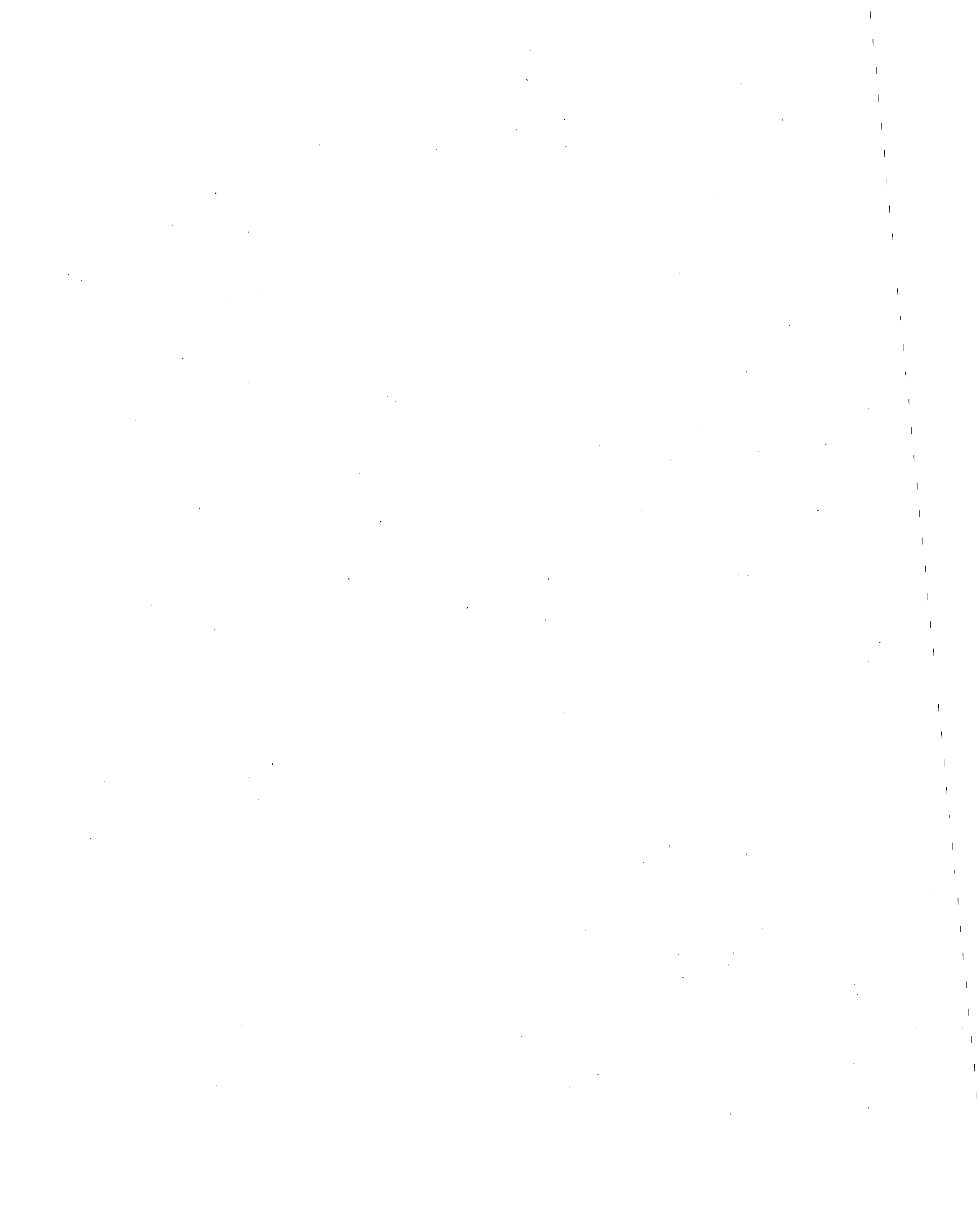
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<p>16. Abstract (Limit: 200 words) A comparison was undertaken of six different criteria for determining significant hearing threshold shift. Each criterion was applied to the first eight audiograms for males participating in 15 different industrial hearing conservation programs. Of the different criteria used, the OSHA STS criterion produced the lowest overall percentage of employees tagged as having suffered a threshold shift. The 15-dB SHIFT and NIOSH SHIFT criteria produced the highest percentages. The mean percentages of employees tagged on an annual basis generally were small, less than 10% in referent data bases and 20% or less in the noncontrol data bases. The 15-dB SHIFT and NIOSH SHIFT criteria tagged 37% and 51% of employees in noncontrol data bases on the first test comparison and averaged 14% and 24% of employees even in referent data bases. The purpose of the significant threshold shift criterion was to tag employees with temporary threshold shifts (TTS) before they develop hearing loss. Therefore, the purpose of the threshold shift criterion selected was not to act as a recordable occupational illness but rather to reflect a significant amount of persistent hearing change.</p>			
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CONTENTS

PURPOSE	1
BACKGROUND INFORMATION	1
LITERATURE REVIEW	5
METHOD FOR THE CURRENT STUDY	14
RESULTS	17
ADVANTAGES AND DISADVANTAGES OF DIFFERENT SHIFT CRITERIA	22
TABLES	23
FIGURES	35
REFERENCES	66

PURPOSE OF THIS STUDY

This investigation was carried out to compare six different criteria for significant hearing threshold shift by applying each criterion to the first eight audiograms for males in 15 different industrial hearing conservation programs. The resulting data can be used to evaluate the advantages and disadvantages of selecting alternative definitions of significant threshold shift.

BACKGROUND INFORMATION

The Role of Audiometry in Hearing Conservation Programs

Occupational and military hearing conservation programs (HCPs) have been widely implemented to prevent the development of on-the-job noise-induced hearing loss among personnel exposed to potentially damaging noise. Component phases of HCPs include sound exposure monitoring to assess the degree of hazard, engineering and administrative noise controls to reduce the hazard, hearing protection devices (earplugs and earmuffs) to reduce the noise entering the wearer's ears, education to motivate personnel to take an active part in protecting their own hearing, and annual audiometric evaluations to detect any significant changes in the hearing thresholds of noise-exposed personnel. In the USA, many industries are required to provide HCPs by the provisions of the Occupational Noise Standard [29 CFR 1910.G (1971)] and the Hearing Conservation Amendment [48 Fed. Reg. 9776 (1983)].

Audiometric evaluations play a critical monitoring function in a HCP. Susceptible individuals may develop noise-induced hearing damage if their hearing protectors are fitted poorly, if the devices are used inconsistently or improperly, or if they provide inadequate noise reduction for the individual's work environment. The individual's baseline audiogram serves as a reference for his/her hearing status at the time of entry into the HCP, and later audiogram results are compared to the baseline to detect hearing changes. Significant hearing changes consistent with noise-induced causation should trigger follow-up actions to increase the degree of protection from noise for the employee. In addition, medical referrals may be made based on audiograms results.

Hearing thresholds: measurement and detection of change

An audiogram is a table or a chart which displays the hearing thresholds measured for the subject in each ear at specified test frequencies. In OSHA-mandated HCPs, thresholds must be measured for pure tone signals at the test frequencies of 500, 1000, 2000, 3000, 4000, and 6000 Hz. At each frequency, the threshold recorded for the ear is the lowest signal output level of the audiometer at which the individual responds in a specified percentage of trials (such as 50%) or in 2 of 3 trials. Thresholds are measured in decibels hearing level (dB HL) with 0

dB HL representing average hearing ability for young people without any otological pathology. Larger threshold values indicate poorer-than-average hearing, while smaller threshold values (negative thresholds such as -5 or -10 dB) indicate better-than-average hearing.

An individual's audiometric threshold at a given test frequency is not an invariant quantity. There is measurement variability associated with the state of the subject (including the subject's attention, motivation, and the influence of upper respiratory problems, drugs, and other factors) and with the testing equipment and methodology [Morrill 1986]. The higher the measurement variability, the larger the difference must be between thresholds measured on two separate audiograms before the difference can be considered potentially indicative of actual hearing change.

A summary of the auditory effects of noise is presented by Ward [1986]. The primary effect is to increase hearing thresholds; thresholds are shifted toward higher values (poorer hearing). Exposure to extremely intense noise may cause an immediate permanent hearing loss known as acoustic trauma. In contrast, exposure to less intense noise causes the gradual development of hearing damage over months and years. During each over-exposure to noise the ear develops a temporary reduction in sensitivity called temporary threshold shift (TTS). This TTS recovers over a period of hours or days when the ear is allowed to rest in a quieter environment. However, if the exposure is high enough or if exposures are repeated, the TTS may not recover completely, and noise-induced permanent threshold shift (NIPTS) begins to develop.

Because TTS serves as a precursor of NIPTS, it is desirable to perform monitoring audiometry on noise-exposed employees during their daily workshifts so that any TTS which is present can be detected, permitting employee protection to be increased so that permanent shifts will not develop or progress. If audiograms are performed prior to noise exposure on the day of testing, then threshold shifts will already be permanent when they are first detected. In this case the audiometric monitoring serves only to document the hearing loss, not to prevent it.

Some people consider industrial audiometry too variable to be useful in detecting beginning threshold shifts [Hetu 1979, Atherley 1981]. Certainly, if testing procedures are too inconsistent, then measurement variability may not be distinguishable from TTS or NIPTS. The challenge is to select a criterion for significant threshold shift which is stringent enough to catch incipient hearing loss, yet not so stringent as to identify large numbers of employees whose thresholds are simply showing normal variability.

This challenge is compounded by the fact that the incipient NIPTS which HCP staff hope to detect is of the same order of magnitude as typical audiometric measurement variability -- about

10 dB. The more consistent audiometric testing procedures are, the better hearing changes can be identified. However, daily TTS would be expected to be larger in magnitude than the developing NIPTS, so testing employees during their workshifts (when TTS may be present) increases the probability of identifying employees who are not adequately protected from noise.

Employee Follow-Up for Significant Threshold Shifts

Certain patterns of hearing change or certain overall audiogram configurations may indicate the need for clinical audiometric evaluation and/or medical examination to determine if causes other than noise-exposure are causing or contributing to a hearing health problem. However, identification of hearing health problems is a side benefit of the HCP rather than its primary purpose, and the selection of audiometric criteria for medical/audiological referral is a separate issue from selecting criteria for significant threshold shifts which may be noise-related.

The focus of audiometric monitoring within the HCP is to identify potentially noise-related hearing changes. If significant change is shown on an audiogram, the HCP staff need to ensure that the individual's hearing protection devices are appropriate (properly fitted, practical in daily use, and adequate for the noise exposure) and that the individual can demonstrate the ability to use them correctly. The individual should also be counseled about the change to increase his/her motivation to prevent progressive hearing loss [Royster and Royster 1990].

This investigation summarized in this report is limited to comparisons of criteria for significant threshold shifts due to noise exposure. Medical referral criteria are not discussed.

Persistent Shifts, Follow-Up Actions, and Baseline Revisions

The identification of a significant threshold shift is intended to trigger follow-up actions to increase the individual's protection from noise. Most hearing conservation experts agree that if a shift is clearly persistent, then the baseline must eventually be revised so that follow-up actions will not be repeated each year unless an additional shift is shown. Therefore, the follow-up activity which HCP staff would need to perform in any given year's test cycle would include those employees who showed significant shifts for the first time, those employees whose shifts were not yet considered persistent, and those employees who showed an additional shift from a baseline which had been revised after an earlier persistent shift. In evaluating the results of the literature studies of significant shift criteria, the reader must assess whether the study methodologies consider the annual follow-up workload.

True Positive versus False Positive Tags

Screening tests for identification of individuals with any type of condition are selected in terms of their ability to identify those individuals who do have the condition of interest (true positive tags) and simultaneously not to identify those individuals who do not have the condition (true negatives). Inevitably, some individuals who do have the condition will be missed (false negatives) and some individuals without the condition will be tagged (false positive tags). The ideal test criterion establishes a trade-off between the cost of providing unnecessary follow-up for false positives and the cost of not providing needed follow-up for false negatives. However, in the absence of an independent "gold standard" test for the condition (an independent error-free test with no measurement variability), it is difficult to separate false positive and false negative tags.

LITERATURE REVIEW

Recommended Significant Threshold Shift Criteria

NIOSH proposed [NIOSH 1972] that both medical referral and follow-up checks of hearing protection device adequacy be based upon a threshold shift from the current baseline in either ear of 10 dB or more at 500, 1000, 2000, or 3000 Hz or of 15 dB or more at 4000 or 6000 Hz, after age corrections. Audiometric monitoring was to be done every two years (rather than annually), and new baselines were to be taken every sixth year or within 60 days after any significant threshold shift.

OSHA proposed [OSHA 1974] that a significant shift be defined as a change of 10 dB or more in the average of thresholds at 2000, 3000, and 4000 Hz in either ear. However, this criterion was not adopted at the time it was proposed. OSHA later [OSHA 1979] instructed compliance officers to consider a shift of 20 dB at any test frequency from 500 through 6000 Hz as significant.

Feldman and Grimes [1977] recommended a dual definition of significant threshold shift, as follows:
either

a) a change of 11 dB or more in the average of thresholds at 2000, 3000, and 4000 Hz,

or

b) a shift of 15 dB or more at any single test frequency from 500 through 6000 Hz.

The Department of the Air Force [1956, 1973] established two alternative shift criteria depending on the individual's baseline hearing status, as described below.

a) For personnel with no threshold worse than 25 dB HL at 500 through 6000 Hz, any shift of 20 dB or more was considered significant.

b) For personnel with any thresholds exceeding 25 dB HL, the following shifts were significant: 10 dB or more at 2000 Hz, 15 dB or more at 3000 Hz, or 20 dB or more at 4000 or 6000 Hz.

Miller [1979] closely followed the Air Force scheme in suggesting that the criterion for significant threshold shift should depend upon the amount of hearing loss shown in the individual's baseline audiogram, as described below:

a) For employees with baseline hearing thresholds of 25 dB HL or better, a change of 20 dB at any test frequency (500 through 6000 Hz) in either ear would be deemed significant.

b) For employees with any baseline threshold exceeding 25 dB HL, a significant threshold shift would be defined as a change of 10 dB or more at 500, 1000, or 2000 Hz, 15 dB or more at 3000 Hz, or 20 dB or more at 4000 or 6000 Hz.

Miller's recommendation was identical to the Air Force policy except that he added 500 and 1000 Hz to the shift criterion for individuals with pre-existing hearing loss.

Waugh and Macrae [1980] recommended the simple criterion of a change of 15 dB or more at any test frequency from 500 through 6000 Hz in either ear.

OSHA proposed a complex definition for significant threshold shift in an initial version of the hearing conservation amendment [46 Fed. Reg. 4078 (1981)] which was later stayed and then eventually replaced. The stayed 1981 definition included four variable options depending on the individual's baseline hearing status and record of previous hearing change. The four options were:

- a) for individuals whose baseline thresholds were all 25 dB HL or less, a shift of 20 dB at any test frequency from 500 through 6000 Hz in either ear would be deemed significant.
- b) for persons with any baseline threshold exceeding 25 dB HL, a significant shift would be 10 dB or more at 500 or 1000 Hz, 15 dB or more at 3000 or 4000 Hz, or 20 dB or more at 6000 Hz in either ear,
- c) for individuals whose average baseline thresholds at 1000, 2000 and 3000 Hz equal or exceed 25 dB in either ear, a shift of 10 dB or more at any frequency from 1000 to 6000 Hz in either ear would be significant, and
- d) for persons who have already shown a significant threshold shift in the past, a shift of 10 dB or more at any frequency from 1000 to 6000 Hz in either ear would be significant.

The Committee on Hearing and Equilibrium of the American Academy of Otolaryngology - Head and Neck Surgery (AAO-HNS) recommended that significant threshold shift be defined as a shift of 10 dB or more in either ear in the average of hearing thresholds at either or both of two frequency ranges: 500, 1000, and 2000 Hz and 3000, 4000, and 6000 Hz [Cantrell et al 1982].

OSHA, in the final version of the Hearing Conservation Amendment [48 Fed. Reg. 9738 (1983)], set forth the following criterion as a "standard threshold shift" (OSHA STS): a change of 10 dB or more in either ear in the average of hearing thresholds at 2000, 3000, and 4000 Hz. Employers were given the option to implement age corrections before determining whether a shift existed and were allowed to discount the shift if it did not persist on a retest audiogram within 30 days.

Empirical Investigations in the Literature Concerning Significant Threshold Shift

Air Force Studies

The Department of the Air Force [Gasaway and Sutherland 1976] carried out an empirical comparison of alternative shift criteria because the Air Force's dual criterion (described above) had proved difficult for hearing examiners to use. Medical

personnel missed "about half" of the individuals whose audiograms actually showed significant shifts. In a search for a simpler yet effective definition, Gasaway and Sutherland compared the following criteria:

- a) 15 dB or more at any frequency
- b) 20 dB or more at any frequency
- c) 20 dB or more at 2000, 3000, or 4000 Hz
- d) 10 dB or more in the average of thresholds at 2000, 3000, and 4000 Hz (later adopted in 1983 by OSHA as OSHA STS).

Comparisons were made by applying each criterion to all audiometric data reported during a 3-month period; this yielded comparisons of the current audiogram to the baseline audiogram for over 23,000 military personnel and over 3,600 civilians. The authors concluded that criterion a), 15 dB or more, identified too high a percentage of personnel, making follow-up impractical. Criteria b) and c) both identified fewer personnel than the complex Air Force criterion, and were therefore less protective. Criterion d) identified more personnel than criterion c) and appeared more acceptable, but the authors concluded that additional studies were needed for an informed choice.

In 1982 the U.S. Air Force submitted a compilation of several Air Force studies to the OSHA docket concerning the noise standard and hearing conservation amendment [Sutherland 1982]. In addition to the previously described 1976 study by Gasaway and Sutherland, three later empirical investigations were summarized in the docket submission. The first of these was a paper by Sutherland and Gasaway which had been presented to the 50th annual scientific meeting of the Aerospace Medical Association in 1979. In this study eight different shift criteria were applied to all the audiometric monitoring data conducted for the Air Force in the years 1975, 1976, and 1977. Both civilian personnel and military personnel in the hearing conservation program were included in the study population. The criteria compared (all applied to either ear) were shifts of:

- a) 20 dB or more at 2000, 3000, or 4000 Hz
- b) 20 dB or more at 1000, 2000, 3000, or 4000 Hz
(the Department of Defense criterion)
- c) 10 dB or more in the average of 2000, 3000, and 4000 Hz
- d) 20 dB or more at any frequency from 500 through 6000 Hz
(the Air Force criterion for personnel with thresholds not exceeding 25 dB)
- e) 10 dB or more at 2000 Hz, 15 dB or more at 3000 Hz, or 20 dB or more at 4000 or 6000 Hz (the Air Force criterion for personnel with some thresholds exceeding 25 dB)
- f) 15 dB or more at any frequency from 500 through 6000 Hz
- g) 10 dB or more at 500, 1000, or 2000 Hz, or 15 dB or more at 3000, 4000, or 6000 Hz
- h) 10 dB or more at any frequency.

Across all criteria, there were higher percentages of tags among the civilian personnel (who were older and had more years of service) than among the military personnel. Of the eight criteria, many tagged over 50% of the population per year; such a

high percentage of tags would make follow-up impractical. The criteria which yielded less than 30% tags annually among the civilian group were criteria a, b, and c as described above. Of these three criteria, the study authors favored b (a shift of 20 dB or more at 1000, 2000, 3000, or 4000 Hz) because it was easy to implement.

The Air Force submission to the OSHA docket also included a study entitled "Selecting a Significant Threshold Shift Criterion for Hearing Conservation Monitoring Audiometry" which compared the Air Force dual criterion, the Department of Defense criterion, and the complex criterion proposed by OSHA in 1981 (all described earlier). An addendum to the docket submission added a fourth criterion: a shift of 15 dB or more at 1000, 2000, 3000, or 4000 Hz. All four criteria were applied to the Air Force's audiometric monitoring data for the year 1980 (both military and civilian personnel). Each individual's 1980 audiogram was compared to the original baseline, which could have been as early as 1956 or as late as 1979. Ranked from highest to lowest according to the percentages of personnel tagged, the criteria compared as follows:

- OSHA criterion (26.6% military, 45.5% civilian)
- 15 dB at 1000-4000 Hz (18.3% military, 25.4% civilian)
- Air Force criterion (13.5% military, 20.1% civilian)
- DOD: 20 dB at 1000-4000 Hz (7.3% military, 11.6% civilian)

The study authors warned that the OSHA proposed criterion was undesirable not only because its complexity would make consistent identifications by audiometric technicians impossible, but also because it yielded an unmanageably high percentage of tags. Additional analyses were conducted to compare the hearing thresholds of personnel of different ages identified by different criteria. For those criteria which identified higher percentages of people, the average hearing thresholds of the identified groups were lower (that is, showed better hearing).

The Air Force submissions to the OSHA docket are commendable for being the earliest empirical comparisons of various criteria. However, the methodology used in these studies is limited. The studies compared current audiograms for selected years back to the original baselines for the study populations, and these baselines varied in date from only one year previously to over twenty years previously. This approach yields cumulative percentages of tags over variable numbers of years. These cumulative percentages of tags do allow different criteria to be rank-ordered according to the relative percentages of the population tagged by each definition. However, this method does not yield any indication of the absolute amount of annual follow-up action effort required for different criteria. In addition, comparisons of the hearing thresholds of the individuals tagged by various criteria in the study year do not indicate what their hearing thresholds would have been in the year when they first would have been tagged by each criterion.

Gasaway [1985] reviewed the Air Force studies and discussed

the relative merits of different criteria, as well as the impact on a hearing conservation program from choosing one criterion over another.

Research by Royster and Royster

Royster and Royster [1982a] carried out a contract research project funded by OSHA and submitted the results to the OSHA docket. The study compared the following five different criteria for significant threshold shift:

- a) 10 dB or more in the average of hearing thresholds at 2000, 3000, and 4000 Hz in either ear (OSHA STS),
- b) 20 dB or more at any frequency from 1000 Hz through 6000 Hz in either ear,
- c) 15 dB or more at any frequency from 1000 Hz through 6000 Hz in either ear,
- d) 15 dB or more at any frequency from 500 Hz through 6000 Hz in either ear,
- e) 15 dB or more at any frequency from 1000 Hz through 6000 Hz in either ear which is present in each of two consecutive annual audiograms, either at the same test frequency or at different test frequencies (15 dB twice).

Each of the five criteria above was applied to each of four audiometric data bases obtained from ongoing industrial HCPs. Within each data base, the analysis was restricted to the first seven audiograms for all white male employees who had received at least seven HCP audiograms. Two of the data bases (one with 409 subjects and one with 73 subjects) were from HCPs which the authors considered to be effective in protecting employees from the auditory effects of noise, and two of the data bases (one with 102 subjects and one with 32 subjects) were from HCPs considered to be less effective, as judged by procedures for audiometric data base analysis which were available at that time (Royster and Royster, 1982b). The five criteria were compared in three ways:

- 1) by the percentages of new tags per year (employees identified for the first time as showing a shift) in comparisons of test 2-7 back to the baseline test 1 (those who would require follow-up actions by HCP staff that year),
- 2) by the total percentages of tags per year (both new tags and persistent tags already shown earlier) in comparisons of test 2-7 back to the baseline test 1, and
- 3) by the cumulative percentage of employees tagged at least once in comparisons of tests 2-7 back to the baseline test 1 (the percentage of employees who would require follow-up actions on the part of the HCP staff at some point during the first seven audiograms).

The OSHA STS criterion (item a. above) yielded the smallest percentages of tagged employees, and the 15 dB criteria (c. and d. above) yielded the highest percentages with little difference according to whether the frequency range included was 500-6000 Hz or 1000-6000 Hz. The 20 dB criterion (b. above) and the 15 dB twice criterion (e. above) yielded very similar, intermediate

percentages of tags. All the criteria except for OSHA STS yielded higher percentages of tagged employees in the HCPs which were considered to be less effective.

In order to assess the appropriateness of the tags for each criterion, Royster and Royster classified the first tag for each employee as a true positive if it persisted on either of the two next annual audiograms, and as a false positive if it did not persist on either test. The 15 dB twice criterion gave the highest percentage of true positive tags (83%), followed by the OSHA STS criterion (69%), while the 20 dB and 15 dB criteria yielded 60-61% true positive tags.

In a later study, Royster and Royster [1986] reported the percentages of shifts using different criteria as applied to the audiometric data contributed to ANSI S12 Working Group 12 (S12/WG12). The focus of the research done by S12/WG12 was to develop ways of assessing HCP effectiveness based on group data variability, using techniques referred to as audiometric data base analysis. For program evaluation purposes, S12/WG12 rejected comparisons of later tests back to baseline in favor of variability from year to year between successive pairs of sequential audiograms. However, percentages of shifts compared to test 1 were reported. The 13 data bases included in the analysis included three control populations (those with very low noise exposure or with HCPs which followed excellent procedures) and ten other populations from HCPs for which the quality was unknown. Analyses were restricted to the first eight audiograms for only those male employees who had at least eight tests. The OSHA STS criterion tagged fewer employees than the AAO-HNS criterion. No attempt was made to classify tags as true positive versus false positive. The authors criticized OSHA STS as less sensitive to developing NIPTS because it averages a frequency (2000 Hz) which is less susceptible to noise damage together with frequencies (3000 and 4000 Hz) which are better indicators of noise damage.

Research by Dobie

Dobie [1983] presented a discussion and investigation of audiometric reliability and validity. Using 200 study subjects (25 workers from each of 8 separate plants combined into a single group), he applied various criteria for significant threshold shift to employees' first two annual HCP audiograms (baseline and test 2). Audiograms were obtained by manual audiometry in 5-dB steps. Dobie evaluated different shift criteria in terms of receiver operating characteristics analysis, which considers the cost of false positive tags and false negative tags. He assumed a ratio of false negative cost to false positive cost of 4:1, meaning that one false negative was judged equally costly as 4 false positives (the HCP staff are willing to do unnecessary follow-up for four employees in exchange for every one employee who actually needs follow-up but is not tagged to receive it). He compared results from using two different methods of judging the number of false positive tags. Each is discussed below.

The types of criteria Dobie compared were:

- a) X dB at any-frequency
- b) X dB at any two-frequency average (500-1000 Hz, 1000-2000 Hz, 2000-3000 Hz, 3000-4000 Hz, and 4000-6000 Hz)
- c) X dB at any three-frequency average (500-2000 Hz, 1000-3000 Hz, 2000-4000 Hz, and 3000-6000 Hz)
- d) X dB at either of two three-frequency averages (500-2000 Hz or 3000-6000 Hz)
- e) X dB at any weighted three-frequency average, with the central frequency weighted equally with the average of the two adjacent frequencies.

Each type of criterion was examined at a wide range of shift magnitude levels from 5 dB to 30 dB, including fractions of a dB.

In his first method of classifying true versus false positive tags, Dobie assumed that the number of false positive tags for any selected shift criterion was equal to the number of employees who showed an improvement of the same amount from test 1 to test 2. This method underestimates true positives because there is a "learning effect" during the earliest years of audiometric testing while previously inexperienced subjects learn the test-taking protocol and become more skilled at responding to the pure tone test signals (Royster and Royster, 1986). In the absence of TTS and NIPTS, the learning effect results in improved mean hearing thresholds for a group of employees over several annual audiograms. Even if NIPTS is developing, the influence of the learning effect reduces the apparent amount of threshold shift. A strong criticism of Dobie's method for classifying tags is that it does not relate to the decision process faced by HCP staff when they review audiograms and provide employee follow-up. HCP staff cannot fail to provide follow-up for a certain percentage of shifts because some shifts may be spurious.

Using this method for classifying positive tags as true or false, Dobie concluded that criteria based on X dB in the average of two or three audiometric test frequencies were preferable to criteria based on shifts of X dB at any single test frequency. Although Dobie he found more favorable receiver operating characteristics for three-frequency averages than for two-frequency averages, the data did not provide any clear indication of the best potential amount of shift (such as 8.3 dB, 10 dB, etc.).

In a second method for differentiating true versus false positives, Dobie classified tags as true positives if the individual was tagged both on test 2 and on test 3, either at the same frequency or frequency-average, or at a different frequency or frequency-average. Tags which were not repeated on test 3 were classified as false. Note that the third test was not always the next annual test: about 30% of third tests were retests performed a few weeks after test 2 if the employee showed significant shifts by the HCP's own internal criteria. These retests may have had lower variability because they were performed more carefully. Dobie warns that this second method

will over-estimate true positives to the degree that apparently persistent shifts may be shown due solely to testing variability. Dobie found this second method of classifying true versus false positives to be incompatible with the use of the receiver operating characteristic analysis for small amounts of shift (less than about 15 dB for single frequencies or about 10 dB for frequency averages) because smaller shifts fell within the range of audiometric variability. For larger amounts of shift, Dobie concluded that frequency-average criteria were superior to any-frequency criteria.

Dobie also compared various criteria applied twice: that is, employees were tagged only if a shift was present both in test 2 and in test 3 as compared to test 1 (either at the same frequency or frequency-average, or at a different one). In this analysis true positives were defined as the total percent of positives minus the percent of employees who showed an improvement of the same amount in both test 2 and test 3. Using this approach, Dobie again concluded that frequency-average criteria were preferable to any-frequency criteria.

Dobie also reanalyzed his data based on the premise that false negatives are more costly for larger amounts of shift (such as 20 dB) than for smaller amounts of shift (such as 10 dB). He compared any-frequency shift criteria with the double three-frequency-average criterion (the average of 500, 1000, and 2000 Hz and/or the average of 3000, 4000, and 6000 Hz). This analysis indicated the AAO-HNS sift criterion (a shift of 10 dB or more in either of the two three-frequency averages) as the optimum choice. For any-frequency criteria, a criterion level of 15 dB shift appeared preferable to lower or higher amounts of shift.

Research by Lane, Dobie, Crawford and Morgan

Lane et al [1985] expanded Dobie's earlier line of research using receiver operating characteristic analyses. These authors analyzed audiometric data from four industrial plants in which workers were given audiograms by mobile testing using self-recording audiometry. Across the four plants, there were 548 employees with at least 2 tests, 85 with at least 6 tests, and only 34 (in only three plants) with 8 tests. Lane et al compared these shift criteria:

- a) X dB at any frequency from 1000-6000 Hz, using shift magnitudes of 5, 10, 15, 20, 25, and 30 dB
- c) X dB at the three-frequency average 2000-4000 Hz, using shift magnitudes of 5, 6.7, 8.3, 10, 11.7, 13.3, 15, 16.7, 18.3, 20, 25, and 30 dB
- d) X dB at either of the two three-frequency averages 500-2000 Hz or 3000-6000 Hz, using shift magnitudes of 5, 6.7, 8.3, 10, 11.7, 13.3, 15, 16.7, 18.3, 20, 25, and 30 dB.

Lane et al followed Dobie's method of classifying true positives as the total percent of positive tags minus the percent of employees who showed an improvement of equal magnitude. The authors acknowledged that this method underestimates true

positives because it ignores learning-related improvement. The audiometric variability was somewhat lower in this study than in that of Dobie [1983], and frequency-average criteria did not show a clear advantage over any-frequency criteria. Based on comparisons of tests 2 through 8 back to test 1, the best frequency-average criterion was 8.3 dB at either 500-2000 Hz or 3000-6000 Hz, and the best any-frequency criterion was 15 dB. However, results varied depending on the particular test being compared back to test 1. Lane et al advocated the use of the AAO-HNS criterion (a change of 10 dB or more either at 500-2000 Hz or at 3000-6000 Hz) as their preference.

Other Research

Mets [1987] carried out a study to determine whether audiometric reliability could be improved if employees received two audiograms at one sitting both at the time of the baseline test and at each subsequent monitoring test. Averaging the two tests per sitting should reduce the measurement variability. Mets evaluated changes in thresholds at 4000 Hz, averaged across both ears, over five years for 47 noise-exposed males. After five years 34% of subjects showed binaurally averaged shifts of 10 dB or more at 4000 Hz, while 55% of subjects showed either no change or improved average thresholds. Mets also reported shifts in the average thresholds at 500-2000 Hz, but not at 3000-6000 Hz. His methodology is not comparable to any of the preceding studies, so his data shed little light on the choice of a criterion.

Donahue and Resta [1990] presented data from the U.S. Army's HCP regarding the percentages of OSHA STSS which were persistent on one or two retests conducted within 60 days of the original shift. Because this study is unpublished, a detailed analysis of the results is not possible at this time.

METHOD FOR THE CURRENT STUDY

Data Bases Evaluated

Fifteen audiometric data bases from industrial HCPs which were contributed to ANSI S12 Working Group 12 (S12/WG12) were included in this study. A list of the data bases and some of their pertinent characteristics is shown as Table 1. Of the 15 data bases, 13 had been included in the publication of Royster and Royster [1986]. Since 1986, the data bases designated as ANSI005 and ANSI006 have been updated with additional years of testing, and the data base ANSI0012 has been added to the analysis.

These audiometric data bases have been analyzed extensively for the purpose of developing procedures to evaluate the effectiveness of HCPs in preventing occupational hearing loss. The procedures developed, as well as the results of the analyses across the data bases, are described in detail in Draft ANSI S12.13-1991, Evaluating the Effectiveness of Hearing Conservation Programs. The data bases ANSI001, ANSI002, ANSI005, and ANSI006 are designated as "controls." ANSI001 and ANSI006 were low-noise-exposed populations. ANSI002 and ANSI005 included employees whose noise exposures ranged from low to high, but personal familiarity with the procedures for hearing protection device fitting and utilization indicated that these HCPs were implementing hearing conservation as well as possible in a real-world environment. The remaining data bases were designated as "non-controls" because less information was available about them, and no assumptions could be made about the level of protection employees received in these programs.

Within each data base, analyses were restricted to the first eight audiograms for all male employees who had at least eight tests. The numbers of subjects included from each data base are shown in Table 1, ranging from 39 to 1056 employees. Data were analyzed for a total of 2903 employees across all 15 data bases.

Audiometric thresholds were recorded in 5-dB steps in all HCPs except for ANSI006, which interpreted self-recording audiometer tracings to 1-dB steps.

In all these data bases, audiograms were generally performed during employees' workshifts. That is, audiograms were not systematically given either at the beginning or at the end of the shift, but were administered at randomly varying times through the shift at the convenience of the testing and production schedules. The testing appointment might be early in the shift one year and late in the shift the next year. Consequently, from one year to another, the employee's thresholds had the potential of being affected by TTS to a greater or lesser degree depending on the amount of time exposed to noise prior to the test. If the employee were inadequately protected from noise, varying amounts of TTS from one year to another therefore could add to the audiometric variability.

Shift Criteria Investigated

Six criteria for significant threshold shift were compared, each in either ear, as listed below together with the abbreviations which will be used for these shifts in the remainder of the report:

- a) OSHA STS: a change of 10 dB or more in either ear in the average of hearing thresholds at 2000, 3000, and 4000 Hz,
- b) AAO-HNS SHIFT: a change of 10 dB or more in the average of hearing thresholds at 500, 1000, and 2000 Hz and/or at 3000, 4000, and 6000 Hz,
- c) NIOSH SHIFT: a change of 10 dB or more at 500, 1000, 2000, or 3000 Hz and/or 15 dB or more at 4000 or 6000 Hz,
- d) 15-dB SHIFT: a change of 15 dB or more at any test frequency from 500 through 6000 Hz in either ear,
- e) 15 dB TWICE: a shift of 15 dB or more at any test frequency from 500 through 6000 Hz which is present in one annual audiogram and is persistent at the same frequency in the same ear on the next audiogram, and
- f) 10 dB AVG. 3-4 kHz: a shift of 10 dB or more in the average of thresholds at 3000 and 4000 Hz in either ear.

Note that the definition of the 15 dB TWICE shift used in this study differs from that used in the 1982 study by Royster and Royster: in the previous study the shifts shown in the two successive audiograms (each compared back to test 1) could be at different frequencies and/or different ears. In the present study a strict persistence requirement was used: the shift must persist in at least one of the same frequencies in the same ear. In addition, the test frequency 500 Hz was included in the 15 dB TWICE criterion in the present study, whereas only 1000-6000 Hz had been included in the 1982 study.

Each criterion was applied to each data base to determine the percentage of employees within that data base who showed a shift of the specified magnitude in comparisons of tests 2 through 8 back to test 1. Shifts were counted three ways:

- 1) new tags: the percentage of employees tagged for the first time by each criterion in a comparison of each test (2 through 8) back to test 1,
- 2) total tags: the percentage of all employees tagged by each criterion in a comparison of each test (2 through 8) back to test 1, and
- 3) percent ever tagged: the percentage of employees tagged at least once in comparisons of all tests (2 through 8) back to test 1.

Age Corrections

Age corrections were not used. Therefore, over the period of about seven years spanned by tests 1 through 8, age-related hearing change would be expected to make some contribution to the percentages of employees tagged. The use of age corrections would decrease the percentages of tags. However, the focus of

the study is to compare the relative performance of different criteria, and this should remain similar with or without age corrections.

Designation of True versus False Positive Tags

Tags were classified as true positive if confirmed by the same shift criterion on the next test. This method was selected because it is the method which must be used by HCP staff when they review audiograms and make decisions about employee follow-up and the adequacy of employee protection. If a shift persists on the next test (whether it is a special retest or the next annual test), the shift must be taken at face value as a true hearing change.

For the three criteria calculated on frequency-averages, a shift was counted as confirmed if the employee's next test showed a tag by that same criterion whether or not the confirming shift occurred in the same ear and/or the same frequency range (applicable to AAO-HNS). That is, the original shift could be counted as confirmed not only by a persistent shift in the same ear at the same frequency-average, but also by a new shift in the other ear at the same frequency-average or at a different frequency-average.

For the any-frequency criteria (15 dB TWICE, 15-dB SHIFT, and NIOSH SHIFT) a shift was counted as confirmed only if the employee's next test showed persistence of the shift at least one of the same frequencies in the same ear. That is, if an employee's test 3 showed a NIOSH SHIFT at 2000 Hz and at 4000 and 6000 Hz in the left ear, then the shift would be confirmed as a true positive if test 4 results showed the shift to be persistent in the left ear at one or more of these same frequencies.

RESULTS

Tables of Results

The percentages of employees who showed shifts by each criterion in comparisons of tests 2 through 8 back to test 1 are shown tabulated as Tables 2-7. Each of these tables includes the percentage of new tags in each test comparison, the percentage of total tags in each comparison, the percentage of employees ever tagged at least once over tests 2-8 compared to test 1, and the percentage of new tags which were classified as true positives versus false positives based on whether or not they were persistent on the next test. Each type of results is discussed separately below.

Percent of Employees Ever Tagged by Each Shift Criterion

The percent of employees tagged at least once in comparisons of tests 2 through 8 back to test 1 is an indication of the total amount of effort HCP staff would need to expend over the approximately seven-year period in providing retesting and/or follow-up for tagged employees. The percentages of employees ever tagged in each data base by each criterion are shown as bar graphs in Figures 1-6. The differences among data bases are immediately apparent upon viewing Figures 1-6. The control data bases, grouped at the left of each graph, show smaller percentages of employees ever tagged than do the non-control data bases. There is wide variation among the non-control data bases.

Comparing the different shift criteria, it is evident that the OSHA STS criterion produces the lowest overall percentages of employees tagged, and the 15-dB SHIFT and NIOSH SHIFT criteria produce the highest percentages (over 90% in many data bases). However, within any one data base, the relative rank-order of percentages of tags by the five criteria is not constant.

The data were averaged across the four control data bases and across the eleven non-control data bases, and these results are presented for all five shift criteria as Figure 7. To obtain these averages, each data base was counted equally, whether it included a small number of employees or a large number. For the upper four criteria shown in Figure 7, there were more than twice as many employees tagged in the averaged non-control data bases as in the averaged control data bases. However, for the NIOSH SHIFT criterion, the mean percent of employees tagged in control data bases was over two-thirds as high as in non-control data bases. In fact, the NIOSH SHIFT tagged a higher percentage of employees in control data bases than most other criteria tagged in non-control data bases. This was also true for the 15-dB SHIFT.

Total Percent of Employees Tagged in Each Test Comparison

The total percent of tags is an indicator of cumulative tags compared to test 1. A single employee is counted in each test comparison for which the current audiogram meets the selected shift criterion compared to test 1. On test 2, the total tags are all new, but on test 3 the percentage of total tags includes both some previously tagged employees and some newly tagged employees. For the previously tagged employees, this does not necessarily indicate that the particular pattern of shifts shown on the first tag is persistent; it may be that the initial shift has disappeared but another shift has appeared in its place which also meets the same shift criterion.

The mean percent total tags per year, averaged across the control data bases and across the non-control data bases, are plotted as Figures 8-13. The OSHA STS criterion produces not only the smallest percentages of tags, but also the smallest difference between the means for the control and non-control data bases. The 15-dB SHIFT and NIOSH SHIFT criteria produce by far the largest percentages of tags. These two criteria yield nearly identical results among the non-control data bases, but the 15-dB SHIFT criterion produces fewer tags than the NIOSH SHIFT among the control data bases due to difference between the 10-dB and 15-dB amounts of shift required at 500 through 3000 Hz to trigger these criteria.

The other three criteria appear quite similar in terms of the percentages of tags identified, especially among the control data bases.

Percent New Tags Per Year

The percent of employees tagged for the first time in comparisons of each annual test (2 through 8) back to test 1 is an indication of the amount of effort HCP staff would need to expend annually in providing retesting and/or follow-up for tagged employees. The mean percents of new tags per year for control data bases and non-control data bases are plotted as Figures 14-18. Note that the 15 dB TWICE criterion produces no tags when test 2 is compared to test 1 because there is no third test available, and this criterion requires a persistent shift to yield a tag. (In actual practice, if this criterion were adopted by a HCP, 15-dB shifts on test 2 could be retested immediately to determine whether they resulted from random measurement error or from TTS, NIPTS, or other factors causing threshold elevation.)

On an annual basis the mean percentages of employees tagged are generally small: less than 10% in control data bases and 20% or less in non-control data bases. This is true for all criteria tested except the 15-dB SHIFT and NIOSH SHIFT criteria, which respectively tag averages of 37% and 51% of employees in non-control data bases on the first test comparison, and averages of 14% and 24% of employees even in control data bases. After the first two baseline comparisons, the percentages of new tags for

the 15-dB SHIFT and NIOSH SHIFT criteria drop off to low levels, but this is because each employee can be counted only once as a new tag, and most employees have already been counted after the test 1 to 3 comparison.

Shown in Figure 20 are the mean percentages of new tags per year, averaged separately across control data bases and non-control data bases. For the 15 dB TWICE criterion, the averages were calculated across tests 3-8 rather than tests 2-8, since this criterion produces no tags on test 2. Again, the same pattern is apparent: the OSHA STS criterion produces the smallest percentages of new tags per year (averaging about 2.5% in control data bases and 8% in non-control data bases), while the 15-dB SHIFT and NIOSH SHIFT criteria produce the largest percentages (averaging about 7-9% in control data bases and about 13% in non-control data bases). The other three criteria yield moderate percentages which are very similar to each other. The 15 dB TWICE, 10 dB AVG. 3-4 kHz, and AAO-HNS shifts each yield about 4% of employees tagged for the first time per year in control data bases, and about 10% in non-control data bases.

Percent True Positive Tags

The first tag for an employee by each shift criterion was classified as a true positive or a false positive according to whether the tag recurred in the next test. As described in the method section, confirmation of a tag required strict persistence in the same ear in the case of the 15 dB TWICE and NIOSH SHIFT criteria. For the other three criteria based on frequency averages, confirmation could occur due to the opposite ear or the alternate frequency average (for AAO-HNS).

First tags which occurred on test 8 could not be classified because test 9 was not available for confirmation. Therefore, this analysis is based on only those first tags which occurred on tests 2-7.

The percentages of true positive tags within each data base for each shift criterion are shown as Figures 21-26. Note that the numbers of subjects upon which these percentages are based are smaller than for the preceding graphs because only those employees who showed shifts are counted. In addition, the numbers of employees tagged within each data base varies according to the particular shift criterion under consideration. For the smallest data bases, especially those in which few tags occurred, the percentages can vary considerably for this reason. For example, in ANSI006 (N=39) there were only 7 employees tagged across tests 2-7 both by OSHA STS and by AAO-HNS SHIFT, so each of the 7 people counted as 14.3%.

The percentages of true positive tags for different criteria, averaged separately across the control data bases and the non-control data bases, are compared in Figure 27. The 15 dB TWICE criterion yields the highest percentages of true positive tags (about 65%), while the other criteria all produce about 45%

true positive tags. This result is not surprising since a shift must persist on a second test before the employee is counted as tagged by 15 dB TWICE.

The data for classifying true positives were reanalyzed by pooling the employees from all 15 data bases in order to eliminate the influence of data base size on the variations in percentages. These results are listed as Table 8 and graphed as Figure 28. The data are essentially unchanged by pooling employees across data bases: the 15 dB TWICE criterion yields 70.9% true positive tags, while the other criteria all yield between 44.4% and 46.1% true positive tags.

Timing of Tags by Different Shift Criteria

If different criteria are equivalent in all other ways, then the criterion which identifies employees earliest as needing follow-up actions will be more protective than criteria which identify the same employee in a later year. Of the five criteria evaluated in this study, the NIOSH SHIFT necessarily identifies employees first because it is based on small shifts at any single frequency. The 15-dB SHIFT likewise would give early tags because it is based on single frequencies; it would be later only in the unlikely event that a frequency-average criterion was triggered by shifts of exactly 10 dB at each frequency included in the average.

The other four criteria were compared with respect to each other to evaluate any differences in how soon employees would be tagged by each. This analysis included only those employees who were ever tagged by any of these four criteria. The year in which the earliest tag occurred for each employee (by whatever criterion or criteria) was noted.

Presented as Figure 29 are the percentages of workers who were tagged earliest by each criterion. Note that an individual could be tagged earliest by all four criteria (if all tags occurred on the same test compared back to baseline), or by only a single criterion, or by two or three criteria. The AAO-HNS SHIFT and the 10 dB AVG 3-4 kHz SHIFT provide the highest percentages of early identifications, followed by OSHA STS, and finally by 15 dB TWICE.

Presented as Figure 30 are the percentages of employees who were tagged one year later than earliest by each criterion. The 15 dB TWICE criterion is the only shift criterion which shows many employees tagged one year later. This result is unremarkable because 15 dB TWICE requires a persistent shift before the initial tag is made. The interesting finding (from Figure 29) is that 15 dB TWICE was still as early as any other criterion in many cases.

Comparison of Data Base Rankings by Significant Threshold Shift Criteria and by Draft ANSI S12.13-1991 Procedures

The three audiometric data base analysis procedures recommended in Draft ANSI S12.13-1991 are Percent Worse (by 15 dB or more), Percent Better or Worse (by 15 dB or more), and the Standard Deviations of Differences in Thresholds. Each procedure is based on examination of pairs of sequential audiograms (such as test 1 to test 2, then test 2 to test 3, test 3 to test 4, etc.) rather than comparisons to a baseline. The draft standard gives separate criterion ranges for acceptable, marginal, or unacceptable results according to whether the data are from early test comparisons (1-2, 2-3, and 3-4) when the learning effect influences the data more strongly, or later test comparisons (5-6 and later). The Percent Better or Worse procedure is used only in later test comparisons.

The three S12.13-1991 procedures were applied to the audiometric data from each of the 15 data bases. Ranks were developed separately for the early test comparisons (based on two procedures) and for the later test comparisons (based on three procedures). Finally the two sets of ranks were averaged to yield a final rank-order. This final ranking is shown as the right-hand column in Table 9.

The six left-hand data columns in Table 9 show the rankings assigned to each data base according to the percentages of employees ever tagged by each of the six significant threshold shift criteria under consideration. For the four control data bases, the rankings are all extremely similar. Among the non-control data bases, there is wider variation in the rank for a single data base according to different criteria.

Spearman rank-correlation coefficients were calculated between the rankings according to the Draft ANSI S12.13-1991 procedures and the rankings according to each of the shift criteria. These correlations, as shown as Table 10, were all high, ranging from $r = 0.746$ for 15 dB TWICE to $r = 0.879$ for OSHA STS.

ADVANTAGES AND DISADVANTAGES OF DIFFERENT SHIFT CRITERIA

None of the shift criteria evaluated is obviously best in every respect. Some pros and cons of each criterion are tabulated as Table 11.

The unique quality of the 15 dB TWICE criterion is that it requires that a shift persist on two tests before the employee is tagged. This quality produces the two biggest advantages of this criterion: a much higher percentage of true positive tags, and the elimination of the need for special retesting to confirm the presence of a shift. However, the persistence requirement also results in the biggest disadvantage of this criterion: it often identifies employees one test later than other criteria. This disadvantage could be overcome by performing an immediate retest (after re-instructing the employee and repositioning the earphones) during the same test session. However, the same time might be spent more productively (in terms of employee protection) by providing limited follow-up actions immediately upon detecting a 15-dB threshold shift at any frequency. By re-checking the fit of the employee's hearing protectors and counselling the individual that a suspicious shift had occurred (which might be either temporary or persistent), the hearing conservationist might be able to motivate the worker to achieve better protection.

The NIOSH SHIFT, which shares with 15 dB TWICE the advantage of not requiring any frequency-averaging, uses such a small amount of shift at 500-3000 Hz (only 10 dB) that it tags more employees due to normal testing variability alone. Hearing conservationists need to spend their follow-up time on those employees who need it most, but the NIOSH SHIFT identifies so many employees that follow-up would lose its significance as a motivational warning event, even if HCP staff could find the time to provide follow-up for all tagged employees. This disadvantage of the NIOSH SHIFT is only partially overcome by increasing the amount of shift to 15 dB at all frequencies (the 15-dB SHIFT). Too many employees are still tagged by the 15-dB SHIFT to allow meaningful follow-up, especially in non-control data bases.

In selecting a significant threshold shift criterion, it is important to remember that its purpose is not to serve as a recordable occupational illness. The ideal shift criterion needs to be more sensitive than a recordability criterion because it should tag employees with TTS before they develop NIPTS. In contrast, a recordability criterion should reflect a significant amount of persistent hearing change.

TABLES

TABLE 1

DATA BASE CHARACTERISTICS

		NUMBER OF MALES WITH 8 AUDIOGRAMS	TYPE OF AUDIOMETER	TESTING FACILITY	SPECIAL FACTORS
CONTROL	ANSI001	98	manual	on-site	
DATA BASES	ANSI002	1056	self-recording	on-site	
	ANSI005	166	manual	on-site	
	ANSI006	39	self-recording	on-site	1-dB step size for thresholds, tests 2-8 at 6 month intervals
NON-CONTROL	ANSI003	46	manual	on-site	
DATA BASES	ANSI004	431	self-recording	on-site	
	ANSI007	41	unknown	unknown	
	ANSI008	44	self-recording	varies	some earlier tests were given prior to that labeled as test 1
	ANSI009	74	manual	on-site	
	ANSI010	246	self-recording	mobile	
	ANSI011	75	unknown	unknown	
	ANSI012	47	self-recording	mobile	
	ANSI015	356	self-recording	mobile	
	ANSI016	70	self-recording	mobile	
	ANSI17A	114	self-recording	mobile	
TOTAL, ALL DATA BASES		2903			

TABLE 2

RESULTS FOR THE OSHA STS CRITERION

DATA BASE	PERCENT NEW TAGS PER YEAR								PCT. EVER TAGGED	PERCENT TOTAL TAGS EACH YEAR								PERCENT TRUE POSITIVE TAGS
	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-2		1-3	1-4	1-5	1-6	1-7	1-8			
1	3.1	2.0	0.0	1.0	2.0	3.1	1.0	12.2	3.1	2.0	3.1	4.1	4.1	7.1	9.2	72.7		
2	5.3	2.7	3.0	3.5	4.6	4.0	3.8	27.0	5.3	6.0	6.4	8.7	12.2	12.9	15.6	38.4		
5	5.4	1.2	3.6	3.0	2.4	3.6	1.8	21.1	5.4	3.0	9.0	10.2	9.0	12.7	10.2	31.3		
6	0.0	2.7	8.1	2.7	2.7	2.7	0.0	18.9	0.0	2.7	10.8	8.1	10.8	13.5	8.1	42.9		
3	8.7	15.2	6.5	6.5	2.2	0.0	8.7	47.8	8.7	21.7	17.4	21.7	21.7	26.1	32.6	44.4		
4	15.8	4.6	2.3	6.0	4.9	4.9	6.3	44.8	15.8	13.7	9.3	13.5	16.5	16.7	22.3	43.4		
7	4.9	7.3	4.9	7.3	9.8	14.6	7.3	56.1	4.9	7.3	9.8	17.1	22.0	29.3	22.0	20.0		
8	20.5	11.4	9.1	6.8	0.0	2.3	11.4	61.4	20.5	18.2	18.2	20.5	15.9	25.0	27.3	22.7		
9	36.5	13.5	6.8	5.4	0.0	0.0	5.4	67.6	36.5	39.2	36.5	41.9	40.5	40.5	40.5	63.0		
10	7.7	12.6	3.7	4.1	3.7	6.1	11.4	49.2	7.7	15.9	9.8	10.2	11.4	19.5	35.4	41.9		
11	18.7	17.3	9.3	1.3	6.7	4.0	4.0	61.3	18.7	25.3	28.0	28.0	33.3	32.0	36.0	55.8		
12	4.3	4.3	10.6	14.9	6.4	12.8	2.1	55.3	4.3	4.3	14.9	23.4	29.8	27.7	25.5	64.0		
15	5.9	4.5	4.2	3.7	5.1	8.4	22.5	54.2	5.9	6.7	7.6	6.5	10.1	15.4	38.8	36.3		
16	1.4	11.4	5.7	10.0	12.9	15.7	11.4	68.6	1.4	11.4	8.6	17.1	31.4	40.0	48.6	55.0		
17	23.7	12.3	7.0	8.8	7.9	7.9	7.0	74.6	23.7	22.8	20.2	31.6	36.8	38.6	48.2	48.1		

TABLE 3

RESULTS FOR THE 15 dB TWICE CRITERION

DATA BASE	PERCENT NEW TAGS PER YEAR								PCT. EVER TAGGED	PERCENT TOTAL TAGS EACH YEAR								PERCENT TRUE POSITIVE TAGS
	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-2		1-3	1-4	1-5	1-6	1-7	1-8			
1	0.0	7.1	4.1	3.1	3.1	4.1	3.1	24.5	0.0	7.1	9.2	9.2	14.3	14.3	18.4	66.7		
2	0.0	7.3	2.8	2.6	4.1	4.0	5.6	26.3	0.0	7.3	7.6	8.9	12.8	16.7	20.1	68.0		
5	0.0	9.7	3.0	4.8	2.4	2.4	3.6	26.1	0.0	8.4	10.8	15.6	15.0	16.2	18.6	81.1		
6	0.0	10.3	0.0	5.1	0.0	5.1	0.0	20.5	0.0	10.3	2.6	10.3	10.3	10.3	5.1	37.5		
3	0.0	26.1	13.0	4.3	8.7	6.5	2.2	60.9	0.0	26.1	34.8	32.6	41.3	50.0	43.5	74.1		
4	0.0	18.9	6.2	3.8	4.5	5.1	3.8	42.3	0.0	18.9	19.6	20.6	22.6	24.3	26.6	67.4		
7	0.0	9.1	13.6	11.4	11.4	9.1	6.8	61.4	0.0	9.1	20.5	31.8	38.6	40.9	40.9	58.3		
8	0.0	31.8	2.3	4.5	9.1	2.3	2.3	52.3	0.0	31.8	25.0	22.7	22.7	22.7	29.5	63.6		
9	0.0	48.6	9.5	8.1	4.1	4.1	6.8	81.1	0.0	48.6	44.6	44.6	48.6	52.7	59.5	72.7		
10	0.0	14.6	11.4	4.1	6.1	6.9	9.8	52.8	0.0	14.6	18.3	19.9	22.8	27.2	40.2	58.5		
11	0.0	33.3	10.7	9.3	8.0	8.0	1.3	70.7	0.0	33.3	36.0	44.0	50.7	54.7	58.7	80.8		
12	0.0	4.3	12.8	4.3	27.7	2.1	8.5	59.6	0.0	4.3	17.0	17.0	46.8	38.3	44.7	75.0		
15	0.0	11.0	8.7	7.3	7.0	11.5	10.7	56.2	0.0	11.0	18.0	23.0	25.8	34.0	44.7	77.2		
16	0.0	5.7	14.3	17.1	17.1	10.0	5.7	70.0	0.0	5.7	18.6	34.3	50.0	55.7	61.4	88.9		
17	0.0	25.4	14.9	7.0	14.0	15.8	7.0	84.2	0.0	25.4	36.0	32.5	43.9	57.0	58.8	75.0		

TABLE 4

RESULTS FOR THE 10 dB AVG. 3-4 kHz CRITERION

DATA BASE	PERCENT NEW TAGS PER YEAR								PCT. EVER TAGGED	PERCENT TOTAL TAGS EACH YEAR								PERCENT TRUE POSITIVE TAGS
	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-2		1-3	1-4	1-5	1-6	1-7	1-8			
1	4.1	2.0	3.1	2.0	4.1	2.0	3.1	20.4	4.1	3.1	5.1	8.2	8.2	9.2	13.3	52.9		
2	8.8	4.5	2.9	3.4	5.5	5.1	4.1	34.3	8.8	8.1	8.0	9.8	14.9	17.5	20.0	39.8		
5	6.6	2.4	5.4	7.8	1.2	4.2	3.6	31.3	6.6	6.0	11.4	15.7	13.3	18.7	21.7	47.8		
6	0.0	10.3	7.7	0.0	5.1	5.1	0.0	28.2	0.0	10.3	10.3	5.1	15.4	17.9	7.7	63.6		
3	13.0	19.6	4.3	8.7	0.0	4.3	6.5	60.9	13.0	26.1	21.7	30.4	28.3	32.6	34.8	47.8		
4	20.6	5.3	2.3	4.9	4.9	4.2	7.7	42.3	20.6	16.7	13.5	17.6	20.0	20.0	29.0	46.2		
7	7.3	9.8	12.2	7.3	7.3	14.6	9.8	61.4	7.3	12.2	17.1	29.3	26.8	36.6	26.8	33.3		
8	29.5	9.1	2.3	11.4	0.0	4.5	6.8	52.3	29.5	22.7	18.2	29.5	15.9	29.5	31.8	32.0		
9	36.5	14.9	5.4	6.8	1.4	2.7	5.4	81.1	36.5	39.2	36.5	40.5	39.2	44.6	47.3	56.0		
10	11.8	16.7	5.7	6.5	3.3	6.5	11.0	52.8	11.8	23.2	18.3	18.7	19.5	30.1	46.3	37.9		
11	26.7	18.7	8.0	4.0	5.3	5.3	4.0	70.7	26.7	32.0	36.0	34.7	44.0	45.3	50.7	54.9		
12	8.5	10.6	8.5	14.9	4.3	10.6	4.3	59.6	8.5	12.8	19.1	36.2	40.4	34.0	40.4	59.3		
15	7.3	6.2	5.3	4.2	6.2	9.3	23.9	56.2	7.3	9.6	10.1	11.0	15.4	21.6	48.0	43.8		
16	5.7	11.4	8.6	12.9	17.1	18.6	7.1	70.0	5.7	12.9	12.9	25.7	40.0	57.1	58.6	51.9		
17	28.9	14.0	6.1	8.8	12.3	6.1	5.3	84.2	28.9	28.1	26.3	34.2	43.9	45.6	52.6	48.3		

TABLE 5

RESULTS FOR THE AAO-HNS SHIFT CRITERION

DATA BASE	PERCENT NEW TAGS PER YEAR								PCT. EVER TAGGED	PERCENT TOTAL TAGS EACH YEAR								PERCENT TRUE POSITIVE TAGS
	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-2		1-3	1-4	1-5	1-6	1-7	1-8			
1	8.2	4.1	3.1	1.0	2.0	2.0	2.0	22.4	8.2	7.1	7.1	10.2	8.2	11.2	13.3	40.0		
2	10.4	4.4	4.0	3.5	4.6	3.6	6.3	36.7	10.4	8.6	8.4	10.2	13.6	15.7	19.6	36.0		
5	6.6	3.0	3.0	3.6	3.6	6.6	6.0	32.5	6.6	5.4	9.6	11.4	11.4	18.1	20.5	47.7		
6	0.0	8.1	0.0	0.0	10.8	0.0	0.0	18.9	0.0	8.1	5.4	0.0	16.2	13.5	5.4	71.4		
3	17.4	21.7	10.9	2.2	10.9	0.0	4.3	67.4	17.4	32.6	34.8	32.6	41.3	34.8	41.3	48.3		
4	20.6	7.9	4.2	5.1	6.7	4.2	8.6	57.3	20.6	18.3	13.0	20.6	24.8	22.3	34.1	42.4		
7	9.8	14.6	7.3	12.2	7.3	12.2	12.2	75.6	9.8	22.0	24.4	39.0	36.6	46.3	41.5	57.7		
8	38.6	9.1	4.5	6.8	11.4	2.3	2.3	75.0	38.6	27.3	22.7	27.3	22.7	29.5	31.8	40.6		
9	43.2	17.6	9.5	4.1	1.4	0.0	1.4	77.0	43.2	44.6	43.2	43.2	41.9	48.6	47.3	53.6		
10	9.8	21.1	5.7	8.9	4.9	4.9	9.3	64.6	9.8	25.2	15.0	26.8	22.8	27.2	44.7	40.4		
11	30.7	16.0	9.3	4.0	8.0	2.7	5.3	76.0	30.7	36.0	37.3	33.3	46.7	44.0	56.0	58.5		
12	6.4	6.4	14.9	17.0	4.3	6.4	8.5	63.8	6.4	6.4	19.1	34.0	38.3	36.2	40.4	57.7		
15	12.1	8.1	5.6	8.1	8.4	9.3	24.4	76.1	12.1	13.8	16.3	19.4	26.1	29.8	58.4	47.3		
16	4.3	12.9	11.4	11.4	22.9	12.9	7.1	82.9	4.3	15.7	21.4	32.9	54.3	64.3	62.9	67.9		
17	28.1	28.1	9.6	5.3	9.6	0.9	3.5	85.1	28.1	39.5	36.8	40.4	54.4	54.4	61.4	46.2		

TABLE 6

RESULTS FOR THE NIOSH SHIFT CRITERION

DATA BASE	PERCENT NEW TAGS PER YEAR								PCT. EVER TAGGED	PERCENT TOTAL TAGS EACH YEAR								PERCENT TRUE POSITIVE TAGS
	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-2		1-3	1-4	1-5	1-6	1-7	1-8			
1	18.4	18.4	6.1	3.1	7.1	3.1	3.1	59.2	18.4	27.6	21.4	23.5	30.6	30.6	35.7	40.0		
2	32.2	13.3	5.8	6.3	7.3	4.5	3.5	72.9	32.2	28.9	26.6	30.6	39.2	43.3	44.8	40.0		
5	29.3	16.2	7.2	7.8	7.2	6.0	2.4	76.0	29.3	36.5	36.5	47.9	49.7	47.3	48.5	47.2		
6	15.4	10.3	10.3	2.6	7.7	7.7	0.0	53.8	15.4	23.1	33.3	33.3	35.9	33.3	28.2	57.1		
3	54.3	21.7	2.2	4.3	0.0	2.2	2.2	87.0	54.3	63.0	63.0	58.7	65.2	67.4	63.0	61.5		
4	51.5	10.6	5.5	5.5	5.1	3.2	3.0	84.5	51.5	46.0	46.6	48.3	52.8	51.3	59.4	53.0		
7	56.8	15.9	4.5	6.8	4.5	2.3	2.3	93.2	6.8	11.4	15.9	27.3	25.0	34.1	25.0	47.5		
8	68.2	9.1	2.3	4.5	0.0	2.3	4.5	90.9	68.2	54.5	65.9	54.5	52.3	61.4	65.9	50.0		
9	85.1	9.5	2.7	0.0	1.4	1.4	0.0	100.0	85.1	89.2	77.0	66.2	77.0	81.1	79.7	79.7		
10	49.6	28.0	2.0	6.9	0.4	1.6	5.3	93.9	49.6	62.2	47.2	58.1	50.0	58.5	76.4	42.7		
11	58.7	26.7	1.3	2.7	4.0	0.0	0.0	100.0	17.9	22.4	20.3	20.3	23.2	23.2	23.6	53.3		
12	25.5	23.4	2.1	21.3	0.0	6.4	2.1	80.9	25.5	42.6	40.4	72.3	57.4	70.2	61.7	54.1		
15	31.5	20.2	8.1	11.0	8.1	5.3	9.0	93.3	31.5	40.4	45.5	48.3	57.3	59.8	85.1	44.3		
16	17.1	27.1	12.9	11.4	8.6	5.7	2.9	85.7	17.1	37.1	55.7	70.0	81.4	85.7	85.7	62.1		
17	68.4	17.5	3.5	2.6	0.9	0.0	0.0	93.0	68.4	71.9	71.1	71.9	84.2	84.2	89.5	60.4		

TABLE 7

RESULTS FOR THE 15-dB SHIFT CRITERION

DATA BASE	PERCENT NEW TAGS PER YEAR								PCT. EVER TAGGED	PERCENT TOTAL TAGS EACH YEAR								PERCENT TRUE POSITIVE TAGS
	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-2		1-3	1-4	1-5	1-6	1-7	1-8			
1	15.3	12.2	4.1	4.1	5.1	4.1	3.1	48.0	15.3	19.4	15.3	19.4	22.4	21.4	26.5	47.7		
2	18.2	8.1	5.1	5.0	7.5	7.3	5.3	56.5	18.2	16.5	14.9	18.2	24.9	30.1	31.9	38.6		
5	12.7	9.7	7.3	9.1	4.8	3.6	7.9	55.2	12.7	18.8	19.4	27.9	26.1	27.3	33.9	43.6		
6	10.3	0.0	10.3	10.3	10.3	0.0	0.0	41.0	10.3	10.3	15.4	25.6	28.2	17.9	10.3	43.8		
3	43.5	26.1	8.7	4.3	2.2	2.2	2.2	89.1	43.5	56.5	54.3	54.3	65.2	58.7	58.7	47.5		
4	35.3	10.0	6.0	7.2	7.9	5.5	6.2	78.1	35.3	33.0	30.4	36.0	40.4	40.4	53.0	42.9		
7	18.2	27.3	13.6	6.8	9.1	6.8	6.8	88.6	18.2	38.6	38.6	52.3	56.8	61.4	61.4	50.0		
8	56.8	9.1	6.8	9.1	2.3	2.3	2.3	88.6	56.8	47.7	47.7	47.7	38.6	52.3	50.0	42.1		
9	71.6	14.9	2.7	1.4	2.7	0.0	2.7	95.9	71.6	73.0	60.8	56.8	64.9	71.6	70.3	59.4		
10	33.7	27.2	5.7	9.8	4.9	4.1	5.7	91.1	33.7	48.8	32.9	44.7	41.1	50.8	66.3	36.7		
11	48.0	26.7	9.3	2.7	4.0	0.0	2.7	93.3	48.0	61.3	57.3	58.7	70.7	70.7	72.0	55.9		
12	10.6	25.5	10.6	23.4	0.0	8.5	2.1	80.9	10.6	34.0	29.8	59.6	51.1	61.7	53.2	54.1		
15	24.2	17.1	9.8	14.6	9.8	6.7	10.4	92.7	24.2	31.5	34.3	44.4	49.7	56.5	78.9	43.0		
16	8.6	20.0	22.9	21.4	10.0	8.6	4.3	95.7	8.6	25.7	45.7	61.4	71.4	77.1	75.7	62.5		
17	51.8	22.8	11.4	5.3	2.6	1.8	0.9	96.5	51.8	55.3	61.4	63.2	78.9	74.6	81.6	43.1		

TABLE 8.

NUMBERS OF CLASSIFIABLE FIRST TAGS (THOSE OCCURRING IN COMPARISONS OF TESTS 2-7 BACK TO TEST 1) ACROSS ALL 15 DATA BASES (N=2903), AND NUMBERS AND PERCENTS OF FIRST TAGS CLASSIFIED AS TRUE POSITIVE, FOR EACH OF 6 SHIFT CRITERIA.

CRITERION	NUMBER OF CLASSIFIABLE TAGS	NUMBER OF TRUE POSITIVE TAGS	PERCENT TRUE POSITIVE TAGS
OSHA STS	958	412	43.0
15 dB TWICE	1056	749	70.9
10 dB AVG. 3-4 kHz	1175	524	44.6
AAO-HNS SHIFT	1291	578	44.8
15-dB SHIFT	2126	858	40.4
NIOSH SHIFT	2268	1045	46.1

TABLE 9

RANKS OF EACH HCP BY EACH SHIFT CRITERION, ACCORDING TO THE PERCENT OF EMPLOYEES TAGGED AT LEAST ONCE OVER TESTS 2-8 COMPARED TO TEST 1, AND RANKS OF EACH HCP ACCORDING TO THE AUDIOMETRIC DATA BASE ANALYSIS (ADBA) PROCEDURES OF DRAFT ANSI S12.13-1991

	DATA BASE	RANK FOR EACH SHIFT CRITERION					ADBA RANK	
		OSHA STS	15 dB TWICE	10 dB AVG. AT 3-4 kHz	AAO-HNS SHIFT	15-dB SHIFT		NIOSH SHIFT
CONTROL	1	1	2	1	2	2	2	3
DATA	2	4	4	4	4	4	3	4
BASES	5	3	3	3	3	3	4	2
	6	2	1	2	1	1	1	1
NON-	3	6	10	6	8	9	8	6
CONTROL	4	5	5	5	5	5	6	7
DATA	7	10	11	11	10	7.5	11	9
BASES	8	12	6	10	9	7.5	9	15
	9	13	14	13	13	14	15	12
	10	7	7	7	7	10	13	8
	11	11	13	12	11	12	14	13
	12	9	9	8	6	6	5	5
	15	8	8	9	12	11	12	11
	16	14	12	14	14	13	7	10
	17	15	15	15	15	15	10	14

TABLE 10

SPEARMAN RANK-CORRELATION COEFFICIENTS BETWEEN DATA BASE RANKS ACCORDING TO EACH SHIFT CRITERION AND RANKS ACCORDING TO THE AUDIOMETRIC DATA BASE ANALYSIS PROCEDURES IN DRAFT ANSI S12.13-1991

	OSHA STS	15 dB TWICE	10 dB AVG. AT 3-4 kHz	AAO-HNS SHIFT	15-dB SHIFT	NIOSH SHIFT
SPEARMAN'S R	0.879	0.746	0.871	0.871	0.833	0.800

TABLE 11

ADVANTAGES AND DISADVANTAGES OF EACH CRITERION FOR SIGNIFICANT THRESHOLD SHIFT

	OSHA STS	15 dB TWICE	10dB AVG 3-4 kHz	AAO-HNS SHIFT	15-dB SHIFT	NIOSH SHIFT
ADVANTAGES						
tags a moderate percentage of employees		x	x	x		
gives highest percentage true positive tags		x				
tags employees earliest						x
shows largest differences between control data bases and non-control data bases		x		x		
no calculation of frequency-averages required		x			x	x
averages noise-susceptible frequencies separately or examines each frequency separately		x	x	x	x	x
no special retesting required to assess persistence		x				
DISADVANTAGES						
tags the lowest percentage of employees	x					
tags such a high percentage of employees that follow-up would be impractical					x	x
shows smallest difference between control data bases and non-control data bases	x					
tags employees early in fewer cases		x				
requires calculations of averages	x		x	xx		
low-frequency average is unlikely to be affected by noise				x		
averages together frequencies which vary in susceptibility to noise	x					
uses a shift size within the range of normal audiometric variability in HCPs						x

FIGURES

FIGURE 1

Percent ever tagged by OSHA STS
over tests 2-8 compared to test 1

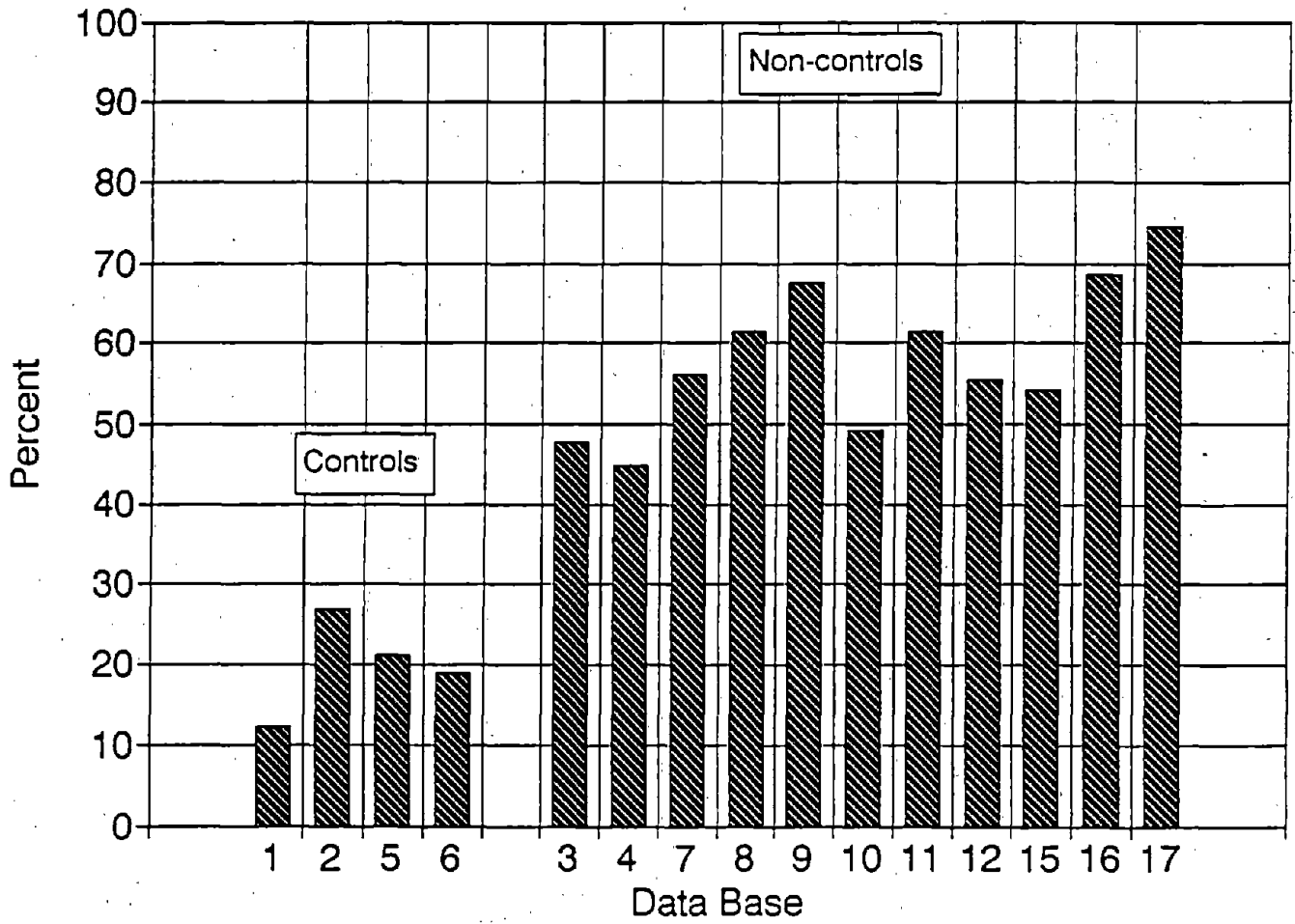


FIGURE 2

Percent ever tagged by 15-TWICE shift
over tests 2-8 compared to test 1

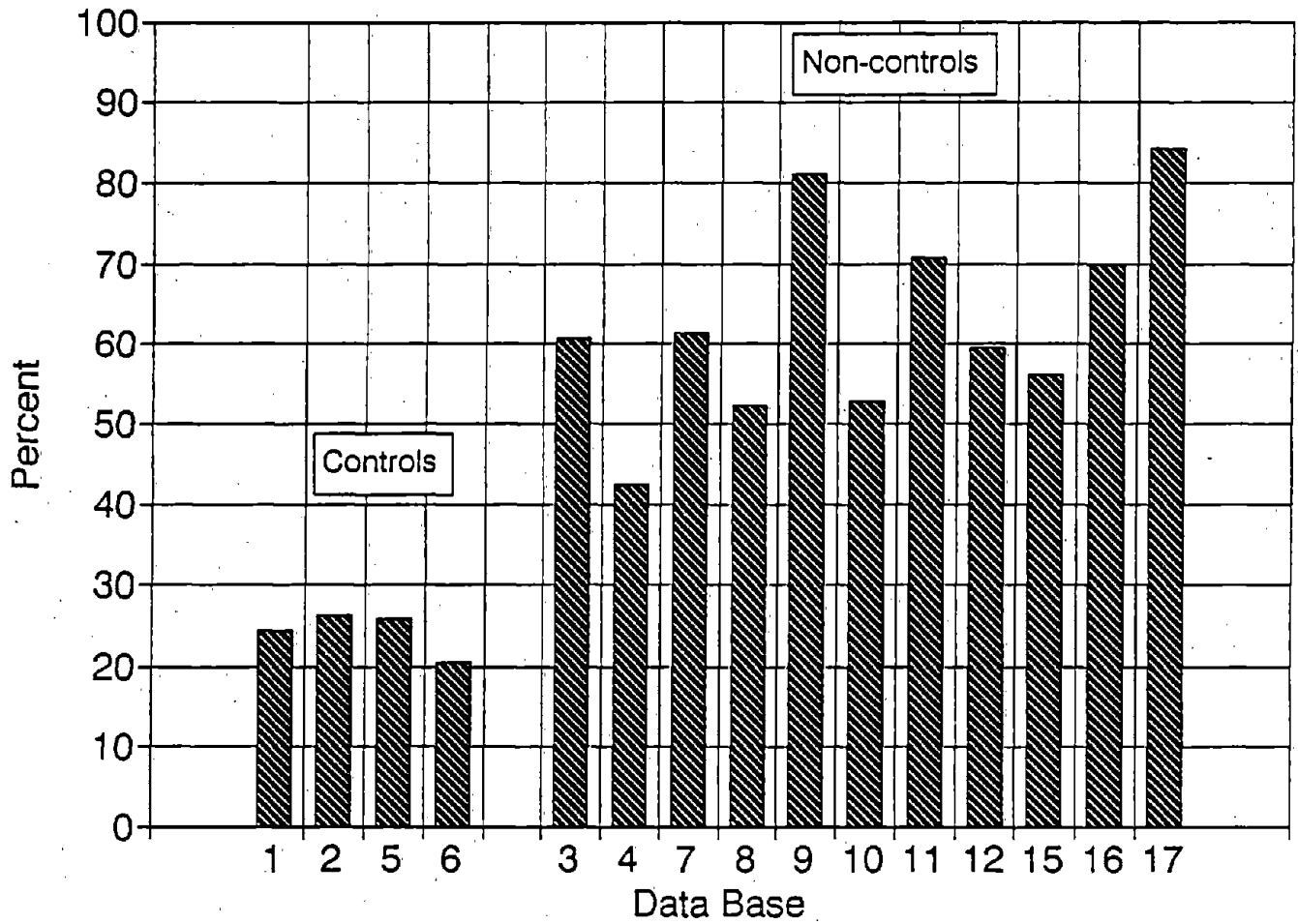


FIGURE 3

Percent ever tagged by 10 dB AVG.3-4kHz
shift over tests 2-8 compared to test 1

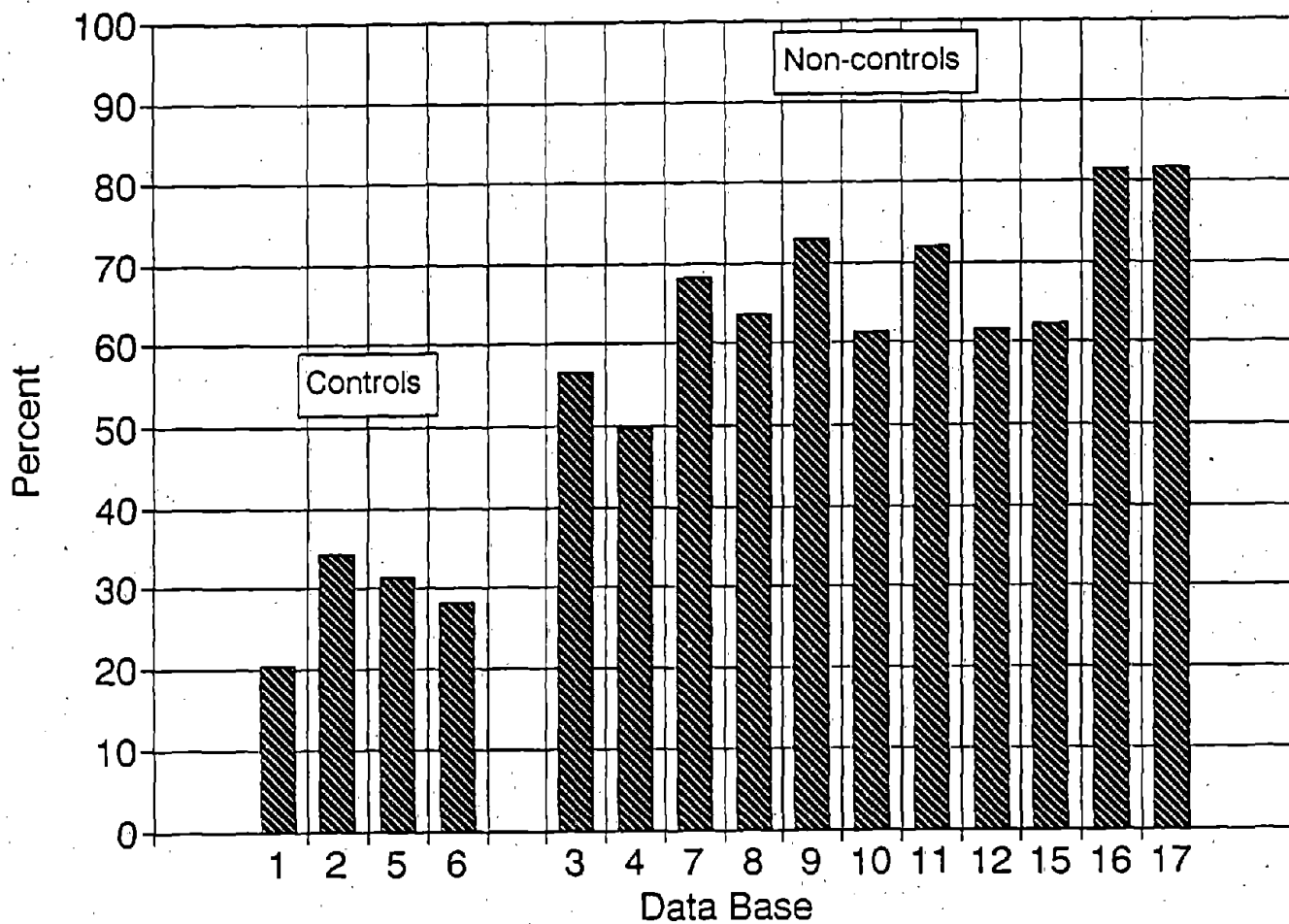


FIGURE 4

Percent ever tagged by AAO-HNS shift
over tests 2-8 compared to test 1

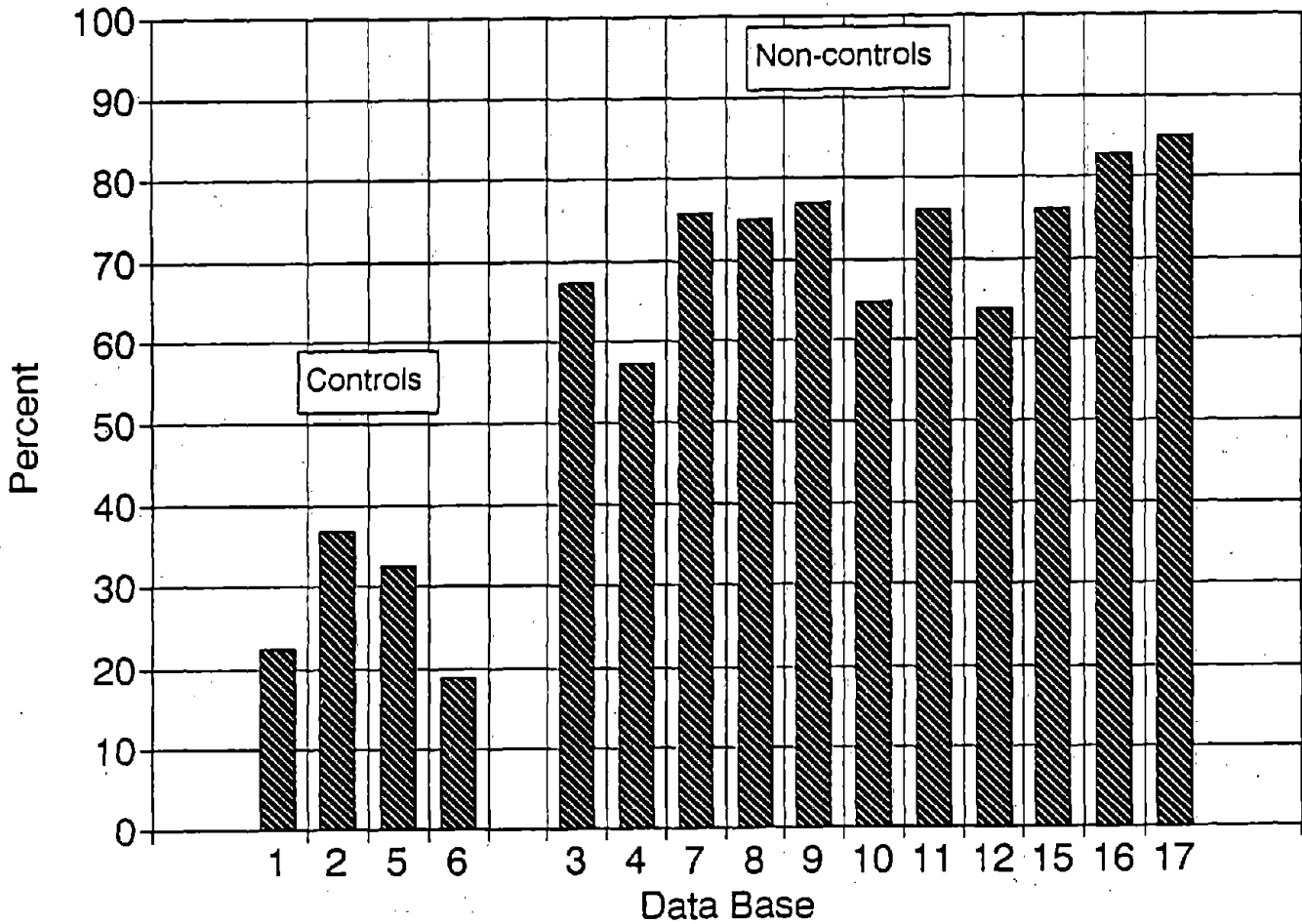


FIGURE 5.

Percent ever tagged by 15-dB shift
over tests 2-8 compared to test 1

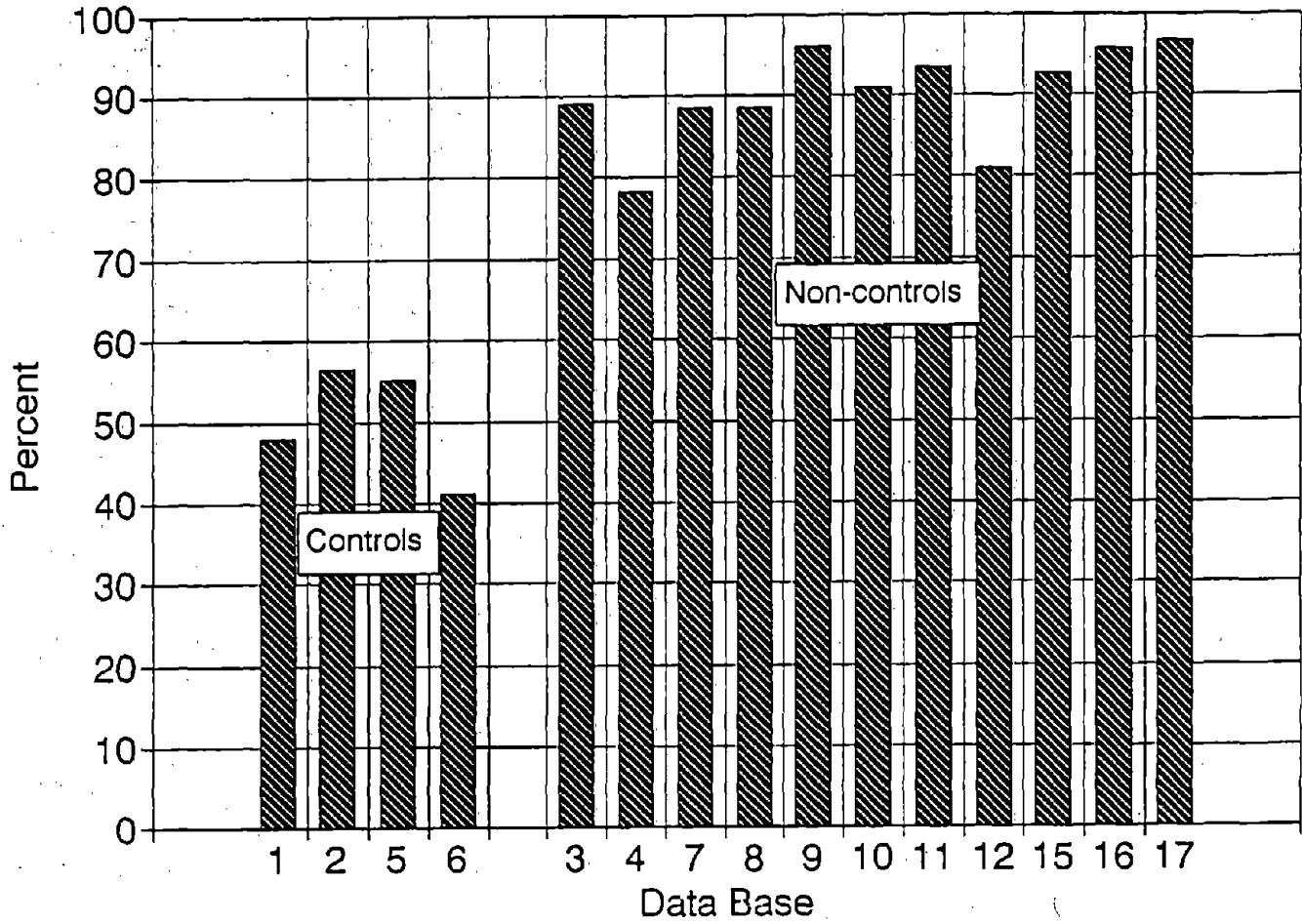


FIGURE 6

Percent ever tagged by NIOSH shift
over tests 2-8 compared to test 1

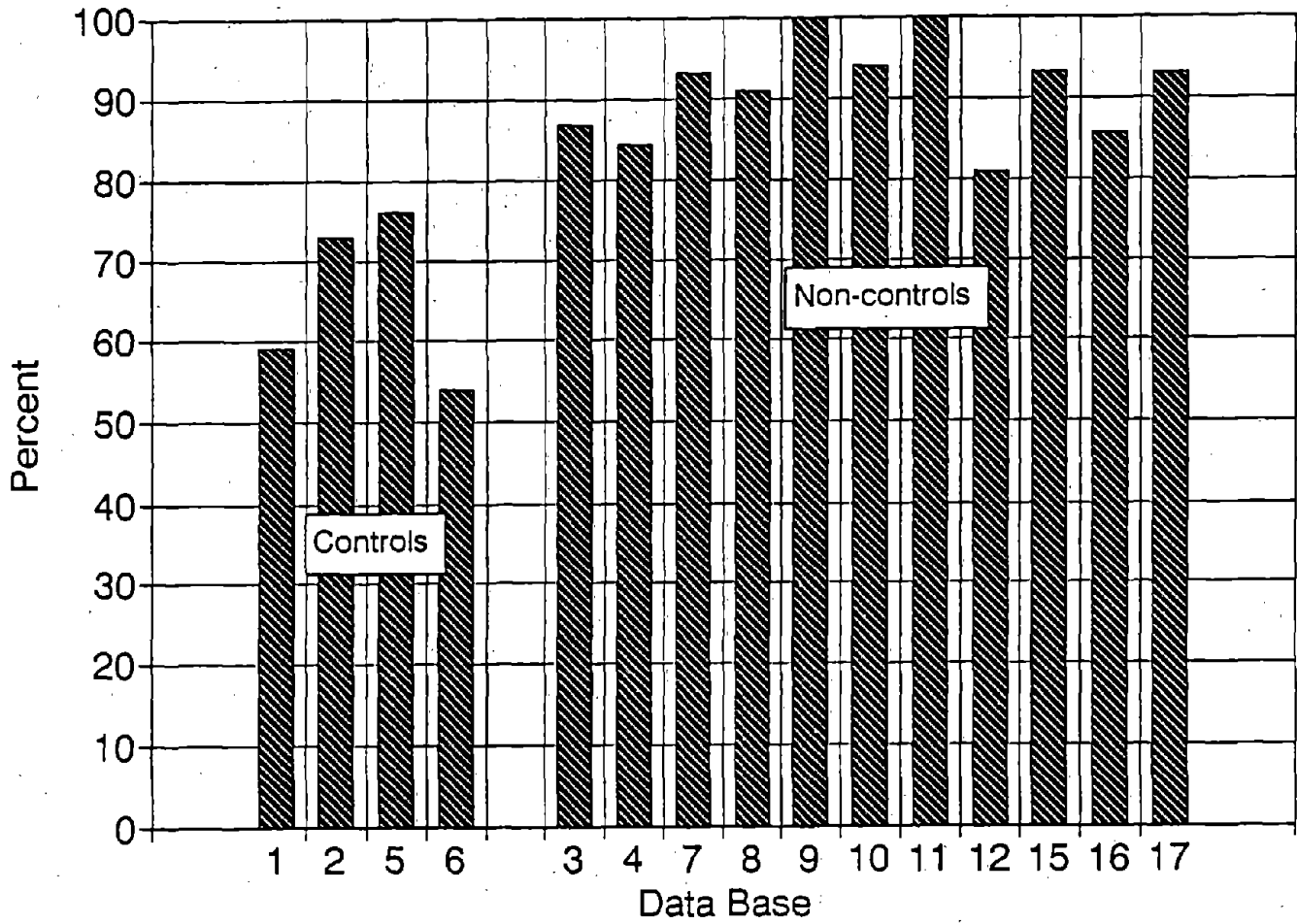


FIGURE 7

MEAN PERCENT OF EMPLOYEES EVER TAGGED
IN TESTS 2-8, CONTROLS vs NON-CONTROLS

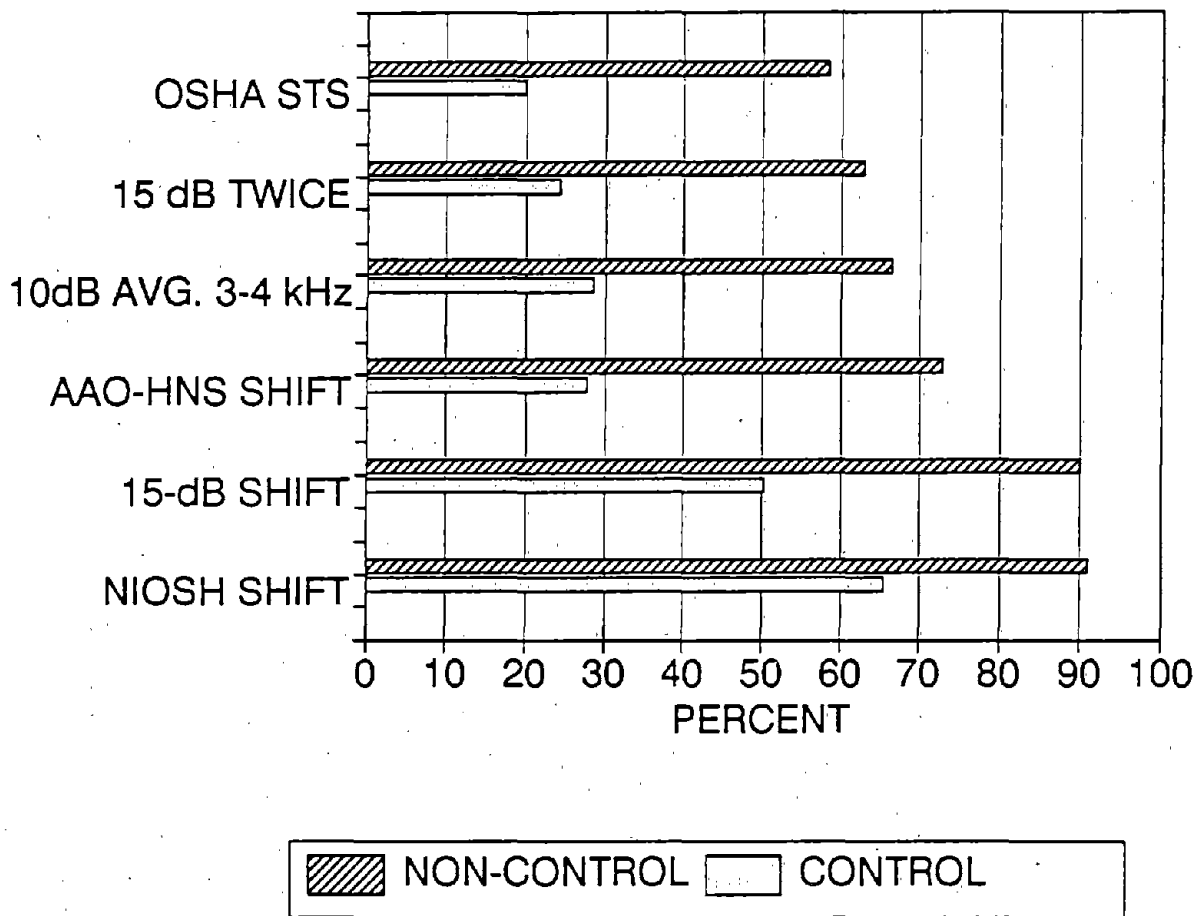


FIGURE 8

Mean percent total OSHA STSs per year
in control vs non-control databases

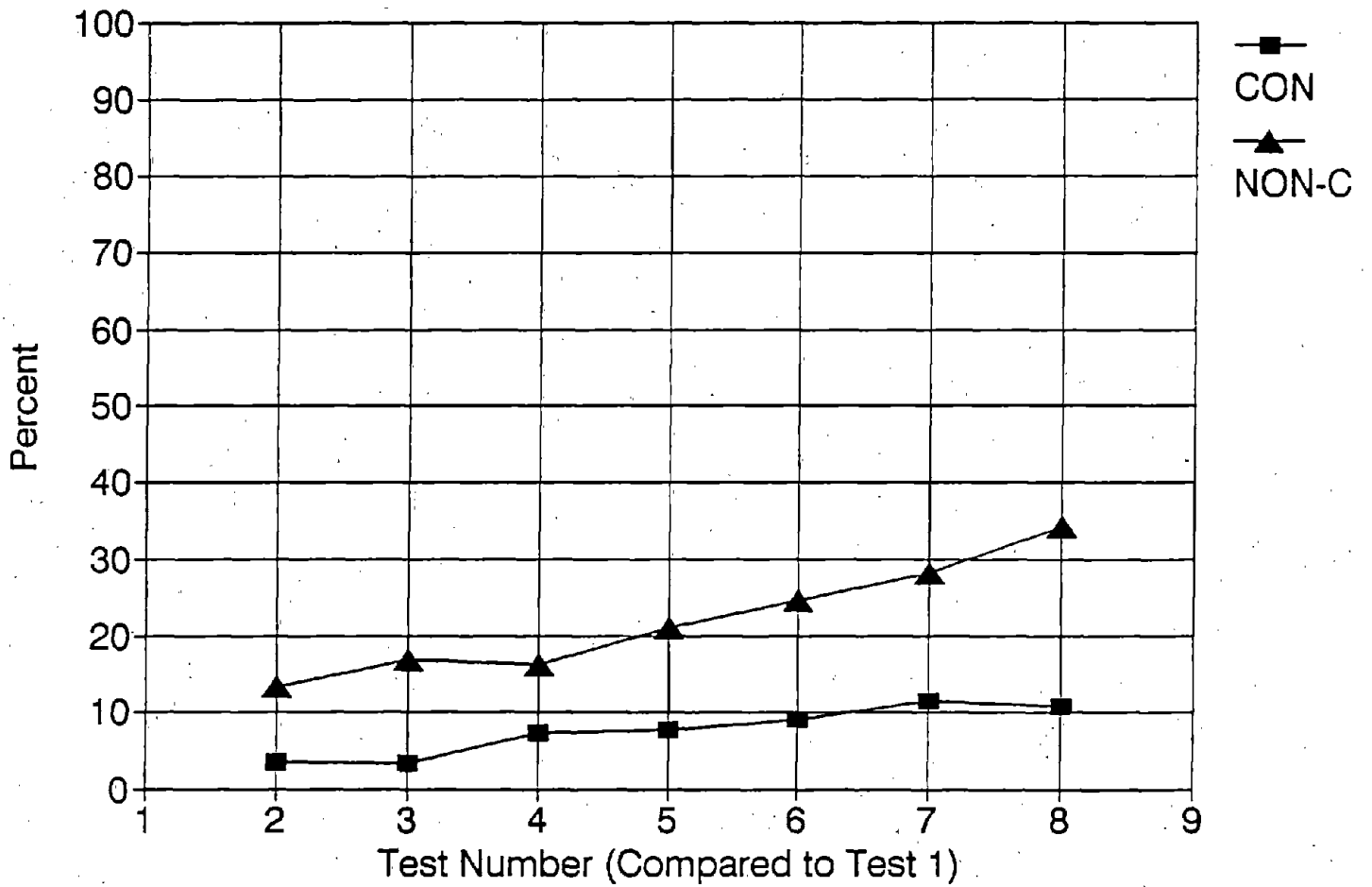


FIGURE 9

Mean percent total 15-TWICE shifts/year
in control vs non-control databases

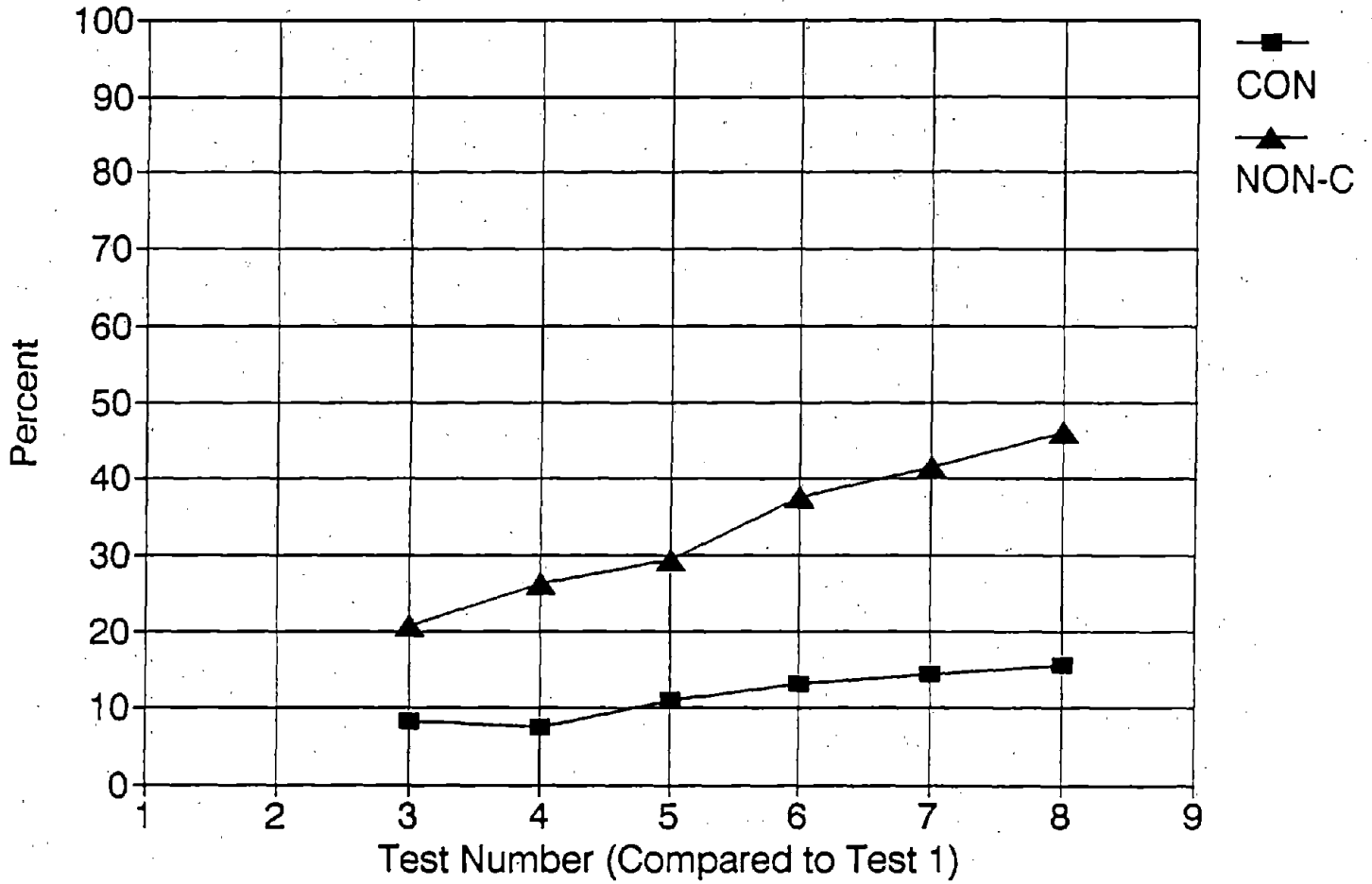


FIGURE 10

Mean pct. total 10dB AVG 3-4kHz shifts
per year in control vs non-control data

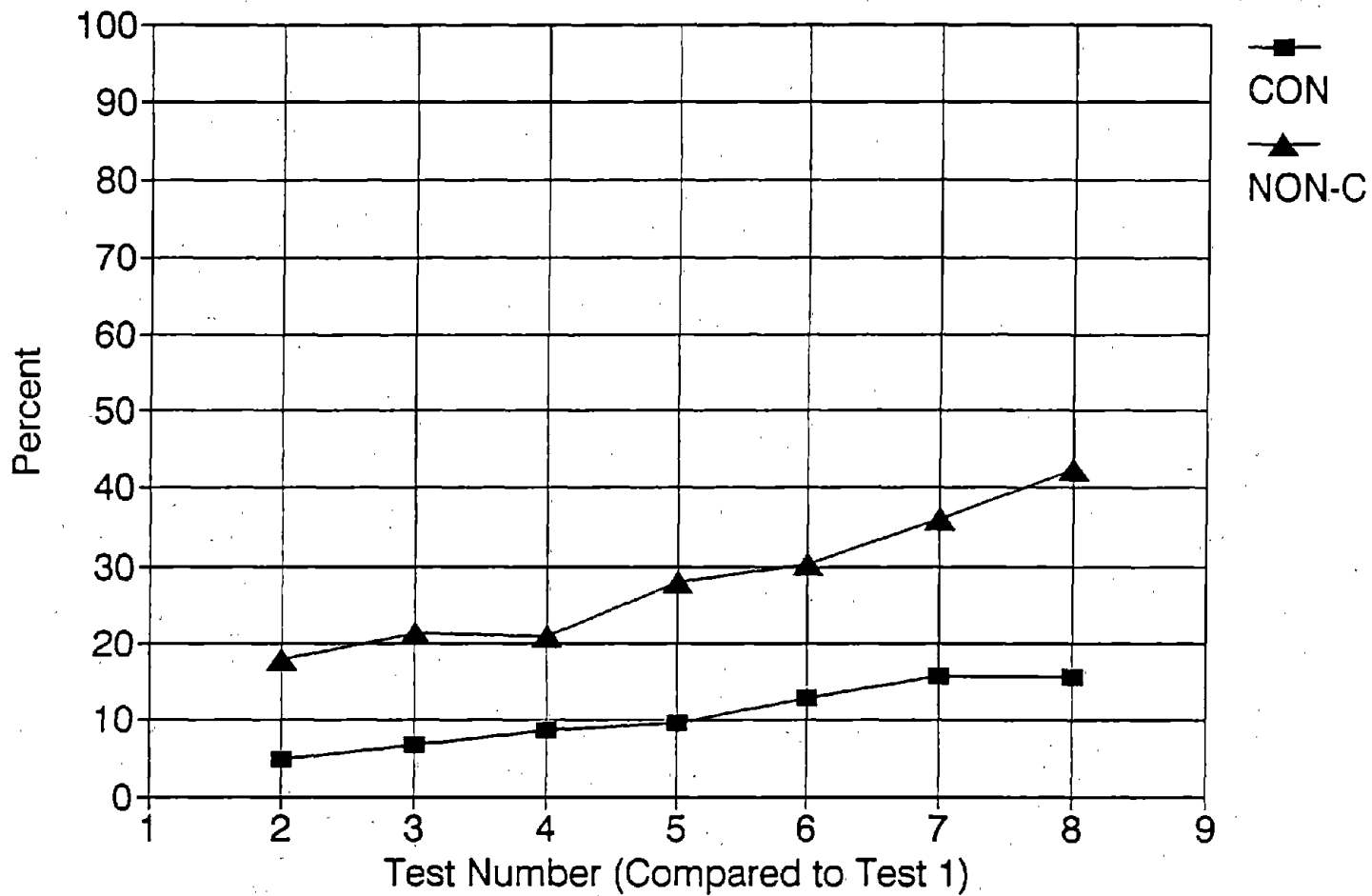


FIGURE 11

Mean percent total AAO-HNS shifts/year
in control vs non-control databases

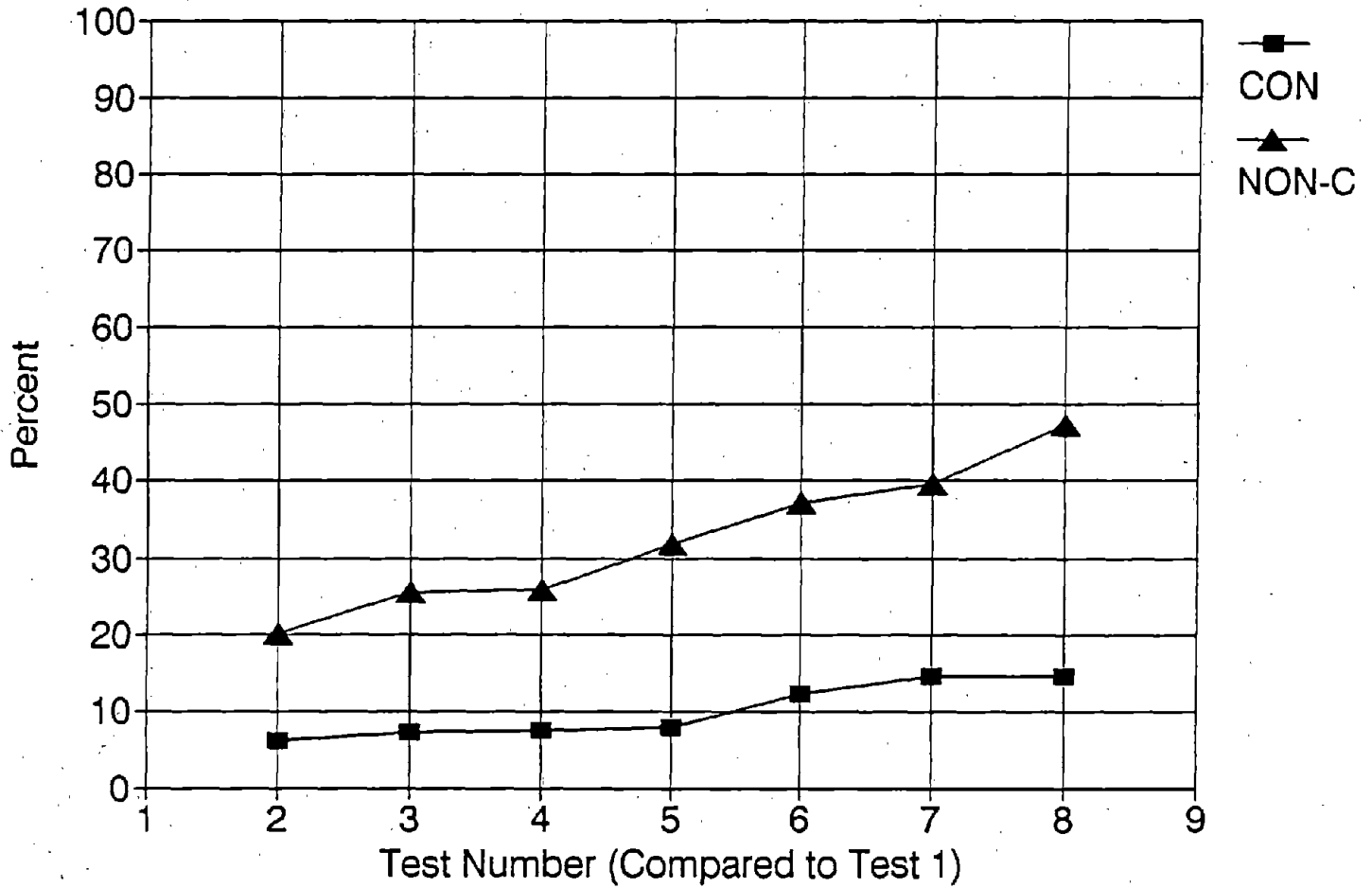


FIGURE 12

Mean percent total 15-dB shifts/year
in control vs non-control databases

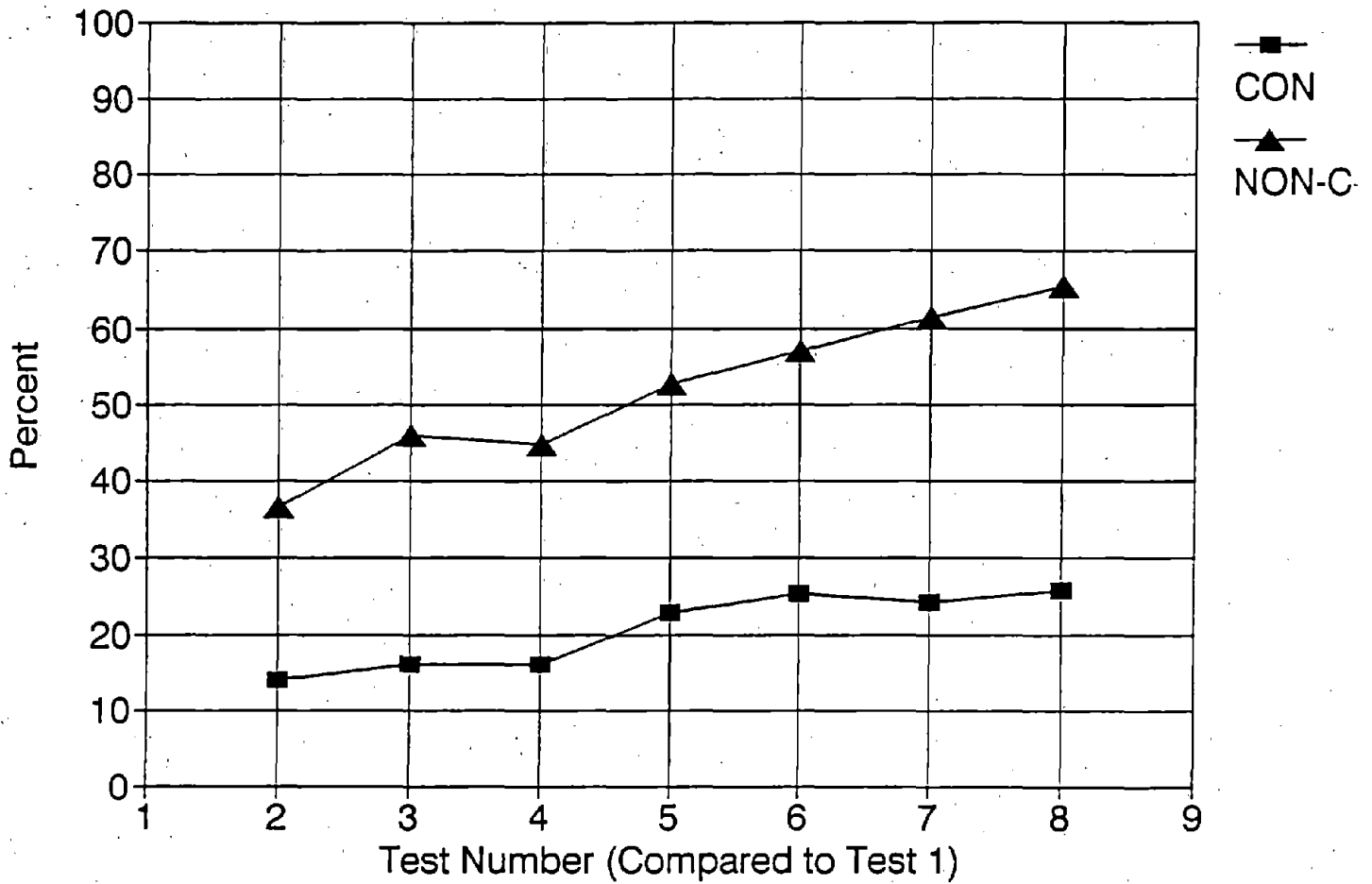


FIGURE 13

Mean percent total NIOSH shifts/year
in control vs non-control databases

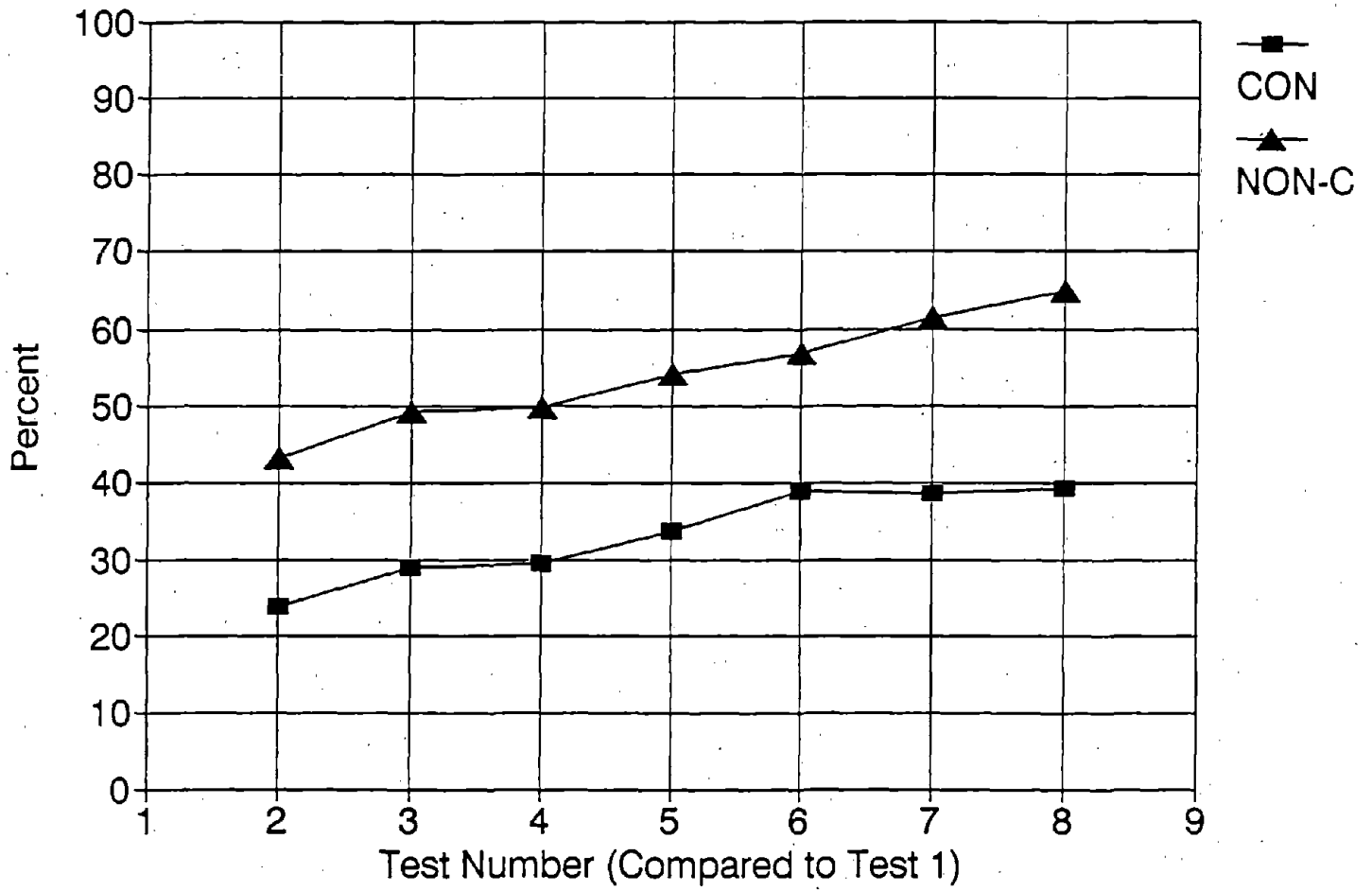


FIGURE 14

Mean percent new OSHA STSs per year
in control vs non-control databases

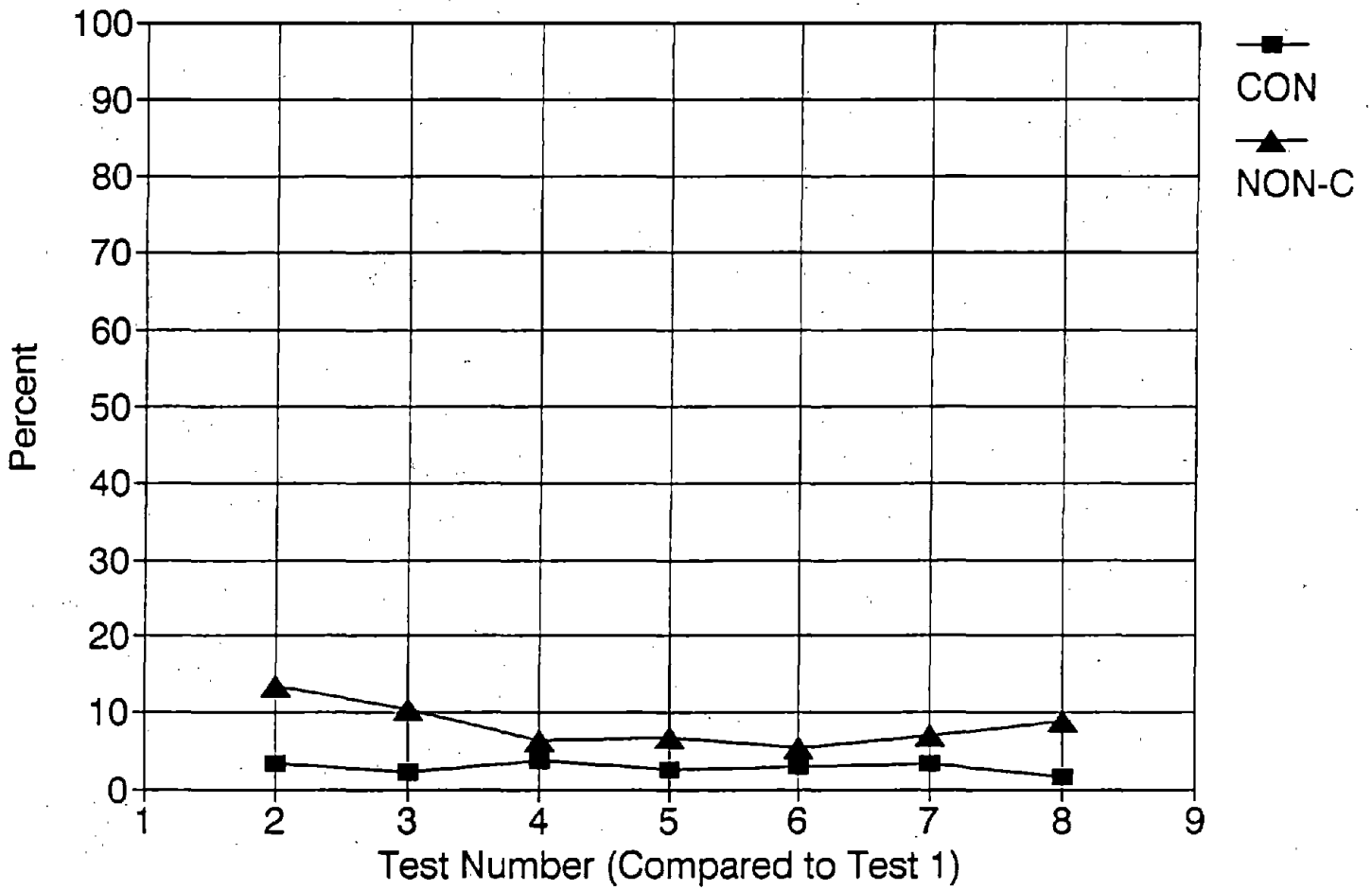


FIGURE 15

Mean percent new 15-TWICE shifts/year
in control vs non-control databases

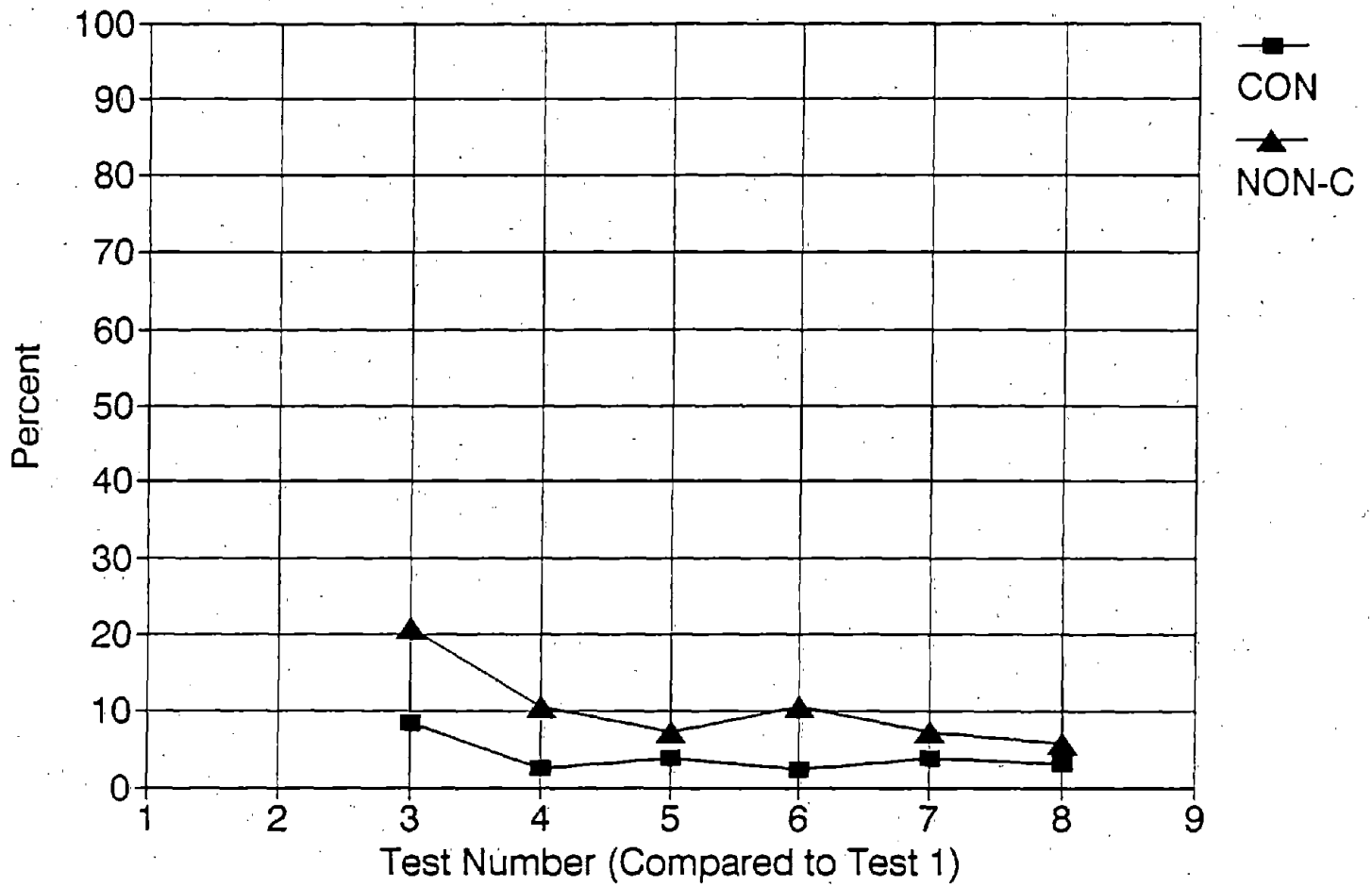


FIGURE 16

Mean pct. new 10 dB AVG.3-4kHz shifts
per year in control vs non-control data

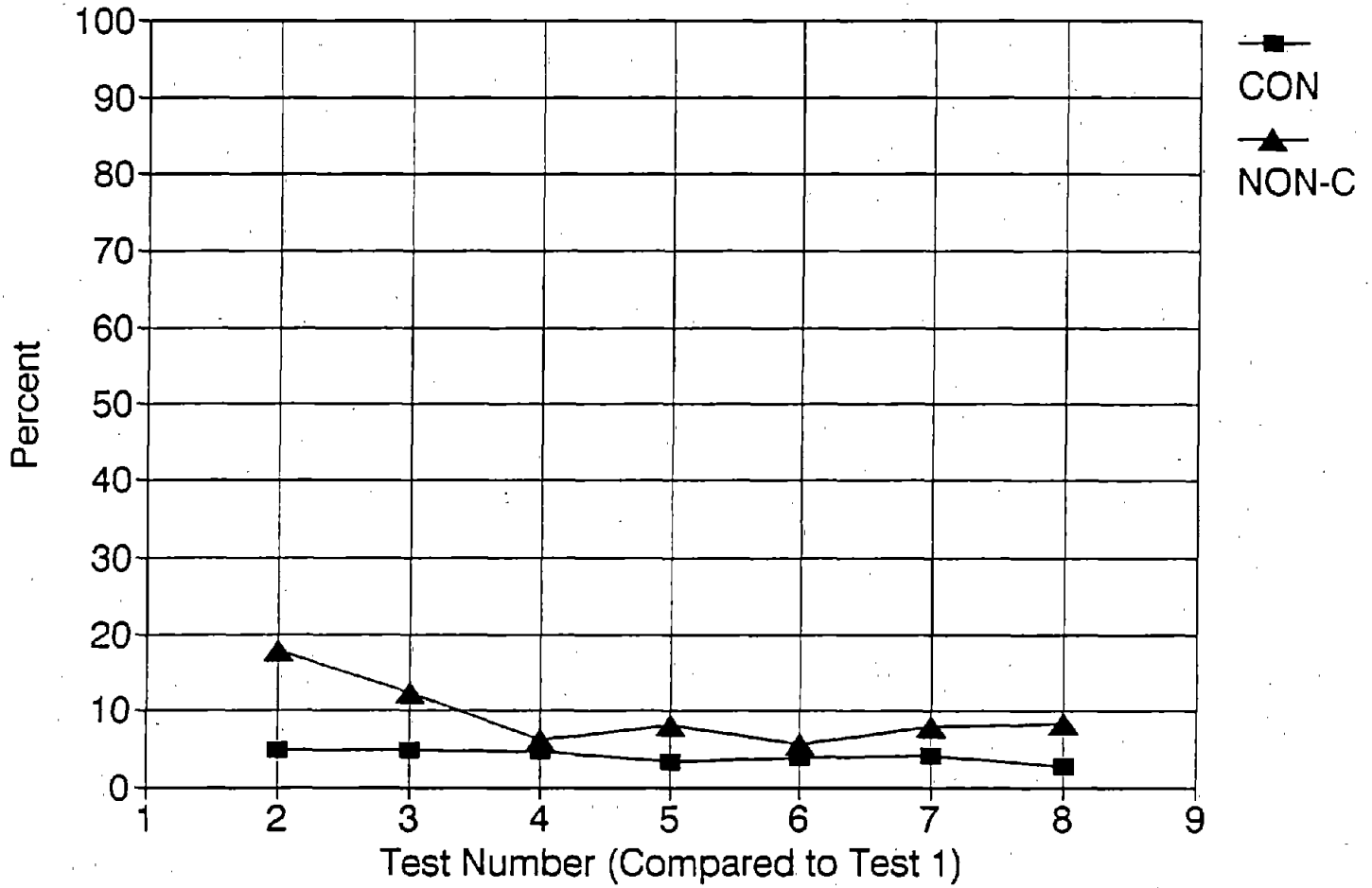


FIGURE 17

Mean percent new AAO-HNS shifts/year
in control vs non-control databases

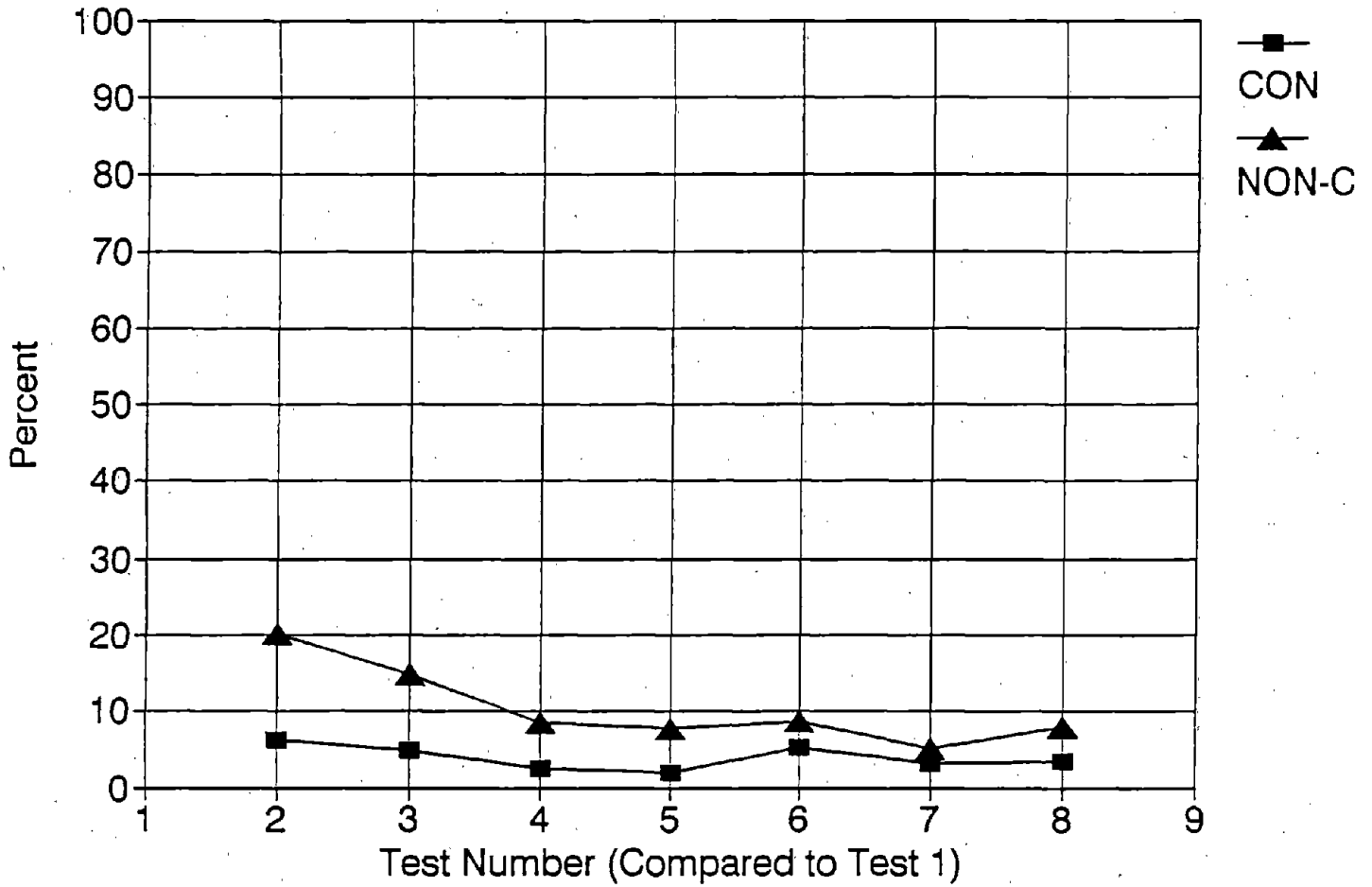


FIGURE 18

Mean percent new 15-dB shifts/year
in control vs non-control databases

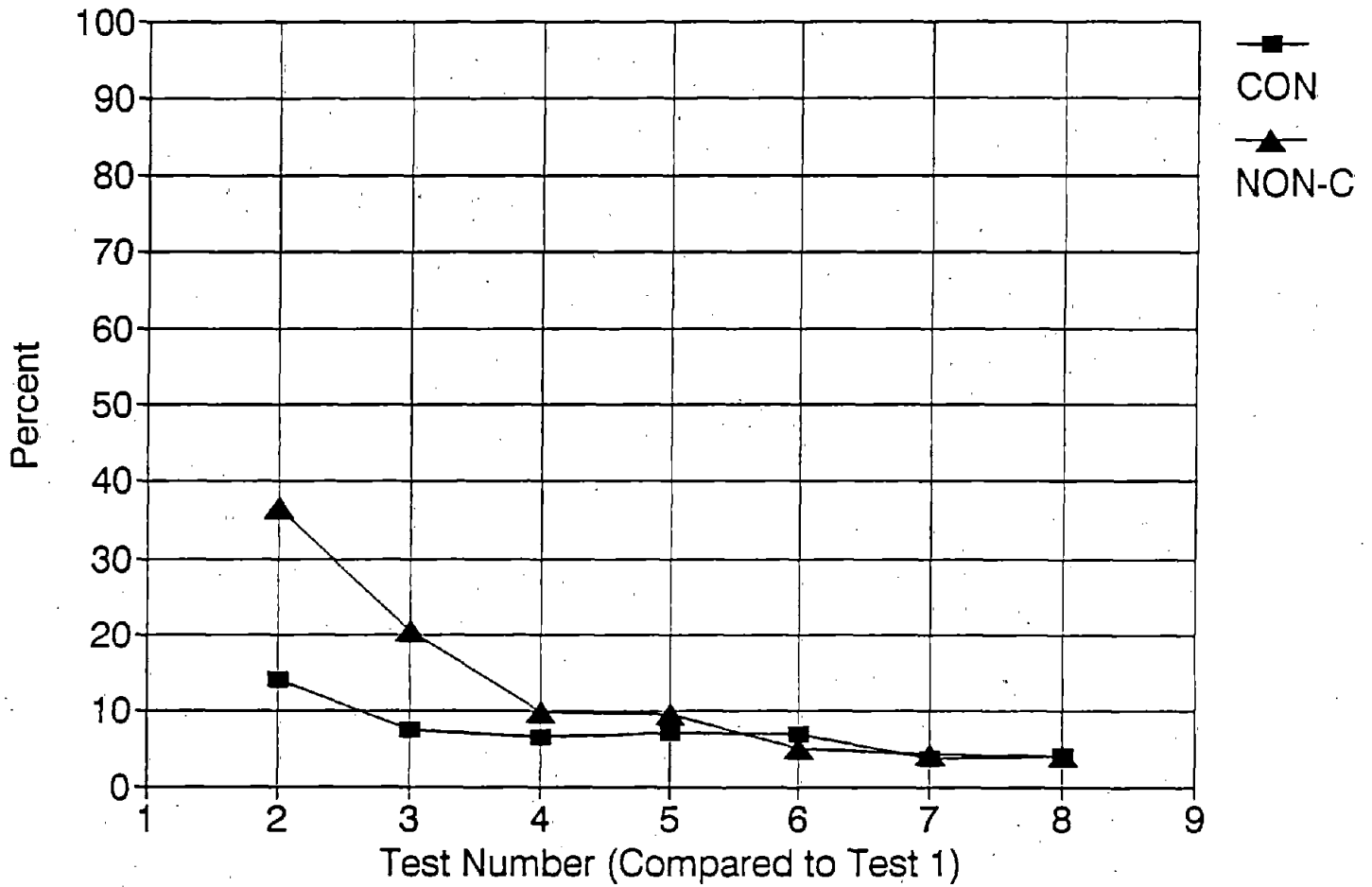


FIGURE 19

Mean percent new NIOSH shifts per year
in control vs non-control databases

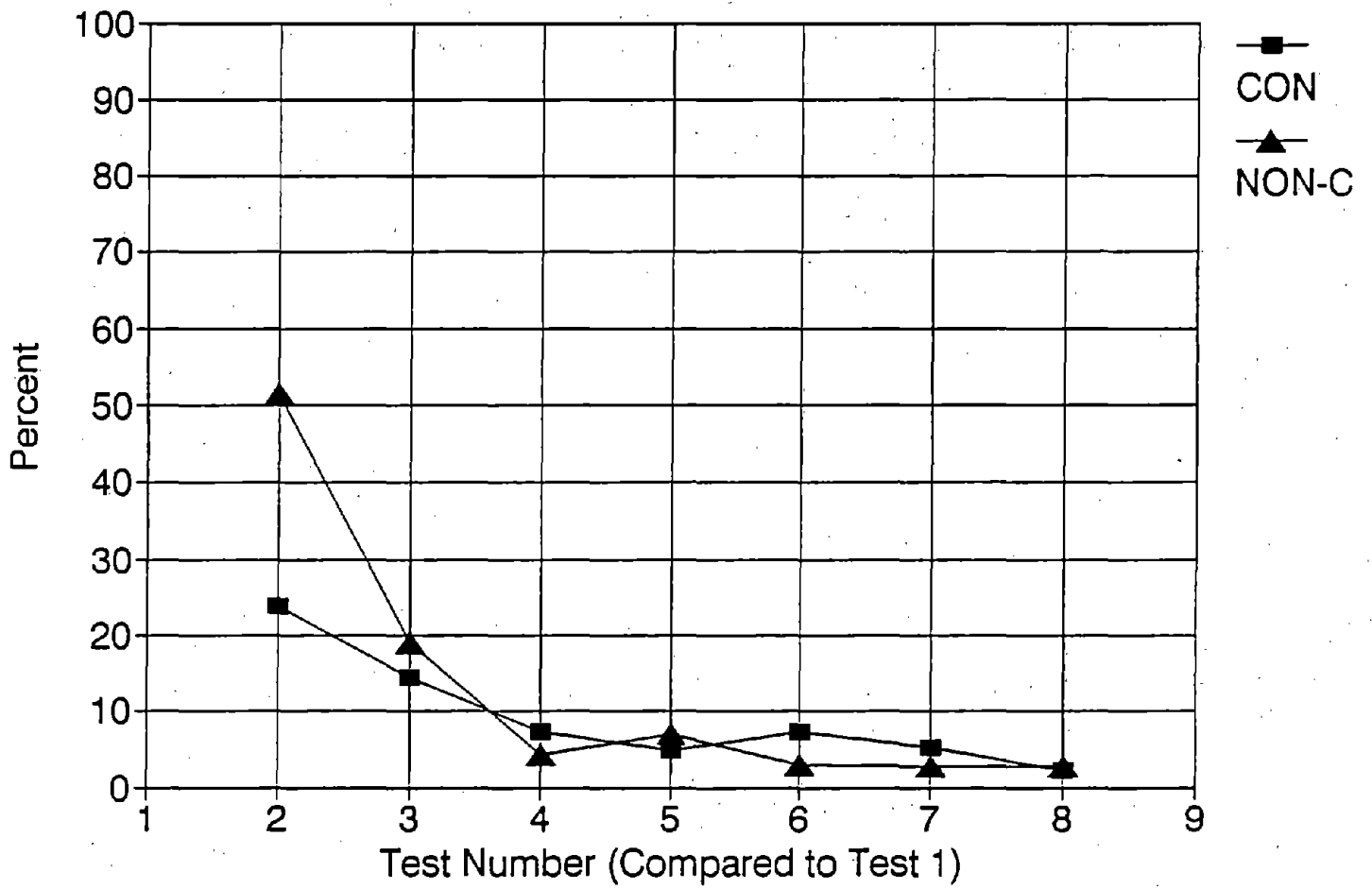


FIGURE 20

MEAN PERCENT NEW TAGS PER YEAR
IN CONTROL DATA BASES vs NON-CONTROLS

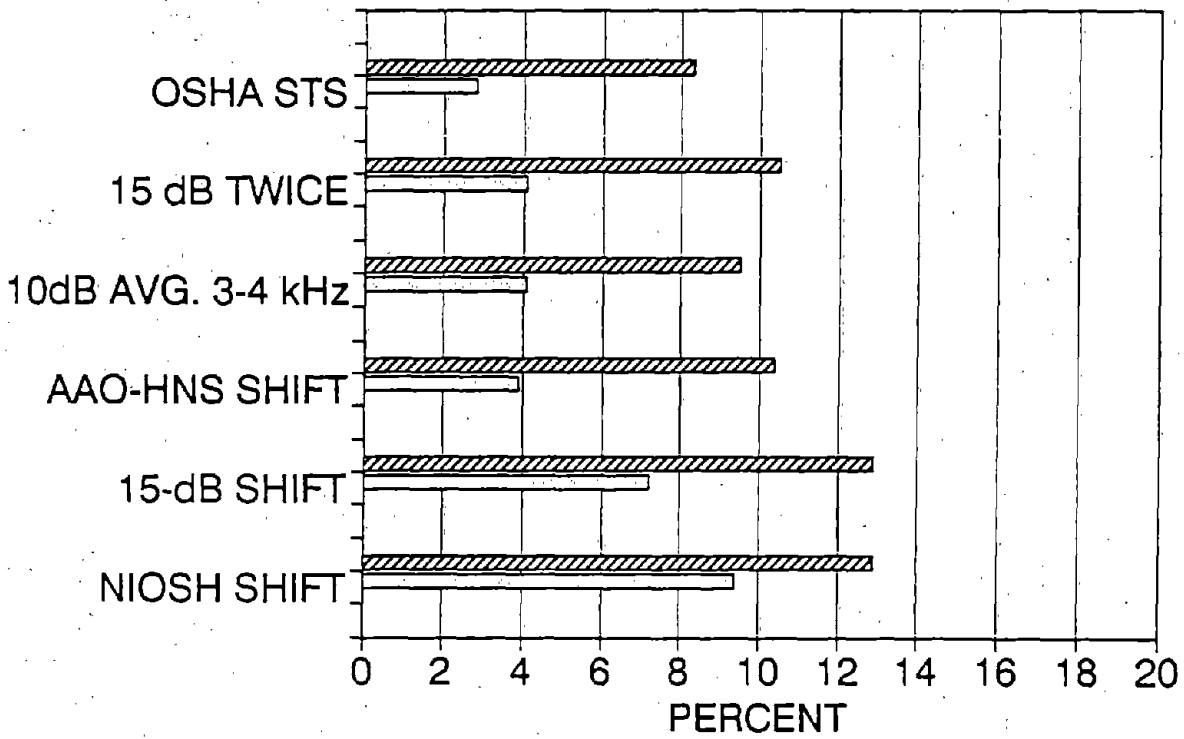


FIGURE 21

Percent OSHA STS first tags classified as true positive

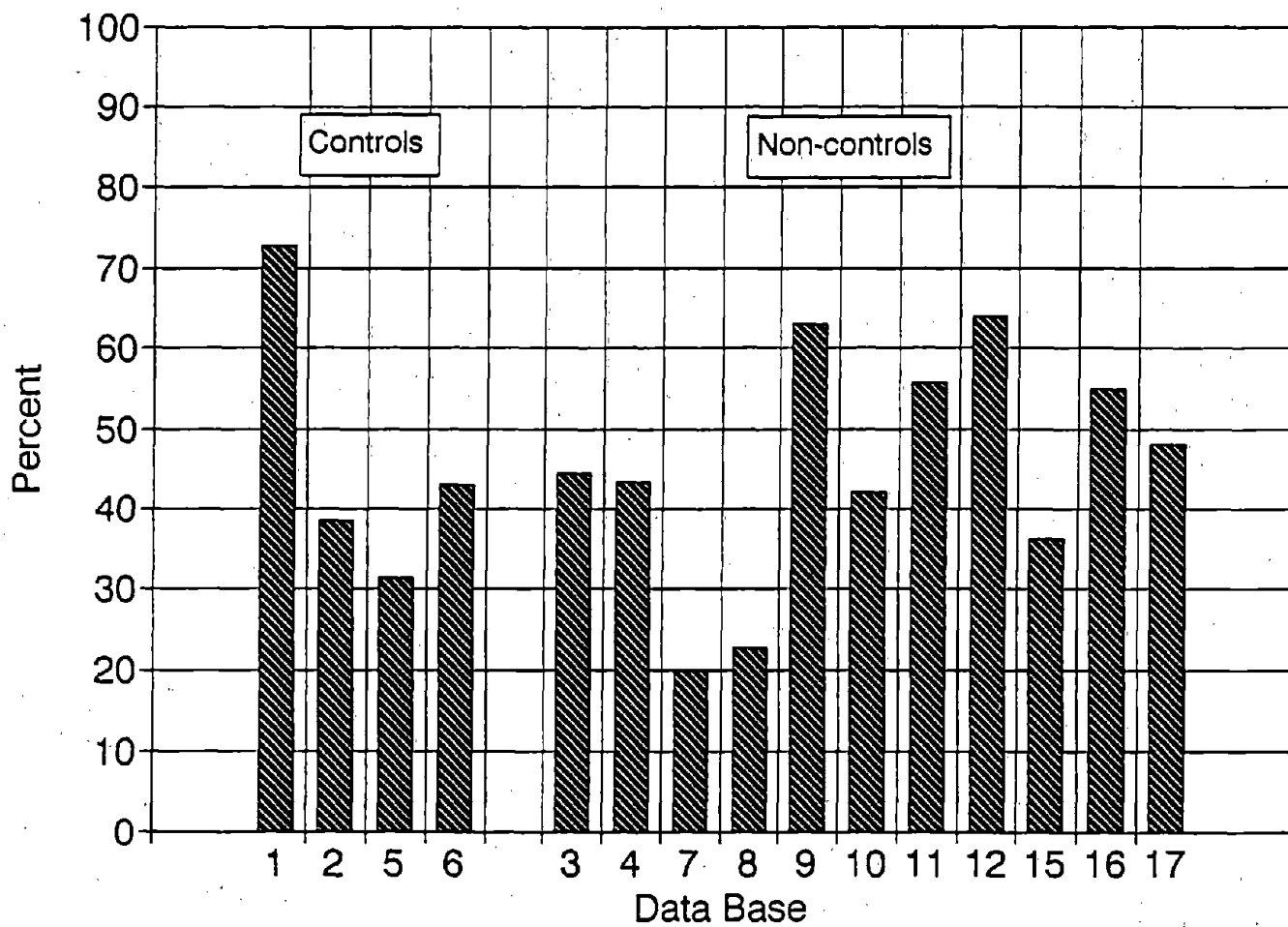


FIGURE 22

Percent 15dB TWICE shift first tags
classified as true positive

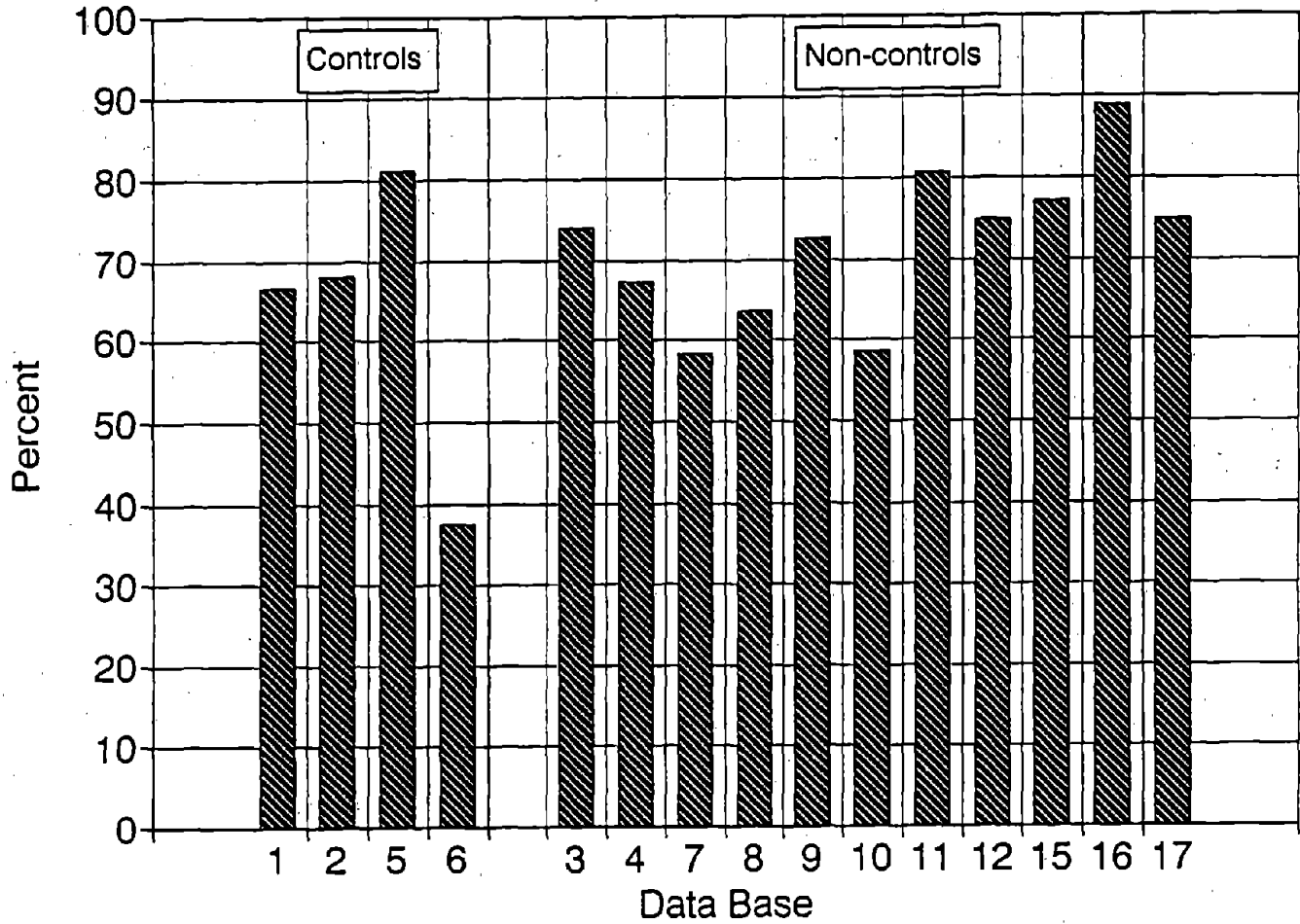


FIGURE 23

Pct. 10dB AVG 3-4kHz shift first tags
classified as true positive

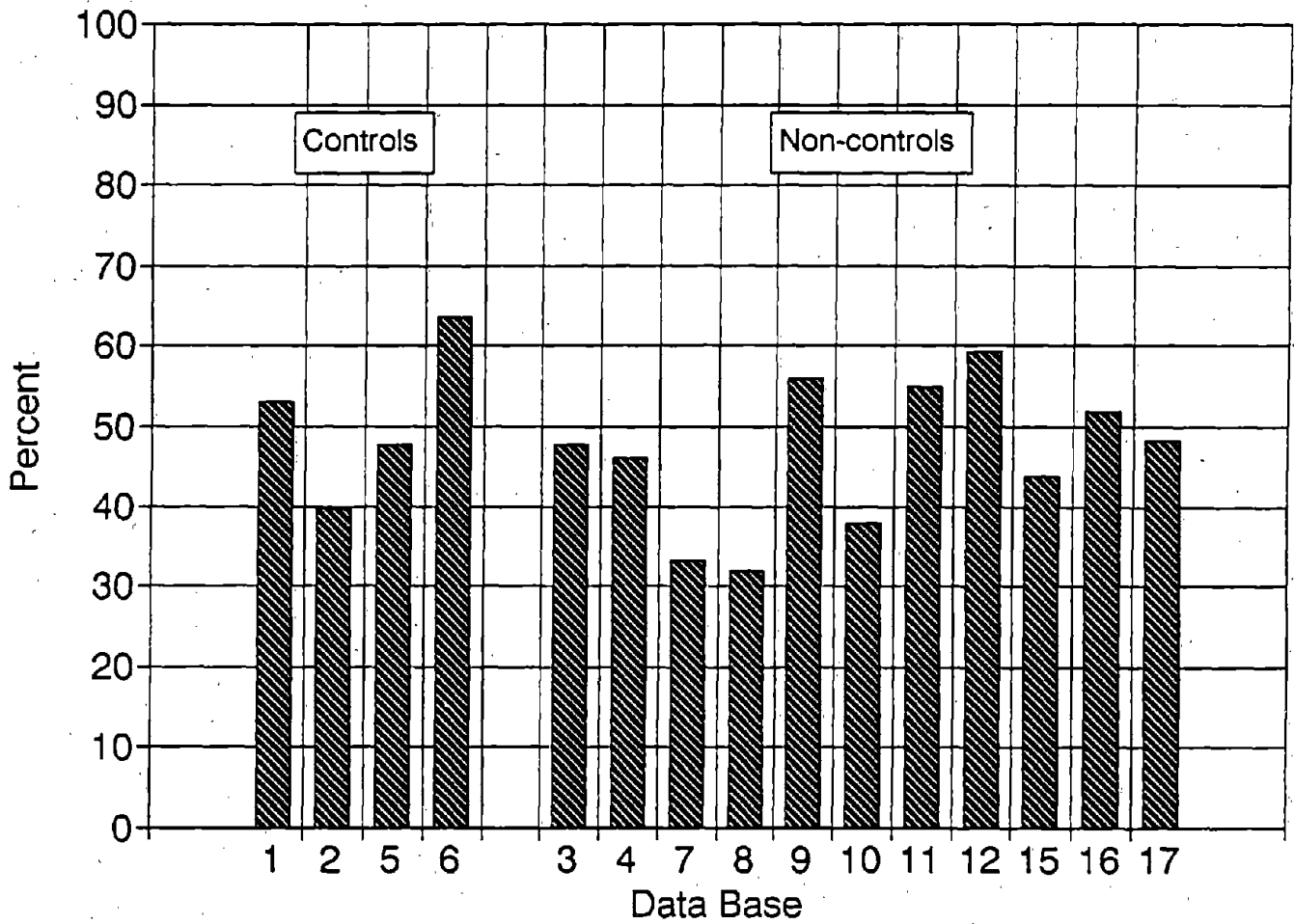


FIGURE 24

Percent AAO-HNS shift first tags
classified as true positive

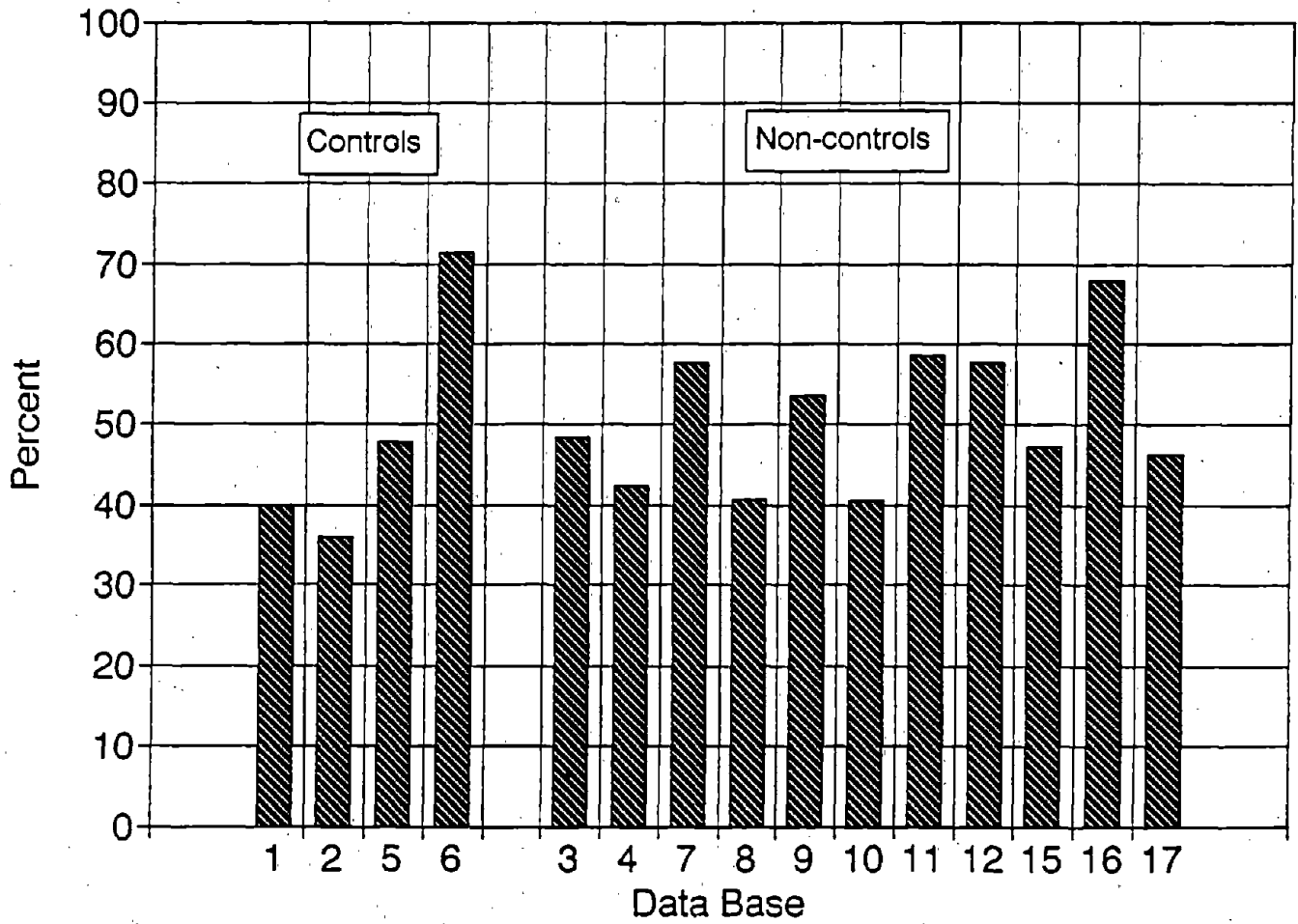


FIGURE 25

Percent 15-dB shift first tags
classified as true positive

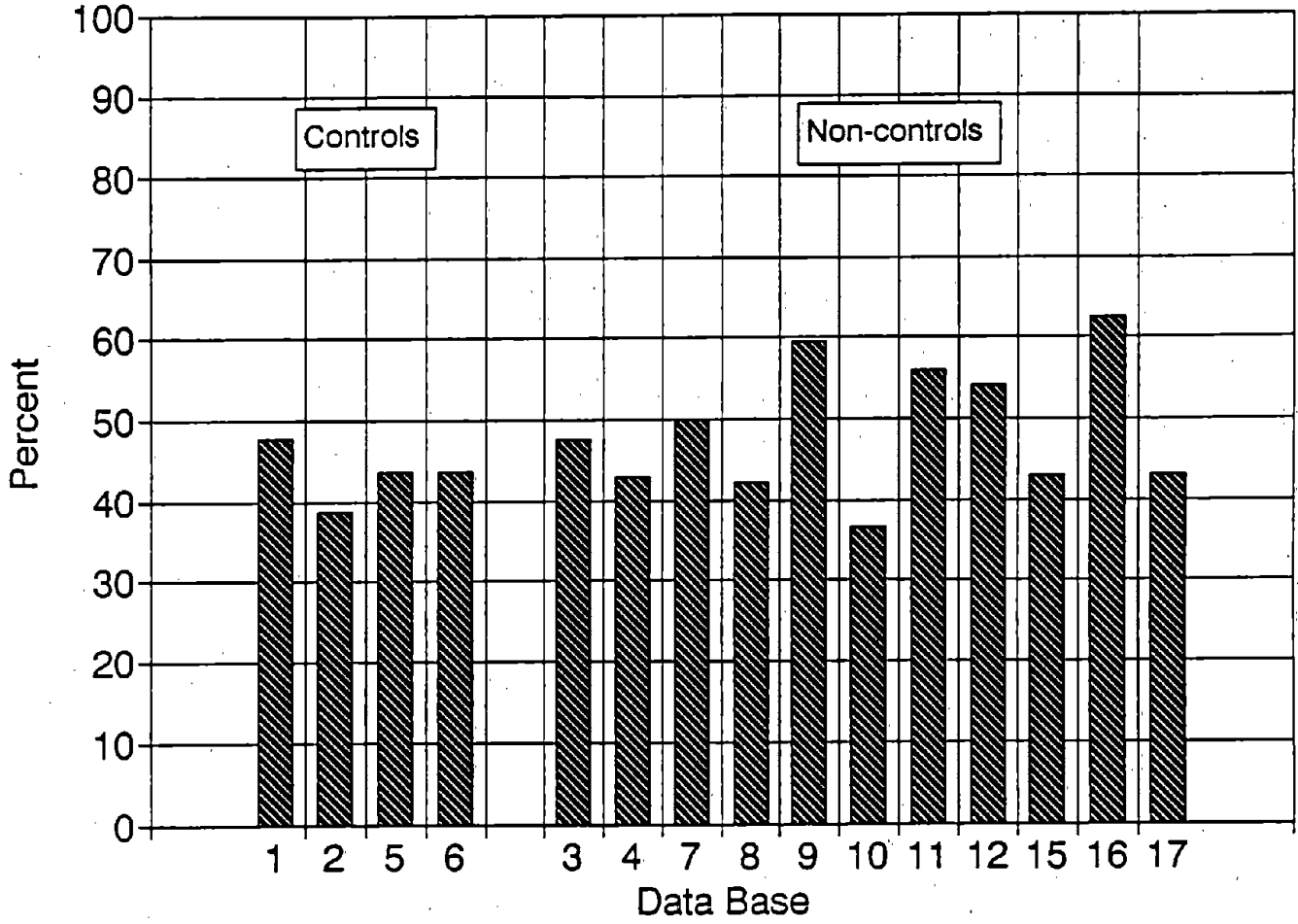


FIGURE 26

Percent NIOSH shift first tags
classified as true positive

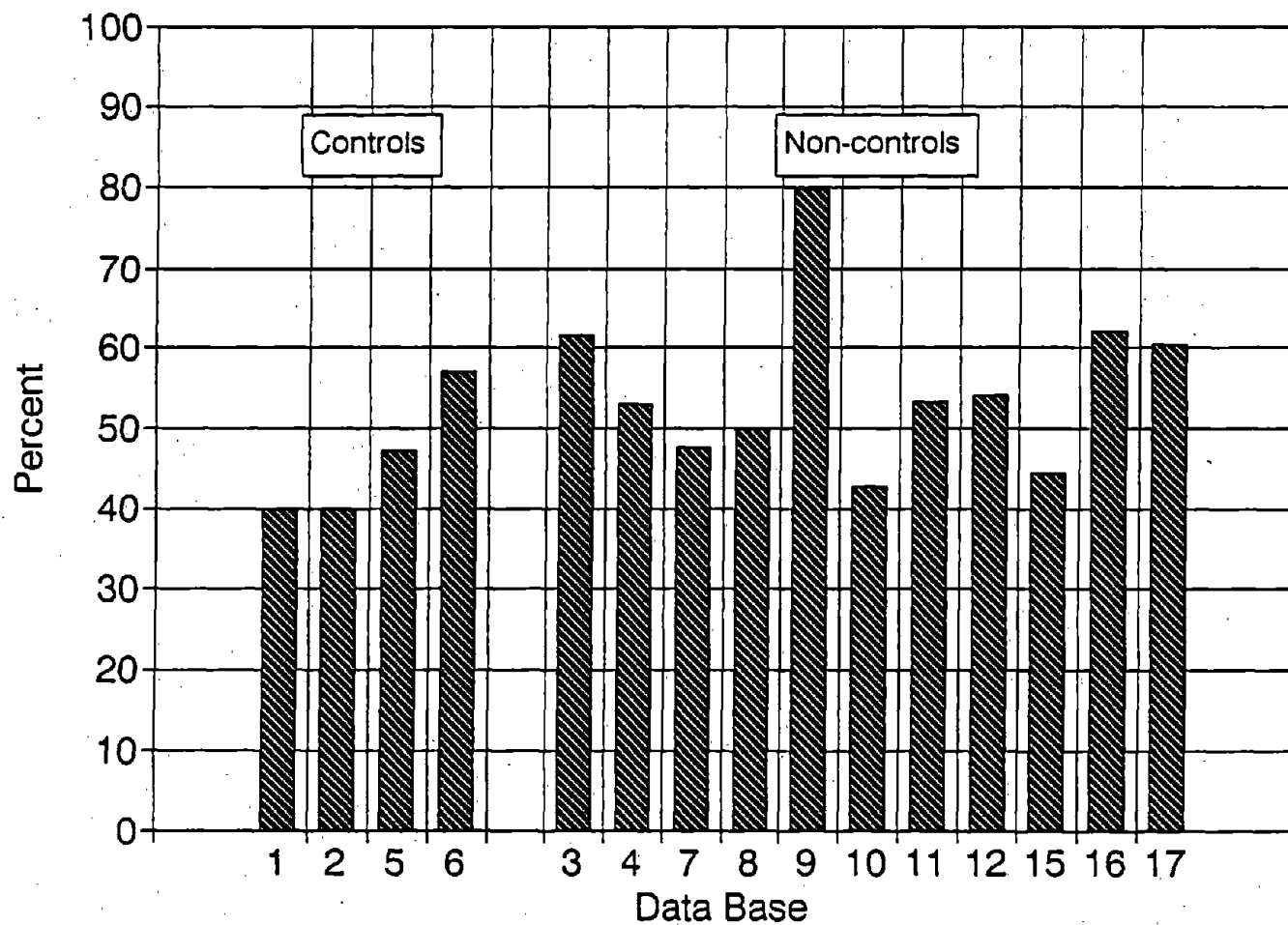


FIGURE 27

MEAN PERCENT OF FIRST TAGS CLASSIFIED TRUE POSITIVE BY NEXT TEST CONFIRMATION

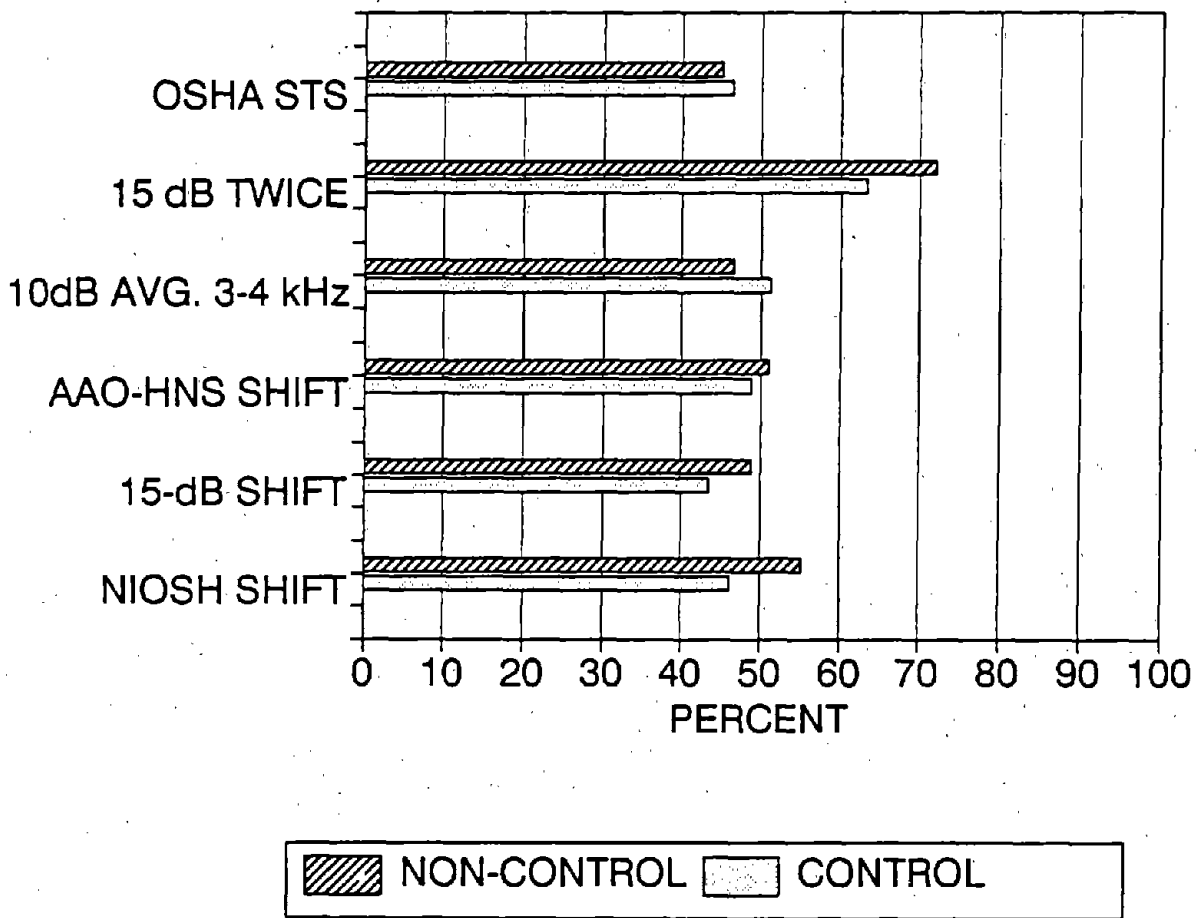


FIGURE 28

PERCENT OF FIRST TAGS CLASSIFIED TRUE POSITIVE, ALL 15 DATA BASES COMBINED

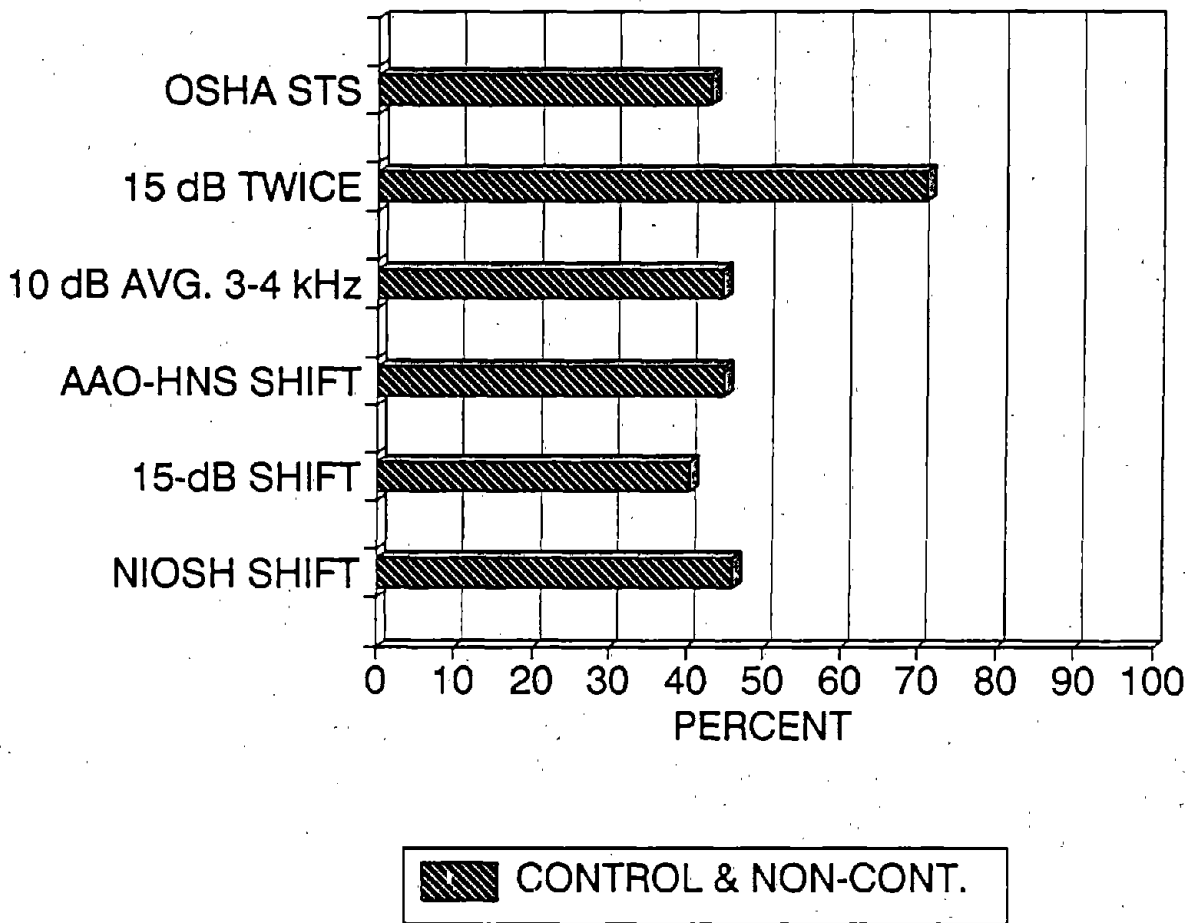


FIGURE 29

PERCENT OF TAGGED WORKERS WHO WERE TAGGED EARLIEST BY EACH CRITERION

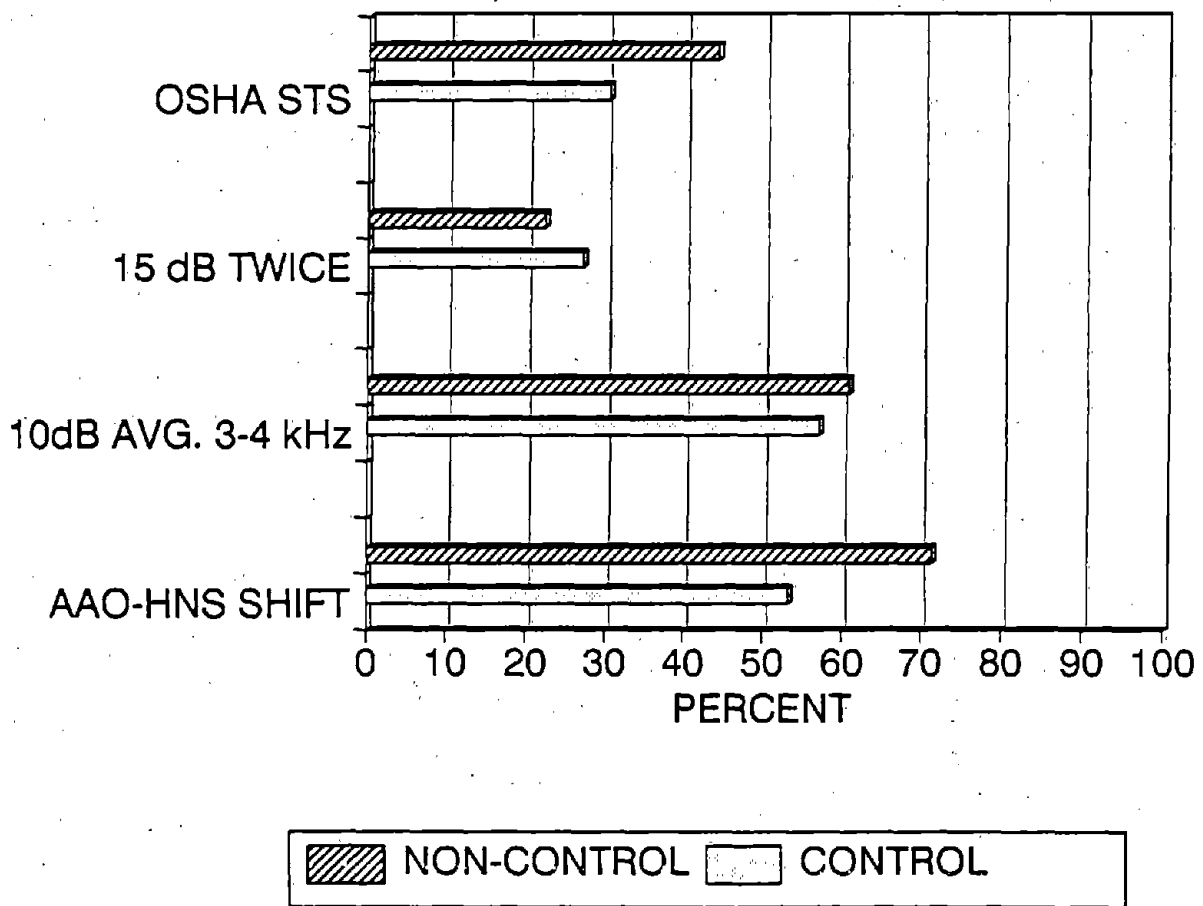
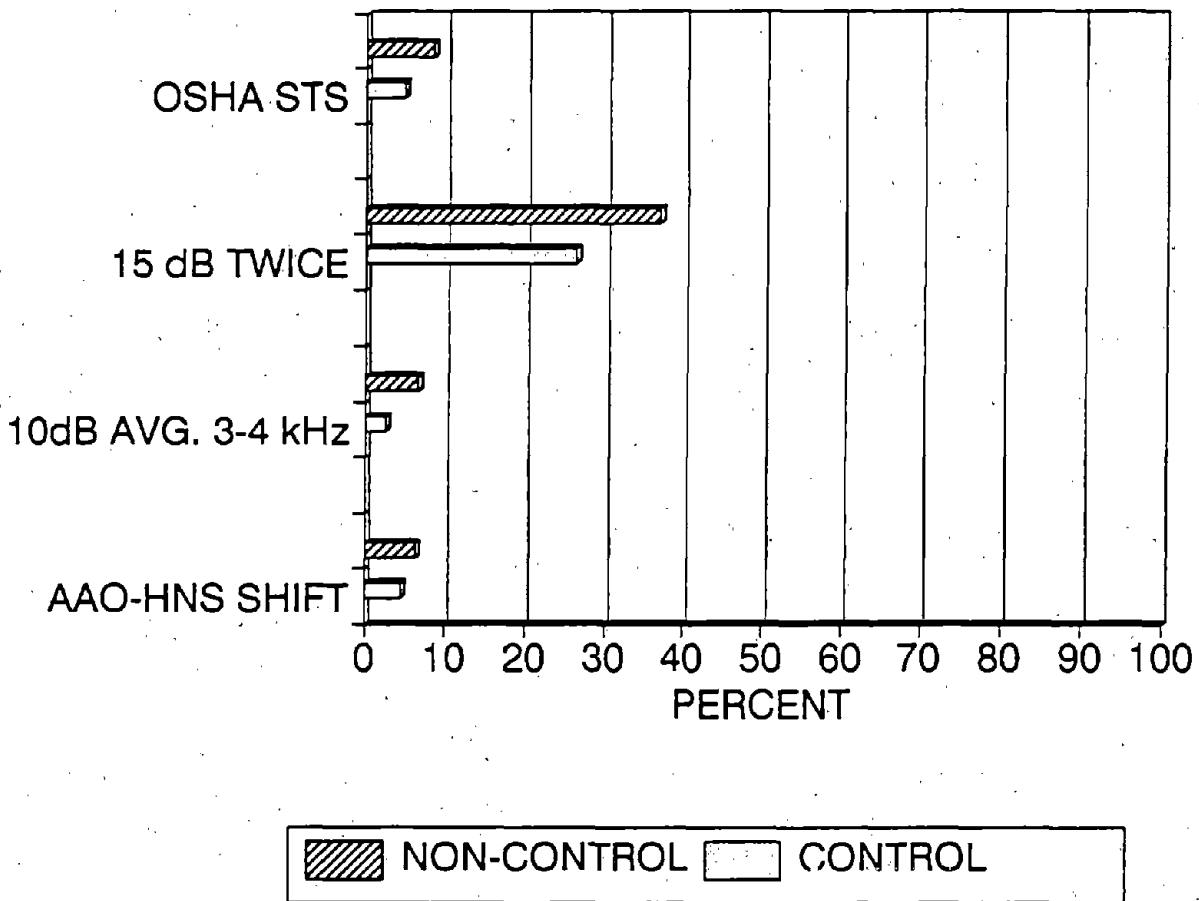
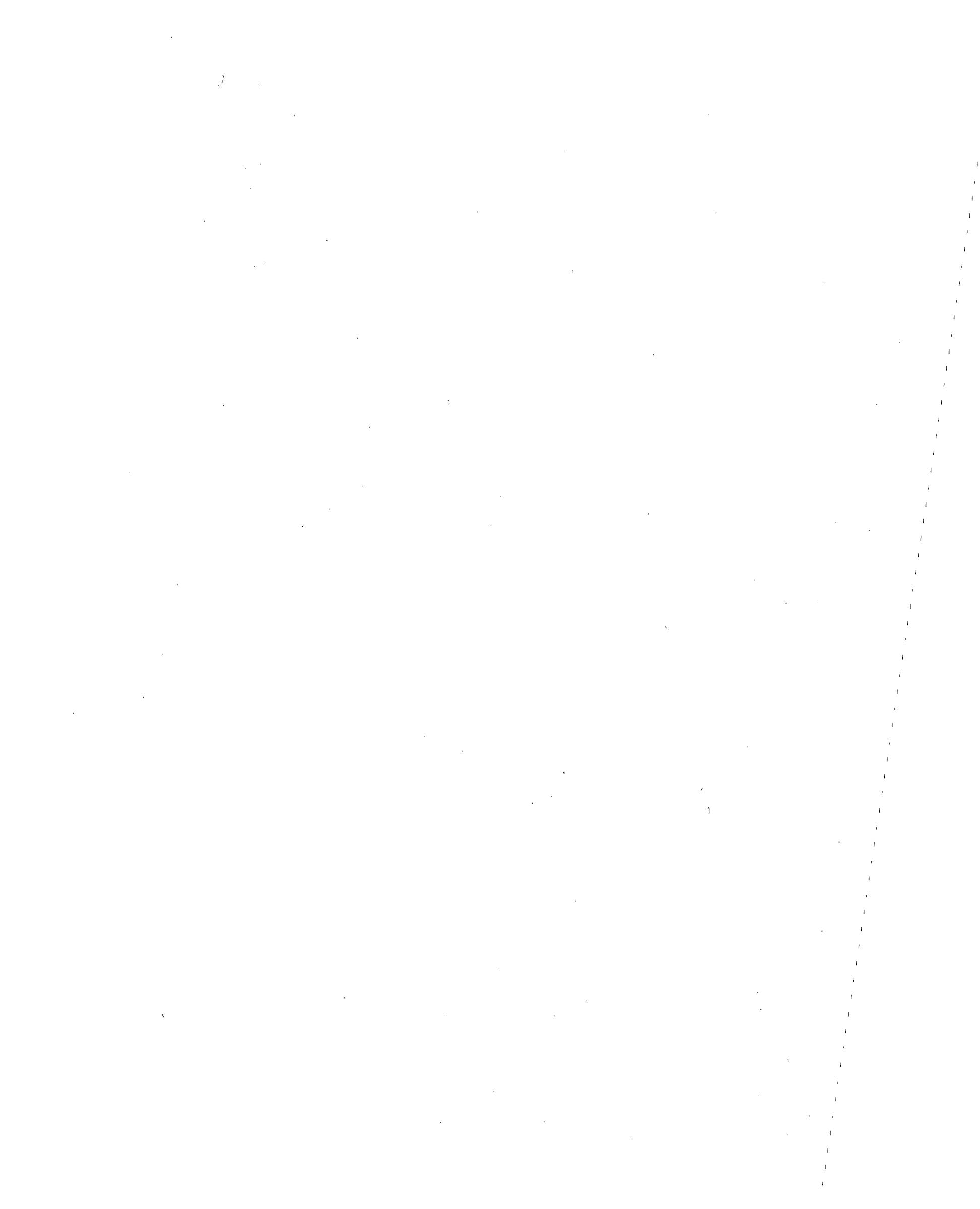


Figure 30

PERCENT OF TAGGED WORKERS WHO WERE TAGGED 1 TEST LATER THAN EARLIEST





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