Department of Toxicology and Pharmacology
University of Arkansas for Medical Sciences
Little Rock, Arkansas 72205

Field Study of Hearing Protector Evaluation Procedure

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Principal Investigator: Thomas W. Rimmer, Sc.D., CIH

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List of Abbreviations

AC	Air conduction sound
BC	Bone conduction sound
BCLB	Bone conduction loudness balance
HPD	Hearing protection device
LB	Loudness balance
NRR	Noise Reduction Rating
REAT	Real ear attenuation at threshold

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ABSTRACT

The Bone Conduction Loudness Balance (BCLB) method of measuring hearing protector attenuation was re-worked from earlier test versions and evaluated in a variety of situations, both laboratory and field. The procedure was implemented for running on any personal computer using the Windows® operating system, and the protocol was simplified to emulate the standard hearing threshold test method. Laboratory testing using 26 previously inexperienced subjects showed that the revised procedure was easily implemented and more than twice as quickly done than the previous procedure, but was somewhat less consistent with the standard REAT testing.

Field HPD testing was evaluated with a total of 68 previously inexperienced subjects at four industrial sites. The mean time required for the BCLB test was about 6 minutes, and nearly all subjects were able to perform the test without difficulty, except for 2 of 68 who had too much hearing loss to hear the bone conduction reference sound at 2000 Hz and one subject who was unwilling to learn the procedure. The primary difficulty was the tendency of some subjects to respond as in a threshold test, with re-instruction required for 17%. When used in a "candid" or unannounced test mode to evaluate HPD effectiveness as actually worn on the job, the procedure found attenuation values less than in a test setting, as was expected. The procedure was no more difficult to implement for candid testing than for other settings.

The BCLB procedure was also used as part of an evaluation of the practicality and effect of using a HPD designed for better speech comprehension in noise (EAR UltraTech®) with 21 hearing-impaired industrial subjects. Use of this HPD produced modest gains (mean improvement = 29%, $p<0.01$) in speech comprehension as measured by correct word identification on a 50-word test when compared with their normal HPD. However, 40% failed to wear the new HPD for extended testing due to discomfort and only 25% of those who did continue to wear it preferred it to their previous HPD.

SIGNIFICANT FINDINGS

- The bone conduction loudness device (BCLB) procedure can be simply implemented using an ordinary personal computer equipped with a basic sound card and basic speakers, with the only additional equipment needed being a bone conduction transducer.

- The changes made in the BCLB protocol have the effect of very significantly reducing the time required for the test.

- The method can be physically used for any type of hearing protective device (HPD) without removing the HPD before testing, since the bone conduction transducer can be held to the head without the need for a strap.

- No specialized training is needed for nearly all industrial workers to become proficient in loudness balancing, provided that their hearing ability at 2000 Hz is adequate to be able to hear the bone conduction reference sound.

- The test protocol may need further modification since a significant percentage of industrial workers initially have difficulty with the test since they tend to respond if a sound is heard rather than immediately recognizing the loudness balance concept.

- Despite the imperfect laboratory agreement with the standard REAT method shown in this study, the field results obtained with the BCLB procedure were comparable to other field study findings and the utility of BCLB as a way assessing HPD performance on the job was demonstrated.

- The BCLB procedure was shown to allow a hearing conservation program confidently to use specialized HPDs with low attenuation by measuring the attenuation rather than making assumptions about it.

- Tests of a HPD type that may help improve speech comprehension among HPD users with significant hearing loss showed that such improvement is highly variable and generally modest. This HPD type (pre-molded silicone rubber earplug) was also found to be unacceptable to a high percentage (40%) of those who tried it for extended use and preferable to their previous HPD by only 25% of those who used it over a two-month period, but all of the workers who did not like the new HPD were accustomed to wearing a user-molded foam earplug.

USEFULNESS OF FINDINGS

The BCLB system was developed as a procedure which could be used to measure the effectiveness or attenuation of any sort of hearing protection device (HPD), unlike most other such procedures that are usable in the field. The present study has demonstrated that the BCLB procedure can be simply implemented using the ubiquitous personal computer with the only specialized equipment being a bone conduction transducer. A program was developed that can be adapted to most computers and operated with no special training. Now that a procedure is readily available, other researchers will be able to evaluate the BCLB procedure independently and if its reliability is validated, hearing conservation programs will have a valuable additional tool.

Because it is quickly learned by previously inexperienced industrial workers and takes no longer than standard threshold testing, BCLB should be able to be used in hearing conservation programs without an excessive burden of time or expense. In this way, HPD users can be trained in proper use of the devices and can choose among devices to find the one that best suits their needs in terms of comfort while still providing adequate protection. Hearing conservation managers can also use the method to verify that noise-exposed workers are adequately protected without the uncertainties of various attenuation estimation procedures. Ultimately, adoption of a practical method like BCLB should provide workers with a safer and more comfortable work environment.

SCIENTIFIC REPORT

Introduction

Purpose of HPD testing:

For the prevention of occupational hearing loss, primary reliance is often placed on hearing protection devices (HPDs) such as earplugs and earmuffs. Unfortunately, the degree of noise reduction (attenuation) given by HPDs is generally much less in actual use than in laboratory certification tests.[1-3] Also, the attenuation varies so greatly between individuals that the amount of protection provided to any particular individual is almost completely unknown. As a result, underprotection of workers exposed to high noise levels can often only be detected by subsequent measurement of their hearing loss. On the other hand, overprotection is also a real possibility, leading to situations in which workers may be at risk of injury due to an inability to hear warnings, may also be socially isolated on the job because they have trouble understanding their co-workers' speech, and may be reluctant to wear HPDs at all because of these problems.

BCLB premise:

The method of determination of HPD effectiveness evaluated in this study is called bone conduction loudness balance (BCLB). It is a one type of loudness balance procedure. The concept of using loudness balance is to require the HPD wearer to adjust the level of an airborne sound to be the same loudness as a reference, fixed-level sound that is not affected by the presence of the HPD. The process can be repeated at a variety of airborne sound frequencies to cover the required range, and the sound levels where balance is attained are noted for each frequency. The wearer then removes the HPD and adjusts the airborne sound to balance the reference sound again. The difference in the level of the airborne sound at each frequency that balances the reference sound with and without the HPD is therefore the attenuation of the HPD. For example, if an airborne sound at 1000 Hz must be adjusted to a level of 50 dB to balance the reference sound with the HPD in place and to a level of 35 dB to balance the same sound when the HPD is removed, then the attenuation of the HPD at 1000 Hz for that wearer is 15 dB (50 dB minus 35 dB).

The BCLB procedure utilizes pulsed sounds delivered by a bone conduction vibrator held against the forehead of the HPD wearer as the reference sound. The variable level sound is delivered by a loudspeaker outside the HPD. The bone conduction sound (a 1/3 octave band of noise at 2000 Hz) is maintained at a constant level loud enough to be easily heard and at a frequency high enough to avoid the occlusion effect (which is an increase in the sensitivity of the inner ear to lower frequency bone conducted sound when the air conduction pathway is blocked). The air conduction sounds from the loudspeaker (1/3 octave bands of noise at a variety of frequencies) are varied in level by the HPD wearer to achieve a subjective impression of equal loudness with the bone conduction sound. The difference in level between the air conduction sounds at a particular frequency required to balance with the HPD on or off was defined as the attenuation of the HPD at that frequency.

Study Format:

The study was intended to improve on the previous implementation of the BLCB procedure[(4)] in several aspects, with the overall objective of making it suitable for normal occupational use and simple to implement in terms of both equipment and procedures. After the changes were made, they then would be tested first in a laboratory setting and then in normal occupational use at several sites with existing hearing conservation programs which might be of the sort to find HPD attenuation testing helpful. All subjects who were tested for evaluation of the BCLB procedure and their HPD attenuation were volunteers who were given the appropriate informed consent forms. All aspects dealing with human subjects were approved by the Institutional Review Board of the University of Arkansas for Medical Sciences.

Phase 1A: Development of BCLB testing system

Objectives:

1. Software - A computer program was needed to implement the BCLB test with the following requirements:
   - A simple interface for the person running the test to enter necessary information about the subject.
   - Flexibility in testing so that a the different test parameters such as BC level, step size and a variety of frequencies could be tested in any desired order or repetition.
   - Consistent operation of the program without input from the operator once testing had begun.

2. Hardware - The goal was to utilize an ordinary personal computer with an ordinary consumer-quality sound card, and ordinary speakers of the sort that are normally supplied for use with a personal computer.

3. Test protocol - The goal was to have a protocol that would accomplish the following:
   - Provide consistent and reliable attenuation results for any type of HPD.
   - As far as possible emulate the established pattern of the Hughson-Westlake procedure normally used for threshold determination during pure-tone audiometry as customarily done as part of an occupational hearing conservation program.
   - Be simple enough so that little if any more instruction to the subject would be needed than is normally provided for routine threshold determination.
   - Be as brief as possible so that it would not impose a burdensome additional aspect to the existing requirements of a hearing conservation program.

Procedure:

1. Software

The program to accomplish the software goals was written using Microsoft Visual Basic®, version 6.0. This is an adaptation of the original Basic programming language which allows the creation of programs which run on personal computers using Microsoft Windows in a type of format familiar to most computer users. It involves the use of different computer screen layouts for different parts of the program, each having "boxes" for the user to manually enter data such as subject name, identification number, and other test parameters. It also has "buttons" which are regions on the screen which cause some program actions when the screen cursor is place over then and the proper mouse button pressed. The program allowed interaction between the tester and the program, as well as between the subject being tested and the program. All subject inputs were made by pressing a mouse button, with the tester positioning the cursor in the appropriate location on the screen to accept the subject input.

2. Hardware

All testing was done using a Toshiba Model 4005CDS portable computer, with its standard sound card, Yamaha Model OPL3-SA. This computer has built in speakers, but in order to separate the speakers from the computer for the BCLB testing, auxiliary speakers were used. These were the "satellite" speakers which were part of the Model CS200 speaker system from Cambridge Soundworks. This system included a large, low-frequency speaker, but that was not used, since the smaller pair of speakers was adequate to produce the sound levels needed and they could conveniently be positioned on each side of the subject for equal sound level at each ear, with a location determined by the size of the test environment. The computer's sound output was sent from one stereo channel to the loudspeakers, and from the other channel to the BC transducer. This was a Radioear model B-71, normally held to the subject's forehead by a fabric strap, fastened in the back with hook-and-loop fasteners. Subject input to the computer was by a Compaq mouse, with the tracking ball removed since only the mouse clicks were needed.

<u>Results and discussion:</u>

1. Software

The written code for the BCLB program is listed in Appendix A. The program uses two screens: one for initial setup and the other for actually running the BCLB procedure. (For one phase of this study, a third screen was used which was used for determination of HPD attenuation by the threshold difference or REAT method).

The setup screen program has three major sections. One was used to set test parameters such as the step change (the minimum amount in dB by which the AC sound level could be changed) and the step duration and pause, timing parameters which would slow down or speed up the test. Other settings involved the initial sound level settings, both for the BC and AC sounds. In practice, only the step change in dB was adjusted, to either 3 or 5 dB. Another setup screen section is to record variable test information such as the subject's personal data, the date and test location.

The third setup screen section was used to specify the digital sound files used for production of the various AC sounds used for testing at the different frequencies. These files were in the [.wav] format, commonly used for audio files, and were produced using the Cool Edit® program (version 96 from Syntrillium Software) by taking 1/3 octave band files from the KKKKK disk. These files were recorded only on the right channel so they could be routed to the amplifier for the AC sound only. There were buttons on the screen to allow additional files to be added (from the computer hard disk) to the program's usage or deleted from usage, as well as arranging the order that they would be presented to the subject.

The setup screen also contains buttons for running the BCLB procedure (as well as the REAT procedure) and for writing the test data to a text file. The screen for actually running the BCLB procedure is described in the section below.

The normal procedure for a BCLB test was set up as follows:

The subject was seated in the test environment and the BC transducer placed on his or her forehead, with the strap fastened using hook and loop fasteners at the back of the head. There was no attempt to measure the tightness of the attachment of the BC transducer, but it was merely fastened firmly enough not to slip. The subject was asked if he was comfortable, then handed the computer mouse.

The next step was to establish the BC level. The subject was instructed to push the mouse button whenever he heard the test sound, which was imitated by the tester as a hissing sound.

The wording of the instruction was: "I want you to just press and release the button when you hear a sound like this [demonstrate with hissing sound]. Even if you aren't sure that you heard it, if you think that you did, then press and release the button."

The tester then returned to the computer and started the test with by clicking on the "UP" button under the Reference Volume section on the Loudness Balance screen. This produced a two second delay, then presentation of a 1/3 octave band of noise at 2kHz (the normal BC reference sound) at a nominal level of 130 dB. The cursor was then moved to the "DOWN" button on the screen to await input from the subject. If the subject pressed the response button, then two pulses of the same sound at a level 10 dB down from the initial level would be presented to the subject. As long as the subject pressed the button, the sound would decrease by 10 dB at each step, until he no longer heard the sound and the response button wasn't pressed. The tester, observing the screen, would see that the reference sound level was no longer being pressed and then would click on the "SET" button. This action added 30 or 40 dB to the reference BC sound level (depending on the type of test) but did not produce the sound for the subject to hear. This reference level was then used for the rest of the test. The process of setting the reference level was not timed, but was estimated to take less than one minute per subject, including the instructions.

After the reference BC level was set, the tester returned to the subject with the following instructions:

- Next, you will hear a series of sounds in pairs, and usually the first one will be louder [demonstrate].
- The first sound in the pair will always be the same, but the second sound in the pair will change in loudness.
- Whenever the second sound is louder than the first, you should press and then quickly release the button.
- Press the button even if you aren't sure that it is louder, but you think it might be. There's no right or wrong answer, I just want to know if you think it's louder.
- Also, you need to keep your head still and look straight forward.
- Any questions?
- Remember, keep your head still and press and release the button whenever you think that the second sound is louder.
- Sometimes the second sound will be so soft that you won't even hear it, but that's ok, just don't press the button in that case.
- We'll start in just a moment.

The tester then returned to the computer and checked the appropriate boxes for "HPD Worn?" and "Second Test?" "Second Test" meant that an initial series of BCLB values had been established and that the second series was to be taken with the HPD use opposite from the first series. The tester would then click on the "START BALANCE" button, move the cursor to the designated area on the screen and observe the test, which would be automatically controlled by the computer from that point until each of the designated frequencies had been tested.

Once the computer took over control of the test, the sequence began with presentation of pair of sounds repeatedly to the subject. The first sound in each pair was always a single pulse (0.5 sec) of the BC sound at the previously established reference level. This was followed by a 0.5 sec of silence, then the

AC sound, a 0.5 sec pulse of a1/3 octave noise band at the first test frequency (1000 Hz). The AC sound always started at a nominal level of 13 dB which was typically near or below the threshold of audibility. If the subject did not press the response button, there was a 1 sec delay, then another pair of sounds was repeated. The second sound in the pair (the AC sound) was increased by 3 step sizes (9 dB, normally) as long as the subject did not respond. This process continued, with the AC sound growing progressively louder, until the subject pressed the button, indicating that he perceived the second sound as louder than the first (AC > BC).

After the first button push, the AC sound was decreased by 4 step sizes (12 dB), and the pair presented again. If the subject did not press the button, the AC sound would then begin to increase by one step size at each presentation. For the second and subsequent button presses, the AC level would decrease by 2 step sizes before the next pair presentation.

A minimum of three positive responses by the subject was required for each frequency, before the LB level of the AC sound was established. If the three responses were all at the same AC level, then that was the level recorded, but if there were any differences then the program evaluated the responses for consistency before recording a level. If there was not sufficient consistency, then the procedure continued until an adequately consistent response was established. The goal was to find the lowest level of response that was repeated in two of three trials, but the first response was not considered in this test. For example, responses of 50, 50 and 53 dB would not meet the consistency requirement, but 53, 50, and 50 dB would be considered to have met it, and the level of 50 dB would be recorded. With the first example (50,50,53), if the next response was 50, then two of the last three responses would be the same lower level and the LB level would be recorded as 50. Using the same example again (50,50,53), if the next (fourth) response was 53, then two of the last three responses would be the same, but not at the lower level, so the testing would continue. If the next (fifth) response were either 50 or 53, the tie would be broken and the LB level would be recorded as the value of the fifth response.

Once the LB level was established for the first frequency, the process would move to the second frequency and begin anew to establish a consistent response at that frequency. The process therefore stepped through all frequencies, determining the LB level at each one and displaying it on the computer screen for the tester to observe. Upon completion of the entire sequence, the time required for the test was displayed on the screen and the message "Test Complete" presented.

After testing all frequencies with the HPD either on or off, the tester then asked the subject to remove the HPD (if it had been on) or to put it on (if it had been off). Without changing the reference BC level, the LB level was established at each frequency as in the first sequence. For each frequency, after the second LB level was determined, the computer subtracted the LB level with the HPD on from the level with it off and displayed the result as attenuation at that frequency.

Upon completion of the second series of LB levels and determining attenuation, the tester clicked on the "Exit" button which caused the computer to delete the current screen and write all data to a file. The recorded information included the subject identification number, the LB level at each frequency and HPD state, attenuation at each frequency, time to complete testing for each HPD state, number of responses to complete each LB level, maximum and minimum AC level response at each frequency and HPD state, and BC reference level. The tester then removed the BC transducer and strap from the subject's head.

Figure 1: The computer screen used for data input to set up the BCLB program

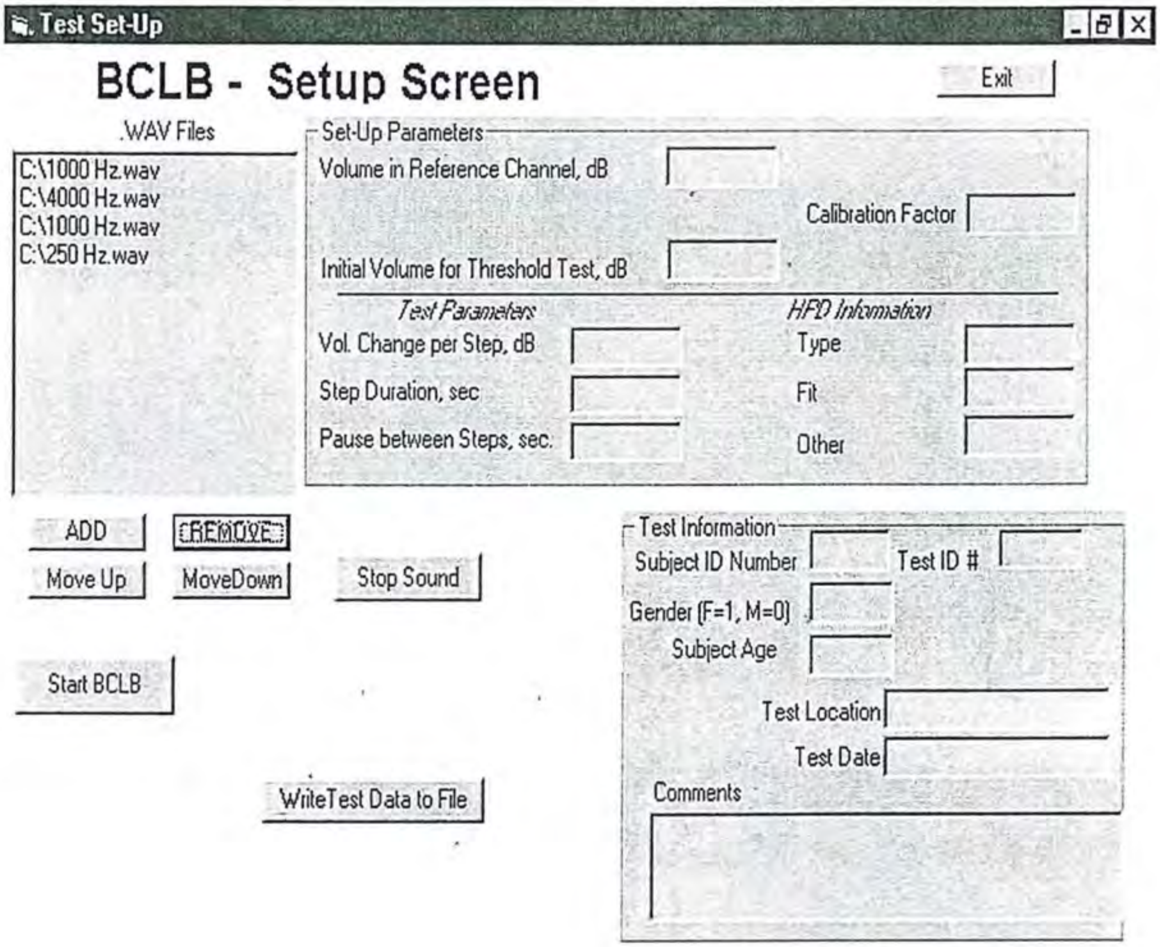
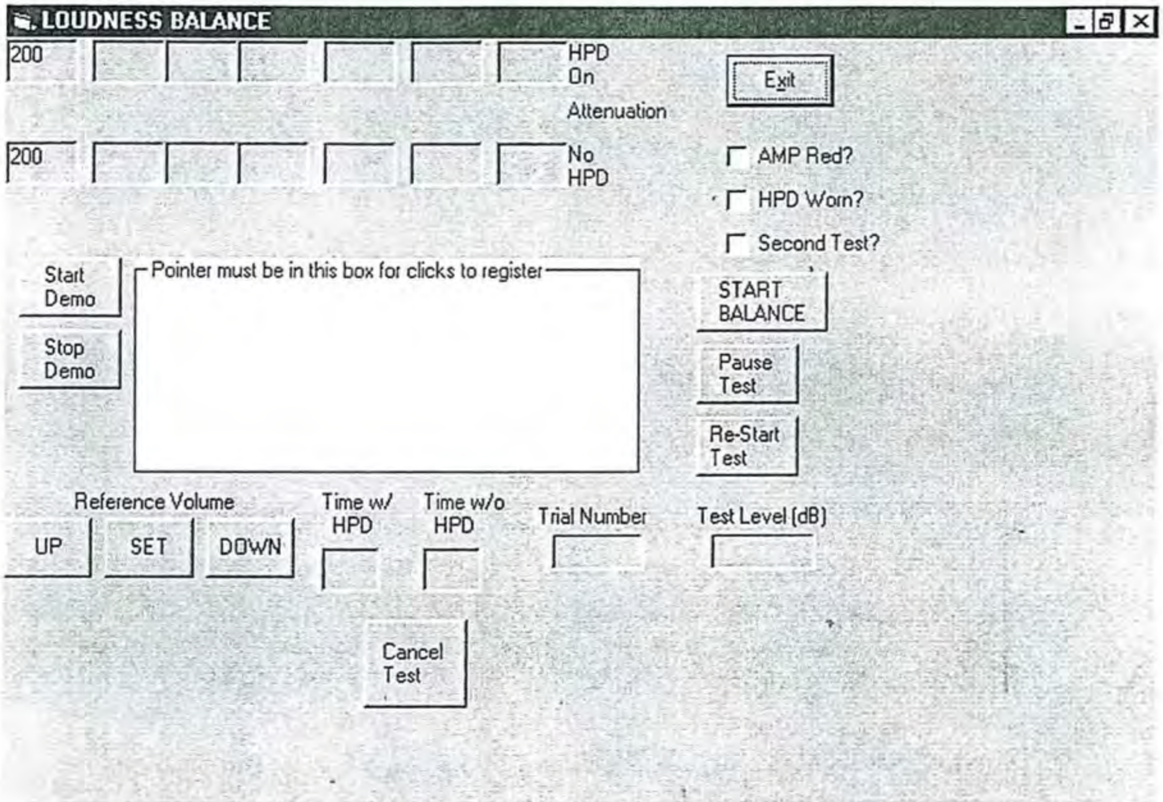


Figure 2: The computer screen used for running the BCLB procedure



Phase IB - Laboratory Testing of Revised BCLB Procedure Practicality

Objectives:

After writing and debugging the computer program for implementation of BCLB, the next step was to try the program using volunteers in a laboratory setting. The objectives of this phase were to find any problems with the program and to test certain variables (bone conduction sound level, step size, and method of attachment of the BC transducer). The effect of the variables was judged by evaluation of the time required to do the test and the consistency of responses.

Procedure:

Eight volunteer subjects (4 men and 4 women, mean age 43 years) were used to test the procedure, without the use of hearing protectors. All subjects were new to LB testing, and were given no practice before collection of data began. Their instructions were as described in the section on the test protocol development. All testing was done inside a large, double-wall Industrial Acoustics Company audiometric booth (2.55 m wide by 2.75 m long by 2.0 m high). The background noise in the booth, and the sound field uniformity around the subject's head location complied with ANSI Standard S12.6-1984.

The first step was to determine the threshold of hearing at 4000, 1000 and 250 Hz, using the BCLB program in its REAT configuration. Next, the BCLB procedure was started, with each procedure finding the LB sound level as detailed in the description of the BCLB implementation protocol. Each iteration of the BCLB test started each time at 4000 Hz, then testing at 1000 Hz and 250 Hz, in that order. With the BC transducer held in place with a strap, two different step sizes were tested (3 dB and 5 dB) and two different bone conduction levels (10 dB apart), with two repetitions for each variable. Also, with the BC transducer held against the forehead by the subject's hand, two different step sizes were tested (3 dB and 5 dB). Thus there were 240 measurements of LB level recorded of which 192 were done with the BC transducer held by the strap (8 subjects x 2 steps x 2 bc levels x 3 frequencies x 2 repetitions) and 48 were done with the transducer held to the forehead by the subject (8 subjects x 2 steps x 1 bc level x 3 frequencies x 1 repetition).

For each test at each frequency, the following data were recorded: final LB level (dB), duration of test (sec), level of bone conduction sound, air conduction sound frequency (Hz), number of trials or responses required to reach the final LB level, and the minimum and maximum LB response levels (dB). Since there were ten different combinations of variables, three frequencies and eight subjects, there were a total of 240 measurements of each of these measurements. The order of variables tested was systematically varied so that no preferential order was established.

Results and Discussion:

1. Time required to conduct BCLB test

Over all 240 tests, the mean time to achieve a consistent balance level for a single frequency was 26.8 sec (s.d.=7.9 sec, minimum 15 sec., maximum 47 sec.). There was a clear indication that a longer time was required at lower frequencies (250 Hz - 29.6 sec; 1000 Hz - 26.3 sec; 4000 Hz - 24.4 sec), a significant difference (p=0.001). Other variables, however, did not significantly influence the time required (step size - p=0.72; use of strap - p=0.99; BC level p=0.52)

The mean time for LB determination of 27 seconds per frequency tested is a very substantial improvement over the mean time seen in the initial implementation of this procedure, 61 seconds per frequency.[(4)] A reduction of more than 50 percent in administration time helps make the BCLB procedure more suited for field implementation. Step size might have been anticipated to have an effect, since the smaller size of 3 dB would be expected to lead to slightly more uncertainty in deciding on a consistent LB level, but the difference was very slight (0.3 seconds longer for 5 dB step size).

2. Number of responses required

The program required that the subject indicate a consistent LB level, as described in the section on BCLB implementation. A minimum of three subject responses (each of which indicated that he or she perceived the AC sound to be louder than the BC sound) was required. If the degree of consistency was insufficient after three responses, the procedure continued to require balance to be indicated until it was sufficiently consistent. The number of responses required to achieve balance was therefore recorded as a measure of the consistency within a given test. The mean number of responses was 3.67 (n=240, sd=0.92) with 62% being equal to the minimum and only 1.7% requiring more than 5 responses (all of which occurred at 250 Hz). Step size, method of transducer application, bc level elevation and subject had no significant effect on the mean number of trials. For the lowest frequency (250 Hz), however, the number of trials was significantly higher than at either 1000 or 4000 Hz.

3. Range of balance (consistency)

The difference between LB level achieved at first and second response was determined (compared for the same step size and BC level). The overall mean difference was 2.2 dB, significantly different from zero (p=.0005). The difference was generally consistent over frequency (2.6 dB at 4000 Hz, 2.4 dB at

1000 Hz, and 1.5 dB at 250 Hz) and step size (2.9 dB at 3 dB step and 1.5 dB at 5 dB step). In addition to the tendency to find a higher balance level on the first trial, subjects were clearly more inconsistent with the 3 dB step than with the 5 dB step. For the 3 dB step, 19% of repeated balances were 6 dB or more apart compared to only 10% being 5 dB apart using the 5 dB step. One subject seemed to be particularly inconsistent: if his responses are excluded from the analysis, then 12% were more than 6 dB apart with the 3 dB step compared to only 5% being over 5 dB apart using the 5 dB step.

The difference was greater for the lower value of the BC level (mean = 3.0 dB) than the higher value (mean = 1.3 dB), but both values were significantly greater than 0.

4. Effect of the strap used to hold the BC transducer in place

The difference between the LB achieved with and without the strap was measured (compared at the same step size and BC level). The mean value of this difference was 0.75 dB over all measurements (n=48) and there was no significant difference from 0 when broken down by step size or frequency. Only 4 out of 48 measurements (8.3%) differed by more than one step size.

Because the subject might hold the transducer either more or less firmly to the forehead than with the consistent pressure applied by the strap, some greater differences might have been expected than were actually seen. However, because of the minor differences observed, there was little need to explore another method of BC transducer attachment, such as tape. The only circumstances under which the strap could not be used would be for testing of earmuffs or canal caps in the "candid" mode where the person was to be tested after wearing the HPD in a normal workday manner and the fit was not to be disturbed.

5. Effect of the BC level

Two different bone conduction levels were tested, 10 dB apart. With the higher BC level, a balance level approximately 10 dB higher would be expected, but that was not observed. The mean elevation of balance level for each subject (with step size held constant) was 3.74 dB (n=48, s.d.=3.75) and there was no significant variation in this mean amount of elevation with changes in frequency or step size. In fact, in 10.4% of the comparisons, there was actually a decrease in balance level as the bc level was increased. On the other hand, 23% of the balance levels increased by 7.5 dB or greater.

6. Effect of step size

Two step sizes were used, 3 and 5 dB. Since it is easier to distinguish two levels that are 5 dB apart than two that are 3 dB apart, it was expected that the test duration and number of trials to achieve balance would be less for the 5 dB step procedure, though the consistency in achieving balance should be less. The number of trials required for balance to be reached indeed was slightly smaller for the 5 dB step (3.6 compared to 3.7 for the 3 dB step), though not statistically significant ($p=0.44$). However, there was actually a slight increase in time required for the 5 dB step (27.0 sec compared to 26.6 sec for the 3 dB step), but again not statistically significant ($p=0.72$). Also, contrary to expectations, range was smaller for the 5 dB step (1.1 dB compared to 1.7 dB for the 3 dB step), a significant difference ($p=0.02$)

Phase 1C: Laboratory comparison of BCLB and REAT procedures

Objectives: Once the initial feasibility of the revised BCLB procedure and the software to implement it had been established, additional testing was done to compare two versions of the procedure (using either loudspeakers or headphones to generate the AC sound) were compared to comparable versions of the REAT method. The REAT procedure which determines HPD attenuation by comparison of hearing threshold with and without the HPD is the standard method against which new alternatives are customarily tested.

Procedure:

Eighteen volunteer subjects were initially tested, but two were excluded from analysis (one because of instrumentation problems and the other because of inability to consistently respond at threshold). Of the sixteen remaining, there were ten women and six men (mean age 34.3 years, range 22-67 years, median 27 years). None of the subjects had previous familiarity with BCLB testing, but all had previous experience with threshold testing. There was no screening for hearing ability nor any practice on any of the procedures before data collection began.

In order to measure a wide range of attenuations, two different HPDs were tested, a pre-molded earplug with a low rated attenuation (EAR UltraTech™) and a user-molded earplug with a high rated attenuation (EAR Classic™). The pre-molded plug was inserted by the subject after instruction by the experimenter. For all subjects, the user-molded plug was tested after insertion by the experimenter for the best possible fit. In addition, for nine of the subjects the user-molded plug was tested after having been inserted by the subject without using the technique of pulling the outer ear for ease of insertion.

For each of the three HPD configurations (or two configurations for some subjects), four different methods of determining attenuation were used: BCLB with loudspeakers, BCLB with headphones, REAT with loudspeakers, and REAT with headphones. For each of these four procedures, attenuation was determined at three different frequencies: 4000, 1000, and 250 Hz, always in that order. The method order was systematically varied.

Results and Discussion:

1. Overall attenuation results:

In general, the attenuation results measured by each of the four different procedures were as expected based on the sound frequency, the type of HPD and the method of fitting. The higher frequencies showed higher attenuation, the user-molded earplug was more effective than the pre-molded, and the experimenter fit produced higher attenuation than the subject fit. Table 1 shows the mean results by method, frequency and HPD type.

Table 1: Overall mean attenuation results for all HPD types and measurement methods, 18 subjects in laboratory settings

Mean Attenuation - All HPD types			
	250 Hz	1000 Hz	4000 Hz
BCLB, sound field	20.5	21.4	29.4
BCLB, headphones	16.1	22.1	29.2
REAT, sound field	12.6	19.3	26.3
REAT, headphones	15.5	19.6	27.9
Mean Attenuation - Pre-molded earplug			
BCLB, sound field	12.9	15.9	19.7
BCLB, headphones	9.0	16.1	17.9
REAT, sound field	7.3	13.9	16.7
REAT, headphones	7.7	12.2	16.3
Mean Attenuation - User molded earplug (subject fit)			
BCLB, sound field	19.3	17.7	27.3
BCLB, headphones	13.7	21.3	28.2
REAT, sound field	10.3	17.7	27.0
REAT, headphones	15.7	18.8	29.0
Mean Attenuation - User molded earplug (experimenter fit)			
BCLB, sound field	28.7	29.1	40.3
BCLB, headphones	24.6	28.5	41.0
REAT, sound field	19.1	25.6	35.6
REAT, headphones	23.7	27.9	39.6

2. Comparison of similar methods:

At the two higher frequencies, the loudspeaker and headphone BCLB procedures gave attenuation results that were not significantly different from each other, with mean differences of less than 1 dB. At 250 Hz, however, the loudspeaker method produced attenuation results that averaged about 4 dB higher than the headphone method, a difference that was fairly consistent over the 3 HPD configurations and that was statistically significant ($p<0.01$). When individual pairs of attenuation values generated by the two methods are compared, the following percentages agree within three step values (9 dB): 76% at 4000 Hz, 75% at 1000 Hz, and 83% at 250 Hz. Figure 3 shows all the pairs of attenuation values.

At the two higher frequencies, the loudspeaker and headphone REAT procedures also gave attenuation results that were not significantly different from each other, though the mean differences showed somewhat more variability than the BCLB results. At 250 Hz, the two REAT methods also had statistically significant ($p<0.01$) differences averaged about 4 dB. However, for REAT the loudspeaker method produced attenuation results that were lower than the headphone method for all 3 HPD configurations, but with the difference increasing as the attenuation increased. When individual pairs of attenuation values generated by the two methods are compared, the following percentages agree within three step values (9 dB): 87% at 4000 Hz, 83% at 1000 Hz, and 83% at 250 Hz. Figure 4 shows all the pairs of attenuation values.

3. Comparison of BCLB and REAT:

Using loudspeakers to generate the AC sound field, the BCLB attenuation results exceeded the REAT attenuations by a mean of 3.7 dB over all frequencies, with the difference being statistically significant only at 250 Hz (mean = 7.9 dB, $n = 41$, $p <0.001$). When individual pairs of attenuation values generated by the two methods were compared, the following percentages agreed within three step values (9 dB): 68% at 4000 Hz, 63% at 1000 Hz, and 61% at 250 Hz. This was poorer agreement between BCLB and REAT than had been observed in earlier studies.[5-6] Figure 5 shows all the pairs of attenuation values.

BCLB and REAT were in better agreement when the headphones were used, with BCLB attenuations exceeding REAT values by a mean of 1.1 dB, with no statistically significant results seen at any frequency. When individual pairs of attenuation values generated by the two methods are compared, the following percentages agree within three step values (9 dB): 80% at 4000 Hz, 88% at 1000 Hz, and 83% at 250 Hz. Figure 6 shows all the pairs of attenuation values.

Figure 3: Comparison of HPD attenuation for all HPD types and configurations, using BCLB method

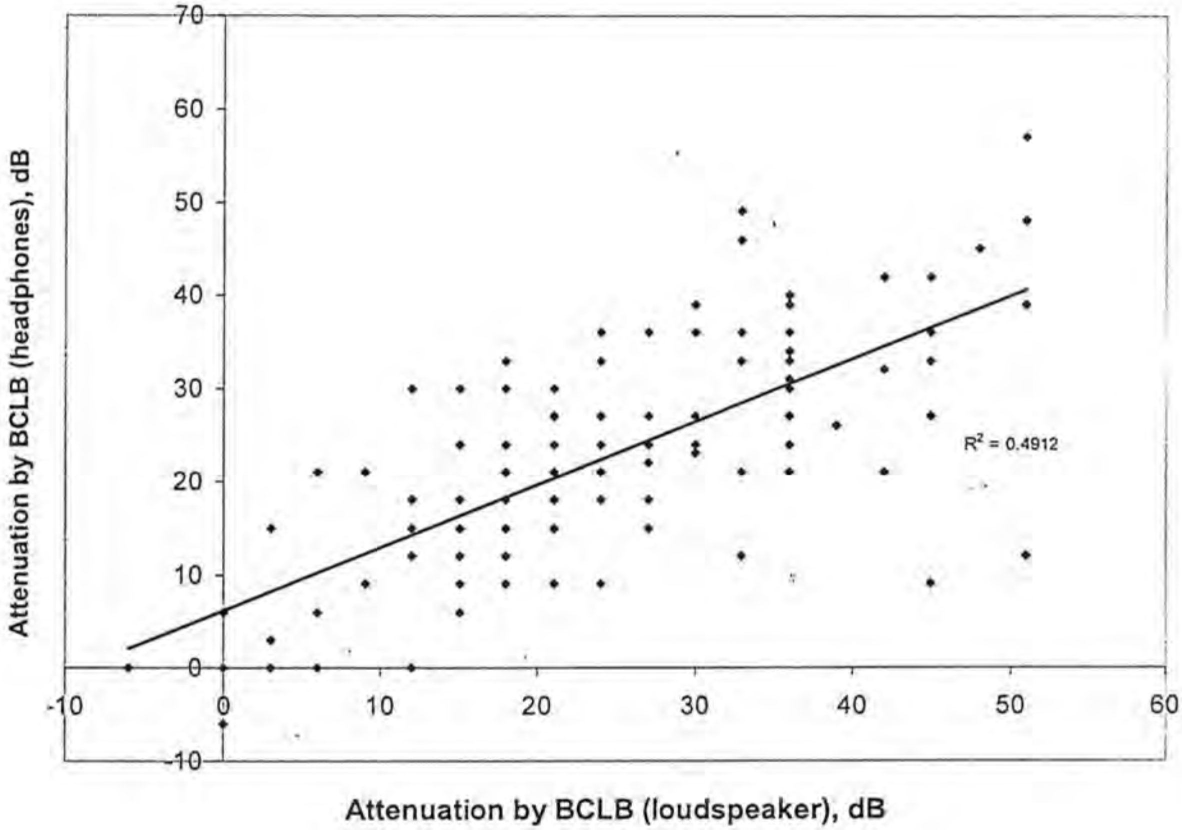


Figure 4: Comparison of HPD attenuation for all HPD types and configurations, using REAT method with loudspeakers and headphones

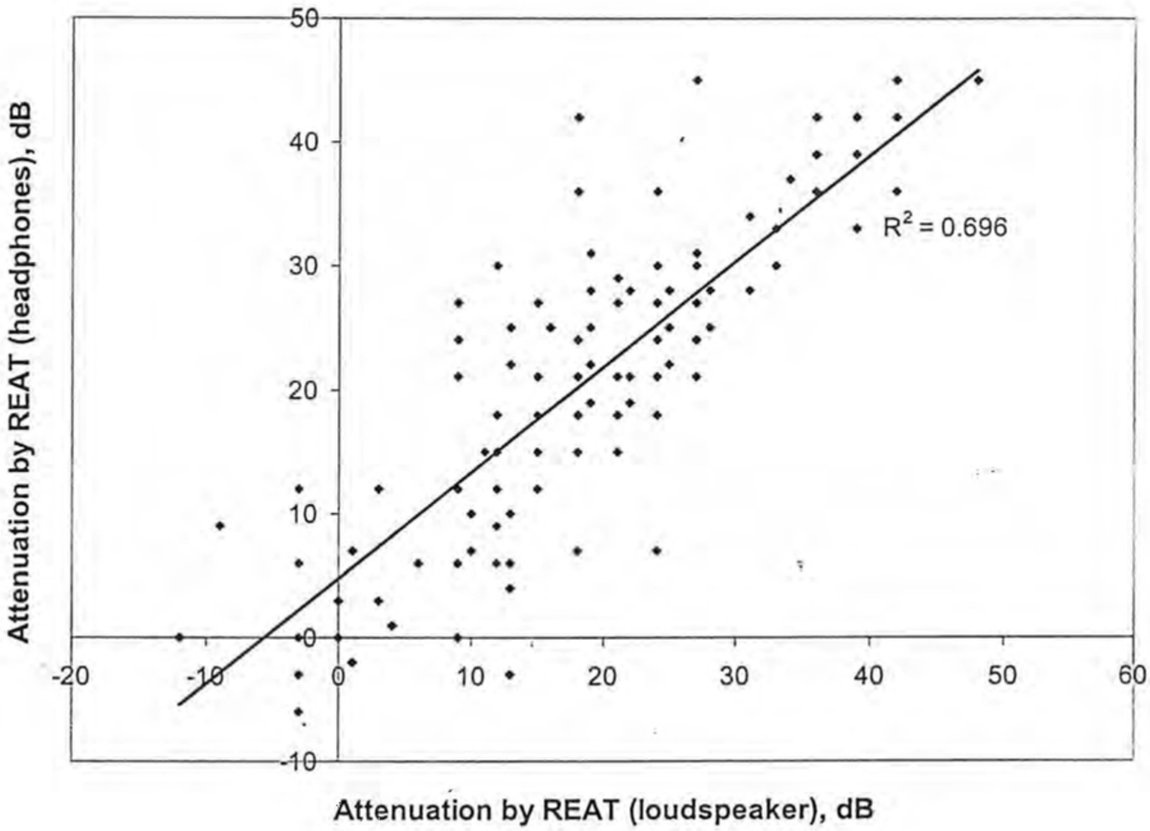


Figure 5: Comparison of HPD attenuation measured with BCLB to attenuation measured with REAT for all HPD configurations, using loudspeakers to generate the sound field

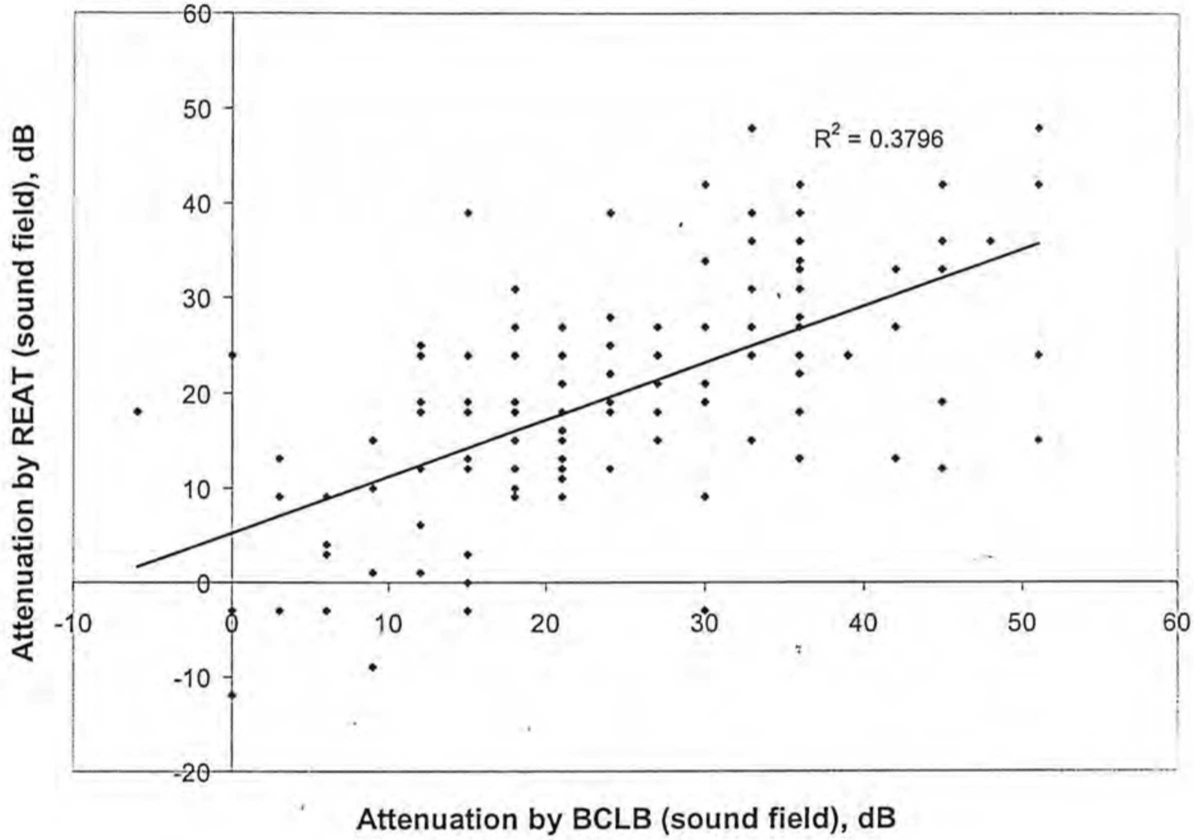
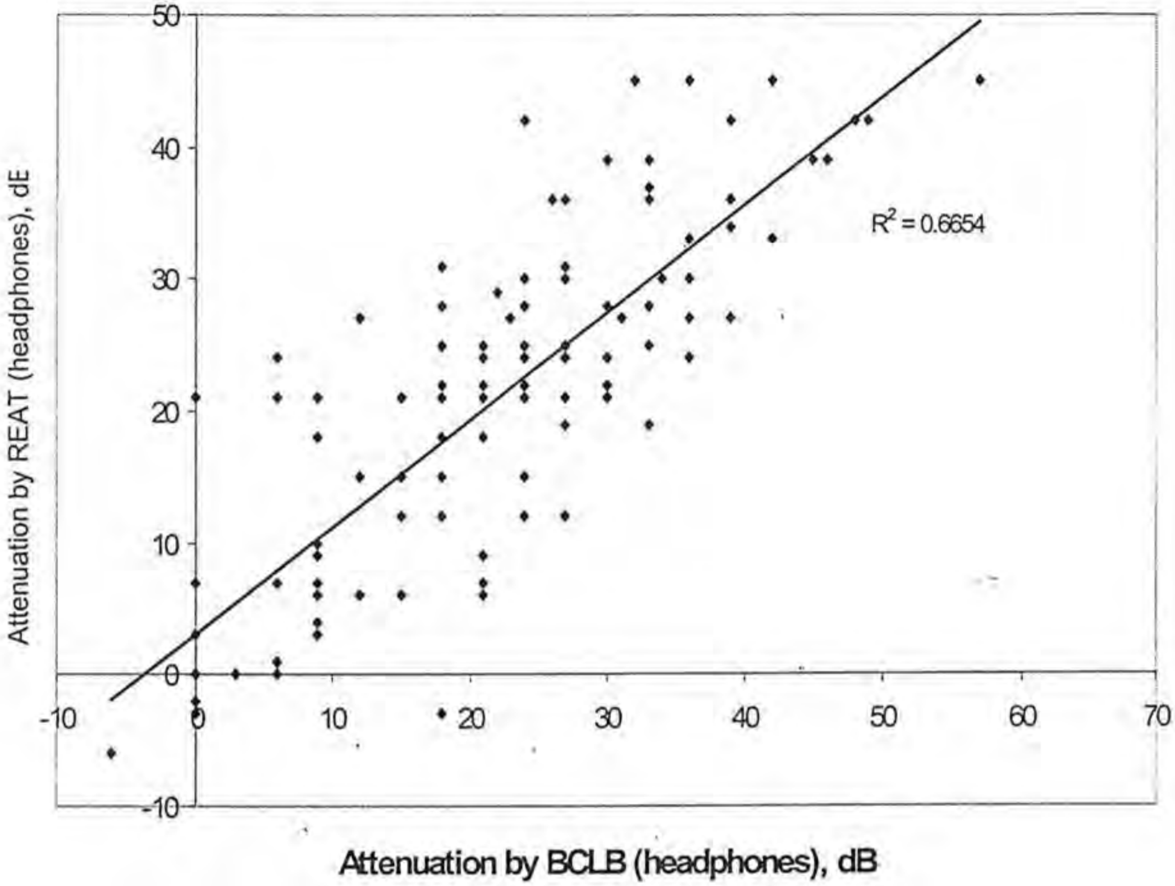


Figure 6: Comparison of HPD attenuation measured with BCLB to attenuation measured with REAT for all HPD configurations, using headphones to generate the sound field



4. Comparison of test times:

The time to complete the BCLB procedure was generally shorter than what was required for the REAT test. Considering a test of both open and occluded ears as a single attenuation test, the mean for BCLB was 3.0 minutes compared to 4.0 minutes for REAT. This did not include the HPD fitting time which was the same for both procedures or the instruction time, which was briefer for REAT than for BCLB.

Phase 2: Field Testing of BCLB procedure

Objective: After the laboratory qualification of the BCLB method, a field test was desirable to see how it would work in an actual occupational environment, with actual workers rather than paid volunteers from a university community. These subjects might be different in terms of experiences, motivation, hearing ability, patience or other factors that could adversely affect the implementation of the procedure. The overall objective was therefore to try the procedure on a wide variety of workers under a variety of conditions to see if there were problems with consistency of responses, excessive time to test, or other difficulties that would indicate obstacles to the actual use of the BCLB procedure.

Procedure: Four different industrial sites were chosen which agreed to allow HPD attenuation testing as part of their hearing conservation program. A total of 68 subjects at the four sites began the testing program, but three were dropped, one each at the first three sites. Each of the remaining 65 subjects (49 male, 16 female, mean and median age 40.0 years, range 20 to 63 years) at the four sites used his or her own normal HPD. All of them were familiar with threshold testing as part of a hearing conservation program, but none had any experience with LB testing. Of the subjects dropped (all male), two were because they had too much hearing loss to hear the BC reference sound and one because of inability to understand the LB concept and a lack of willingness to take time for re-instruction).

Site 1, with 25 subjects tested, was a large manufacturing facility with a long-term, in-house audiometric testing program. Subjects were asked to participate as they reported for their annual audiometric examination, and all who were asked agreed to be tested by BCLB after their regular exam was completed. In addition, all of the subjects who were available were retested later on a "candid" basis. Candid testing is the process of evaluating realistic HPD performance since the attenuation was tested as the HPD was worn on a normal workday, without the opportunity for the wearer to reinsert or reposition the HPD for a better fit.

Sites 2 and 3, with 14 and 11 subjects respectively, were both small metal fabrication facilities which utilized a mobile van audiometric service. As at Site 1, subjects were asked to participate as they reported for their annual hearing test, and the BCLB test was done after the hearing test was completed.

Site 4 was a large hardwood flooring manufacturer which also used a mobile van audiometric service, but in this case, the BCLB testing was done independently of the audiometric testing. Potential subjects were identified by their supervisor, relieved of their jobs and sent to a conference room where they were asked to participate in the testing. All of the 16 subjects asked to participate agreed. As at the later testing at site 1, all tests were done in a "candid" arrangement so that the HPD was not being put on or inserted under test conditions but was tested as it was actually being used on a normal workday.

The BCLB procedure was modified slightly from the earlier form in that instead of testing 4000, 1000 and 250 Hz (in that order), the order was 1000, 4000, 1000, and 250 Hz (in that order). This change was made to provide a validity check at 1000 Hz to be able to ensure that the subject had understood the procedure and was able to make a reasonably repeatable loudness balance response. If the first and second LB levels did not agree within 6 dB (two steps of 3 dB), then the test was stopped and the subjects re-instructed. This modification of the BCLB procedure was done to make the test comparable to the validity test that is normally implemented in industrial audiometric testing, in which the testing begins with 1000 Hz, moves to 500 Hz, then back to 1000 Hz. If the two threshold results are in disagreement by 10 dB or more, then the test is stopped for re-instruction of the subject.

At sites 1-3, the subject was not wearing his or her normal HPD when testing began since they had just finished their hearing test. The sequence was therefore to start the BCLB procedure with unoccluded ears, then the subjects were asked to insert or put on their normal HPD, just as they would wear it on the job. The BCLB procedure was then repeated with the HPD in place, and attenuation at each frequency was determined. At site4, the subjects reported to the test room wearing their normal HPD without adjusting it after leaving their work location, so the BCLB test was done first with the HPD in place, and next with it removed.

<u>Results and Discussion</u>:

1. Consistency of response:

Since the BCLB test was repeated at 1000 Hz for both the occluded and open ear condition, each subject had two measures of consistency of response. The mean values of the difference in response from the first time to the second was 0.5 dB for the open ear test and -0.4 dB for the occluded ear test, neither statistically significant different from 0 or from each other. Overall, 97% of the repeated tests at 1000 Hz were within two step values (±6 dB) as seen in Figure 7.

2. Time for test:

The mean time to actually establish the BCLB attenuation was about 4 minutes (249 seconds, s.d.= 47.5 sec, range 185 to 386 sec), not including the time for instruction, determination of the reference BC level and insertion or removal of the HPD, which added approximately another 2 minutes to the test for a total of 6 minutes per test. The test times, when analyzed by age, gender and race, showed slightly longer times for older subjects, male subjects, and white subjects (mean increases of 5% - 8%), but none of these were statistically significant ($p = 0.24$ for age, 0.38 for gender, 0.18 for race).

3. Re-instruction rates:

Some subjects needed to be re-instructed because either they had inconsistent results on the retest at 1000 Hz, or more commonly because they were producing obviously low LB levels that indicated they were responding as in a threshold test rather than making the loudness balance. Overall, 17% of the tests had to be stopped for re-instruction because of this problem. The rate was slightly lower for older, female and white subjects, but statistically significant only for race ($p<0.01$).

4. Attenuation values:

As expected and as is usual with nearly all HPDs, the measured attenuation increased with increasing frequency, from a mean of 12.5 dB at 250 Hz to 15.8 dB at 1000 Hz to 25.7 dB at 4000 Hz. Most of the HPDs were of the user-molded foam type earplug (n=55), with small numbers of pre-molded plastic earplugs (n=7) and even smaller numbers of earmuffs (n=2) and canal caps (n=1). The user-molded earplugs had a higher mean attenuation at 4000 Hz (26.5 dB) than the pre-molded plugs (21.5 dB), but the mean values were within 2 dB at the lower frequencies and were not statistically significant at any frequency.

More importantly, since the objective of field HPD attenuation measurements is to evaluate the degree of protection of individuals, the range of attenuations shows the kind of wide distribution that has been commonly observed in field studies using other HPD attenuation measurement methods. Figure 8 shows the distribution for the three test frequencies over all HPD types, from which the frequency trend is clear, but also evident is the wide range of measured values at each frequency. Over all HPDs tested, the standard deviations ranged from 9.4 to 10.0 dB at the different frequencies. Even within a single HPD type (such as the EAR Classic® user-molded plug) the standard deviations were much higher (8.0, 10.4, and 11.8 dB at 4000, 1000, and 250 Hz, respectively) than the manufacturer's laboratory data (3.1, 3.6, 5.0 dB at 4000, 1000, and 250 Hz, respectively) as is to be expected from field usage.

5: Candid testing results:

At sites 1-3, the initial testing was done with the HPD fitting being accomplished in the hearing test environment, not in the workers' normal work areas. Presumably, in this environment and under the observation of the experimenter, the workers might take more effort to properly use the HPD, even though they were instructed to wear the HPD as they normally used it and no comment was made by the experimenter about the fit or how to wear the HPD. However, at site 4, the workers were removed from their normal work station wearing their HPD as usual, so this "candid" test might be expected to reveal a lower attenuation value. As shown in Table 2, a comparison of the attenuation achieved with the user-molded earplugs for sites 1-3 showed higher mean values at all frequencies than the mean attenuation values at site 4, but none of the differences were statistically significant. There were not enough of the other HPD types for a meaningful comparison.

Table 2: Comparison of attenuation for user-molded foam earplugs at sites with and without candid testing

	250 Hz	1000 Hz	4000 Hz
Mean attenuation (std. Deviation) at sites 1-3 (47 subjects)	13.8 (10.4)	17.1 (10.8)	27.0 (9.7)
Mean attenuation (std. Deviation) at site 4 (13 subjects, candid test)	8.8 (7.5)	13.0 (5.8)	24.7 (7.6)
P value for difference	0.11	0.19	0.43

Of course, the attenuation differences seen in Table 2 may not be due to the differences between the two testing situations, but instead due to training, motivation or other factors, including HPD differences within the category of user-molded foam earplug.

At site 1, after the initial BCLB testing conducted along with the annual hearing tests, follow-up visits were made for candid testing of the same subjects, subject to their availability. Of the 25 subjects, 18 were available for a candid follow-up test, and 13 of those for a second follow-up. Table 3 shows the mean attenuation values for those subjects. At each frequency, statistically significant ($p<0.05$) lower attenuation was measured during the candid testing than in the initial testing, but the second candid test showed results that were not significantly different from the first.

Table 3: Comparison of HPD attenuation for initial and follow-up evaluations at Site 1			
	250 Hz	1000 Hz	4000 Hz
Mean attenuation (std. Deviation) at initial test (18 subjects)	18.8 (9.6)	22.5 (9.6)	31.3 (8.4)
Mean attenuation (std. Deviation) at first follow-up (18 subjects, candid test)	15.3 (9.9)	16.4 (11.4)	26.3 (10.1)
Mean attenuation (std. Deviation) at second follow-up (13 subjects, candid test)	13.0 (10.2)	17.5 (7.8)	26.3 (8.6)

The time required for the testing was also compared for the initial test to the follow-up tests. For the initial test, the mean time was 6.6 min (including 2.0 minutes for instruction and related matters), for the first follow-up it was 6.1 minutes, and for the second follow-up it was 6.15 minutes. Comparisons of the paired times for the same subjects showed non-significant improvement (p=0.10) from the initial test to the first follow-up, but a statistically significant improvement when comparing the initial to the second follow-up (p=0.02). The number of subjects requiring a relatively long time (more than 7 minutes) also showed a clear decrease from test to test (31% to 11% to 8%). However, the practical significance of the time data is that there appears to be only a slight (less than 1 minute or about 15%) shortening of the time to complete the BCLB test from a completely naïve subject to one with more experience, suggesting that even naïve subjects did not find the test particularly difficult.

Figure 7: Comparison of repeated loudness balance level tests at 1000 Hz, for 65 industrial workers

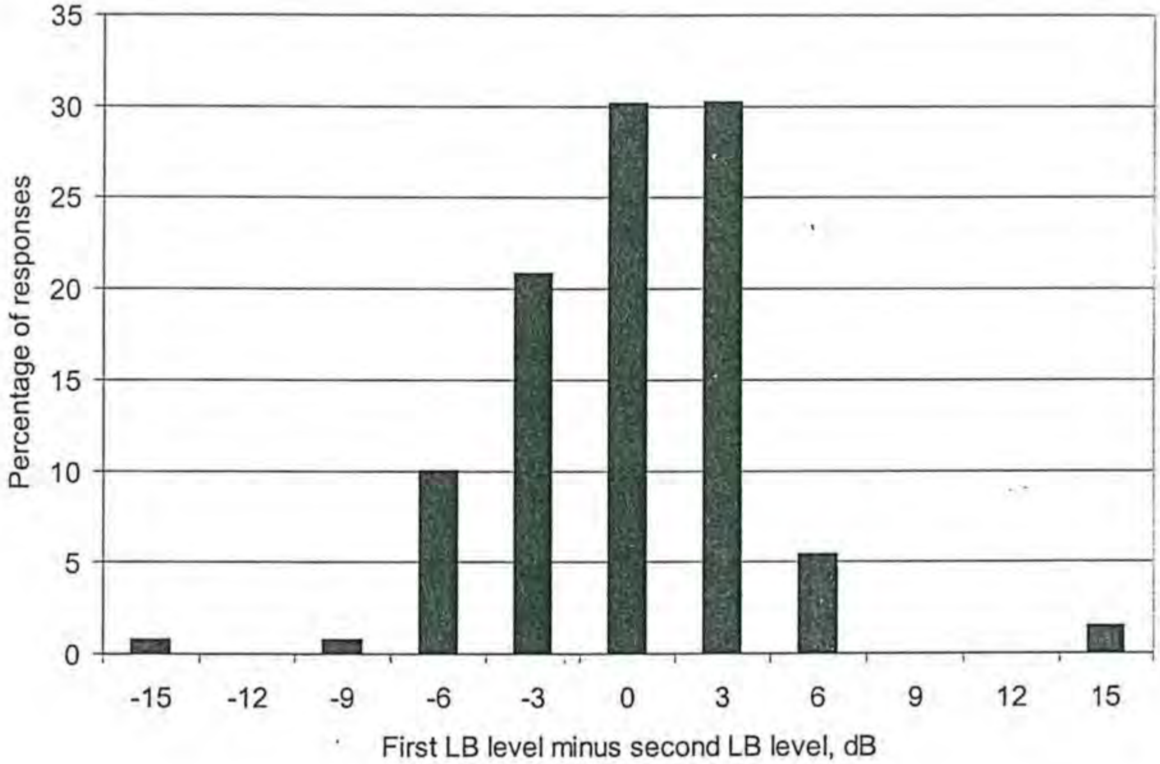


Figure 8: Distribution by frequency of mean attenuation values for all HPDs tested (n=65)

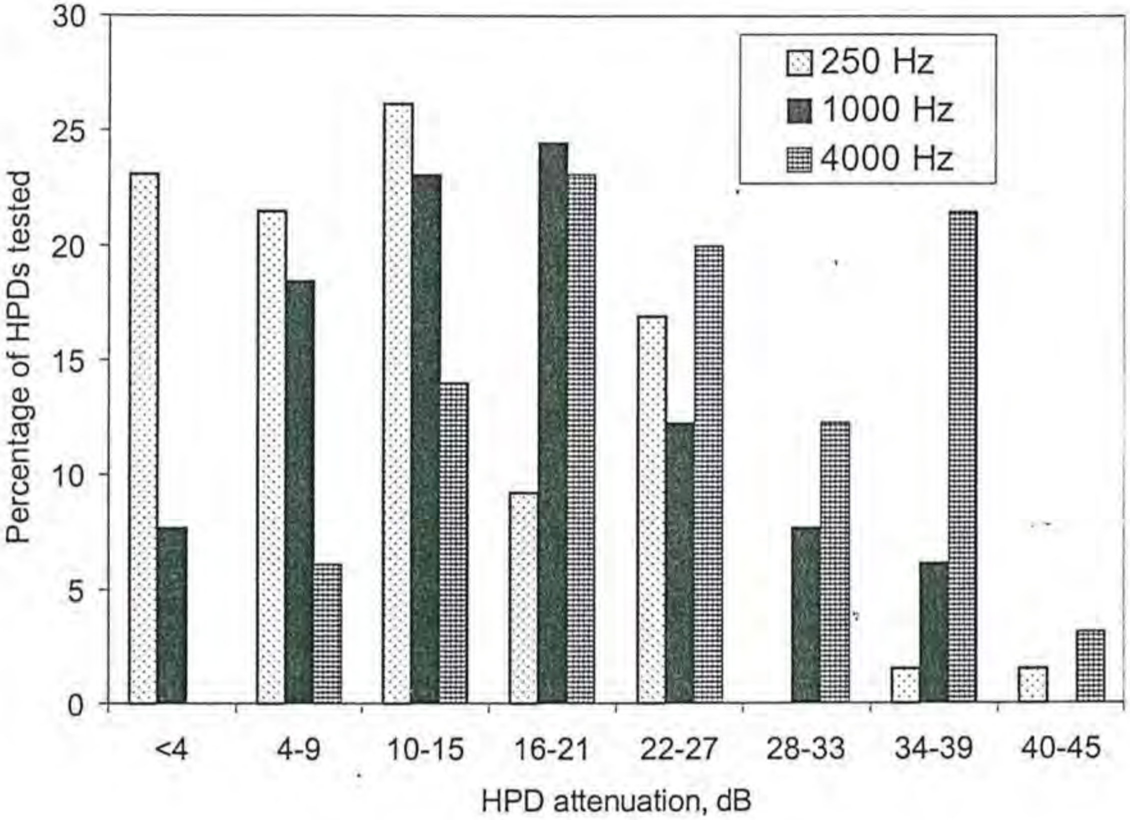
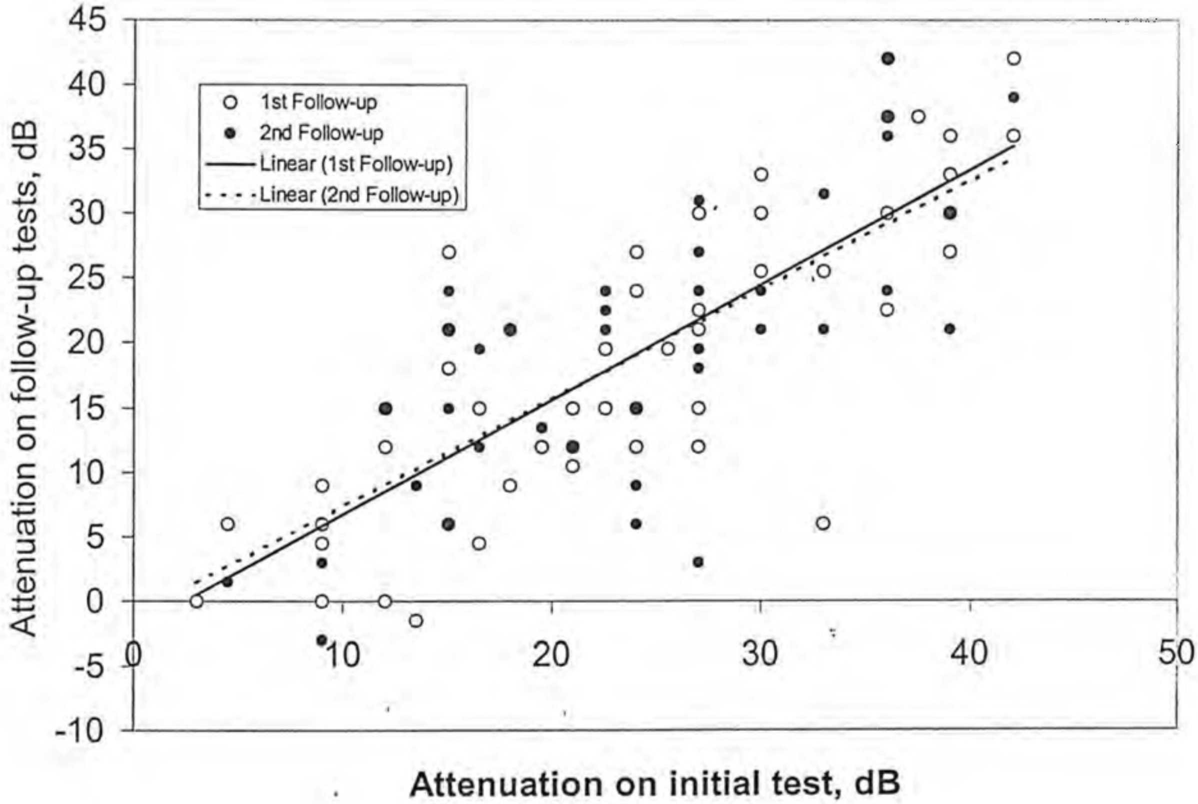


Figure 9: Comparison of attenuation on initial test with follow-up tests for all HPD types and frequencies



Phase 3: Use of BCLB procedure for testing a new HPD type

Objective: After the field qualification of the BCLB method, it was used in a practical test to evaluate a low-attenuation HPD which might have benefits for workers with hearing loss. Since most HPDs have substantial attenuation at high frequencies where hearing loss is most likely, it was hypothesized that an HPD with a flatter and lower attenuation spectrum would allow better understanding of speech under noisy workplace conditions. However, since the Noise Reduction Rating (NRR) of this type of HPD is so low, field testing by an easily used method such as BCLB would be necessary to ensure that its attenuation was adequate to protect the workers using it.

Procedure: The same industrial site (a large manufacturing facility) where the initial field testing was done was also used for this phase of the study. Hearing conservation records were reviewed to find subjects with a moderate degree of hearing loss (average threshold of 30 dB or more at 2000, 3000, and 4000 Hz) and 29 workers were asked to participate. A total of 24 agreed (20 male and 4 female), but one declined to participate after testing started since he objected to trying a new HPD, one could not hear the BC sound, and one could not reliably take the BCLB test or understand any words on the speech discrimination test. The remaining 21 subjects included 17 males and 4 females.

The low and flat-attenuation HPD chosen for study was the EAR UltraTech™ with an NRR of 12 dB. With such a low NRR, the conventional conservative practice of subtracting 7 dB and dividing the result by 2 to figure the effective degree of protection would mean that this HPD could only be used in relatively low noise environments. However, the manufacturer states for this HPD in the accompanying instructions that it:

- Reduces sound without distortion
- Protects while preserving natural sound quality
- For users with a critical need to hear machinery and verbal communications

The subjects were brought from their work stations to the testing location while wearing their normal HPD. After the study objectives and procedures were explained to them, they were then given the following series of tests:

1. The BCLB test to determine the LB levels at frequencies of 250, 1000, 2000, and 4000 Hz while wearing their normal HPD.
2. A 50-word speech discrimination test while continuing to wear the HPD in an environment of 85 dBA white noise. The test was a tape recorded NU-6 word list which was scored by the examiner for percent correct responses.

3. The BCLB test to determine the LB levels at frequencies of 250, 1000, 2000, and 4000 Hz with the HPD removed. The HPD attenuation was computed at this point.
4. The BCLB test to determine the LB levels at frequencies of 250, 1000, 2000, and 4000 Hz while wearing the UltraTech HPD. The UltraTech attenuation was then calculated from the results of this test and the open ears BCLB test.
5. A different 50-word speech discrimination test while wearing the UltraTech HPD in the 85 dBA white noise environment.

If the subject successfully completed the BCLB tests and had sufficient measured attenuation with the UltraTech earplug to bring his or her protected noise exposure to 85 dBA or less, then he or she was asked to continue to wear the UltraTech plug. Over the next two month period, the subjects were brought back in for two more candid measurements of the UltraTech attenuation as worn on the job. Not all subjects were available for re-testing, however, since some declined to wear the UltraTech plug long enough.

At the completion of the final attenuation measurements, the subjects were asked by means of a questionnaire to compare their original HPD with the UltraTech earplug in terms of comfort , ease of insertion, effect on speech comprehension while using, and overall acceptability. The questions were as listed below, with the order of answers reversed on alternate questionnaires to avoid bias.

The following questions relate to a comparison between the new earplugs and the ones that you wore previously (previous plugs were _________________):

Compared to the previous plugs, the new ones are:
1 Much more comfortable
2 Somewhat more comfortable
3 About as comfortable
4 Somewhat less comfortable
5 Much less comfortable

Compared to the previous plugs, the new ones are:
1 Much more difficult to insert properly
2 Somewhat more difficult to insert properly
3 About as difficult to insert properly
4 Somewhat easier to insert properly
5 Much easier to insert properly

Compared to the previous plugs, the new ones:

1 Cause much more difficulty with understanding speech
2 Cause somewhat more difficulty with understanding speech
3 Cause about the same degree of difficulty with understanding speech
4 Cause somewhat less difficulty with understanding speech
5 Cause much less difficulty with understanding speech

Compared to the previous plugs,
1 I like the new ones much better
2 I like the new ones somewhat better
3 I don't have a preference between them
4 I like the old ones somewhat better
5 I like the old ones much better

Results and Discussion:

1. Use of BCLB procedure with hearing impaired subjects

One subject could not hear the 2000 Hz BC reference sound, which was unsurprising since he had air conduction thresholds of 70 and 75 dB for his left and right ears at 2000 Hz. Another subject had difficulty with reliably taking the BCLB test; his thresholds averaged 60 dB over the 2000-4000 Hz range. Both of those subjects were excluded from further testing or analysis. Of the remaining 21 subjects who were tested with BCLB, only 3 had to be re-instructed because of inconsistent results on their first BCLB test, a rate of 14% which was comparable to the 17% rate observed with un-screened industrial subjects in the earlier field testing. In addition, 7 of the 21 were unable to hear the air conduction sound at 4000 Hz at the maximum level that the system could generate while wearing their user-molded foam earplugs. The attenuation values for those subjects with the original HPDs at 4000 Hz are therefore an underestimate.

2. Attenuation comparison of original HPD with UltraTech attenuation

Generally speaking, the attenuation of the subjects' currently used HPDs significantly exceeded the attenuation of the UltraTech earplugs at all frequencies, as seen in Table 4. However, for those subjects using a similar earplug type (pre-molded silicone rubber), the differences were much less and not statistically significant. As is ordinarily seen in field tests, the UltraTech attenuation values as measured on the job were well below the manufacturer's rating (as measured by ANSI S3.19-1974).[1-3]

Table 4: Mean attenuation values (standard deviation) for original and UltraTech earplugs for 21 subjects				
HPD type	250 Hz	1000 Hz	2000 Hz	4000 Hz
Original (n=21)	13.7 (9.7)	19.6 (11.0)	25.9 (11.6)	27.6 (12.8)
Original (foam earplug, n=18)	13.5 (8.4)	20.5 (9.7)	27.8 (9.7)	29.8 (11.0)
Original (pre-molded, n=3)	15.0 (18.2)	15.5 (18.2)	14.0 (17.0)	14.0 (16.5)
UltraTech, n=21	6.6 (5.1)	10.2 (5.7)	15.6 (8.0)	14.8 (8.1)
UltraTech, manufacturer's rating	15.3 (2.8)	18.9 (3.0)	22.5 (3.4)	19.8 (2.8)

2. Change in measured attenuation of UltraTech plug over time

Of the 21 subjects originally tested with the UltraTech earplugs, 8 discontinued their use before being retested, in all cases because they stated that the earplugs were uncomfortable (all 8 of these subjects had originally used a foam earplug rather than a pre-molded one). One subject was not allowed to use the UltraTech plugs because of low attenuation measured. Of the 12 remaining, 11 were tested twice over a two-month interval and one subject was tested only once because he had not been available otherwise.

In comparison with the initial attenuation testing of the UltraTech plug, the mean values tended to fall at the lowest frequency (250 Hz), but held fairly constant at the higher frequencies. Table 5 shows the mean values for the different tests, for the same subjects, not for all 21 initial subjects.

Table 5: Mean attenuation values (standard deviation) for initial and follow-up tests for UltraTech earplugs				
HPD type	250 Hz	1000 Hz	2000 Hz	4000 Hz
Initial test (n=12)	5.8 (5.6)	9.6 (5.3)	13.3 (6.2)	14.8 (5.5)
First follow-up (n=12)	5.8 (5.5)	10.1 (5.7)	17.0 (7.8)	14.5 (4.2)
Second follow-up (n=11)	2.7 (4.3)	7.6 (6.8)	14.5 (5.7)	14.7 (3.7)

3. Speech discrimination differences with UltraTech plug

The mean correct word identification rate was 45.2% with the original HPDs and it improved to 54.9% with the UltraTech earplugs, a 29% increase relative to the original score and a statistically significant difference ($p<0.01$). The increase was far from uniform, however, as seen in Figures 10 and 11, which show a substantial number of decreases in word identification rate (7 of 21 subjects), though the overall average was an improvement.

Of course, the possibility existed that the improvement was merely due to decreases in attenuation with the UltraTech earplug relative to the original HPD, but as seen in Table 6, the correlation between attenuation and correct word identification rate is generally opposite for the two HPD types. With the conventional HPDs, word identification generally drops with increasing attenuation, but with the UltraTech, it generally rose.

Table 6: Correlation between HPD attenuation and word identification rate for 21 subjects

	250 Hz	1000 Hz	2000 Hz	4000 Hz
With original HPD	-0.04	-0.07	-0.13	0.18
With UltraTech HPD	0.12	0.59	0.35	- 0.11

4. Subjective acceptance of UltraTech plugs:

Table 7 summarizes the results of the questionnaire in which subjects were asked to compare the UltraTech plug to their original HPD. These were the 12 subjects who completed wearing the UltraTech plugs until the end of the study, but if the 8 subjects who didn't continue wearing the UltraTech plugs because of comfort issues are factored in, the results would be substantially different. Instead of 4 of 12 subjects preferring the UltraTech to their original HPD, the rate changes to only 4 of 20 preferring the UltraTech. All of those who did not like the UltraTech had originally worn user-molded foam earplugs; of the 3 subjects who originally had worn a pre-molded plastic earplug, 2 preferred the UltraTech and 1 had no preference. All of the subjects who answered the questionnaire found the UltraTech equal or preferable for speech understanding, however, which is the primary motivation for using the UltraTech.

Table 7: Subjective comparison of UltraTech earplug to original earplug among subjects who wore the UltraTech earplug for an extended period (n=12)					
	The UltraTech was much worse	The UltraTech was somewhat worse	The UltraTech was about the same	The UltraTech was somewhat better	The UltraTech was much better
Comfort	1	3	3	5	0
Ease of insertion	0	3	1	6	2
Speech comprehension	0	0	5	4	3
General acceptability	2	3	3	4	0

Figure 10: Distribution of improvements in speech discrimination scores from original HPD to UltraTech HPD

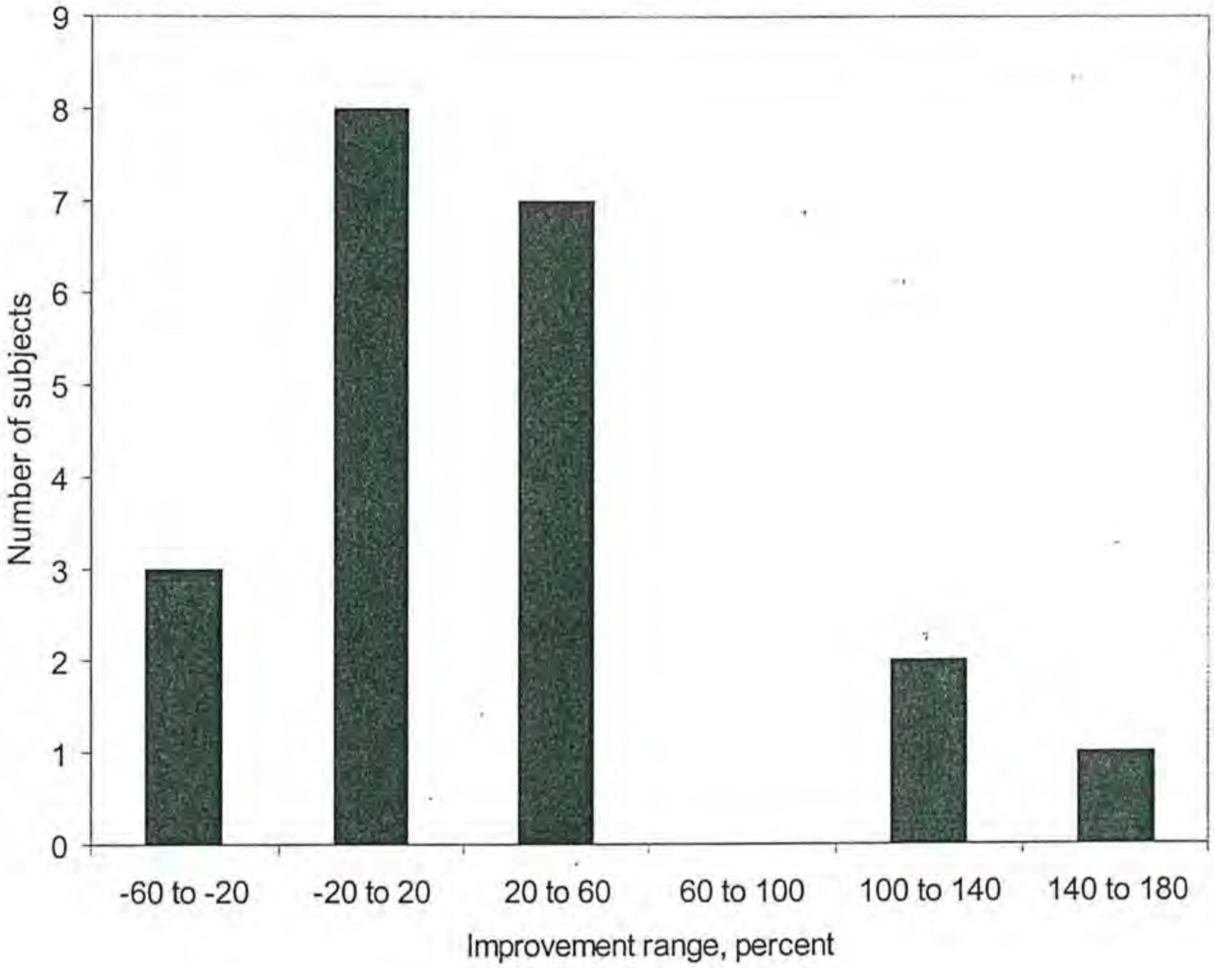
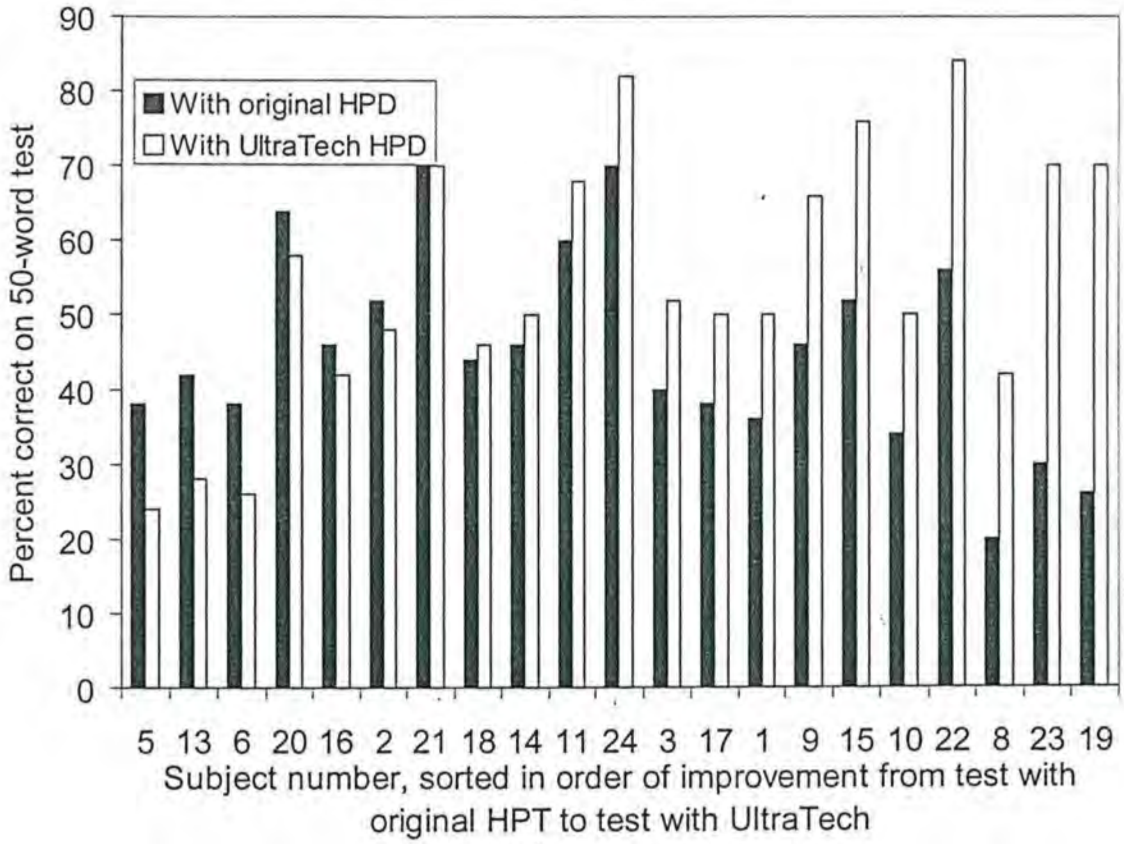


Figure 11: Speech discrimination scores for original HPD and UltraTech HPD for 21 subjects



Acknowledgments

The principal investigator would like to acknowledge the invaluable assistance of all of the experimental subjects who participated in the study as well as the very cooperative management personnel of the facilities where the experimental work was conducted: the Audiology and Speech Pathology Department of the University of Arkansas at Little Rock, Remington Arms Company (Lonoke, Arkansas), Robbins Hardwood Flooring, (Searcy, Arkansas), Hall Tank Company (North Little Rock, Arkansas), and Fabrication Services, Inc (Little Rock, Arkansas). The consultation with Jane B. Prince, Ph.D. and the staff of Arkansas Audiomedical, Inc. and the field assistance of Linda K. Ording, graduate student assistant, were also much appreciated. Thanks also to Eliot Berger of the Aearo Company for provision of sample HPDs and to Dan Rimmer for programming advice.

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Appendix A

The following is the programming code in Visual Basic® for the BCLB program. It consists of three forms (for the set-up screen and the screens to run the BCLB and REAT procedures) as well as two modules containing common variables and other information.

Form 2 - This form is to run the screen for the BCLB test

```
Option Explicit

Dim Running As Boolean, Same As Boolean
Dim NumFreq As Integer, Freq As Integer, Wav As String
Dim DatTestVol() As Long
Dim Min As Single, midd As Single, Max As Single, Avg As Single, Last3 As Single
Dim AmpCal As Integer, CalFactor As Single
Dim Index As Integer, Equal As Integer, Trials As Integer
Dim Start As Long, Finish As Long, StartAll As Long, FinishAll As Long
Dim TimeOcc As Long, TimeOpen As Long, Length As Long
Dim L1 As Long, L2 As Long, L3 As Long, L4 As Long, L5 As Long, L6 As Long, L7 As Long, L8 As Long
Dim V1 As Long, V2 As Long, V3 As Long, V4 As Long, V5 As Long, V6 As Long, V7 As Long, V8 As Long
Dim Threshold As Single, Balance As Single
Dim FrequencyIndex As Integer, Frequency As String
Dim SecondTest As Boolean, HPDWorn As Boolean


Private Sub Check1_Click()
If Check1.Value = vbChecked Then
AmpCal = 16
Check1.BackColor = &HFF&
Else: AmpCal = 0: Check1.BackColor = &H8000000B
End If
End Sub
'This code is to indicate that the sound card amplifier
'has been increased by 16 dB from the normal setting.


Private Sub chkHPDWorn_Click()
If chkHPDWorn.Value = vbChecked Then
  HPDWorn = True
Else: HPDWorn = False
End If
End Sub

Private Sub chkSecondTest_Click()
If chkSecondTest.Value = vbChecked Then
  SecondTest = True
Else: SecondTest = False
End If
End Sub

Private Sub cmdExitForm_Click()
  StopSound
  UnClip
  Open "c:\bclb1\data\BalanceData.txt" For Append As 2
  Write #2, TestID, HPDType, HPDOther, lblOcc1, lblOpen1, lblAtt1, lblOcc2, lblOpen2, lblAtt2, lblOcc3,
 lblOpen3, lblAtt3, lblTimeOcc, lblTimeOpen, RefVol
  Close #2
  Unload Me
End Sub
```

```
Private Sub cmdPauseTest_Click()
Restart = False
Do While Restart = False
  DoEvents
Loop
End Sub
Private Sub PauseTest()
Restart = False
Do While Restart = False
  DoEvents
Loop
End Sub

Private Sub cmdStartButton_Click()
TestChannel = "Left"
Restart = True
Running = True
StartTest
End Sub

Private Sub cmdStartDemo_Click()
  Dim DemoVol As Single, Y As Integer
  DemoVol = RefVol - 10
  Y = 1
  Demo = True
  If TestChannel = "Right" Then
  SetMasterVolume 4000, 8000
  Else: SetMasterVolume 60000, 8000
  End If
  Do While Demo = True
    Pause (1)
    'Y = Y + 1
    Debug.Print DemoVol
    SetVolume CLng(dB_Vol(RefVol)), CLng(dB_Vol(DemoVol))
    PlaySound ("c:\bclb1\4000new.wav")
    Pause (2)
    DemoVol = DemoVol + 8
   DoEvents
   'If Y = 6 Then StopSound
    Loop
  StopSound
End Sub

Private Sub cmdStopDemo_Click()
'DemoVol = RefVol - 10
Demo = False
End Sub

Private Sub Command1_Click()
Form5.Show
TestChannel = "Right"
'RefVolIndex = 0
End Sub

Private Sub Command2_Click()
StopSound
UnClip
Unload Me
End Sub
```

```
Private Sub Form_Load()
   Dim hwnd As Long
   Running = False                ' Running is boolean showing test in progress
   NumFreq = Form1.lstWAV.ListCount  ' Number of wav files in list
   Label3.Top = 0
   Label3.Left = 0
   Label3.Width = Frame1.Width
   Label3.Height = Frame1.Height
   'DataPoints = 0
   Label1.Visible = True
   Label2.Visible = True
   lblLeft.Visible = True
   lblRight.Visible = True
   lblOcc1 = 200: lblOpen1 = 200
   SecondTest = False
   HPDWorn = False

End Sub

Sub StartTest()
  Dim i As Integer, j As Integer, k As Integer, m As Integer, wavfile As String
  Frame2.Visible = True
  StartAll = Timer
  For i = 1 To NumFreq              'start loop for wav files
   RightVol = 6000
   LeftVol = 60000
   CalFactor = CalFactorInit - AmpCal
   TestVol = 16 - StepChange
   If HPDWorn = True Then TestVol = 16 + (7 - StepChange) * StepChange
   FrequencyIndex = i
   V1 = 200: V2 = 200: V3 = 200: V4 = 200: V5 = 200
   V6 = 200: V7 = 200: V8 = 200: Balance = 200
   L1 = 0: L2 = 0: L3 = 0: L4 = 0: L5 = 0: L6 = 0: L7 = 0: L8 = 0
   wavfile = Form1.lstWAV.List(i - 1)    'set wavfile to next one
   k = 0: m = 0: Index = 0: Length = 0
   Frequency = Mid(wavfile, 10, 4)
   AssignFrequency
   midd = Empty: Min = Empty
   Start = Timer
     For j = 1 To 25                 'start loop for reps/frequency
       Pause (StepPause)               ' pause for the delay between steps
       If j = 1 Then
       TestVol = TestVol
       ElseIf j = 2 Then TestVol = TestVol - (StepChange * 4)
       Else: TestVol = TestVol - (StepChange * 2)
       End If
       'SetVolume CLng(dB_Vol(RefVol)), CLng(dB_Vol(TestVol))
       Same = False          'Same is changed to True when testee left-clicks
       Pause (Duration)
       Do While Same = False
         k = k + 1
         SetVolume CLng(dB_Vol(RefVol - AmpCal)), CLng(dB_Vol(TestVol + CalFactor))
         If TestVol > (96 - CalFactor) Then
         RightVol = ((TestVol - (96 - CalFactor)) * 2000) + 6000
         Else: RightVol = 6000
         End If
         lblRight = Str(TestVol)
         SetMasterVolume LeftVol, 4000
         PlaySound ("c:\bclb1\2000lft.wav")
```

```
            Pause (0.5)
            SetMasterVolume 4000, RightVol
            'If (k = 1 And i = 1) Then
            '   PlaySound (0)    ' Start playing sound
            '   Else: PlaySound (wavfile)
            'End If
            PlaySound (wavfile)
            Pause (0.6)
            StopSound
            Pause (Duration)
            If j = 1 Then
               TestVol = TestVol + (StepChange * ((9 - StepChange) / 2))
               Else: TestVol = TestVol + StepChange
            End If
            If TestVol > (120 - CalFactor) Then
               TestVol = (120 - CalFactor)
               m = m + 1
            Else: m = 0
            End If
            If m = 2 Then Same = True
            'Pause (Duration)
         Loop
         StopSound               ' Turn the sound off
         'If k = 1 Then
         '   Pause (2)
         '   Warning.Visible = True
         '   Exit Sub
         'End If
         If j = 1 Then
            TestVol = TestVol - (StepChange * ((9 - StepChange) / 2))
            Else: TestVol = TestVol - StepChange
         End If
         If m > 0 Then TestVol = (120 - CalFactor)
         Index = j
         AssignVol
         Evaluate
         lblLeft = Index
         Debug.Print Balance; Avg; Min; midd; Max
         If Balance < 200 Then
            j = 25
            Finish = Timer
            Length = Finish - Start
            Trials = Index
         End If
         Pause (StepPause)
      Next j
   AssignTime
   Open "c:\bclb1\data\BalanceData2.txt" For Append As 1
   Write #1, TestID, Frequency, Balance, Min, midd, Max, Avg, Length, Trials
   Close #1
   If HPDWorn = True Then
      AssignOccLevel
   Else
      AssignOpenLevel
   End If
   If SecondTest = True Then AssignAttLevel
   Next i
   FinishAll = Timer
   If HPDWorn = True Then
      lblTimeOcc = FinishAll - StartAll
```

```
    Else
        lblTimeOpen = FinishAll - StartAll
    End If
    MsgBox "Test Complete"
    Running = False
    PauseTest
End Sub

Sub AssignTime()
Select Case FrequencyIndex
    Case 1: L1 = Length
    Case 2: L2 = Length
    Case 3: L3 = Length
    Case 4: L4 = Length
    Case 5: L5 = Length
    Case 6: L6 = Length
    Case 7: L7 = Length
    Case 8: L8 = Length
    End Select
End Sub
Sub AssignFrequency()
'Allows display of frequency on test screen
Select Case FrequencyIndex
    Case 1: Label5 = Frequency
    Case 2: Label6 = Frequency
    Case 3: Label9 = Frequency
    Case 4: Label10 = Frequency
    Case 5: 'Label4 = Frequency
    Case 6: 'L6 = Length
    Case 7: 'L7 = Length
    Case 8: 'L8 = Length
    End Select
End Sub

Static Sub AssignOccLevel()
'Sets the selected level for occluded ears
Select Case FrequencyIndex
    Case 1: lblOcc1 = Balance
    Case 2: lblOcc2 = Balance
    Case 3: lblOcc3 = Balance
    Case 4: lblOcc4 = Balance
    Case 5: lblOcc5 = Balance
    Case 6: lblOcc6 = Balance
    Case 7: lblOcc7 = Balance
    Case 8: lblOcc8 = Balance
    Case Else
    End Select
End Sub
Static Sub AssignOpenLevel()
'Sets the selected level for open ears
Select Case FrequencyIndex
    Case 1: lblOpen1 = Balance
    Case 2: lblOpen2 = Balance
    Case 3: lblOpen3 = Balance
    Case 4: lblOpen4 = Balance
    Case 5: lblOpen5 = Balance
    Case 6: lblOpen6 = Balance
    Case 7: lblOpen7 = Balance
    Case 8: lblOpen8 = Balance
    Case Else
```

```
  End Select
End Sub

Static Sub AssignAttLevel()
'Calculates the attenuation at each frequency
If lblOcc1 = 200 Then Exit Sub
If lblOpen1 = 200 Then Exit Sub
Select Case FrequencyIndex
  Case 1: lblAtt1 = lblOcc1 - lblOpen1
  Case 2: lblAtt2 = lblOcc2 - lblOpen2
  Case 3: lblAtt3 = lblOcc3 - lblOpen3
  Case 4: lblAtt4 = lblOcc4 - lblOpen4
  Case 5: lblAtt5 = lblOcc5 - lblOpen5
  Case 6: lblAtt6 = lblOcc6 - lblOpen6
  Case 7: lblAtt7 = lblOcc7 - lblOpen7
  Case 8: lblAtt8 = lblOcc8 - lblOpen8
  Case Else
End Select
'lblAtt8.Visible = True
End Sub

Sub Pause(tm As Single)     'a routine that pauses tm milliseconds
  Dim tstart As Single
  tstart = Timer         ' Timer is a built in function that returns the no. of secs past middnight
  Do While Timer < tstart + tm
    DoEvents           ' this allows other events to occur during the pause
    If Same = True Then Exit Sub   'if user left-clicks during the pause, exit
  Loop
End Sub
Sub Evaluate()
'Makes the decision about whether a consistent balance level has
'has been reached.
Select Case Index
  Case 1: Balance = 200
  Case 2:
    If V1 <= V2 Then: Min = V1: midd = V2: Max = midd ':End If
    If V2 < V1 Then: Min = V2: midd = V1: Max = midd '': End If
  Case 3:
    If V3 > Max Then Max = V3
    If (V3 > midd And Min = midd) Then midd = V3
    Avg = (V1 + V2 + V3) / 3
    Last3 = Avg
    If V3 < Min Then: midd = Min: Min = V3: Exit Sub ': End If
    If V3 = Min Then: Balance = V3: Exit Sub ': End If
    If V3 < midd Then Max = midd: midd = V3: Exit Sub ': End If
  Case 4:
    If V4 > Max Then Max = V4
    Avg = (3 * Avg + V4) / 4
    Last3 = (V2 + V3 + V4) / 3
    If Last3 - midd >= StepChange Then midd = midd + StepChange
    If Last3 - Min >= StepChange Then: Min = midd: midd = midd + StepChange
    If V4 = Min Then: Balance = V4: Exit Sub ': End If
    If V4 < Min Then: midd = Min: Min = V4: Exit Sub ': End If
    If V4 < midd Then midd = V4
  Case 5:
    Avg = (4 * Avg + V5) / 5
    Last3 = (V3 + V4 + V5) / 3
    If Last3 - midd >= StepChange Then midd = midd + StepChange
    If Last3 - Min >= StepChange Then: Min = midd: midd = midd + StepChange
    If (V5 = Min Or V5 = midd) Then: Balance = V5: Exit Sub ': End If
```

```
    If V5 < Min Then: midd = Min: Min = V5: Exit Sub ': End If
    If V5 < midd Then midd = V5
    If V5 > Max Then Max = V5
  Case 6:
    Avg = (5 * Avg + V6) / 6
    Last3 = (V4 + V5 + V6) / 3
    If Last3 - midd >= StepChange Then midd = midd + StepChange
    If Last3 - Min >= StepChange Then: Min = midd: midd = midd + StepChange
    If (V6 = Min Or V6 = midd) Then: Balance = V6: Exit Sub ': End If
    If V6 < Min Then: midd = Min: Min = V6: Exit Sub ': End If
    If V6 < midd Then midd = V6
    If V6 > Max Then Max = V6
  Case 7:
    Avg = (6 * Avg + V7) / 7
    Last3 = (V5 + V6 + V7) / 3
    If Last3 - midd >= StepChange Then midd = midd + StepChange
    If Last3 - Min >= StepChange Then: Min = midd: midd = midd + StepChange
    If (V7 = Min Or V7 = midd) Then: Balance = V7: Exit Sub ': End If
    If V7 < Min Then: midd = Min: Min = V7: Exit Sub ': End If
    If V7 < midd Then midd = V7
    If V7 > Max Then Max = V7
  Case 8:
    Avg = (7 * Avg + V8) / 8
    Last3 = (V5 + V6 + V7) / 3
    If V8 > Max Then Max = V8
    If Last3 - midd >= StepChange Then midd = midd + StepChange
    If Last3 - Min >= StepChange Then: Min = midd: midd = midd + StepChange
    If (V8 = Min Or V8 = midd) Then: Balance = V8: Exit Sub ': End If
    If V8 < Min Then: midd = Min: Min = V8: Balance = midd: Exit Sub ': End If
    If V8 < midd Then midd = V8: Balance = V8
  End Select

End Sub

Sub AssignVol()
'Assigns a balance level to each trial for purposes of
'using in the Evaluate subroutine
Select Case Index
  Case 1: V1 = TestVol: L1 = Length
  Case 2: V2 = TestVol: L2 = Length
  Case 3: V3 = TestVol: L3 = Length
  Case 4: V4 = TestVol: L4 = Length
  Case 5: V5 = TestVol: L5 = Length
  Case 6: V6 = TestVol: L6 = Length
  Case 7: V7 = TestVol: L7 = Length
  Case 8: V8 = TestVol: L8 = Length
  'Case 9: V9 = TestVol: L9 = Length
  'Case 10: V10 = TestVol: L10 = Length
  Case Else
End Select
End Sub

Private Sub Frame2_MouseDown(Button As Integer, Shift As Integer, X As Single, Y As Single)
  ' This routine interprets testee mouse clicks
  Dim i As Long, j As Long
  '
  If Button = 2 Then          'right button
    If Running = True Then Exit Sub   'if already running, exit
    Running = True
    StartTest              ' run the StartTest routine
```

```
  ElseIf Button = 1 Then       'left button
     If Not Running Then      ' if test has'nt started,exit
        Exit Sub
     End If
     Same = True             ' set Same to True to show testee left-clicked
  End If
End Sub
Sub SetMasterVolume(LeftVol As Long, RightVol As Long)
  Dim l3D As Long
  Dim R As Long, cbs As Long, sMixError As Long
  Dim hmx As Long

sMixError = mixerOpen(hmx, 0, 0, 0, 0) 'open mixer 0

Dim uDetails As MIXERCONTROLDETAILS

'  set left and right master volumes
uDetails.cbStruct = CLng(LenB(uDetails))
uDetails.dwControlID = 5   'Master Volume control ID
uDetails.cChannels = 2
uDetails.item = 0
ReDim uunsigned(1 To uDetails.cChannels) As MIXERCONTROLDETAILS_UNSIGNED
uDetails.cbDetails = LenB(uunsigned(1)) ' * uDetails.cChannels
uDetails.paDetails = VarPtr(uunsigned(1).dwValue)
uunsigned(1).dwValue = LeftVol
uunsigned(2).dwValue = RightVol
mixerSetControlDetails hmx, uDetails, MIXER_SETCONTROLDETAILSF_VALUE

End Sub


Private Sub lblTimeOcc_Click()
lblTimeOcc = TimeOcc
End Sub

Private Sub lblTimeOpen_Click()
lblTimeOpen = TimeOpen
End Sub

Private Sub RefDown_Click()
StopSound
Pause (1)
RefDown.Caption = "Down"
SetMasterVolume 60000, 4000
RefVol = RefVol - 10
lblRefVol = RefVol
SetVolume CLng(dB_Vol(RefVol)), CLng(dB_Vol(0))
PlaySound ("c:\bclb1\2000lft.wav")     ' Start playing sound
Pause (0.5)
PlaySound ("c:\bclb1\2000lft.wav")     ' Start playing sound
Pause (0.5)
StopSound
RefDown.Caption = "X"
Debug.Print RefVol
End Sub

Private Sub RefUP_Click()
Pause (2)
SetMasterVolume 60000, 4000
RefVol = RefVol + 10
```

```
lblRefVol = RefVol
SetVolume CLng(dB_Vol(RefVol)), CLng(dB_Vol(0))
PlaySound ("c:\bclb1\2000lft.wav")
Pause (1)
StopSound
End Sub

Private Sub RestartTest_Click()
Restart = True
Warning.Visible = False
End Sub

Private Sub SetRefVol_Click()
RefVol = RefVol + 30
lblRefVol = RefVol
End Sub
```

Form 1 - This is for the test set-up screen

```
Option Explicit

Dim CurrentVolBoth As Long
Dim CurrentVolLeft As Long
Dim CurrentVolRight As Long
Dim ChangePercent As Single
Dim SubjectID As Integer

Private Sub chkTestMode_Click()

End Sub

Private Sub cmdExit_Click()
  Unload Me
  End
End Sub

Private Sub cmdMoveDown_Click()
  Dim temp As String, li As Integer
  li = lstWAV.ListIndex
  If li < lstWAV.ListCount - 1 Then
    temp = lstWAV.List(li + 1)
    lstWAV.List(li + 1) = lstWAV.List(li)
    lstWAV.List(li) = temp
    lstWAV.ListIndex = lstWAV.ListIndex + 1
    SaveWavList
  End If
End Sub

Private Sub cmdMoveUp_Click()
  Dim temp As String, li As Integer
  li = lstWAV.ListIndex
  If li > 0 Then
    temp = lstWAV.List(li - 1)
    lstWAV.List(li - 1) = lstWAV.List(li)
    lstWAV.List(li) = temp
    lstWAV.ListIndex = lstWAV.ListIndex - 1
    SaveWavList
  End If
End Sub
```

```
Private Sub cmdWavAdd_Click()
   On Error GoTo errhandler
   CommonDialog1.Filter = "Wave Files (*.wav)|*.wav|All Files (*.*)|*.*"
   CommonDialog1.CancelError = True
   CommonDialog1.ShowOpen
   lstWAV.AddItem CommonDialog1.FileName
   SaveWavList
   Exit Sub
errhandler:
End Sub

Private Sub cmdWavRemove_Click()
  If lstWAV.ListIndex >= 0 Then
     lstWAV.RemoveItem lstWAV.ListIndex
     SaveWavList
  End If
End Sub

Private Sub Command1_Click()
   Form2.Show
   TestChannel = "Left"
   'RefVolIndex = 0
End Sub

Private Sub cmdStop_Click()
   Dim wflags As Integer, X As Long
   wflags = SND_ASYNC Or SND_NODEFAULT Or SND_LOOP
   X = sndPlaySound(0&, wflags%)
End Sub

Private Sub Command2_Click()
   Dim L As Long, R As Long, i As Long, j As Long, k As Integer, X As Long
   Dim sL As String, sR As String
   For i = 1 To 65500 Step 50
      SetVolume 0, i
   Next i
   For i = 1 To 65500 Step 50
      SetVolume i, 0
   Next i
   For i = 1 To 65500 Step 50
      SetVolume i, i
   Next i
   cmdStop_Click
End Sub

Private Sub Command3_Click()
   Form5.Show
   TestChannel = "Right"
   'RefVolIndex = 0
End Sub

Private Sub Command5_Click()
Open "c:\bclb1\data\TestData.txt" For Append As 3
Write #3, "1", TestID, SubjectID, txtGender.Text, txtSubjectAge.Text, txtLocation.Text, txtDate.Text
Write #3, "2", TestID, HPDType, HPDFit, HPDOther
Write #3, "3", TestID, StepChange, CalFactorInit, InitVol
Close #3
End Sub

Private Sub Form_Load()
```

```
  Dim X As Integer, a As Long
  Dim BothVolumes As Long

  GetWavList        'fill the wav list box with saved files
  SetParameters      'refresh all of the other saved parameters

' This code will retrieve the current volume setting
'  X = waveOutGetVolume(0, BothVolumes)

End Sub

Sub SaveWavList()
   Dim i As Integer
   On Error Resume Next
   DeleteSetting "hptest", "wavfiles"
   For i = 0 To lstWAV.ListCount - 1
      SaveSetting "hptest", "wavfiles", i, lstWAV.List(i)
   Next i
End Sub

Sub GetWavList()        ' rebuild wav list from stored valude
   Dim i As Integer, Settings As Variant
   Settings = GetAllSettings(appname:="hptest", section:="wavfiles")
   If IsEmpty(Settings) Then Exit Sub
   For i = LBound(Settings, 1) To UBound(Settings, 1)
      lstWAV.AddItem Settings(i, 1)
   Next i
End Sub

Sub SetParameters()      ' set parameter values from stored info
   RefVol = GetSetting("hptest", "general", "RefVol", 50#)
   txtRefVol = Str(RefVol)
   Reps = GetSetting("hptest", "general", "Reps", 1)
   txtReps = Str(Reps)
   InitVol = GetSetting("hptest", "general", "InitVol", 50#)
   txtInitVol = Str(InitVol)
   TestChannel = GetSetting("hptest", "general", "TestChannel", "Right")
   If TestChannel = "Right" Then
      optRight = True
   Else
      optLeft = True
   End If
   txtStepChange = GetSetting("hptest", "general", "StepChange", "2")
   StepChange = Val(txtStepChange)
   txtStepDuration = GetSetting("hptest", "general", "Duration", "2")
   Duration = Val(txtStepDuration)
   txtStepPause = GetSetting("hptest", "general", "StepPause", "2")
   StepPause = Val(txtStepPause)
   txtCalFactor = GetSetting("hptest", "general", "CalFactor", "2")
   CalFactorInit = Val(txtCalFactor)

End Sub

Private Sub OpenEars_Click()

End Sub

Private Sub optLeft_Click()
   'TestChannel = "Left"
   'SaveSetting "hptest", "general", "TestChannel", TestChannel
```

```
End Sub

Private Sub optRight_Click()
   'TestChannel = "Right"
   'SaveSetting "hptest", "general", "TestChannel", TestChannel
End Sub

Private Sub Text3_Change()

End Sub

Private Sub txtHPDFit_Change()
HPDFit = Val(txtHPDFit.Text)
End Sub

Private Sub txtHPDOther_Change()
HPDOther = Val(txtHPDOther.Text)
End Sub

Private Sub txtHPDType_Change()
HPDType = Val(txtHPDType.Text)
End Sub

Private Sub txtSubjectID_Change()
SubjectID = Val(txtSubjectID.Text)
End Sub

Private Sub txtTestID_Change()
TestID = Val(txtTestID.Text)
End Sub

Private Sub txtCalFactor_Change()
   SaveSetting "hptest", "general", "CalFactor", txtCalFactor.Text
   CalFactorInit = Val(txtCalFactor.Text)
End Sub

Private Sub txtInitVol_Change()
   SaveSetting "hptest", "general", "InitVol", txtInitVol.Text
   InitVol = Val(txtInitVol.Text)
End Sub

Private Sub txtRefVol_Change()
   SaveSetting "hptest", "general", "RefVol", txtRefVol.Text
   RefVol = Val(txtRefVol.Text)
   RefVol2 = Val(txtRefVol.Text)
End Sub

Private Sub txtReps_Change()
   SaveSetting "hptest", "general", "Reps", txtReps.Text
   Reps = Val(txtReps.Text)
End Sub

Private Sub txtStepChange_Change()
   SaveSetting "hptest", "general", "StepChange", txtStepChange.Text
   StepChange = Val(txtStepChange.Text)
End Sub

Private Sub txtStepDuration_Change()
   SaveSetting "hptest", "general", "Duration", txtStepDuration.Text
   Duration = Val(txtStepDuration.Text)
```

```
End Sub

Private Sub txtStepPause_Change()
   SaveSetting "hptest", "general", "StepPause", txtStepPause.Text
   StepPause = Val(txtStepPause.Text)
End Sub
```

Form 5 - This is for the screen to run the REAT test

```
Option Explicit

Dim Running As Boolean, Same As Boolean
Dim NumFreq As Integer, Freq As Integer, Wav As String
Dim DatTestVol() As Long, Init As Integer
Dim Min As Single, midd As Single, Max As Single, Avg As Single, Last3 As Single
Dim Index As Integer, Equal As Integer, Trials As Integer
Dim Start As Long, Finish As Long, StartAll As Long, FinishAll As Long
Dim TimeOcc As Long, TimeOpen As Long, Length As Long
Dim L1 As Long, L2 As Long, L3 As Long, L4 As Long, L5 As Long, L6 As Long, L7 As Long, L8 As Long
Dim V1 As Long, V2 As Long, V3 As Long, V4 As Long, V5 As Long, V6 As Long, V7 As Long, V8 As Long
Dim Threshold As Single, Balance As Single
Dim FrequencyIndex As Integer, Frequency As String
Dim AmpCal As Integer, CalFactor As Single
Dim SecondTest As Boolean, HPDWorn As Boolean

Private Sub Check1_Click()
If Check1.Value = vbChecked Then
AmpCal = 16
Check1.BackColor = &HFF&
Else: AmpCal = 0: Check1.BackColor = &H8000000B
End If
End Sub


Private Sub chkHPDWorn_Click()
If chkHPDWorn.Value = vbChecked Then
   HPDWorn = True
Else: HPDWorn = False
End If
End Sub

Private Sub chkSecondTest_Click()
If chkSecondTest.Value = vbChecked Then
   SecondTest = True
Else: SecondTest = False
End If
End Sub

Private Sub cmdExitForm_Click()
   StopSound
   UnClip
   Open "c:\bclb1\data\ThresholdData.txt" For Append As 2
   Write #2, TestID, HPDType, HPDOther, lblTOcc1, lblTOpen1, lblTAtt1, lblTOcc2, lblTOpen2. lblTAtt2.
  lblTOcc3, lblTOpen3, lblTAtt3, lblTTimeOcc, lblTTimeOpen
   Close #2
   Unload Me
End Sub

Private Sub cmdPauseTest_Click()
Restart = False
```

```
Do While Restart = False
   DoEvents
Loop
End Sub

Private Sub PauseTest()
Restart = False
Do While Restart = False
   DoEvents
Loop
End Sub

Private Sub cmdStartButton_Click()
Restart = True
Running = True
StartTest
End Sub

Private Sub Command1_Click()
   Form2.Show
   TestChannel = "Left"
   'RefVolIndex = 0
End Sub

Private Sub Command2_Click()
StopSound
UnClip
Unload Me
End Sub

Private Sub Form_Load()
   Dim hwnd As Long
   Running = False                ' Running is boolean showing test in progress
   NumFreq = Form1.lstWAV.ListCount   ' Number of wav files in list
   Label3.Top = 0
   Label3.Left = 0
   Label3.Width = Frame1.Width
   Label3.Height = Frame1.Height
   'DataPoints = 0
   Label1.Visible = True
   Label2.Visible = True
   lblLeft.Visible = True
   lblRight.Visible = True
   lblTOcc1 = 200: lblTOpen1 = 200
End Sub

Sub StartTest()
   Dim i As Integer, j As Integer, k As Integer, m As Integer, wavfile As String
   Frame2.Visible = True
   StartAll = Timer
   For i = 1 To NumFreq              'start loop for wav files
    Threshold = 200
    RightVol = 6000
    LeftVol = 4000
    CalFactor = CalFactorInit - AmpCal
    SetMasterVolume LeftVol, RightVol
    'If HPDWorn = True Then RightVol = 38000
    FrequencyIndex = i
    V1 = 200: V2 = 200: V3 = 200: V4 = 200: V5 = 200
    V6 = 200: V7 = 200: V8 = 200: Equal = 0
```

```
L1 = 0: L2 = 0: L3 = 0: L4 = 0: L5 = 0: L6 = 0: L7 = 0: L8 = 0
wavfile = Form1.lstWAV.List(i - 1)    'set wavfile to next one
k = 0: m = 0: Index = 0: Length = 0
Frequency = Mid(wavfile, 10, 4)
AssignFrequency
Init = 10
If Frequency = "1000" Then Init = 0
midd = Empty: Min = Empty: Max = Empty: Avg = Empty
Start = Timer
  For j = 1 To 25                        'start loop for reps/frequency
    Pause (StepPause)                        ' pause for the delay between steps
    If j = 1 Then TestVol = InitVol + Init
    If (j = 1 And HPDWorn = True) Then TestVol = InitVol + 16
    If j > 1 Then TestVol = TestVol - (StepChange * 2)
    'SetVolume CLng(dB_Vol(RefVol)), CLng(dB_Vol(TestVol + CalFactor))
    Same = False            'Same is changed to True when testee left-clicks
    Pause (Duration)
    m = m + 1
    Do While Same = False
      k = k + 1
      SetVolume CLng(dB_Vol(0)), CLng(dB_Vol(TestVol + CalFactor))
      If TestVol > (96 - CalFactor) Then
        RightVol = ((TestVol - (96 - CalFactor)) * 2000) + 6000
        'SetMasterVolume LeftVol, RightVol
      Else: RightVol = 6000
      End If
      SetMasterVolume LeftVol, RightVol
      lblRight = Str(TestVol)
      Pause (1)
      PlaySound (wavfile)     ' Start playing sound
      Pause (0.5)
      Debug.Print RightVol 'PlaySound (wavfile)
      Pause (Duration)
      If j = 1 Then
        TestVol = TestVol + (StepChange * 2)
        Else: TestVol = TestVol + StepChange
      End If
      If TestVol > (120 - CalFactor) Then
        TestVol = (120 - CalFactor)
        m = m + 1
      Else: m = 0
      End If
      If m = 2 Then Same = True
    Loop
    StopSound              ' Turn the sound off
    If j = 1 Then
      TestVol = TestVol - (StepChange * 2)
      Else: TestVol = TestVol - StepChange
    End If
    If m > 0 Then TestVol = (120 - CalFactor)
    If k > j Then
      Index = Index + 1
      AssignVol
    End If
    Evaluate
    lblLeft = Index
    If Threshold < 200 Then
      j = 25
      Finish = Timer
      Length = Finish - Start
```

```
            Trials = Index
          End If
          Pause (StepPause)
        Next j
      AssignTime
      Open "c:\bclb1\data\ThresholdData2.txt" For Append As 1
      Write #1, TestID, Frequency, Threshold, Min, midd, Max, Avg, Length, Trials
      Close #1
      If HPDWorn = True Then
        AssignOccLevel
      Else
        AssignOpenLevel
      End If
      If SecondTest = True Then AssignAttLevel
      Next i
      FinishAll = Timer
      If HPDWorn = True Then
        lblTTimeOcc = FinishAll - StartAll
      Else
        lblTTimeOpen = FinishAll - StartAll
      End If
      MsgBox "Test Complete"
      Running = False
      PauseTest
    End Sub
    Sub AssignFrequency()
    Select Case FrequencyIndex
      Case 1: Label4 = Frequency
      Case 2: Label5 = Frequency
      Case 3: Label6 = Frequency
      Case 4: 'Label4 = Frequency
      Case 5: 'Label4 = Frequency
      Case 6: 'L6 = Length
      Case 7: 'L7 = Length
      Case 8: 'L8 = Length
      End Select
    End Sub

    Sub AssignTime()
    Select Case FrequencyIndex
      Case 1: L1 = Length
      Case 2: L2 = Length
      Case 3: L3 = Length
      Case 4: L4 = Length
      Case 5: L5 = Length
      Case 6: L6 = Length
      Case 7: L7 = Length
      Case 8: L8 = Length
      End Select
    End Sub

    Static Sub AssignOccLevel()
    'Sets the selected level for occluded ears
    Select Case FrequencyIndex
      Case 1: lblTOcc1 = Threshold
      Case 2: lblTOcc2 = Threshold
      Case 3: lblTOcc3 = Threshold
      Case 4: lblTOcc4 = Threshold
      Case 5: lblTOcc5 = Threshold
      Case 6: lblTOcc6 = Threshold
```

```
    Case 7: lblTOcc7 = Threshold
    Case 8: lblTOcc8 = Threshold
    Case Else
    End Select
End Sub

Static Sub AssignOpenLevel()
'Sets the selected level for open ears
Select Case FrequencyIndex
    Case 1: lblTOpen1 = Threshold
    Case 2: lblTOpen2 = Threshold
    Case 3: lblTOpen3 = Threshold
    Case 4: lblTOpen4 = Threshold
    Case 5: lblTOpen5 = Threshold
    Case 6: lblTOpen6 = Threshold
    Case 7: lblTOpen7 = Threshold
    Case 8: lblTOpen8 = Threshold
    Case Else
    End Select
End Sub

Static Sub AssignAttLevel()
'Calculates the attenuation at each frequency
If lblTOcc1 = 200 Then Exit Sub
If lblTOpen1 = 200 Then Exit Sub
Select Case FrequencyIndex
    Case 1: lblTAtt1 = lblTOcc1 - lblTOpen1
    Case 2: lblTAtt2 = lblTOcc2 - lblTOpen2
    Case 3: lblTAtt3 = lblTOcc3 - lblTOpen3
    Case 4: lblTAtt4 = lblTOcc4 - lblTOpen5
    Case 5: lblTAtt5 = lblTOcc5 - lblTOpen5
    Case 6: lblTAtt6 = lblTOcc6 - lblTOpen6
    Case 7: lblTAtt7 = lblTOcc7 - lblTOpen7
    Case 8: lblTAtt8 = lblTOcc8 - lblTOpen8
    Case Else
End Select
'lblTAtt8.Visible = True
End Sub

Sub Pause(tm As Single)     'a routine that pauses tm milliseconds
    Dim tstart As Single
    tstart = Timer          ' Timer is a built in function that returns the no. of secs past midnight
    Do While Timer < tstart + tm
        DoEvents            ' this allows other events to occur during the pause
        If Same = True Then Exit Sub    'if user left-clicks during the pause, exit
    Loop
End Sub

Sub Evaluate()
Select Case Index
    Case 1: Threshold = 200
    Case 2:
        If V1 <= V2 Then: Min = V1: midd = V2: Max = midd ':End If
        If V2 < V1 Then: Min = V2: midd = V1: Max = midd '': End If
    Case 3:
        If V3 > Max Then Max = V3
        If (V3 > midd And Min = midd) Then midd = V3
        Avg = (V1 + V2 + V3) / 3
        Last3 = Avg
        If V3 < Min Then: midd = Min: Min = V3: Exit Sub ': End If
```

```
    If V3 = Min Then: Threshold = V3: Exit Sub ': End If
    If V3 < midd Then Max = midd: midd = V3: Exit Sub ': End If
  Case 4:
    If V4 > Max Then Max = V4
    Avg = (3 * Avg + V4) / 4
    Last3 = (V2 + V3 + V4) / 3
    If Last3 - midd >= StepChange Then midd = midd + StepChange
    If Last3 - Min >= StepChange Then: Min = midd: midd = midd + StepChange
    If V4 = Min Then: Threshold = V4: Exit Sub ': End If
    If V4 < Min Then: midd = Min: Min = V4: Exit Sub ': End If
    If V4 < midd Then midd = V4
  Case 5:
    Avg = (4 * Avg + V5) / 5
    Last3 = (V3 + V4 + V5) / 3
    If Last3 - midd >= StepChange Then midd = midd + StepChange
    If Last3 - Min >= StepChange Then: Min = midd: midd = midd + StepChange
    If (V5 = Min Or V5 = midd) Then: Threshold = V5: Exit Sub ': End If
    If V5 < Min Then: midd = Min: Min = V5: Exit Sub ': End If
    If V5 < midd Then midd = V5
    If V5 > Max Then Max = V5
  Case 6:
    Avg = (5 * Avg + V6) / 6
    Last3 = (V4 + V5 + V6) / 3
    If Last3 - midd >= StepChange Then midd = midd + StepChange
    If Last3 - Min >= StepChange Then: Min = midd: midd = midd + StepChange
    If (V6 = Min Or V6 = midd) Then: Threshold = V6: Exit Sub ': End If
    If V6 < Min Then: midd = Min: Min = V6: Exit Sub ': End If
    If V6 < midd Then midd = V6
    If V6 > Max Then Max = V6
  Case 7:
    Avg = (6 * Avg + V7) / 7
    Last3 = (V5 + V6 + V7) / 3
    If Last3 - midd >= StepChange Then midd = midd + StepChange
    If Last3 - Min >= StepChange Then: Min = midd: midd = midd + StepChange
    If (V7 = Min Or V7 = midd) Then: Threshold = V7: Exit Sub ': End If
    If V7 < Min Then: midd = Min: Min = V7: Exit Sub ': End If
    If V7 < midd Then midd = V7
    If V7 > Max Then Max = V7
  Case 8:
    Avg = (7 * Avg + V8) / 8
    Last3 = (V5 + V6 + V7) / 3
    If V8 > Max Then Max = V8
    If Last3 - midd >= StepChange Then midd = midd + StepChange
    If Last3 - Min >= StepChange Then: Min = midd: midd = midd + StepChange
    If (V8 = Min Or V8 = midd) Then: Threshold = V8: Exit Sub ': End If
    If V8 < Min Then: midd = Min: Min = V8: Threshold = midd: Exit Sub ': End If
    If V8 < midd Then midd = V8: Threshold = V8
  End Select

End Sub

Sub AssignVol()
Select Case Index
  Case 1: V1 = TestVol: L1 = Length
  Case 2: V2 = TestVol: L2 = Length
  Case 3: V3 = TestVol: L3 = Length
  Case 4: V4 = TestVol: L4 = Length
  Case 5: V5 = TestVol: L5 = Length
  Case 6: V6 = TestVol: L6 = Length
  Case 7: V7 = TestVol: L7 = Length
```

```
   Case 8: V8 = TestVol: L8 = Length
   'Case 9: V9 = TestVol: L9 = Length
   'Case 10: V10 = TestVol: L10 = Length
   Case Else
End Select
End Sub

Private Sub Frame2_MouseDown(Button As Integer, Shift As Integer, X As Single, Y As Single)
   ' This routine interprets testee mouse clicks
   Dim i As Long, j As Long
   '
   If Button = 2 Then          'right button
      If Running = True Then Exit Sub    'if already running, exit
      Running = True
      StartTest              ' run the StartTest routine
   ElseIf Button = 1 Then       'left button
      If Not Running Then       ' if test has'nt started,exit
         Exit Sub
      End If
      Same = True            ' set Same to True to show testee left-clicked
   End If
End Sub

Sub SetMasterVolume(LeftVol As Long, RightVol As Long)
   Dim l3D As Long
   Dim R As Long, cbs As Long, sMixError As Long
   Dim hmx As Long

sMixError = mixerOpen(hmx, 0, 0, 0, 0) 'open mixer 0

Dim uDetails As MIXERCONTROLDETAILS

' set left and right master volumes
uDetails.cbStruct = CLng(LenB(uDetails))
uDetails.dwControlID = 5   'Master Volume control ID
uDetails.cChannels = 2
uDetails.item = 0
ReDim uunsigned(1 To uDetails.cChannels) As MIXERCONTROLDETAILS_UNSIGNED
uDetails.cbDetails = LenB(uunsigned(1)) ' * uDetails.cChannels
uDetails.paDetails = VarPtr(uunsigned(1).dwValue)
uunsigned(1).dwValue = LeftVol
uunsigned(2).dwValue = RightVol
mixerSetControlDetails hmx, uDetails, MIXER_SETCONTROLDETAILSF_VALUE

End Sub

Private Sub lblTTimeOcc_Click()
lblTTimeOcc = TimeOcc
End Sub

Private Sub lblTTimeOpen_Click()
lblTTimeOpen = TimeOpen
End Sub

Private Sub RestartTest_Click()
Restart = True
End Sub
```

Module 1

```
Option Explicit
```

```
Declare Function waveOutGetVolume Lib "winmm.dll" (ByVal uDeviceID As Long, lpdwVolume As Long) As
  Long
Declare Function waveOutSetVolume Lib "winmm.dll" (ByVal uDeviceID As Long, ByVal dwVolume As
  Long) As Long
Declare Function sndPlaySound Lib "winmm.dll" Alias "sndPlaySoundA" (ByVal lpszSoundName As String,
  ByVal uFlags As Long) As Long

Declare Function lineGetVolume Lib "winmm.dll" (ByVal uDeviceID As Long, lpdwVolume As Long) As Long
Declare Function lineSetVolume Lib "winmm.dll" (ByVal uDeviceID As Long, ByVal dwVolume As Long) As
  Long

Declare Function waveOutGetPitch Lib "winmm.dll" (ByVal hWaveOut As Long, lpdwPitch As Long) As Long
Declare Function waveOutSetPitch Lib "winmm.dll" (ByVal hWaveOut As Long, ByVal dwPitch As Long) As
  Long
Declare Function waveOutGetID Lib "winmm.dll" (ByVal hWaveOut As Long, lpuDeviceID As Long) As Long
Declare Function GetWindowRect Lib "user32" (ByVal hwnd As Long, lpRect As RECT_TYPE) As Long
Declare Function ClipCursor Lib "user32" (lpRect As Any) As Long
Declare Function GetDesktopWindow Lib "user32" () As Long
Declare Function SetCursorPos Lib "user32" (ByVal X As Long, ByVal Y As Long) As Long

Type RECT_TYPE
   Left As Long
   Top As Long
   Right As Long
   Bottom As Long
End Type

Global Const SND_ASYNC = &H1
Global Const SND_NODEFAULT = &H2
Public Const SND_LOOP = &H8

Global Demo As Boolean
Global Restart As Boolean
Global RefVol As Single   ' volume in reference channel (0 - 100)
Global RefVol2 As Single
Global Reps As Integer    ' repetitions for each frequency
Global InitVol As Single  ' initial volume in test channel
'Global ChangeRate As Single  ' volume increase rate, %/sec
Global TestChannel As String ' Left or Right
Global TestVol As Single
Global TestID As Single
Global StepChange As Single
Global Duration As Single
Global StepPause As Single
Global CalFactorInit As Single
Global lblRefVol As Single
Global lblOpen1 As Single, lblOpen2 As Single, lblOpen3 As Single, lblOpen4 As Single
Global lblOpen5 As Single, lblOpen6 As Single, lblOpen7 As Single, lblOpen8 As Single
Global lblOcc1 As Single, lblOcc2 As Single, lblOcc3 As Single, lblOcc4 As Single
Global lblOcc5 As Single, lblOcc6 As Single, lblOcc7 As Single, lblOcc8 As Single
Global lblAtt1 As Single, lblAtt2 As Single, lblAtt3 As Single, lblAtt4 As Single
Global lblAtt5 As Single, lblAtt6 As Single, lblAtt7 As Single, lblAtt8 As Single
Global lblTimeOpen As Single, lblTimeOcc As Single
Global lblTOpen1 As Single, lblTOpen2 As Single, lblTOpen3 As Single, lblTOpen4 As Single
Global lblTOpen5 As Single, lblTOpen6 As Single, lblTOpen7 As Single, lblTOpen8 As Single
Global lblTOcc1 As Single, lblTOcc2 As Single, lblTOcc3 As Single, lblTOcc4 As Single
Global lblTOcc5 As Single, lblTOcc6 As Single, lblTOcc7 As Single, lblTOcc8 As Single
Global lblTAtt1 As Single, lblTAtt2 As Single, lblTAtt3 As Single, lblTAtt4 As Single
Global lblTAtt5 As Single, lblTAtt6 As Single, lblTAtt7 As Single, lblTAtt8 As Single
```

```
Global lblTTimeOpen As Single, lblTTimeOcc As Single
Global HPDType As Integer, HPDFit As Integer, HPDOther As Integer

Sub SetVolume(LVol As Long, RVol As Long)        ' low level routine to control volume
   Dim sR As String, sL As String, X As Long
   If LVol > 63000 Then LVol = 63000
   If RVol > 63000 Then RVol = 63000
   If LVol < 0 Then LVol = 0
   If RVol < 0 Then RVol = 0
   sR = "0000"
   Mid(sR, 5 - Len(Hex(RVol))) = Hex(RVol)
   sL = "0000"
   Mid(sL, 5 - Len(Hex(LVol))) = Hex(LVol)
   X = waveOutSetVolume(0, CLng("&H" & sR & sL))
   'Debug.Print CLng("&H" & sR & sL), "&H" & sR & sL
   End Sub

Sub PlaySound(wavfile As String)    ' routine to play wavfile
  Dim X As Integer
  Dim wflags As Integer
  wflags = SND_ASYNC Or SND_NODEFAULT    'SND_ASYNC allows other activity while playing
                                         ' SND_LOOP causes wav file to repeat
  X = sndPlaySound(wavfile, wflags%)    ' Play the wave file.

End Sub

Sub StopSound()
   Dim wflags As Integer, X As Long
   wflags = SND_ASYNC Or SND_NODEFAULT
   X = sndPlaySound(0&, wflags%)
End Sub

Sub UnClip()        ' free the mouse
   Dim typ_rect As RECT_TYPE
   GetWindowRect GetDesktopWindow, typ_rect
   ClipCursor typ_rect
End Sub

Function dB_Vol(dB As Single) As Long        'calculate system volume based on dB input and the calibration
  factor
   dB_Vol = 10 ^ ((dB) / 20#)
'   Debug.Print CalFactor, dB, dB_Vol

End Function
```

Module 2

```
Option Explicit
Global LeftVol As Long
Global RightVol As Long
Public Const MIXER_GETCONTROLDETAILSF_VALUE = &H0&
Public Const MIXER_SETCONTROLDETAILSF_VALUE = &H0&
Public Type MIXERCONTROLDETAILS
     cbStruct As Long       ' size in Byte of MIXERCONTROLDETAILS
     dwControlID As Long    ' control id to get/set details on
     cChannels As Long      ' number of channels in paDetails array
     item As Long           ' hwndOwner or cMultipleItems
     cbDetails As Long      ' size of _one_ details_XX struct
     paDetails As Long      ' pointer to array of details_XX structs
End Type
```

```
Public Type MIXERCONTROLDETAILS_UNSIGNED
  dwValue As Long
End Type
Public Type MIXERCONTROLDETAILS_BOOLEAN
    fValue As Long
End Type
Public Declare Function mixerOpen Lib "winmm.dll" (phmx As Long, ByVal uMxId As Long, ByVal
  dwCallback As Long, ByVal dwInstance As Long, ByVal fdwOpen As Long) As Long
Public Declare Function mixerSetControlDetails Lib "winmm.dll" (ByVal hmxobj As Long, pmxcd As
  MIXERCONTROLDETAILS, ByVal fdwDetails As Long) As Long
```

Publications

Rimmer, T.W. and Ording, L.K.: "Field Evaluation of the Bone Conduction Loudness Balance Method for Measuring Hearing Protector Attenuation," American Industrial Hygiene Conference, New Orleans, LA, June 7, 2001.

DEPARTMENT OF HEALTH AND HUMAN SERVICES

Public Health Service
Centers for Disease Control
and Prevention (CDC)

Memorandum

Date: March 25, 2002

for From: Michael J. Galvin, Jr., Ph.D., Lead Program Activity Stephanie Shack
Office of Extramural Programs, NIOSH, D30

Subject: Final Report Submitted for Entry into NTIS for Grant 5 R01 OH003741-02.

To: William D. Bennett
Data Systems Team, Information Resources Branch, EID, NIOSH, P03/C18

The attached final report has been received from the principal investigator on the subject NIOSH grant. If this document is forwarded to the National Technical Information Service, please let us know when a document number is known so that we can inform anyone who inquires about this final report.

Any publications that are included with this report are highlighted on the list below.

Attachment
cc: Sherri Diana, EID, P03/C13

List of Publications

Rimmer, T.W. and Ording, L.K. Field evaluation of the bone conduction loudness balance method for measuring hearing protector attenuation. American Industrial Hygiene Conference, New Orleans, La. June 7, 2001.

Title: Field Study Hearing Protector Evaluation Procedure
Investigator: Thomas W. Rimmer, Sc.D.
Affiliation: University of Arkansas
City & State: Little Rock, AR
Telephone: (501) 686-5289
Award Number: 5 R01 OH003741-02
Start & End Date: 9/30/1998–9/29/2001
Total Project Cost: $82,674
Program Area: NORA
Key Words:

Abstract:
The Bone Conduction Loudness Balance (BCLB) method of measuring hearing protector attenuation was re-worked from earlier test versions and evaluated in a variety of situations, both laboratory and field. The procedure was implemented for running on any personal computer using the Windows® operating system, and the protocol was simplified to emulate the standard hearing threshold test method. Laboratory testing using 26 previously inexperienced subjects showed that the revised procedure was easily implemented and more than twice as quickly done than the previous procedure, but was somewhat less consistent with the standard real ear attenuation at threshold (REAT) testing.

Field hearing protection device (HPD) testing was evaluated with a total of 68 previously inexperienced subjects at four industrial sites. The mean time required for the BCLB test was about 6 minutes, and nearly all subjects were able to perform the test without difficulty, except for 2 of 68 who had too much hearing loss to hear the bone conduction reference sound at 200 Hz and one subject who was unwilling to learn the procedure. The primary difficulty was the tendency of some subjects to respond as in a threshold test, with re-instruction required for 17%. When used in a "candid" or unannounced test mode to evaluate HPD effectiveness as actually worn on the job, the procedure found attenuation values less than in a test setting, as was expected. The procedure was no more difficult to implement for candid testing than for other settings.

The BCLB procedure was also used as part of an evaluation of the practicality and effect of using a HPD designed for better speech comprehension in noise (EAR UltraTech®) with 21 hearing-impaired industrial subjects. Use of this HPD produced modest gains (mean improvement = 29%, $p<0.01$) in speech comprehension as measured by correct word identification on a 50-word test when compared with their normal HPD. However, 40% failed to wear the new HPD for extended testing due to discomfort and only 25% of those who did continue to wear it preferred it to their previous HPD.

Publications

Rimmer, T.W. and Ording, L.K. Field evaluation of the bone conduction loudness balance method for measuring hearing protector attenuation. American Industrial Hygiene Conference, New Orleans, La. June 7, 2001.