Canadian Acoustics /
Acoustique canadienn
1988, 16 (3):15-28

SOME COMMENTARY ON THE EVALUATION OF MUFF STYLE HEARING PROTECTION UNDER THE CANADIAN STANDARD

M.G. Faulkner, K.H. Gough and G.C. Kiss
Mechanical Engineering Acoustics and Noise Unit
University of Alberta
Edmonton, Alberta T6G 2G8

ABSTRACT

The results of a comprehensive study on the evaluation of hearing protection devices are discussed with respect to the Canadian standard. Overall the Canadian standard is more realistic in its philosophy than are other standard rating schemes.

SOMMAIRE

Les résultats d'une étude extensive concernant l'évaluation des protecteurs individuels contre le bruit sont discutés en regard des dispositions de la norme canadienne. D'une manière générale, la norme canadienne comporte une approche plus réaliste que d'autres procédures normatives d'évaluation.

I. INTRODUCTION

The CSA Z94.2-1984 standard [1] for the evaluation of personal hearing protection devices (PHPDs) is a further attempt to produce a rating scheme which reflects the acoustic protection a user should expect from a particular PHPD. This standard, like the majority of others used in North America, Europe and Australia, is based on the Real Ear Attenuation at Threshold (REAT) technique. While there has been and continues to be a determined effort to develop an acoustic test fixture which would replace the subjective REAT tests, REAT is still believed to be the most representative of the actual situation. This is because it uses subjective testing. The results are the optimum expected because the highly controlled lab evaluations will not be duplicated in field use. It is believed that because of this subjective testing, with all its inherent difficulties, results obtained from different labs show wide variation [2,3,4]. While some variation is to be expected because of differences in the subjects and variations in the PHPD quality, it is also believed that ambiguities in the standard can allow biased results to be obtained while supposedly following the procedures given [5].

The CSA standard relies on the REAT test methodologies prescribed in ANSI S12.6-1984 [6]. However, there are several differences in the overall standards and the schemes used to rate PHPD effectiveness. Two major differences are:

1. The CSA requires that PHPDs undergo extensive preconditioning before being subjectively tested using the REAT technique. This preconditioning involves mechanical flexing, vibration and impact tests, thermal and pressure cycling as well as repeated soiling and cleaning of the head/protector interface seal. This is an attempt, for PHPDs which are reusable, to approximate the effects of a certain amount of field use as well as a durability test. This approach was adopted by CSA in an effort to help account for the fact that field attenuations do not approach the higher average values found in the laboratory

test situation [7].

2. The CSA attenuation rating of protectors uses a coarser classification system (A,B or C) compared to the Noise Reduction Rating (NRR) used for U.S. labelling. The ABC scheme is based solely on the mean laboratory values while the NRR derates this mean by two standard deviations. CSA derating is done by including correction factors in the selection of a PHPD for a particular noise environment. The CSA allows changes to be easily implemented in the derating while the NRR derating is locked-in to the standard deviations obtained in the laboratory. Should a lab find techniques which reduce its standard deviations, the NRR values would rise, however, the actual protection afforded in practice would not change [5].

A study on the evaluation of PHPDs applying CSA Z94.2-M1984 was conducted by Faulkner, Gough and Kiss [8]. No tests using this standard had been carried out on PHPDs in Canada prior to this study. Previously, CSA ratings were derived by reinterpreting the data collected elsewhere. The Mechanical Engineering Acoustics and Noise Unit (MEANU) study evaluated a cross section of commonly used muffs under the CSA standard and compared the results with the means and deviations reported by the manufacturers. In general these results were obtained following ANSI procedures. The study also evaluated several additional variables not specifically covered in the standard. These included (a) details of the psychophysical methods used to obtain REAT data, (b) specific procedures for the selection of the listening jury for the REAT data, and (c) the comparison of the REAT subjective data with objective data obtained on a acoustic test fixture (ATF) in accordance with specifications obtained in an earlier ANSI standard [9].

II. METHODS, EQUIPMENT AND SUBJECTS

A. Test Facilities

The REAT testing was done in a hearing research chamber with the audio stimuli provided by a computer driven audiometer. The entire installation, shown schematically in Figure 1, was designed to offer the maximum flexibility possible for the testing procedures. The system shown was used for screening potential subjects, performing pure tone audiometric studies of subjects and also programmed to measure binaural threshold using two different techniques.

The hearing research chamber was designed to meet the requirements of both ANSI standards [6,9]. This meant that the volume must be large enough to allow reverberation times (RTs) from 0.5 to 1.6 seconds depending on the frequency band. The actual results showed a maximum RT of 1.54 seconds at 500 Hz and a minimum of 0.50 at 8000 Hz. This chamber was operated inside the confines of a large (311 cubic meters) reverberation room so that the background noise inside the hearing research chamber would meet those required by ANSI. In fact the background noise was well below the minimums with a sound pressure level of 14 dB in the 125 Hz octave band which decreased to -7 dB at 1000 Hz and -3 at 8000 Hz.

These two binaural techniques, which presented filtered 1/3 octave band noise through loudspeakers, was completely carried out by computer prompting [10]. The first method was a modified version of the Hughson-Westlake method [11] where the ascending/descending increments were changed from 5/10 dB to 2/4 dB. The second method was a modified version of automatic audiometry. The

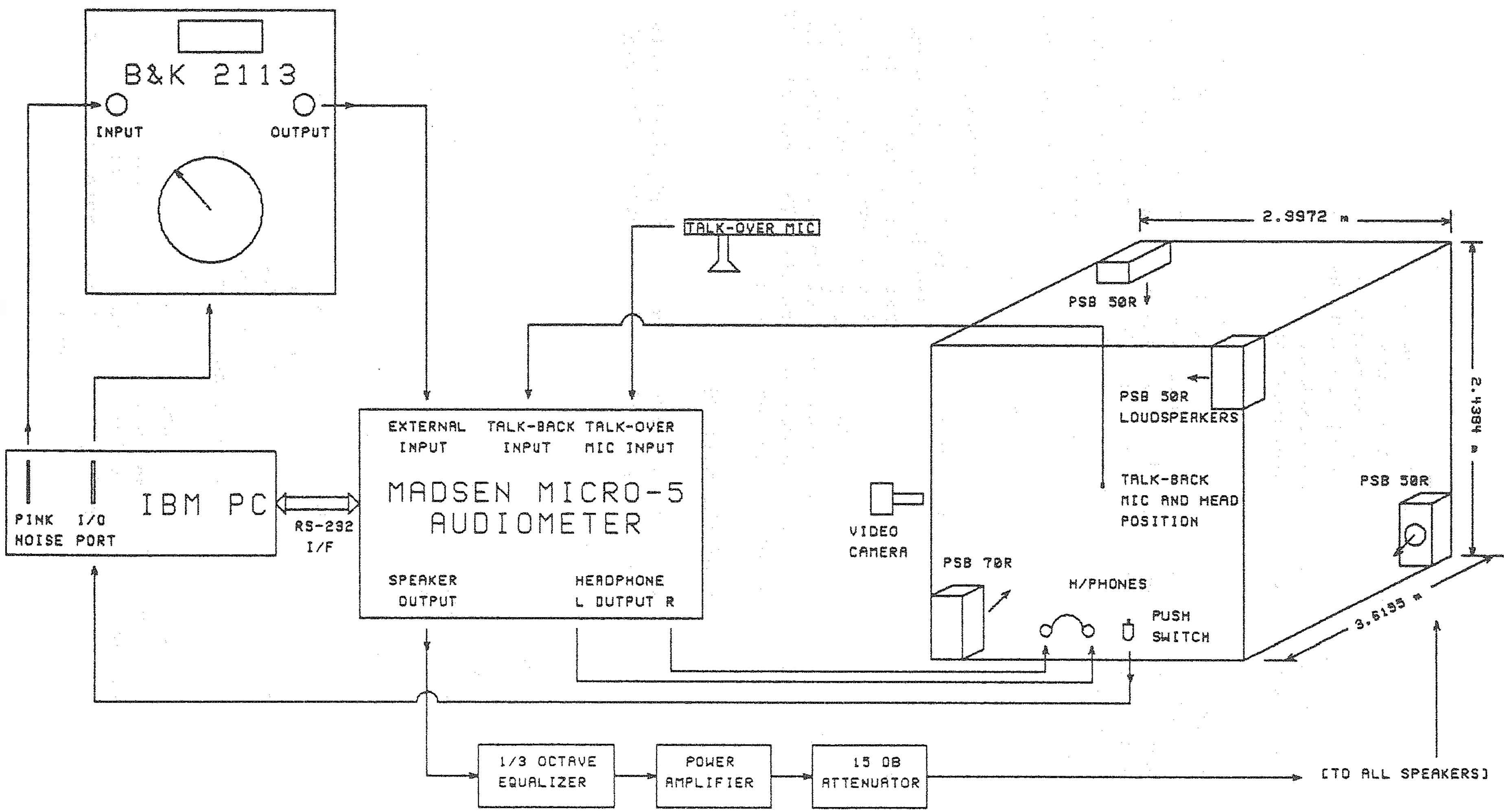

Fig. 1 Hearing Research Chamber Equipment Arrangement

pulsed tones were continuously presented and the sound level varied continuously in one dB steps (at a rate of 1 dB/second) either up or down depending on the subjects response to hearing the tones. Each test began with the 1000 Hz 1/3 octave band and then evaluated successively higher bands before beginning at the lowest band and increasing until the 1000 Hz band was repeated. This repetition of the 1000 Hz band allowed a check of the subject's response at the beginning and end of each threshold determination.

The resulting saw-tooth traces produced were interpreted according to the requirements in ANSI S12.6 [6]. In the case of the automatic method interpretations of the trace were made more restrictive than required by ANSI in two ways. First the range of excursions allowed (any peak to valley difference) was decreased from 20 to 12 dB. Second, the stipulation that any peak not be lower than any valley was further restricted so that any peak could not be within 2 dB of any valley. It is believed that these restrictions were possible because of the use of a lower rate of change in level (1 dB/second) compared with the CSA standard (5 dB/second) [see CSA Z107.4-M86].

The objective tests were done using an ATF built to ANSI specifications [9]. The ATF was installed in a large reverberation chamber 230 m^3 rather than the hearing research chamber. This was done because the sound reinforcement system was capable of producing the higher sound pressure levels required by ANSI. The physical attenuating properties of each cup of the muffs was measured by measuring the open (unoccluded) sound pressure level of the microphone compared to the level with the cup in position on the ATF. In order to evaluate the variations in attenuation measured on the ATF, several different measurements were made on one cup of several protectors.

B. Preconditioning of the Muff PHPDs

The CSA standard outlines a series of physical tests that muff-type PHPDs must be subjected to prior to REAT evaluation. The eight physical tests are:

1. temperature cycling
2. leakage
3. high temperature storage
4. low temperature impact
5. cleanability
6. vibration
7. suspension system durability
8. cold weather handling

A specialized vacuum chamber was constructed with a sealed removable lid. This chamber was placed inside an oven for heating and the oven inside a cold room which allowed all the temperature and vacuum tests to be done. Impact tests were done at -7°C (normal temperature applications) and did not include tests at -29°C which is specified for cold applications (cold weather handling).

The vibration tests were done on an electrodynamic shaker table, while the suspension durability was done on a servo-hydraulic testing machine. Cleanability involved ten cycles of first soiling and then cleaning the surfaces of the muffs of a vaseline/graphite mixture. More complete details of the extensive preconditioning are given by Faulkner et al [8].

C. Subject Selection and Testing

From an original group of 18 candidates, ten subjects were eventually selected on the basis of:

(a) achieving hearing threshold levels no better than -10 dB HL and no worse than 20 dB HL at all frequencies (in accordance with ANSI Standard S12.6) and,

(b) providing experimenter approved performance on a set of definitive criteria based upon the general descriptions for the selection of subjects in accordance with ANSI Standard S12.6 (3.4.2.2).

The criteria referred to in item (b) above were intended to provide a more definitive approach to the selection of subjects for REAT testing under laboratory conditions than those referred to in the ANSI Standard and alluded to in the Canadian Standard. Figure 2 presents a scheme for the selection criteria employed in this study. Our selection criteria were directed toward describing the behaviours of subjects at each of three phases of the REAT procedures; (a) initial screening of subjects, (b) conditions for participation in the project, and (c) monitoring of performance during the testing situation. As our intent in arriving at descriptions of subject behaviours was to be as objective as practically feasible under the three phases of the REAT procedures, we referred to our criteria as "pragmatic descriptors" of the subjects' behaviours. A rationale for this approach to subject selection, training, and monitoring under REAT testing procedures has been presented previously [12].

Under the testing schedule two subjects were alternated on each test day, providing a substantial rest period for each subject between test procedures. Each individual subject wore the same protector for the entire test. The attenuation threshold for each listener was based on measures of open thresholds made on three separate trials and on measures of occluded thresholds made on the same number of trials. The occluded and unoccluded trials were alternated. On each separate trial the hearing protector under test was refitted by the subjects under the supervision of the experimenter. All muff-type PHPDs were worn in the over-the-head position.

III. RESULTS AND DISCUSSION

A summary of the overall results obtained from the REAT evaluation of the PHPDs is shown in Table 1. Included are the NRR and CSA ratings given by the manufacturer or inferred from the data supplied by them. The data obtained during this study is broken down to indicate whether (a) the PHPD had been preconditioned (PC) or was as received (new) (b) the data was collected using the Hughson-Westlake (HW) method or the automatic (auto) procedure. For the Safeco 290, the PHPD was also retested after the subjects gained experience and the results are shown for both tests. As outlined above, the Canadian standard includes an extensive preconditioning procedure which is to be done before the REAT tests. This preconditioning, which in some respects is similar to the British standard [13], is not done in the ANSI procedure. The comments in Table 1 summarize the physical changes in the protectors which were noted after the preconditioning. For the PHPDs tested two of them showed minor damage which could lower their effectiveness. The other three were virtually undamaged as noted by visual inspections.

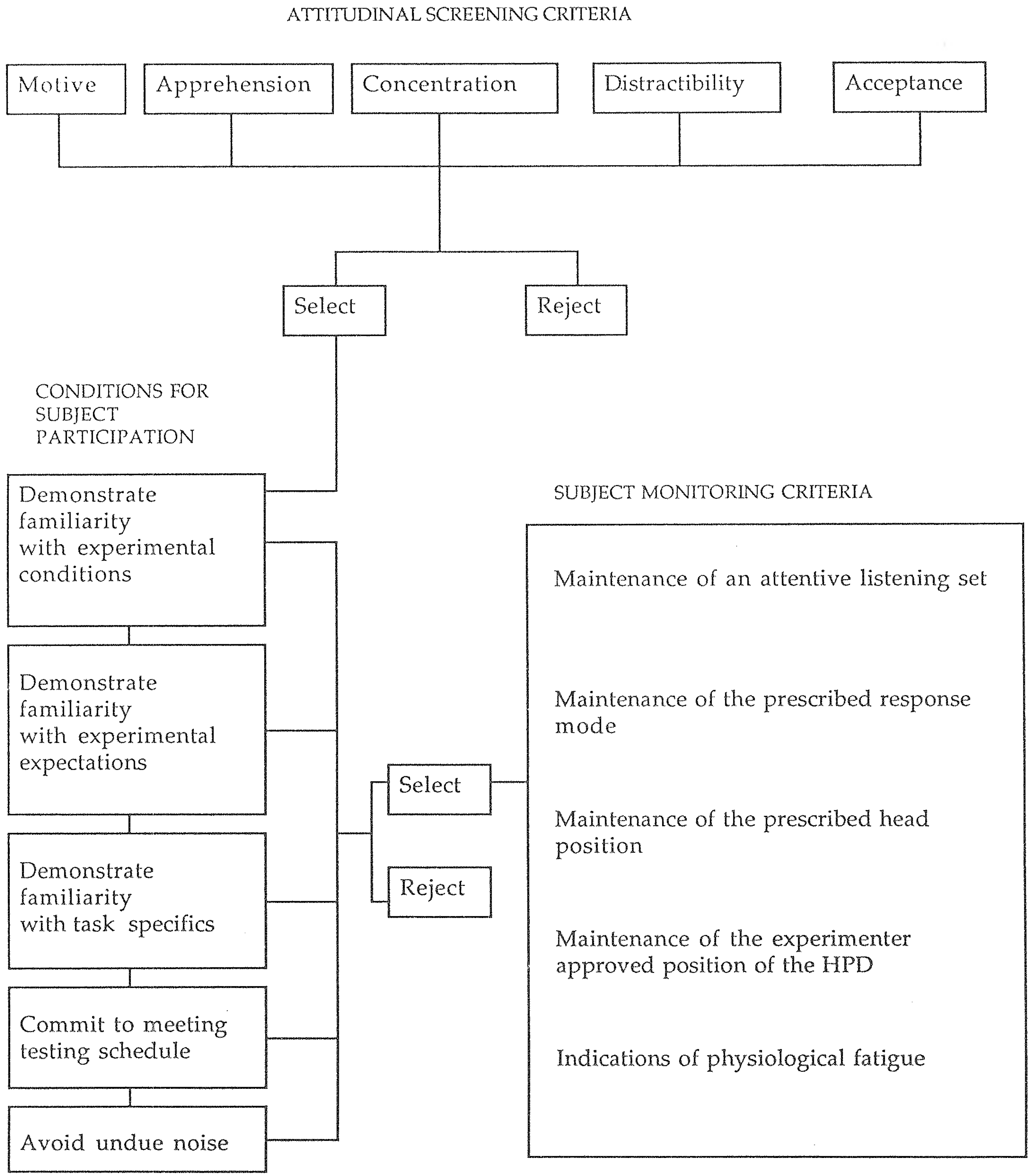

Fig. 2 Pragmatic Descriptors of Subject Behaviors

Table 1

Summary of Comparisons of REAT Test Data for PHPDs

PHPD	Manufacturer	REAT Data NRR	REAT Data CSA	MEANU REAT Data NRR	MEANU REAT Data CSA	Preconditioning Effects
Safeco 290	Safeco Manfrg	23	A			
PC/Inexp. Listen				22	A	Negligible
PC/Exp. Listener		23	A			
EAR 1000	Cabot Corp	24	B			
PC/H-W Method				20	B	Cushions wrinkled
PC/Auto Method				21	B	and slightly deformed
Bilsom 2315	Bilsom Int'l	24	A			
PC/H-W Method				19/20	B	Negligible-
New/H-W Method				19/20	B	headband
New/Auto Method				20	B	cushion became loose
Peltor H7A	Peltor Inc	27	A			
PC/Auto Method				25/26	A	One cushion
New/Auto Method				25	A	split
Hellberg No	Hellberg	24	AL			
PC/Auto Method				25	A	Negligible inner cup foam yellowed

All muffs tested in the over-the-head position

The results of the REAT data which compare new versus preconditioned muffs are shown in Figures 3 and 4 for two different muff manufacturers. Figure 3 was obtained using the Hughson-Westlake method while Figure 4 used the automatic procedure. The four points (2 for each test) which are shown at 1000 Hz are a result of the repeat of 1000 Hz 1/3 octave threshold at the conclusion of each subjective evaluation (see section II, subsection A). For both these PHPDs there is no clear indication of the new protector having either higher or lower attenuation than the preconditioned one. Even though at lower frequencies the new PHPD is generally slightly higher in attenuation than the preconditioned, this difference is well within the variations expected from the standard deviations of the data (see the lower curves in Figures 3 and 4). At the medium to high frequencies the data cross several times so that no trend as to which of the protectors exhibits better attenuation characteristics is shown. Overall there is no significant difference in the results.

A more detailed comparison of the new versus preconditioned muffs was done using the ATF. Shown in Figures 5 and 6 are the results when each side of two pairs of the preconditioned and two of the new protectors were evaluated. For each of the PHPDs, each of the two cups was evaluated 3 times for a total of twelve tests. Figure 5 shows the results for the Bilsom 2315 while Figure 6 is for the Peltor H7A. For the Bilsom the only statistically significant variations occurred at the high frequencies (3150-8000 Hz) as the variation between new and preconditioned was up to twice the standard deviation of the results. The Peltor H7A (Figure 6) showed less variation as all the differences were well within the experimental error. With the small differences between new and preconditioned

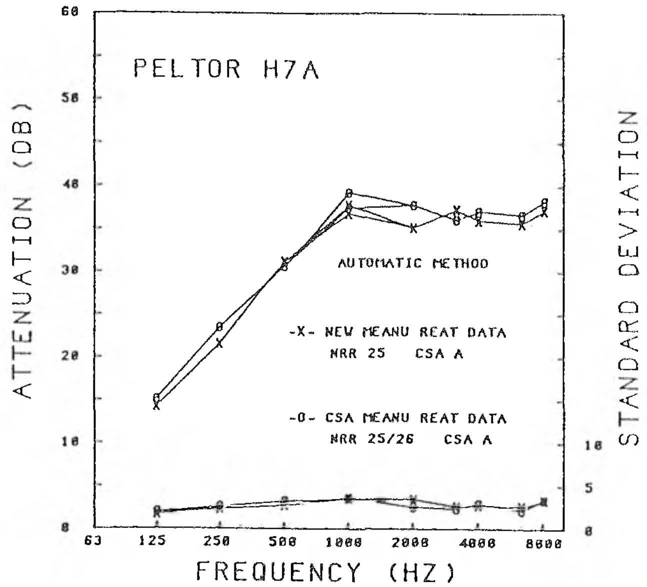

Fig. 3 Comparison of New Versus Pre-Conditioned Muffs by MEANU - Bilsom 2315

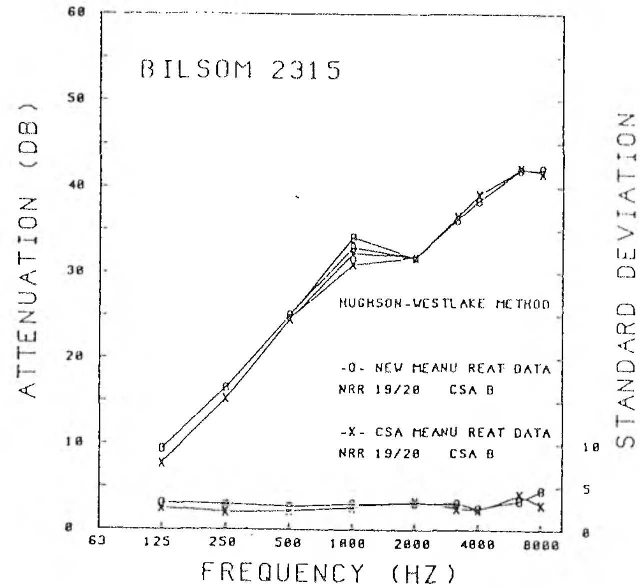

Fig. 4 Comparison of New Versus Pre-Conditioned Muffs by MEANU - Peltor H7A

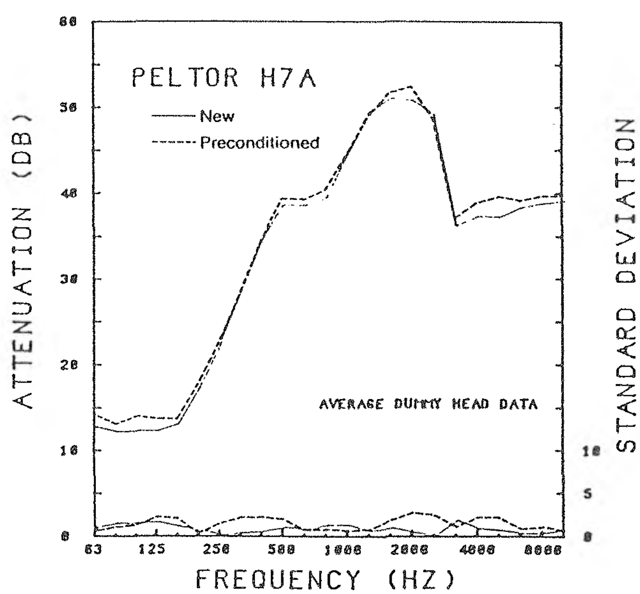

Fig. 5 Dummy Head Data - Bilsom 2315

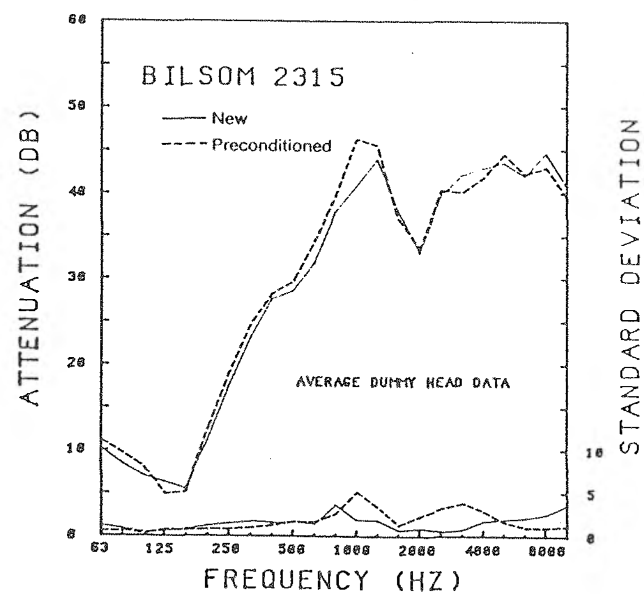

Fig. 6 Dummy Head Data - Peltor H7A

PHPDs shown on the ATF, it is not surprising that the REAT data is also quite consistent. The small physical changes which had bee noted during the preconditioning did not appear to cause any overall degradation of the subjective attenuation properties.

It is thought that the selection of subjects and the procedures used in determining their thresholds is responsible for much of the variations seen between labs evaluating the same PHPDs. In order to reduce certain of the variables associated with subject selection, the procedures outlined in section IIC were implemented. As a further check on consistency of each subject all threshold data began and ended with an evaluation at 1000 Hz. This was an attempt to ensure that the subject remained consistent over at least the one test. This retesting showed the subjects mean variation at the 1000 Hz band was 1 dB using the Hughson-Westlake procedure and 1/2 dB when using the automatic procedure. Even with this small variation in the REAT data there could be an overall change in a protector's NRR rating. (This is the reason that there are sometimes two NRR values given in Table 1).

A further check on the consistency of the subjects was done by retesting the first protector evaluated in the program. This meant that the same subjects evaluated the same PHPD after evaluating 4 additional protectors. The subjects were now more experienced since none had any previous experience as listeners prior to the first tests. The results of this test are shown in Figure 7 and indicate relatively little change in either the average attenuation shown or in the standard deviations of the results. It appears that the added experience did not affect the results under the testing procedures used.

A second variable, the audiometric procedure, was also investigated. The use of both the Hughson-Westlake and the automatic procedures with the same PHPD allowed a direct comparison of results obtained using the two techniques. Figure 8 shows no consistent variation in either the average values or the standard deviations obtained. This is true even though the subjects preferred the automatic procedure and it was consistently faster to administer. The subjects reported that they felt more involved in the testing when the automatic procedure was implemented. As mentioned previously, the retesting at 1000 Hz showed an increase of precision when the automatic procedure was used.

While it is easy to calculate the various ratings of PHPDs after the data is collected, it is important to appreciate what level of precision is actually possible. Figure 9 shows the mean of the standard deviations for 8 of the subjects used for the REAT tests and includes their individual results for all the protectors they evaluated. In general, this indicates that a standard deviation of less than 2 dB was not obtained except for a limited number of subjects. To attempt more precision than is indicated by these results would seem fruitless. PHPD rating schemes such as NRR using a 1 dB resolution are somewhat misleading.

To compare the variability of the REAT tests with those in the ATF measurements, a series of 10 measurements were made using one cup of a particular protector. The results of this test are shown in Figures 10 and 11 for two protectors. Overall the standard deviation is somewhat less than 1 dB but shows some frequencies which consistently have larger variations than others. This appears to occur when there are rapid changes in slope of the attenuation curve and are thought to be due to slight shifts in resonances in the muff/ATF cavity

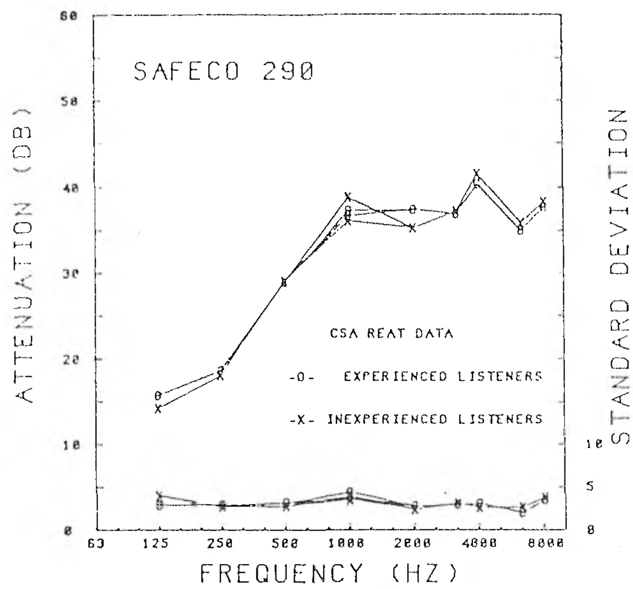

Fig. 7 Comparison of Experienced and Inexperienced Listeners for the SAFECO 290

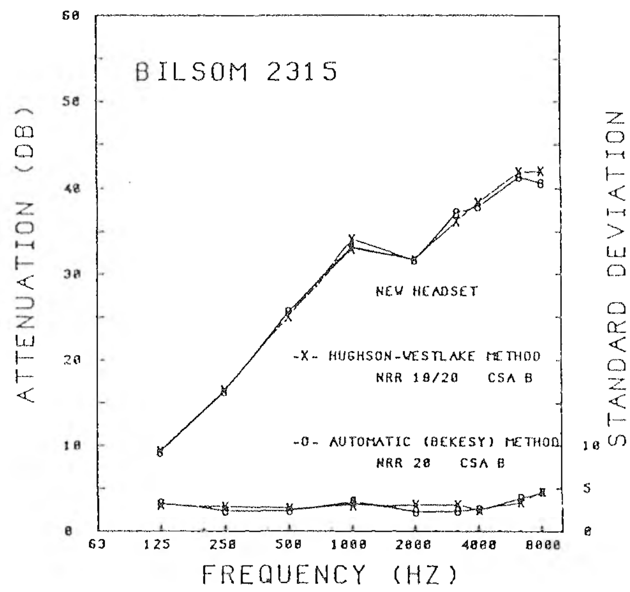

Fig. 8 Comparison of Testing Procedures for the Bilsom 2315

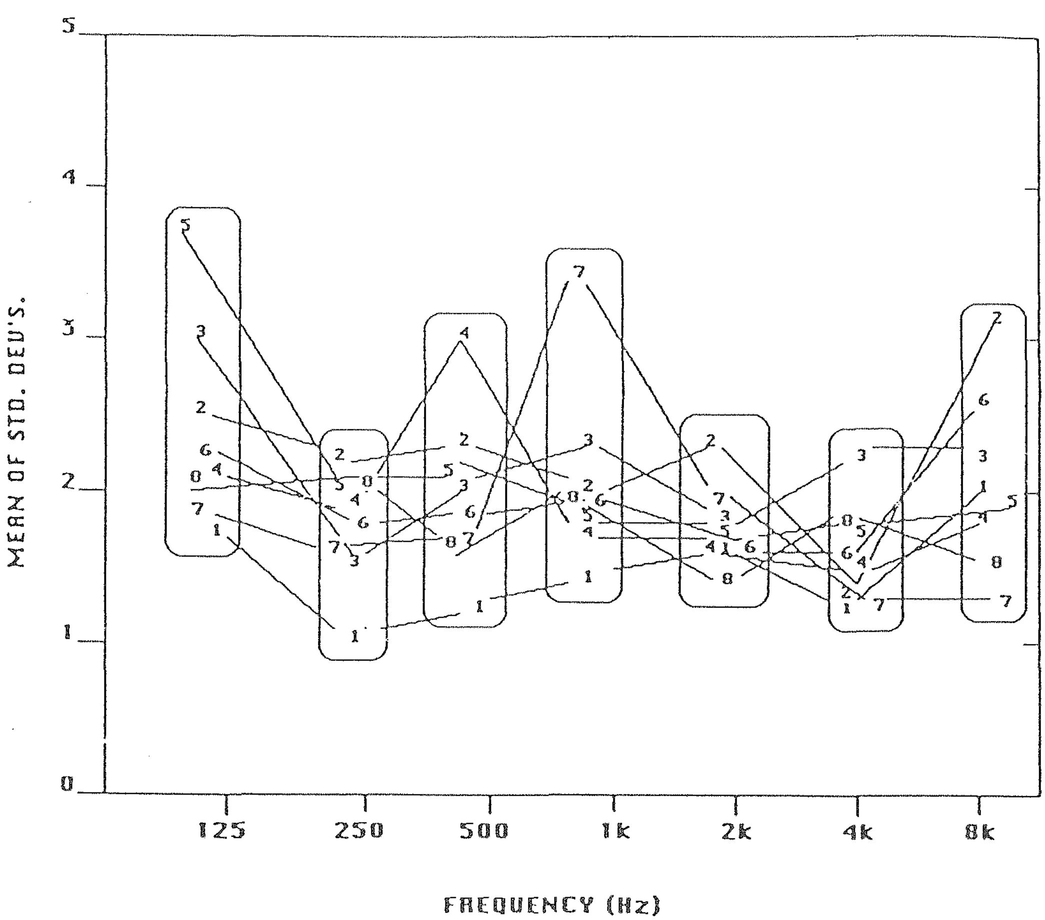

Fig. 9 Mean Standard Deviations for REAT Results for Eight Subjects Over Ten Hearing Protectors

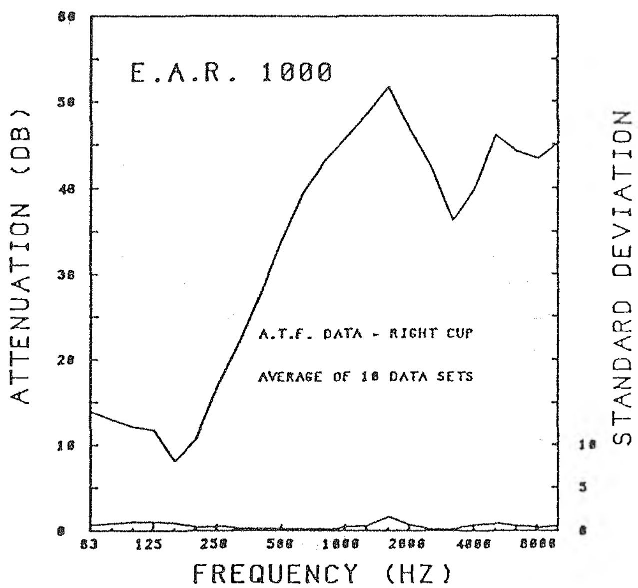

Fig. 10 Summary of ATF Data for E.A.R. 1000

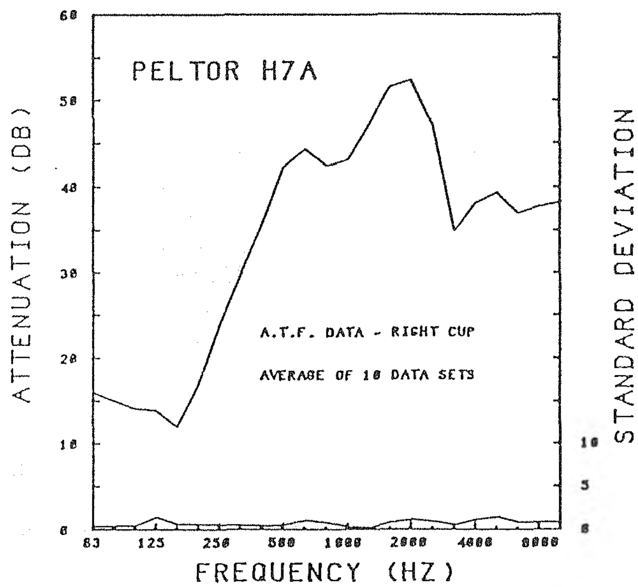

Fig. 11 Summary of ATF Data for Peltor H7A

which occur when the muff is repositioned before each measurement.

IV. SUMMARY AND CONCLUSIONS

This article describes the results of a study conducted to evaluate muff-type PHPDs in accordance with the Canadian standard CSA Z94.2-M1984, and its references to the ANSI standard S12.6-1984. Five PHPDs were pre-conditioned following CSA requirements and tested under REAT procedures described under ANSI S12.6-1984. The attenuation results for the pre-conditioned PHPDs under REAT conditions were compared with new units of the same makes and models of PHPDs in an "as-received" condition from the supplier. Ten subjects participated in the REAT testing procedures and were selected in accordance with a paradigm developed for the study and reported in detailed elsewhere [12].

Of the five PHPDs subjected to the CSA pre-conditioning procedures, two suffered damage which could impair the effectiveness of the units, while the remaining three PHPDs showed only negligible effects from the procedures.

To demonstrate the attenuation differences which might occur between "new" vs pre-conditioned PHPDs under REAT procedures, the results obtained for two different PHPDs were presented. No trend was apparent for the slight differences obtained for the "new" vs pre-conditioned versions for the two PHPDs tested.

A further comparison of the new vs pre-conditioned versions of the same PHPDs was carried out using the ATF described in ANSI S3.19-1974 (R1979). The results for two pairs of new and pre-conditioned versions of the same makes and models of PHPDs showed differences between the two versions which were generally within the experimental error expected for the tests.

Aside from the definitive approach to subject selection, referred to as pragmatic descriptors of subject behaviours, other procedures were introduced which were intended to reduce subject variability during the REAT testing conditions. These included retesting each subject at 1000 Hz during the REAT procedures to determine the reliability of the subjects' responses; retesting the first PHPD evaluated in the study after the subjects had acquired experience under the REAT conditions; and testing all subjects under two audiometric procedures (Hughson-Westlake and automatic audiometry) for one PHPD. The results for each of these procedures indicated no consistent variation in either the average values or the standard deviations obtained. However, the subjects' preference under REAT conditions was for the automatic audiometric procedure.

The mean of the standard deviations obtained for each of 8 subjects over all ten PHPDs under REAT conditions, was in the order of 2dB. This result indicates that the NRR use of a 1 dB resolution could be somewhat misleading.

The following conclusions may be drawn from the study:

1. Pre-conditioning muff-style PHPDs accordidng to CSA Z94.2 does not degrade the acoustic performance of the PHPDs.

2. It does not seem reasonable to use a rating scheme which differentiates between PHPDs on standard deviation values of less than 2-3 dB.

3. Automatic audiometric procedures should be standardized for REAT testing procedures.

4. Computer prompting in REAT testing permits increased precision in obtaining auditory thresholds.

V. ACKNOWLEDGMENTS

The authors wish to acknowledge the support of the Alberta Department of Community and Occupational Health who funded this project under the Occupational Health and Safety Heritage Grant Program (Grant 85-60R). Copies of the study report [8] can be obtained from this agency at 5th Floor, 10709 Jasper Avenue, Edmonton, Alberta, T5J 3N3.

REFERENCES

[1] CSA Standard Z94.2 - M1984 "Hearing Protectors", Canadian Standards Association, Rexdale, Ontario 1984.

[2] Shipton, M.S., "Hearing Protector Testing - an EEC Inter-laboratory Comparison", Proceedings 12th Inter. Cong. on Acoustics, Toronto, B9-3, July 1986.

[3] Poulsen, T., "Nordic Round Robin Test on Hearing Protection Measurements", Proceedings 12th Inter. Cong. on Acoustics, Toronto, B9-4, July 1986.

[4] Berger, E.H., Kerivan, J.E. and Mintz, F., "Inter-Laboratory Variability in the Measurement of Hearing Protector Attenuation", Sound and Vibration Vol. 16, #1, 1982.

[5] Forshaw, S.E., "The Revised CSA Standard on Hearing Protectors", Proceedings Amer. Speech & Hearing Assoc., Toronto, November 1985.

[6] ANSI Standard, S12.6 - 1984, "Method for the Measurement of the Real-Ear Attenuation of Hearing Protectors", American National Standards Institute, New York, 1984.

[7] Behar, A., "Field Evaluation of Hearing Protectors", J. Noise Control Engineering, 24, 1, p. 13-18, 1985.

[8] Faulkner, M.G., Gough, K.H. and Kiss, G., "Evaluation of Personal Hearing Protection Devices Under Z94.2 - M1984", Report to Alberta Community and Occupational Health under Grant 85-60R, May 1987.

[9] ANSI Standard S3.19 - 1974 (R1979), "Method for the Hearing Protectors and Physical Attenuation of Ear Muffs". American National Standards Institute, New York, 1979.

[10] Kiss, G.C., Faulkner, M.G. and Gough, K.H., "Automated Psychoacoustic Test Procedures", Proceedings Acoustics Week '87, Calgary, p. 192-197, October 1987.

[11] Martin, Frederick N., "Introduction to Audiology", 3rd Edition, Prentice Hall Inc., Englewood Cliffs, 1986.

[12] Gough, K.H., Kiss, G.C. and Faulkner, M.G., "Pragmatic Descriptors of Subject Behaviours Under REAT Laboratory Conditions", Proceedings Acoustics Week '87.

[13] BS 5108-1974, "Method of Measurement of the Attenuation of Hearing Protectors at Threshold", British Standards Institute, London, 1974.