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Original Article

The effect of wearing an anti-flash hood on the noise attenuation of earmuffs

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Abstract: The insertion losses of four pairs of earmuffs, including one noise-excluding headset, were measured in one-third octave bands in a diffuse broadband noise field using a head-like acoustic test fixture. The acoustic test fixture contained realistic ear simulators with microphones at the eardrum positions. The insertion losses were measured (i) with the earmuffs on their own, (ii) with the earmuffs worn over an anti-flash hood, and (iii) for one earmuff, with the earmuff worn under the hood. The other three earmuffs could not be fitted under the hood. The insertion loss of the anti-flash hood on its own was also measured. Wearing an anti-flash hood *under* the earmuffs greatly reduced the protection against noise, by 20–23 dB at high frequencies, by 17–20 dB at middle frequencies, by 12–16 dB at low frequencies, and by 16–20 dB overall. Only one earmuff was slim enough to fit under an anti-flash hood. Wearing an anti-flash hood *over* this earmuff had only a marginal effect on the earmuff insertion loss, of the order of 1 dB. If anti-flash hoods could be designed to fit over other types of earmuffs and headsets, the protection of these earmuffs and headsets would be virtually maintained.

Key words: Sound attenuation, Insertion loss, Anti-flash hoods, Earmuffs, Hearing protection, Hoods

Introduction

An ‘anti-flash hood’, also known as a ‘flash hood’, is a fire-resistant hood intended to protect the wearer’s head, face and neck from severe flash burns caused by short exposures to radiant heat from fire or explosions. Anti-flash hoods are worn by navy personnel whenever a fire breaks out onboard ship, during periods of heightened readiness, or in training exercises. They are usually worn with anti-flash gloves or gauntlets to protect hands and arms. Anti-flash gear is only intended to protect against short, unexpected exposures to flames or radiant heat; it is not intended to protect against long exposures to fire or intense heat. Although anti-flash gear may be worn by first-response fire-fighting parties, regular shipboard fire-fighters will usually wear full flame-resistant and insulating protective gear similar to that worn by civilian fire fighters.

Other personal protective equipment, such as safety glasses, a helmet or hearing protection, may also be needed. Hearing protection or noise-excluding headsets will be mandatory in areas or compartments where high levels of continuous or impulsive noise are expected from engines, machinery or weapons fire. Without an anti-flash hood, earmuffs are the most widely used type of hearing protection, so it is natural that personnel may also use earmuffs when an anti-flash hood is needed. It has been observed that, on a few occasions where hearing protection is required in conjunction with an anti-flash hood, earmuffs have been worn over the hood. Wearing earmuffs over the hood has been considered to be a rapid process without introducing delays in the operations being conducted.

In the EU and the UK, earmuffs must be tested in accordance with EN 352-1:2002[1)] and the sound attenuation must be measured in accordance with the real-ear-at-threshold (REAT) method of ISO 4869-1:2018[2)]. An earmuff supplier must then provide attenuation data, in the form specified in ISO 4869-2:2018[3)], along with the earmuff. The attenuation data provided routinely by the manufacturer or supplier is for the earmuff worn under ideal conditions on its own. It would be impractical to measure the attenuation of earmuffs used with every conceivable item of personal protective equipment (PPE). However, other PPE can reduce the sound attenuation of earmuffs by disturbing the seal against the head[4–10)]. Earmuffs worn over hoods can only provide limited attenuation. Since 1993, if not earlier, CEN has advised that if a hood is worn, hearing protection should be worn under the hood[11)]. CEN’s recently revised guidance on using hearing protection with other protective equipment is that “hearing protectors are usually used under a hood”, though “some hoods may be designed to be worn under specific hearing protectors”[12)].

The objective of this study was therefore to determine whether the protection afforded by earmuffs is reduced when an anti-flash hood is worn, either over or under the earmuffs. To this end the insertion losses of earmuffs commonly issued to service personnel were measured on an artificial head or test fixture (i) when worn on their own, without a hood, (ii) when worn over an anti-flash hood, and (iii) if possible, when worn underneath an anti-flash hood.

The insertion loss of an earmuff is the sound level measured at the ear (in decibels) *without* the earmuff minus the sound level (in decibels) at the ear *with* the earmuff. The term ‘sound attenuation’ is usually, though not always, reserved for the noise reduction measured on a panel of human listeners using the ‘real-ear at threshold’ method, whereas the term ‘insertion loss’ is used when the actual sound levels, rather than thresholds, are measured. This distinction is useful and is used in this paper.

The insertion loss can be measured in each one-third octave band separately. These one-third octave band insertion losses can be used to calculate a noise spectrum and level at the ear by subtracting the insertion loss in each one-third octave band from the ambient external noise in that band. The effective overall A-weighted noise level at the ear can then be calculated by A-weighting the bands and summing the values in each band.

Equipment and procedures

The earmuffs and anti-flash hood

Four pairs of earmuffs were tested. These were:

- Thunder T3 earmuffs with headband, from Howard Leight by Honeywell (NSN-4240-99-130-8500) (Honeywell, Roseville, CA, USA)
- H515FB (Bull’s Eye I) folding earmuffs with headband, from 3M Peltor (NSN-4240-99-773-1232) (3M Peltor, UK)
- H10A earmuffs with headband, from 3M Peltor (NSN-4240-99-957-6913) (3M Peltor, UK)
- Inductive Loop Headset, (“Magloop”) from HBS Electronics Ltd. (NSN-5965-99-754-1087) (HBS Electronics Ltd., Sudbury, Suffolk, UK)

One sample of each was tested. All were new, and all are currently in service with the UK military including the Royal Navy. Fig. 1 shows the four types of earmuff.

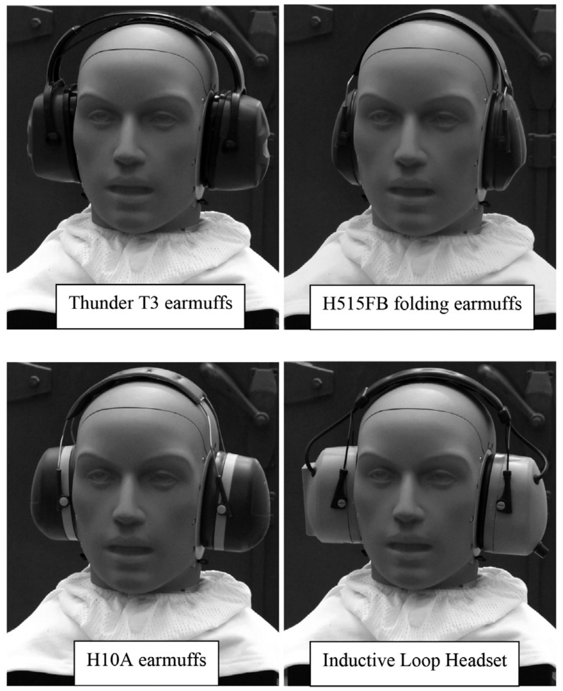

Fig. 1. Hearing protectors used in the study.

Although described in its instruction leaflet as a headset, the HBS model does not have a microphone.

The anti-flash hood (NSN-8415-99-130-4874) (Cooneen Group, Fivemiletown, County Tyrone, Northern Ireland,

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*NSN is the NATO Stock Number, essentially a part number to uniquely identify equipment used by the military services.

UK) was 100% cotton and produced by Cooneen Defence Ltd. It is currently in use with the UK Royal Navy.

Facilities and instrumentation

The tests were carried out in the Small Reverberation Chamber[13] of the Institute of Sound and Vibration Research at the University of Southampton. This chamber is isolated from the rest of the building and has non-parallel walls, with mean edge lengths of 6.40 m × 4.60 m × 4.30 m high, and a volume of 131 m^3. The measured background noise levels were below 30 dB(A) and 40 dB(C). The insertion losses were measured using a G.R.A.S. 45CB Acoustic Test Fixture (ATF)[14] (G.R.A.S. Sound and Vibration, Skovlytoften, Holte, Denmark).

The G.R.A.S. 45CB ATF is a head and shoulders simulator designed specifically for the objective measurement of insertion loss of active and passive hearing protectors in high-level continuous or impulsive noise. It is designed to comply with ANSI/ASA S12.42[15] *"American National Standard Methods for the Measurement of Insertion Loss of Hearing Protection Devices in Continuous or Impulsive Noise Using Microphone-in-Real-Ear or Acoustic Test Fixture Procedures"*. ANSI/ASA S12.42 specifies the features of an ATF that are needed to realistically model a median real head for measuring the insertion loss of hearing protection. These features include the pinnae, simulated flesh around the ears, a median length of ear canal, heating to body temperature, sufficient self-insertion loss, and occluded ear simulators and microphones with appropriate acoustic impedance. When the 2010 version of the standard was issued there were no acoustical test fixtures (ATFs) or head and torso simulators (HATS) that included all these features.

Other designs of ATF are available which model a median human head, ears and torso to different extents. The ISO 4869-3;2007[16] ATF is a solid metal cylinder with sloping ends, one of which contains a pressure microphone. Insertion losses are derived from the sound levels measured at the microphone with and without the earmuff cups. The ATF is basic and measurements are repeatable, which makes it ideal for its main purpose of quality control. No attempt is made to replicate any of the anatomical features of an ear, head and torso, or the acoustic impedance of a human ear, and ISO 4869-3 specifically states insertion losses are not representative of the real-ear attenuation or protection afforded by an earmuff.

More complex ATFs include the KEMAR (Knowles Electronic Manikin for Acoustic Research) manikin[17] and the B&K type 4128 Head and Torso Simulator (HATS)[18]. These are simulators of the human head and ear and comply with IEC/TS 60318-7:2017[19]. Although these model the general features of the external ear, including the ear canal and the acoustic impedance, both were primarily designed for the evaluation of hearing aids, telephones and headphones, and binaural sound recording or the assessment of noise, vibration and harshness (NVH) rather than for assessing hearing protection. Berger[20, 21] has identified in detail the limitations of KEMAR which make it unsuitable for measuring insertion losses of hearing protection representative of insertion losses measured on a median person. The B&K HATS also has many of the same deficiencies as the KEMAR manikin, although the measurement of insertion loss of hearing protection is one of the applications given in the product data sheet[18]. In particular, with this HATS, there is no flesh-like surface around the ear for the earmuff to seal against, and the discontinuity between the hard material of the head and the flesh-like material of the pinnae may cause leakage. Neither the KEMAR manikin nor the B&K HATS include a heating element.

More complex still, the ATF as described by Parmentier *et al.*[22] from the Institut Franco-Allemand de Recherches de Saint-Louis (ISL) is anthropometrically correct with high self-insertion loss, and flesh simulation around the ear, but the ear canal is shorter than required by ANSI/ASA 12.42 and it lacked the heating to body temperature. Harmery *et al.*[23] have reported that the ISL ATF has since been modified to incorporate heating as required by the ANSI/ASA standard, but does not mention whether the length of the ear canal has been increased to comply with the standard.

The G.R.A.S. 45CB used here is therefore the only commercially available ATF specifically designed to include all the features that the ANSI/ASA standard specifies as necessary for measuring the insertion loss of hearing protectors.

Fig. 2 is a schematic diagram of the equipment used.

A 10-second long sound file, with two non-coherent channels of broadband (pink) noise, was generated on a Dell Latitude E6410 laptop PC (Dell Technologies, Round Rock, TX, USA) using the Adobe Audition (v3) program. The sound file was replayed repeatedly as a 'loop' from the laptop sound card to two, two-channel Yamaha TX4n power amplifiers (Yamaha, Hamamatsu, Shizuoka, Japan). The power amplifiers incorporate programmable gain and equalization. One amplifier was set to feed frequencies above 100 Hz to two Community R2-52Z full range loudspeakers (Community Professional Loudspeakers, Chester, PA, USA), while the other power amplifier fed frequencies below 100 Hz to two Turbosound B18 sub-woofers (Turbosound Ltd, Horsham, West Sussex, UK).

The main full-range loudspeakers were placed on top of the sub-woofers and were directed into two corners of the reverberant chamber to optimise the diffuse field in the room.

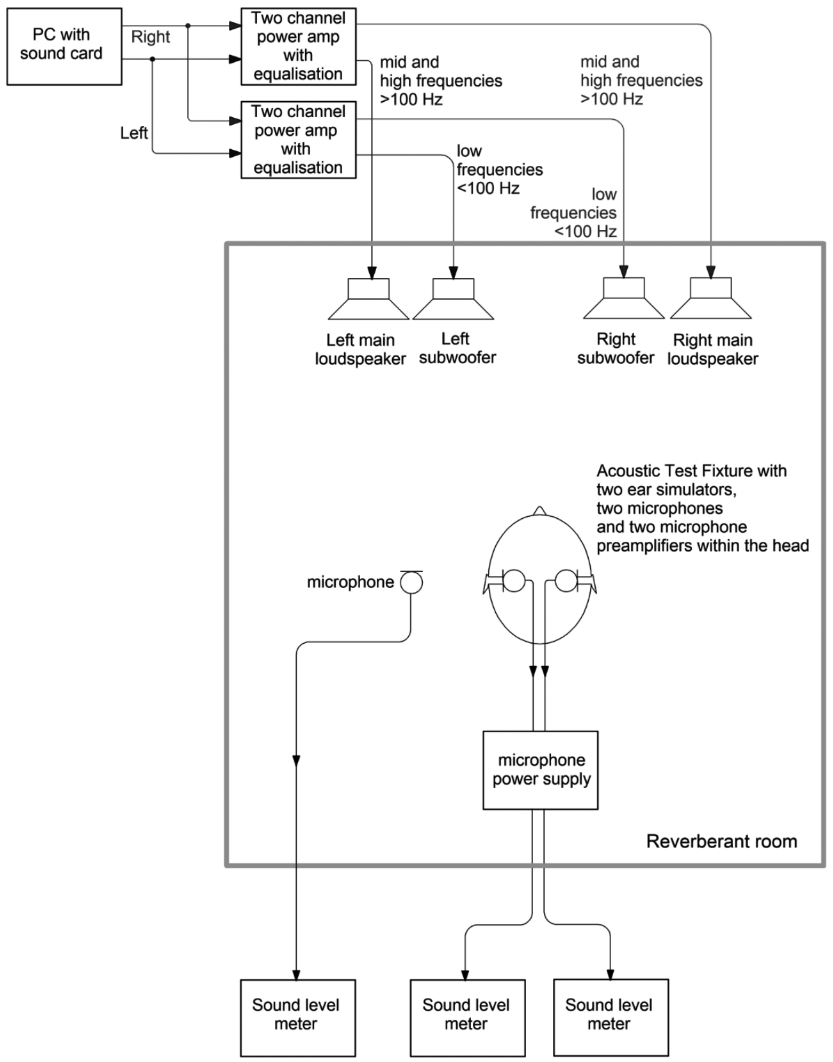

Fig. 2. Block diagram of the equipment used.

The microphone and preamplifier of a Brüel & Kjær (B&K) type 2250 sound level meter (Brüel & Kjær, Nærum, Denmark) were positioned 30 cm from the side of the manikin's head at ear height, and were connected via an extension cable to the input of the sound level meter in the control room. Fig. 3 shows the spectrum of the sound field measured with this microphone in the reverberant room. Seventy-five tests were carried out in all, each lasting 30 s, and the spectrum in Fig. 3 shows the mean level in each of the one-third octave bands averaged over all the tests. The figure also shows the average A- and C-weighted levels; these are the L_{Aeq} and L_{Ceq}, respectively.

The spectrum in the room was stable and repeatable; the standard deviation of the band levels over all the tests was ≤ 0.1 dB from 31.5 Hz to 8 kHz, and ≤ 0.2 dB from 10 kHz to 20 kHz. The mean overall levels were 100.6 dB(A) and 101.2 dB(C), each with a standard deviation ≤ 0.3 dB.

Measurements of insertion losses during previous tests in the same room with the same loudspeaker set up have shown that the sound field in this room, measured without a human subject or ATF, meets the requirements of ANSI/ASA S12.42-2010 clause 8.2.1 for uniformity in all frequency bands, and clause 8.2.2 for directionality in all frequency bands up to and including 8 kHz. The sound field also meets the requirements for a random incidence field in clause 5.2.2 of ISO 4869-3:2007 up to and including 8 kHz.

The ATF incorporates two G.R.A.S. type RA0045-S7 ear simulators, one in each ear. Each ear simulator contains a G.R.A.S. type 40BP 'quarter-inch' pressure microphone at the eardrum position, and each microphone is connected

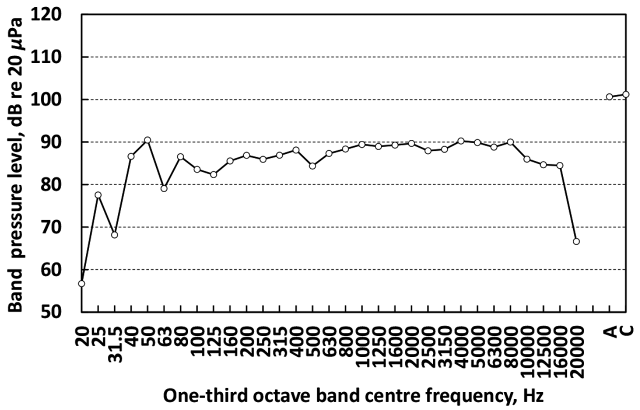

Fig. 3. The one-third octave band spectrum in the room.

via a G.R.A.S. type 26AS-S3 to an ATF output socket. The preamplifiers were each connected to a B&K type 2250 sound level meter in the control room via a G.R.A.S. type 12AA microphone power module. There were, therefore, three sound level meters in use during the tests, one to measure the noise field in the room with a microphone at 30 cm from the manikin's head, one to measure the sound levels at the manikin's left eardrum microphone, and one to measure the levels at the manikin's right eardrum microphone.

Each of the sound level meters was programmed to measure the one-third octave band spectra, and the overall average A- and C-weighted level (the L_{Aeq} and L_{Ceq}) over the 30 s duration of each test. The measured levels and spectra from each test were saved to a memory card within each sound level meter.

The calibration of each ATF ear simulator and its associated sound level meter (B&K 2250) was checked before and after the tests using a B&K type 4220 pistonphone and a G.R.A.S. type RA0157 adapter. The calibrations were stable; pre- and post-test calibration difference was less than 0.05 dB for the left ear, but slightly poorer, 0.4 dB for the right ear. Although the difference of 0.4 dB for the right ear was higher than desirable, the experimental design, which interleaved measurements at the occluded and unoccluded ear for each hearing protector, would have ensured that any short-term change in the sensitivity of the right ear simulator would cancel out in calculating the insertion loss.

The calibration of the external microphone, 30 cm from the head, and its associated sound level meter was checked before and after the tests using a B&K type 4231 sound level calibrator (Brüel & Kjær, Nærum, Denmark). The calibration was stable; the difference between the calibrations before and after the tests was less than 0.04 dB.

The B&K 2250 sound level meters are calibrated every two years and the B&K 4231 calibrator is calibrated annually; these are calibrated in a DANAK accredited laboratory. The B&K 4220 (Brüel & Kjær, Nærum, Denmark) pistonphone is calibrated annually in a UKAS accredited laboratory.

Procedure

Seventy-five individual tests were carried out in total, divided into 5 sets of 15. In each of the 75 tests, the sound from the loudspeakers was turned on and the sound levels were measured at the left and right ears of the ATF and at the external microphone position in the room.

The full sequence of tests was as follows, with the test number showing the order in which the tests were carried out:

Set 1	*Test number*
Bare head/ATF open ear	1, 4, 7, 10, 13
Thunder T3 earmuffs on ATF	2, 5, 8, 11, 14
Thunder T3 earmuffs over hood on ATF	3, 6, 9, 12, 15

Set 2	*Test number*
Bare head/ATF open ear	16, 19, 22, 25, 28
H515FB earmuffs on ATF	17, 20, 23, 26, 29
H515FB earmuffs over hood on ATF	18, 21, 24, 27, 30

Set 3	*Test number*
Bare head/ATF open ear	31, 34, 37, 40, 43
H10A earmuffs on ATF	32, 35, 38, 41, 44
H10A earmuffs over hood on ATF	33, 36, 39, 42, 45

Set 4	*Test number*
Bare head/ATF open ear	46, 49, 52, 55, 58
HBS Electronics Ltd, Inductive Loop Headset on ATF	47, 50, 53, 56, 59
HBS Electronics Ltd, Inductive Loop Headset over hood on ATF	48, 51, 54, 57, 60

Set 5	*Test number*
Bare head/ATF open ear	61, 64, 67, 70, 73
Hood only on ATF	62, 65, 68, 71, 74
H515FB earmuffs under hood on ATF	63, 66, 69, 72, 75

The first set of tests, Set 1, enabled the insertion loss of the Thunder T3 earmuffs and of the Thunder T3 earmuffs worn over an anti-flash hood to be calculated. First, in test number 1, the sound levels were measured at the open ears of the bare head of the ATF and in the room. Then in test number 2, the Thunder T3 earmuffs (Honeywell, Roseville, CA, USA) were placed on the ATF, and the sound levels at the ears and in the room were measured again. In test number 3, the anti-flash hood was placed over the ATF with the Thunder T3 earmuffs over the hood, and the sound levels at the ears and in the room were measured again. These three tests were then repeated, as tests 4, 5 and 6 and so on, until sound levels at the ears and in the room had been measured five times for each of the test conditions. That completed the first set of tests. ANSI/ASA S12.42-2010 for measuring insertion loss on an ATF requires only two measurements at the open ears and two at the protected or closed ears while ISO 4869-3:2007 requires a minimum of three. Given the potential variability in the fitting of earmuffs over an anti-flash hood, five measurements were undertaken with the open ears and five with the protected ears in this study.

The second, third and fourth set of tests followed the same pattern, but with the H515FB earmuffs, the H10A earmuffs and the HBS headset instead of the Thunder T3 earmuffs respectively.

For the fifth set, the intention was to measure the insertion loss of the anti-flash hood on its own and the insertion losses of each hearing protector worn under the hood. However, only the H515FB earmuffs (3M Peltor, UK) were slim enough to be worn under the hood. Measurements with the anti-flash hood over the other earmuffs were not possible; the hood was too tight to cover both the left and right earcups of these simultaneously, so no tests could be carried out despite spending time attempting to achieve a fit. It was concluded that no-one would attempt to wear the hood over earmuffs in practice unless the earmuffs were the slimline Peltor H515FB (3M Peltor, UK), or the similar Peltor H61FA (3M Peltor, UK) which was not tested here. Even with slimline earmuffs, in practice it would be far quicker and easier to put the hood on first and the earmuffs second.

Fig. 4 shows the Peltor H515FB (3M Peltor, UK) slimline earmuffs worn over (left) and under (right) the anti-flash hood.

Fig. 4. The Peltor H515FB earmuffs worn over and under the anti-flash hood.

The neck of the anti-flash hood was narrower than the part of the hood that covered the head, and some effort was required to stretch the narrow neck of the hood and to pull it over the ATF head each time. It was decided to leave the hood loosely around the neck of the ATF when not needed, as shown in Fig. 1. The presence of the hood around the neck will have a negligible effect on the sound levels at the ears of the ATF bare head. However, the hood could easily be pulled up into position on the ATF when required, without risk of tearing it.

Either earcup of the could be placed over either ear of the ATF, as the two earcups of each pair of earmuffs were identical with no front/back or left/right indication. These three pairs of earmuffs were placed on the ATF without regard to which earcup covered which ear.

One earcup of the HBS Inductive Loop Headset (HBS Electronics Ltd., Sudbury, Suffolk, UK) incorporated a battery compartment for an AA cell, while the other was fitted with a volume control knob. As with the earmuffs, this headset was designed to be worn either way round, with the battery compartment on either the left or right ear of the ATF. However, as the two earcups were slightly different and identifiable, the earcup with the battery compartment was always placed on the ATF's right ear.

In each test, the earmuffs were placed on the ATF so that the earcups fully enclosed the ear and the headband was then adjusted so that it touched the top of the ATF. The delay, or settling time, between fitting the earmuffs on the ATF and starting the test measurements exceeded 30 s for each test.

Results

Measured insertion losses

Fig. 5 shows the mean insertion losses measured on the left ear and on the right ear of the ATF for each of the four earmuffs on their own, and for each of the four earmuffs when worn over the anti-flash hood. Fig. 5 also shows the insertion loss of the anti-flash hood on its own.

Apart from the HBS headset, the two sides of each pair of earmuffs are nominally identical and the earmuffs can be worn either way round. These earmuffs were placed on the ATF randomly, i.e. without assigning the earcups to the left or right ear. The insertion losses measured on the left ear of the ATF would therefore be expected to be virtually the same as those measured on the right ear with the same pair of earmuffs.

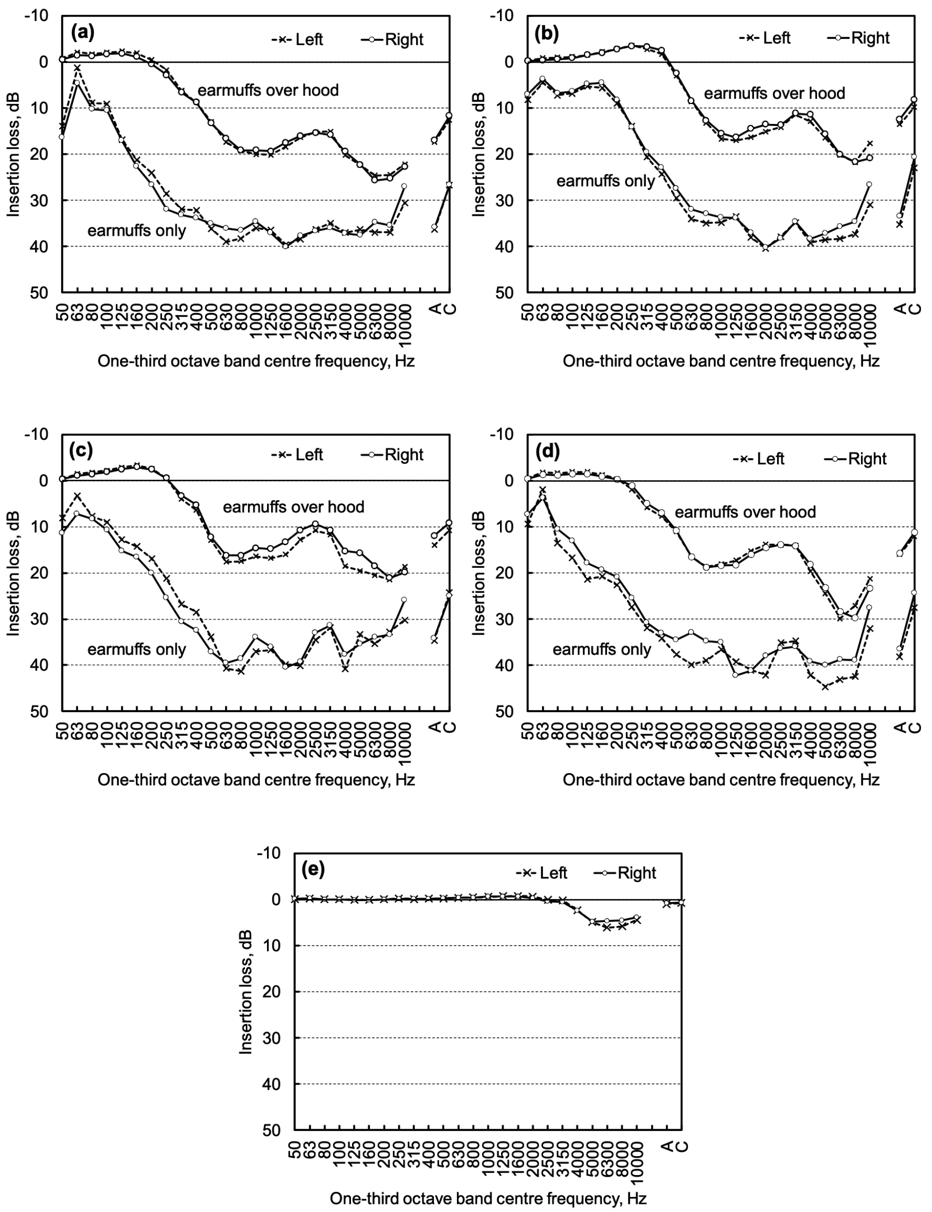

Fig. 5. Mean insertion losses of the earmuffs and the anti-flash hood measured on the left and right ears of the ATF. (a) Thunder T3 earmuffs alone and over the anti-flash hood. (b) Peltor H515FB earmuffs alone and over the anti-flash hood. (c) Peltor H10A earmuffs alone and over the anti-flash hood. (d) HBS inductive loop headset alone and over the anti-flash hood. (e) Anti-flash hood only.

Fig. 5 shows that the differences in measured insertion losses between the left and right ear of the ATF were indeed small in most cases. Student's t-tests were used to compare the mean insertion loss and the variance in insertion loss measured on the left and right ears of the ATF for each type of hearing protection in each one-third octave band. Although small, the differences between left and right ears were sufficient to reach statistical significance in some frequency bands for some earmuffs. These statistically different insertion losses are all listed in Table 1.

For clarity, the frequencies with 1% significance have not also been shown in the 5% column. Forty entries in Table 1 were significant at the 5% level out of a total of 216 possible entries (9 hearing protectors × 24 frequency bands). This is greater than might occur by chance, but as the insertion loss on the right ear was sometimes greater and sometimes less than on the left, there was no systematic left-right difference.

Table 1. Frequency bands in which insertion loss differed between left and right ears.

Hearing protection	Frequency bands in which insertion loss differed between left and right ears, Hz	
	At 5% significance	At 1% significance
Thunder T3	630; 1,000	6,300; 8,000; 10,000
Thunder T3 over hood	--	--
Peltor H515FB	400; 500; 630; 800, 1,000; 6,300	5,000; 10,000
Peltor H515FB over hood	--	--
Peltor H10A	4,000	800; 1,000; 10,000
Peltor H10A over hood	1,000; 1,250; 1,600; 2,000; 2,500; 5,000	4,000
HBS Inductive loop	--	630; 800; 1,000; 2,000; 4,000; 5,000; 6,300; 8,000; 10,000
HBS Inductive loop over hood	4,000	5,000; 6,300; 8,000; 10,000
Hood only	6,300; 8,000	--

The HBS Inductive Loop Headset (HBS Electronics Ltd., Sudbury, Suffolk, UK) was not symmetrical and was always placed on the ATF with the volume control knob on the ATF left ear. The anti-flash hood was also not reversible. Some small differences in insertion loss measurements between the two ears might therefore be expected with the HBS headset, with the anti-flash hood, and with the HBS headset worn over the anti-flash hood. The reason or reasons for the significant differences between left and right ears for the other earmuffs, which are nominally symmetrical, and when placed on the ATF without differentiating between the left and right earcups, are not known. One possibility is that the earmuffs happened to be fitted with the same earcup on the same ear of the ATF each time, and that there were small but real differences between the earcups. Another possibility is that the sound field in the room was not perfectly diffuse, despite meeting the requirements of ISO 4869-3:2007 and ANSI/ASA S12.42-2010 for directionality in all frequency bands up to and including 8 kHz. Possibly the small left-right differences could be the result of a fitting order artefact whereby the experimenters tended to place an earcup over the right ear before the left ear, although equal care was taken in fitting both ears. Small differences at low frequencies could result from a leakage path between the earcup and the ATF with a slightly different fit on the two ears. However, despite being *statistically* significant in some cases, the differences between the insertion losses measured on the right and those on the left ear are small, and not significant in practice. Consequently, the best estimate of the insertion loss of each earmuff alone, or of each earmuff in combination with the anti-flash hood, will be obtained by combining the measurements at the left and right ears of the ATF. Accordingly, the data from the left and right ears were pooled to give the mean insertion losses calculated from both ears. These insertion losses are shown in Fig. 6.

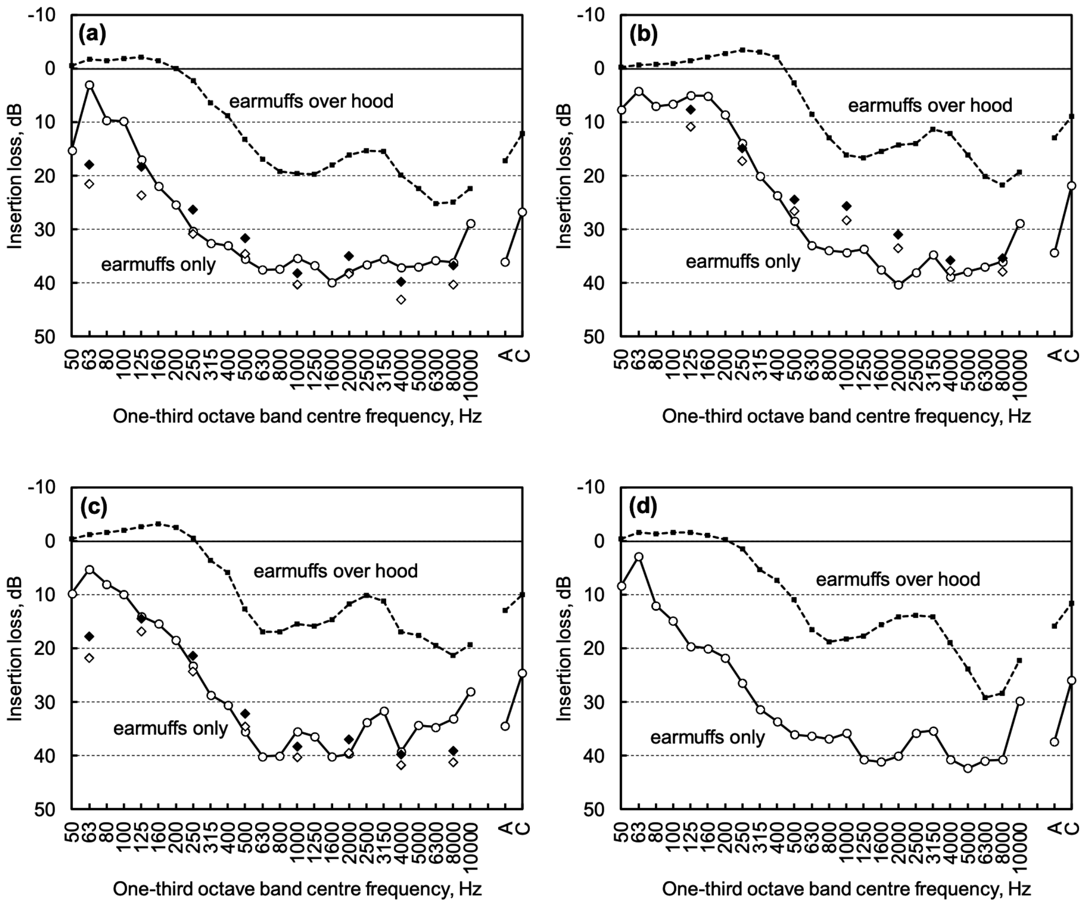

Fig. 6. Mean insertion losses of the earmuffs and the anti-flash hood, both ears, and manufacturers' attenuation values for the earmuffs (if available). (a) Thunder T3 earmuffs alone and over the anti-flash hood. (b) Peltor H515FB earmuffs alone and over the anti-flash hood. (c) Peltor H10A earmuffs alone and over the anti-flash hood. (d) HBS inductive loop headset alone and over the anti-flash hood. ◊-Manufacturers' declared mean attenuation values. ♦-Manufacturers' declared Assumed Protection Values (*APVs*). The manufacturer's attenuation and *APVs* were not available for the HBS inductive loop headset at the time of writing, but *H*, *M*, *L* and *SNR* values were supplied on instruction leaflet.

The mean insertion losses are also tabulated in Tables 2 (earmuffs alone) and 3 (earmuffs over the anti-flash hood), together with the margins of error. The means and margins of error were calculated within each set of measurements listed in *Procedure* above.

Figs. 6 (a) and (c) show that the insertion losses of the Thunder T3 and the Peltor H10A as measured on the ATF without a hood are broadly similar to the manufacturers' declared mean attenuation values, as measured using the REAT method on adults, over most of the frequency range, except at the low frequency extreme of 63 Hz and high frequency extreme of 8 kHz. However, Fig. 6 (b) shows that the insertion loss of the Peltor H515FB folding earmuffs is 6 dB to 7 dB greater than the manufacturer's declared mean attenuation at the middle frequencies of 1,000 Hz and 2,000 Hz. There is not enough information to determine whether the insertion loss measurements are too great, the manufacturer's data too low, or some combination of the two, but this needs further investigation. Berger[24] and Berger and Kerivan[25] both identify the occlusion effect whereby physiological noise can mask test stimuli in REAT methods. However, this effect is only apparent below 500 Hz so cannot explain the difference between the manufacturer's REAT data and the measured insertion loss for the Peltor H515FB earmuffs. Berger and Kerivan also noted discrepancies between REAT and insertion loss measurements at 2 kHz when bone conduction limited the attenuation for hearing protection measured on real ears but not the insertion loss measured on ATFs. However, the difference between the manufacturer's REAT attenuation and insertion loss at 1 kHz and 2 kHz for the Peltor H515FB earmuffs cannot be attributed to bone conduction, otherwise the effect would also be apparent for the Thunder T3 (Honeywell, Roseville, CA, USA) and Peltor H10A earmuffs (3M Peltor, UK), both of which give greater attenuation than the Peltor H515FB earmuffs.

Table 2. Insertion losses of the earmuffs alone, mean of both ears

Band centre frequency, Hz	Insertion loss, dB							
	Thunder T3		H515FB		H10A		HBS headset	
	Mean	Margin of error	Mean	Margin of error	Mean	Margin of error	Mean	Margin of error
50	15.18	±2.24	7.63	±1.80	9.72	±3.52	8.35	±1.51
63	2.96	±1.98	4.12	±2.08	5.23	±2.27	2.80	±1.41
80	9.58	±1.07	6.99	±1.01	8.02	±2.41	12.00	±2.84
100	9.82	±1.12	6.60	±1.04	9.87	±2.52	14.89	±3.05
125	16.96	±1.73	5.03	±1.28	14.04	±2.63	19.60	±3.09
160	21.91	±1.82	5.08	±0.86	15.42	±1.81	20.03	±2.44
200	25.34	±2.19	8.62	±0.57	18.46	±2.37	21.73	±2.34
250	30.25	±2.29	13.97	±0.55	23.28	±2.71	26.44	±2.72
315	32.56	±1.49	20.07	±1.07	28.69	±2.72	31.31	±3.10
400	32.98	±1.18	23.59	±1.20	30.52	±2.65	33.57	±2.87
500	35.56	±1.27	28.48	±1.36	35.51	±2.50	36.07	±2.18
630	37.55	±1.52	32.98	±1.13	40.12	±1.31	36.35	±2.58
800	37.36	±1.12	33.93	±1.03	39.97	±1.04	36.85	±1.64
1,000	35.34	±0.62	34.26	±0.59	35.44	±1.12	35.79	±0.66
1,250	36.73	±0.74	33.66	±0.38	36.38	±0.73	40.73	±1.12
1,600	39.84	±1.81	37.54	±0.89	40.18	±0.63	41.09	±0.34
2,000	38.00	±1.51	40.31	±1.24	39.67	±0.99	40.06	±1.46
2,500	36.50	±1.55	38.02	±1.52	33.81	±0.90	35.73	±1.03
3,150	35.43	±1.28	34.72	±0.81	31.66	±0.74	35.33	±1.10
4,000	37.09	±1.89	38.76	±1.61	39.22	±1.83	40.63	±1.16
5,000	36.91	±1.64	37.83	±0.96	34.34	±1.84	42.33	±1.29
6,300	35.80	±0.96	36.99	±1.26	34.67	±1.34	40.92	±1.16
8,000	36.15	±0.79	36.01	±1.60	33.12	±2.17	40.69	±1.26
10,000	28.80	±1.00	28.81	±1.34	28.06	±1.46	29.75	±1.23
A-weighted	36.05	±0.94	34.34	±0.73	34.43	±0.86	37.32	±0.66
C-weighted	26.68	±1.30	21.81	±1.08	24.60	±2.67	25.92	±1.83

The insertion loss is within the range of the mean insertion loss ± the margin of error with 95% confidence.

The manufacturer's attenuation values were not available for the HBS headset, and a comparison between the attenuation values and the insertion losses was therefore not possible.

The Peltor H515FH folding earmuffs were the only earmuffs which were slim enough to fit *under* the anti-flash hood. Fig.7 (a) shows the insertion losses of these earmuffs when worn underneath the anti-flash hood as measured at the left and the right ears of the ATF. The differences in measured insertion losses between the left and right ears were small, and the data from the left and right ears were pooled to give the mean insertion loss calculated from both ears. These data are shown in Fig. 7 (b). The mean insertion losses and the margins of error are tabulated in Table 4.

Table 3. Insertion losses of the earmuffs over the anti-flash hood, mean of both ears

Band centre frequency, dB	Insertion loss, dB							
	Thunder T3 over hood		H515FB over hood		H10A over hood		HBS headset over hood	
	Mean	Margin of error	Mean	Margin of error	Mean	Margin of error	Mean	Margin of error
50	−0.61	±0.11	−0.24	±0.06	−0.40	±0.08	−0.44	±0.09
63	−1.77	±0.51	−0.62	±0.50	−1.27	±0.54	−1.58	±0.62
80	−1.50	±0.55	−0.76	±0.51	−1.65	±0.52	−1.41	±0.54
100	−1.88	±0.27	−0.97	±0.10	−2.07	±0.21	−1.68	±0.19
125	−2.08	±0.63	−1.50	±0.34	−2.67	±0.49	−1.68	±0.55
160	−1.50	±0.65	−2.10	±0.15	−3.17	±0.30	−1.13	±0.48
200	0.01	±0.86	−2.83	±0.29	−2.52	±0.71	−0.35	±0.69
250	2.27	±0.79	−3.49	±0.39	−0.58	±0.93	1.50	±0.85
315	6.41	±0.87	−3.04	±0.84	3.62	±1.09	5.35	±1.08
400	8.75	±1.10	−2.12	±1.07	5.80	±1.15	7.26	±1.04
500	13.12	±1.02	2.71	±0.89	12.60	±0.88	10.86	±0.69
630	16.95	±0.94	8.47	±0.83	16.92	±1.16	16.48	±0.71
800	19.23	±0.95	12.94	±0.70	16.84	±0.94	18.71	±0.84
1,000	19.56	±0.86	16.06	±0.70	15.49	±1.03	18.24	±1.06
1,250	19.73	±0.97	16.70	±0.84	15.80	±1.31	17.73	±1.19
1,600	17.95	±0.87	15.40	±1.42	14.63	±1.58	15.59	±1.12
2,000	16.16	±0.83	14.28	±1.29	11.75	±0.99	14.15	±1.02
2,500	15.29	±1.23	13.93	±1.15	10.07	±0.66	13.88	±0.91
3,150	15.46	±1.57	11.30	±1.15	11.21	±0.77	14.09	±1.09
4,000	19.80	±1.94	12.14	±1.61	16.90	±1.52	18.86	±1.68
5,000	22.33	±2.08	16.07	±1.27	17.63	±1.85	23.84	±1.49
6,300	25.13	±2.53	20.14	±1.35	19.48	±1.53	29.12	±1.66
8,000	24.86	±2.26	21.70	±1.79	21.28	±1.58	28.37	±2.08
10,000	22.43	±1.58	19.24	±2.18	19.25	±1.67	22.28	±2.04
A-weighted	17.15	±1.06	12.97	±0.90	12.95	±0.86	15.81	±1.00
C-weighted	12.13	±0.62	8.97	±0.59	9.93	±0.61	11.62	±0.56

The poorer insertion loss below 125 Hz on the left ear of the ATF compared to the right indicates suggests a small acoustic leak. This is possibly caused by the hood being fitted over the right ear first, then pulled over the left in each case, resulting in a slightly poorer fit on the left ear, which was not apparent during the testing.

Discussion

Comparison of measurements on the left and right ears of the ATF

The Thunder T3, the H515FB and the H10A earmuffs each have earcups which are not designated left or right. Assuming the two sides of each pair of earmuffs are interchangeable and the earmuffs are placed on the ATF randomly, without differentiating between the left and right earcups, then the insertion losses measured on the left ear of the ATF should be the same as on the right, within the experimental uncertainty and repeatability of fitting. Although there were some statistically significant differences between the insertion losses as measured on the left and right ears, these differences were too small to be of practical significance and the insertion losses were averaged over the two ears. In practice a user would don these earmuffs randomly without differentiating between left and right earcups, so the averaging of the left and right insertion losses will also reflect the repeated practical use of these muffs.

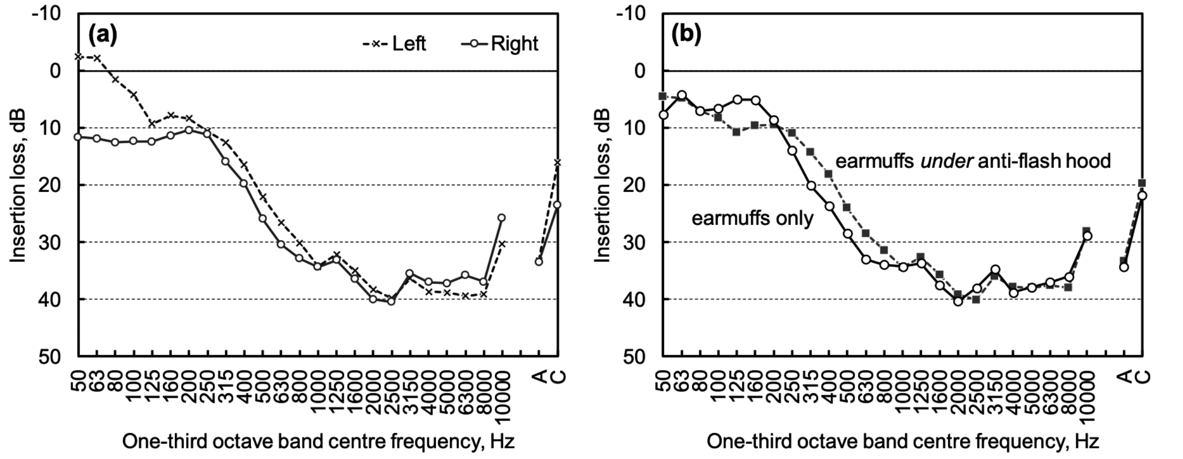

Fig. 7. Mean insertion loss of the Peltor H515FH earmuff worn *underneath* the anti-flash hood. (a) mean of measurements on the left and right ears of the ATF separately. (b) mean of measurements on both ears, with the insertion loss of the earmuffs alone, from Fig. 6 (b), for comparison.

The HBS Inductive Loop Headset, however, has differences between the two earcups. One earcup contains the battery compartment and the other a volume control. Although this headset can be worn either way round, with the volume control on either the left or the right, it was always tested with the earcup containing the battery compartment on the right ear and the earcup with the volume control on the left ear of the ATF. At most frequencies, the insertion losses of the two earcups were similar, but the earcup with the volume control had slightly poorer insertion loss in the 63 Hz, 5,000 Hz and 6,300 Hz bands. This may or may not be a peculiarity of the individual sample tested. Whether a regular user, who could be right-or left-handed, would always wear this headset the same way round, with the volume control always on the same side, is not known. However, for the purposes of these tests, the insertion losses were averaged over both the left and right side of the headset.

Effect of wearing the earmuffs or the headset over an anti-flash hood

Fig. 6 compares the insertion losses of the earmuffs or headset without a hood, with the insertion losses of the same earmuffs or headset when worn over the anti-flash hood. In every case, the anti-flash hood reduced the inser-

Table 4. Insertion losses of the earmuffs under the anti-flash hood, mean of both ears.

Band centre frequency, dB	Insertion loss, dB			
	H515FB under hood		Hood only	
	Mean	Margin of error	Mean	Margin of error
50	4.58	±6.50	−0.10	±0.05
63	4.81	±5.99	−0.30	±0.62
80	7.01	±5.04	−0.06	±0.60
100	8.27	±4.15	−0.08	±0.14
125	10.84	±2.00	0.05	±0.35
160	9.57	±1.62	0.06	±0.13
200	9.38	±1.26	−0.06	±0.19
250	10.89	±1.14	−0.20	±0.05
315	14.25	±1.26	−0.12	±0.56
400	18.11	±1.28	−0.17	±0.57
500	24.00	±1.66	−0.25	±0.37
630	28.47	±2.14	−0.39	±0.41
800	31.47	±1.68	−0.46	±0.23
1,000	34.30	±0.79	−0.64	±0.19
1,250	32.64	±0.74	−0.69	±0.07
1,600	35.72	±0.95	−0.75	±0.13
2,000	39.12	±1.43	−0.50	±0.43
2,500	40.13	±1.20	0.24	±0.61
3,150	35.90	±1.18	0.32	±0.84
4,000	37.80	±1.46	2.30	±1.75
5,000	37.98	±0.88	4.80	±1.11
6,300	37.58	±1.03	5.39	±0.90
8,000	37.96	±0.76	5.13	±0.75
10,000	28.04	±1.43	4.15	±0.76
A-weighted	33.32	±0.90	0.88	±0.68
C-weighted	19.74	±3.94	0.69	±0.59

tion loss of the hearing protection considerably in all frequency bands. In the lowest frequency bands, the insertion losses were slightly negative, indicating that the noise levels at the covered ear were higher than at the uncovered ear.

The reduction in insertion losses is not surprising, because the anti-flash hood prevents the cushions of the earmuff from sealing to the head, allowing sound to leak under the earmuffs to the ears. This is particularly so when the extra thickness of the hood's seams passes under the earmuff cushions. This leak could also account for the slight amplification at low frequencies, akin to cupping a hand over the ear.

The insertion losses measured by the reduction in the A-weighted sound levels, labelled as 'A' in Fig. 6, give single number estimates of the insertion loss of each pair of earmuffs with or without the anti-flash hood. However, the reduction in the A-weighted sound levels strictly only applies to the pink noise spectrum used in these tests: in the real world, the reduction in the A-weighted level will depend on the ambient noise spectrum. To quantify the reduction in insertion loss, it is more useful to consider the high-, medium- and low frequency ranges separately.

When quoting the attenuation of a hearing protector, the manufacturer or supplier has to declare, not only the mean attenuation and assumed protection values (*APV*) in each one-third octave frequency band spaced one octave apart, but also the '*H*', '*M*', and '*L*' values, which give a measure of the attenuation for predominantly high, medium and low frequencies respectively. The *H*, *M* and *L* values are calculated from the assumed protection values measured using the REAT method on human adults following a procedure described in international standard ISO 4869-2. The *H*, *M* and *L* values enable an estimate of the sound attenuation to be made from the A- and C-weighted sound levels if a full octave-band spectrum is not available. An '*SNR*' or Single Number Rating must also be computed as described in ISO 4869-2.

In this study, the procedure of ISO 4869-2:1994[26] was used to calculate the *H*, *M*, *L* and *SNR* values, but using the insertion loss measurements from our tests rather than the attenuation values from the standard measurement procedure with real listeners. The mean insertion losses in the 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz, 4,000 Hz and 8,000 Hz one-third octave bands were noted for each hearing protector with and without the anti-flash hood. One standard deviation was subtracted from the mean in each case, as in the calculation of the assumed protection values, and the resulting *APV*-like values were used to calculate the *H*, *M*, *L* and *SNR* values in accordance with the standard. Because these *H*, *M*, *L* and *SNR* values were calculated from insertion losses measured on an ATF, rather than the usual attenuations measured with human listeners, they will be referred to as H_{ATF}, M_{ATF}, L_{ATF} and SNR_{ATF} in this paper, to distinguish them from the standard *H*, *M*, *L* and *SNR* values.

The H_{ATF}, M_{ATF}, L_{ATF} and SNR_{ATF} values calculated here enable insertion losses and the effect of anti-flash hoods on earmuff insertion losses to be summarised and compared in the same low-, medium- and high-frequency bands, and overall, that are used with human data from ISO 4869-1.

Note that the previous, 1994, version of ISO 4869-2[26] was used in our calculations, not the most recent issue, ISO 4869-2:2018[3]. In the 1994 edition, the *H*, *M*, *L*, and *SNR* values were computed from the group mean and standard deviation in each test band, and this method can be applied to the ATF measurements. In the 2018 version, the attenuation values are computed from the individual attenuation values of each subject and then combined to provide both a mean value and a standard deviation value so that the population distribution can be estimated. This is not possible for measurements on an ATF. However, according to the foreword of the 2018 version, the values derived using this edition deviate from those derived using the previous 1994 edition by less than 1 dB before rounding.

Table 5 shows the calculated values of H_{ATF}, M_{ATF}, L_{ATF} and SNR_{ATF} for each earmuff type with and without the anti-flash hood.

In all cases, wearing the anti-flash hood under the earmuffs or headset severely degraded the noise reduction of the earmuffs at all frequencies.

Effect of wearing the anti-flash hood over the earmuffs

Table 5 also shows the calculated values of H_{ATF}, M_{ATF} and L_{ATF} for the H515FB earmuffs when worn under the anti-flash hood:

- the H_{ATF} was reduced by 1 dB, from 36 dB to 35 dB,
- the M_{ATF} was reduced by 1 dB from 23 dB to 22 dB,
- the L_{ATF} remained unchanged at 12 dB, and
- the SNR_{ATF} remained the same at 25 dB.

These reductions are small; essentially the anti-flash hood made little difference in practice.

Compatibility of anti-flash hoods with hearing protection

Hearing protection and anti-flash hoods are both essential in some situations, and therefore must be capable of being used together without significantly degrading the degree of protection of either. One such situation may include protecting the operator of a weapon whereby flash might occur during firing. It is noted that this would be an unlikely event but, should it occur, the combination of anti-flash hood and hearing protection should protect the operator.

Table 5. Summary of insertion loss values in the low, medium and high frequency bands and overall

Hearing protection	Insertion loss on the ATF, dB			
	H_{ATF}	M_{ATF}	L_{ATF}	SNR_{ATF}
Thunder T3 earmuffs	36	31	19	32
Thunder T3 earmuffs over the anti-flash hood	16	12	4	14
H515FB earmuffs	36	23	12	25
H515FB earmuffs over the anti-flash hood	13	6	0	9
H515FB earmuffs under the anti-flash hood	35	22	12	25
H10A earmuffs	36	29	18	31
H10A earmuffs over the anti-flash hood	14	9	2	12
HBS inductive loop headset	39	31	19	33
HBS headset over the anti-flash hood	16	11	3	13

EN 13189-1:2020[27] requires earmuffs to pass a test of ignitability. A steel rod heated, to around 650 ºC is applied for 5 seconds. If any part of the earmuff ignites or continues to glow after the removal of the rod, the earmuff fails the ignition test. Any exposure to a fire sufficiently intense and sustained to damage the hearing protection would therefore cause severe burns to the person, and anti-flash gear would not be used under those conditions. Anyone exposed to such intense heat would wear full protective clothing similar to that worn by civilian firefighters, not anti-flash gear.

The tests with the H515FB earmuffs showed only a slight degradation in the insertion loss when the anti-flash hood was placed over them, so if anti-flash hoods could be designed to fit over other types of earmuffs and headsets, the protection of these earmuffs and headsets would be virtually maintained.

An alternative in most cases may be for personnel to wear earplugs under rather than earmuffs over the anti-flash hoods. However, earplugs need to be correctly fitted to be effective, and in practice, the rated noise attenuation may not be achieved[28, 29]. Earplugs may also not be suitable for persons with ear infections. The compressible foam earplugs currently available to service personnel take time to fit properly and time may not be available. They may also work loose and fall out of the ear into the anti-flash hood, especially if fitted in haste, and it would be impracticable to refit them without removing the hood. Premoulded or custom moulded earplugs would be a good and viable alternative. These are reasonably easy and quick to fit and are compatible with most other forms of PPE. Anti-flash hoods would not need to be redesigned. However, custom moulded earplugs are not routinely provided to most service personnel, apart from military musicians, so a change in policy would be needed.

Effect of anti-flash hoods worn under headphones

The tests carried out on the HBS headset only addressed the noise reduction; the levels of speech from the earphones was not investigated. If the insertion loss of a headset is reduced by wearing an anti-flash hood, the noise levels at the ear will increase, the speech-to-noise ratio will be reduced, and speech intelligibility will be degraded or lost. Whether earplugs could be worn under an anti-flash hood with a headset over the hood, while maintaining adequate speech communication, would need to be determined.

Using insertion loss data to assess protection

The one-third octave band insertion losses of a hearing protector, with or without an anti-flash hood, can be used to calculate a noise spectrum and level at the ear by subtracting the insertion loss in each one-third octave band from the ambient external noise in that band. The effective overall A-weighted noise level at the ear can then be calculated by A-weighting the bands and summing the values in each band. If the ambient noise spectrum is not known, the H_{ATF}, M_{ATF} and L_{ATF} values can be used to estimate the noise levels at the ear from the A-and C-weighted levels of the ambient noise using the procedure in ISO 4869-2.

Although these procedures will give a good indication of the noise levels at the ear, insertion loss measurements are not a substitute for attenuation data measured on a panel of people using the well-established standard method of ISO 4869-1. Attenuation data are already available from the manufacturers for these earmuffs used on their own, but there are no comparative data for the earmuffs when worn over or under an anti-flash hood. If earmuffs are to be worn with anti-flash hoods, the assumed protection values (*APV*), the *H*, *M* and *L* values and the *SNR* will need to be obtained at an accredited test house. Until then, the insertion losses measured here are the only data available for earmuffs worn with an anti-flash hood. Fig. 6 (a) and 6 (c) show that insertion loss measured for two of the earmuffs gives a good indication of the attenuation as measured by the ISO 4869-2 method, suggesting that insertion losses of the earmuff and anti-flash hood combinations will also be similar to the attenuation data from ISO 4869-1, but this remains to be verified.

Conclusions

The insertion losses of four earmuffs were measured in one-third octave bands using a head-like Acoustic Test Fixture.

When the earmuffs were worn over an anti-flash hood, the insertion loss at all frequencies (that is, high frequencies (H_{ATF}), medium frequencies (M_{ATF}) and low frequencies (L_{ATF})) was reduced (see Table 5). Therefore, wearing an anti-flash hood under the earmuffs or a headset greatly reduced their noise reduction. With a headset, the increase in noise at the ear would reduce speech-to-noise ratios and speech intelligibility would be degraded or lost.

Of the hearing protectors tested, the H515FB folding earmuffs were the only ones slim enough to be worn under the anti-flash hood. Wearing these earmuffs under an anti-flash hood had little if any effect on their insertion loss; the insertion loss at high frequencies (H_{ATF}) was reduced by 1 dB from 36 dB to 35 dB; the insertion loss at middle frequencies (M_{ATF}) was reduced by 1 dB from 23 dB to 22 dB; the insertion loss at low frequencies (L_{ATF}) and the single number insertion loss (SNR_{ATF}) remained unchanged at 12 dB and 25 dB, respectively.

If anti-flash hoods could be designed to fit over other types of earmuffs and headsets, the protection of these earmuffs and headsets would be virtually maintained.

As earmuffs are likely to be worn with anti-flash hoods in some naval exercises, the assumed protection, *H*, *M* and *L* values and the *SNR* for each combination of earmuff and hood should be measured in accordance with ISO 4869-1 at an accredited test house. Few tests would be needed as the number of earmuff types and anti-flash hoods regularly used by the military is small and, with few exceptions, limited to those tested here.

Premoulded or custom moulded earplugs could be worn under anti-flash hoods instead of earmuffs over the hood, but may not be universally acceptable.

Disclaimer

The contents of this publication, including any opinions and/or conclusions expressed, are those of the authors alone and do not represent UK MOD Policy.

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