Title: Verification testing of a web-based Personal Sound Attenuation (fit-testing) system.

Client: **Audiology Online Limited**
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Version 1

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Summary

Audiology Online Limited commissioned Positive Acoustics to undertake testing of an online system designed for the measurement of the level of attenuation (insertion loss) of hearing protection systems (HPDs) in real world usage.

The test is an adapted form of Real Ear Attenuation Threshold (REAT) test and is similar to that defined by ISO 4869-2: 2018 although with a number of adaptations. In particular it uses pure tones (as per audiometric screening) rather than filtered pink noise. The test is aimed at the home user for a form of 'fit testing' that would allow them to assess the actual as opposed to the specified level of protection offered by their HPDs.

Testing was undertaken on 20 inexperienced volunteer subjects (11 male and 9 female) who had been provided with custom-made earplugs (using an ER-17 filter). Users self-selected a hearing threshold value for pure tones at octave values from 250 Hz to 8 kHz with and without earplugs inserted, and the attenuation at each frequency was calculated and used to determine SNR, HML, APV and Group Attenuation values.

Results indicated that the test gave an acceptable level of reliability, with performance in line with other studies of hearing protection in real use of inexperienced subjects. Mean values were around 6 dB below manufacturer specification, which is in line with a range of other studies, in particular the HSE study of 2008.

The general conclusion is that this system provides an acceptable means of a user testing their Personal Sound Attenuation (PSA) in order to assess the actual as opposed to specified level of attenuation provided by earplugs. It is recommended to implement a Personal Attenuation Rating (PAR) calculation to produce a single number value which can be considered a comparison of an individual's attenuation to the published SNR or NRR values.

It is recommended that a study testing trained users is considered in order to assess if reliability is improved with user training in earplug fitment.

A study using the same test with small loudspeakers to test over the ear HPDs is considered insufficiently reliable at this stage to be usable, and requires further testing.

Introduction

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The test is an adapted form of Real Ear Attenuation Threshold (REAT) test and is similar to that defined by ISO 4869-2: 2018 although with a number of adaptations. In particular it uses pure tones (as per audiometric screening) rather than filtered pink noise. The test is aimed at the home user for a form of 'fit testing' that would allow them to assess the actual as opposed to the specified level of protection offered by their HPDs. The design concept of the test is that should a first test indicate a lower level of protection than expected, the user would be re instructed on insertion and invited to do the test again.

As the system is designed to be used outside of a laboratory environment using readily available equipment in the home or on-site, conventional sound reproduction systems were used in the testing process. Two variants of the test were used, one using Circumaural Headphones, and one using a small stereo loudspeaker system set up with speakers at 90 and 270 degrees to the listener, who was sat in the direct field.

This report assesses the appropriateness of the test and systems for the provision of information regarding real world attenuation of HPDs, in particular custom moulded earplugs.

Background

Hearing Protection Systems need to be rated according to the level of hearing protection (attenuation) provided to the user. These are typically rated using laboratory measurements which provide a high degree of repeatability and do not take into account the variations that are caused by differences in manufacturing, the physiology of the user or the level of experience and skill in the use of the system (particularly in fitment). These elements can cause significant variation in the actual hearing protection provided by a system to an individual (Michael 1999; IRNS, 2008; Berger, 2005; Witt, 2011).

For 'universal fit' systems (with no variation in design between systems) it is considered sufficient to test a sample of the manufacturing run of each system, as each system is identical.

Custom moulded earplugs are unique to each individual. In order to manufacture these an impression of the ear is taken using either a silicone mould which is then 3D scanned, or by using a specialized 3D scanner to directly scan the ear. The 3D scan is then used to create a new mould which is used to manufacture the earplug. There are several points in this manufacturing process which bypass the quality control procedures for universal fit systems, and so it is important to be able to check the level of real-world protection offered to an individual for custom earplugs.

1. Details of Measurements

1.1 Measurement Location

Measurements were taken in studio facilities at Solent University, Southampton. These are acoustically treated rooms designed as recording studios. Tests were run simultaneously in each of 4 rooms.

A reference background noise measurement (3 minute LA_{EQ}) was taken in each room.

1.2 Test date

Friday 8 November 2019.

1.3 Instrumentation and Apparatus Used

Make	Model	Description	Serial number
Apple	iPad Air 2	Tablet Computer	N/A
Apple	iPad Air 2	Tablet Computer	N/A
Apple	iPad Air	Tablet Computer	N/A
Apple	iPad Mini	Tablet Computer	N/A
Bruël and Kjaer	2250	Sound Level Meter	2638744
Bruël and Kjaer	4231	Calibrator	3006275
Beyerdynamic	DT770	Headphones	N/A
Beyerdynamic	DT770	Headphones	N/A
Beyerdynamic	DT770	Headphones	N/A
Beyerdynamic	DT770	Headphones	N/A

1.4 Applicable Guidance and Standards

There are no specific standards for this form of testing, as it is designed to be an unsupervised test rather than a laboratory test. A number of standards were therefore taken into account to develop the testing process and the data analysis. Research papers were also taken into account and are listed in the references.

- BS EN 352-1:2002. *Hearing Protectors – General Requirements. Part 1: Ear Muffs*
- BS EN 352-2:2002. *Hearing Protectors – General Requirements. Part 2: Ear Plugs*
- BS EN ISO 8253-1:2010. Acoustics, Audiometric Test methods. Part 1 Pure tone air and bone conduction audiometry.
- ISO 4869-1: 2018. *Acoustics – Hearing Protectors Part 1: Subjective method for the measurement of Sound Attenuation.*
- ISO 4869-2:2018. *Acoustics – Hearing Protectors Part 1: Estimation of effective A-weighted*

sound pressure levels when hearing protectors are worn.

- ISO 4869-5: 2006 *Method for estimation of noise reduction using fitting by inexperienced test subjects.*

1.5 Personnel Present

Professor Chris Barlow (Positive Acoustics Ltd)

Mark Ashmore (Audiology Online Limited)

1.6 Document overseen by

Professor Chris Barlow

2. Description of Test

2.1 Description of system under test

The system under test (SUT) is a web application for the assessment of Personal Sound Attenuation (PSA) from earplugs. It is designed to be used with home computers, tablet computers or web enabled smart phones. For the purposes of this test the application was tested using iPad tablet computers and Beyerdynamic DT770 Circumaural headphones.

The SUT provides pure tones in octave band frequencies from 250 Hz to 8 kHz, using the audio output of the computer in a similar manner to Pure tone audiometry (BS ENISO 8253-1:2010. The operator uses an on-screen slider incremented in 1 dB steps to set the level at which the first tone is just perceptible. This process is repeated for each tone and stored by the system.

The operator is then required to insert their earplugs and repeat the process and the PSA for each tone is calculated as the difference between the unoccluded and occluded ear.

This testing system is an adaptation of the Real Ear Attenuation Threshold (REAT) test, and is similar in scope to ISO 4869-5: 2006, though using pure tones rather than using filtered pink noise. Adaptations of audiometric test methods have been used in a number of cases for fit testing of earplugs (Dantscher 2015, Tufts *et al*, 2012).

The test is designed for general use so sets of sound reproduction systems typical of those available at home or on-site were used for comparative testing.

The first test used Beyerdynamic DT770 Circumaural Headphones to replay the test tones, while the other used small active multimedia loudspeakers (Genelec 6110) positioned in the direct field, 30cm away from the head and at 90 degrees and 270 degrees to the listener (directly on-axis to the left and right ears).

Both headphones and loudspeakers were connected directly to the headphone output of the iPad with no other interface or volume control. The volume setting for each iPad was set at 60% and locked so that the user was not able to adjust it during or between the tests.

Loudspeaker use is standard in REAT testing (Berger, 2005), however Circumaural headphones are considered appropriate for REAT testing where earplugs are being tested (Berger, 2005, Tufts *et al* 2015).

ISO4869-1 defines requirements for a calibrated diffuse field when loudspeakers are in use. This is impracticable in a home user environment where the user is likely to have neither the expertise nor the equipment in order to set up the diffuse field, and an alternative direct field approach was used as a test of its potential as well as a means of comparison against the use of circumaural headphones.

2.2 Sample delivery date

8 November 2019

2.3 Test Procedure

Participants:

Participating subjects were the respondents to an email for volunteers, and were selected on the basis of first response. The first 30 respondents were chosen for screening. Participants were aged between 19 and 45 years of age.

All volunteers underwent otoscopy before participation and nine respondents were discounted at this stage due excessive cerumen in the ear canal, or other aspects such as piercings of the tragus which could affect the fit of the earplug.

Twenty-one subjects had impressions taken of their ear by an appropriately qualified audiologist. These were used to manufacture custom moulded flat frequency response (ER-17) earplugs for each of the subjects.

One subject was unable to participate on the test day resulting in twenty subjects (9 Female and 11 Male) participating in the testing process.

Setup:

The test took place in a suite of recording studios with a low noise floor. A 3-minute LA_{EQ} was measured in each room to calculate the background noise level, and NR rating calculated from the measurements.

Sound was replayed from iPad tablet computers using the Safari web browser on iOS 11 or 12, using Beyerdynamic DT770 Circumaural headphones.

Method:

Each subject was required to undertake the complete test of unoccluded ear followed by occluded ear two times using headphones and once using the loudspeaker system. For a further comparison, each subject also undertook the test using the loudspeaker system and a pair of earmuff type (over ear circumaural) ear defenders.

The sequence of tests for each subject was pseudo randomized in order to reduce learning effects. Subjects undertook all versions of the tests in the same room, removing and reinserting their hearing protection for each test. Subjects were randomly allocated to each of the four rooms used for the testing.

Each user entered their data onto the system for each test and this data was collected for analysis by the system. For each user the selected hearing threshold was measured in dBFS for unoccluded and occluded ear at each tone. This was then used to calculate the PSA for each tone.

In order to compare data to manufacturer specification, this data was then used to calculate values for Assumed Protection Value (APV) as well as Single Number Rating (SNR) and High Medium Low (HML) values for the attenuation, using the method defined in ISO 4869-2:2018. Group Attenuation was calculated in line with ISO 4869-5:2006**.**

These are to be considered an adapted calculation due to the differences in the test method, but provide a means of comparing manufacturer specification which are expressed using these values to the test results.

Test-retest variation for each tone on each ear was also calculated.

3. Results

On analysis of the data the results from two subjects showed significant inconsistencies which gave negative or zero attenuation and which was assessed as user error with regards to the operation of the test, with the most likely cause being misunderstanding the order of the test process (i.e. using earplugs when an unoccluded ear was required). As participants were not observed during the test this cannot be confirmed. These results were therefore not included for analysis.

Background noise:

Background noise measurements are presented for each test room in table 1. Octave band L_{Smax} data are specified in for ISO 4869-1 :2018. This data was not measured, but the permissible values of ISO 4869-1 meet an overall Noise Rating (NR) of 41. Each room was significantly below this figure, with the highest NR being 28, and the lowest being 21.

Each room was therefore suitable for effective measurement of HPD attenuation using this test method.

Room	1	2	3	4
Level (dB LA_{EQ})	28.0	30.7	30.2	28.0
NR	21	28	25	22

Table 1: Background noise measurements & NR classification

Mean Attenuation

The mean, median and standard deviation attenuation values of the sample group for each frequency are presented in Table 2.

Frequency (Hz)	Mean Attenuation (dB)	stdev	Median attenuation (dB)
250	11.8	6.6	12
500	16.3	8.7	17
1000	16.9	7.8	17
2000	13.4	6.7	13
4000	18.1	6.9	19
8000	18.3	10.0	18

Table 2: Mean, median and standard deviation attenuation values for each tone

The mean and median values track very closely to the manufacturer specification, however there is a very high level of standard deviation which would suggest from this test that a significant proportion of subjects would not achieve the manufacturer's specified attenuation while others would achieve higher levels of protection than specification.

These results are similar to those found by a range of studies which examined the real-world attenuation of HPDs (Berger, 2005; Witt, 2011; Shultz, 2011) with around one third of users achieving higher attenuation than specified, and around one-third achieving significantly lower levels of protection.

SNR

SNR attenuation values are calculated from the sample group taking into account the standard deviation from the mean. They are presented at a probability level (the proportion of the sample which would achieve the stated attenuation). Standard data for most manufacturers is presented at the 84% level (SNR 84), meaning that 84% of subjects would achieve the stated protection.

The adapted SNR results calculated from this sample group are presented in Table 2.

SNR_j	17.7		
SNR_m	15.8	SNR_s	4.6
SNR84 (dB)	**11.0**	**SNR50 (dB)**	**16.0**

Table 2: Adapted SNR results

It is widely acknowledged that HPD performance in real world situations rarely meets specified values. The majority of countries 'derate' earplug and HPD performance (INRS, 2008), with the UK HSE suggesting that HPDs are derated by 4 dB.

SNR84 for this sample was shown to be 11 dB, which is 6 dB below the manufacturer specification. SNR50 is at 16 dB, showing that around half the sample are achieving protection close to the laboratory specification of the plugs.

These results are in line with data reported from a number of studies (HSE, 2008; Berger 2005; Witt, 2011) which found that real world attenuation is typically around 6 dB lower than the laboratory specification, with a wide standard deviation which is reduced when training in fitment is provided.

HML

HML values predict the high, medium and low frequency protection of HPDs from a sample group and use the same probability levels for a sample group as for SNR. Results calculated from the test group are shown in Table 3.

The H84 and M84 are 10 dB and the L85 is 9 dB, which are between 4 dB (H) and 8 dB (L) worse than manufacturer specifications. This shows a reduction in low frequency performance, which has also been shown in other studies.

H84 (dB)	10.0	H50 (dB)	14.0
M84 (dB)	10.0	M50 (dB)	15.0
L84 (dB)	9.0	L50 (dB)	13.0

Table 3: Adapted HML results

APV

The Assumed Protection Value is calculated for a sample group for each octave band in accordance with ISO 4869-2:2018 (Equation 1).

$$APV_{fx} = m_f - \alpha\, s_f$$

Equation 1: APV calculation

where

subscript *f* represents the centre frequency of the octave band (in this case, the tone frequency)

subscript *x* represents the selected protection performance (probability)

m_f is the mean sound attenuation determined in accordance with ISO 4869-1

s_f is the standard deviation determined in accordance with ISO 4869-1

α is the inverse of the standard normal cumulative distribution for a specific protection performance, having the values given in ISO 4869-2

As with the previous calculations, this is an adaptation of this calculation due to the use of pure tones rather than filtered pink noise.

Figure 1 shows the calculated APV84 and APV50 for this sample group against the manufacturer specification of APV84. These show a rather larger variation against specification than other calculations, with particularly reduced low frequency performance. This calculation was particularly affected by the high standard deviation in test results, which again reflects results from other studies of inexperienced users.

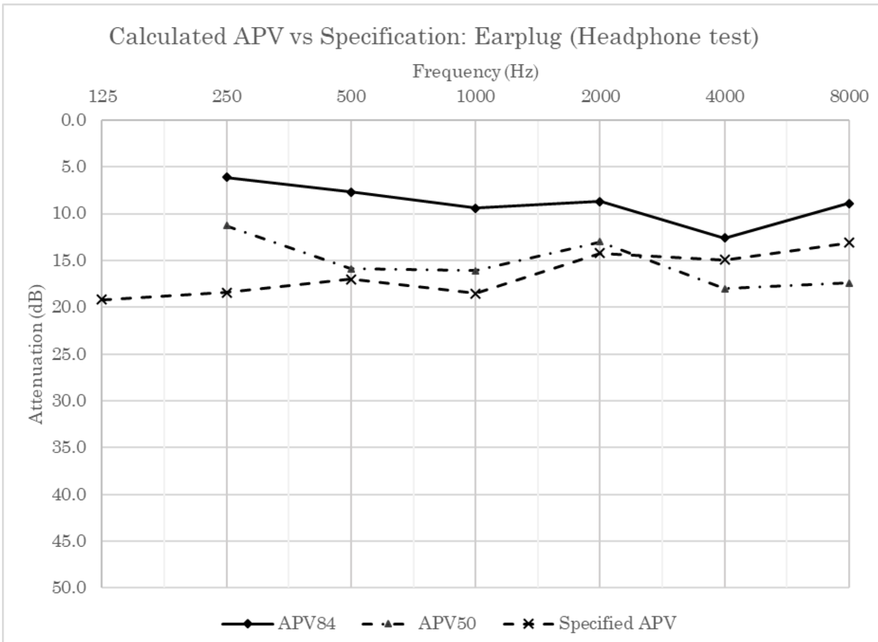

Figure 1: ISO 4869-2 plot of Calculated APV vs Specification

Group Attenuation

Group attenuation was calculated in accordance with ISO 4969-5, which assesses REAT for inexperienced users. However this standard specifies training and monitoring of test subject in fitment of the earplugs, which reduces the standard deviation.

Figure 2 shows the calculated Group Attenuation vs manufacturer specification with the headphone test.

The mean values track fairly closely to the manufacturer specification at all frequencies except the 250 Hz tone. This is consistent with other results, and indicates potential unreliability in low frequency performance. This could be an artefact of the test system, but has also been reported in other studies. Tufts et al report higher standard deviations at 125, 250 and 500 Hz, and also report an increased standard deviation when circumaural headphones are used.

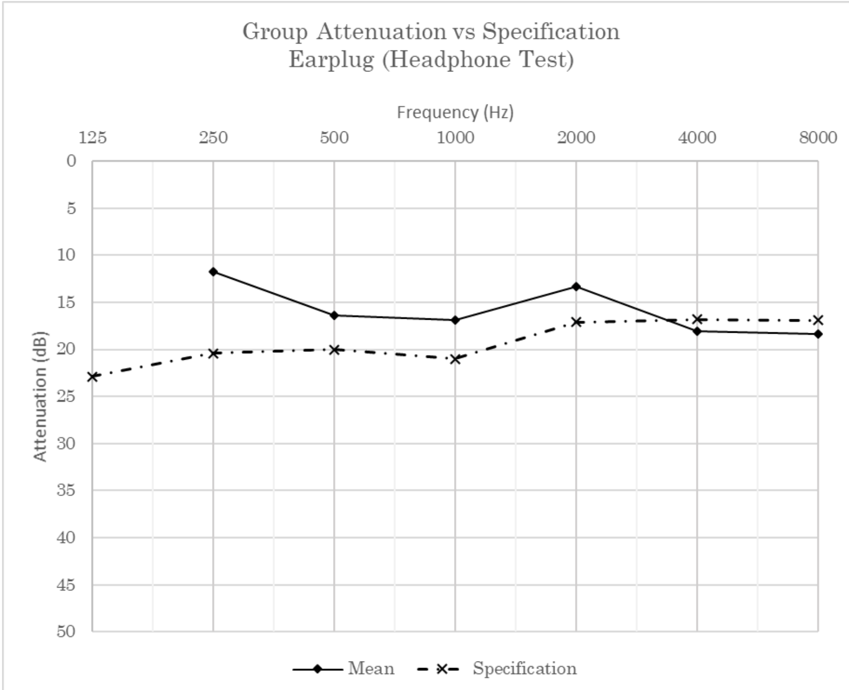

Figure 2: ISO 4869 plot: Group attenuation vs Specification

Figure 3 shows the mean Group Attenuation at each frequency for the earplugs with loudspeaker and headphone tone presentation. The results track very closely with a statistical similarity in the results and indicate a good level of reliability in the test.

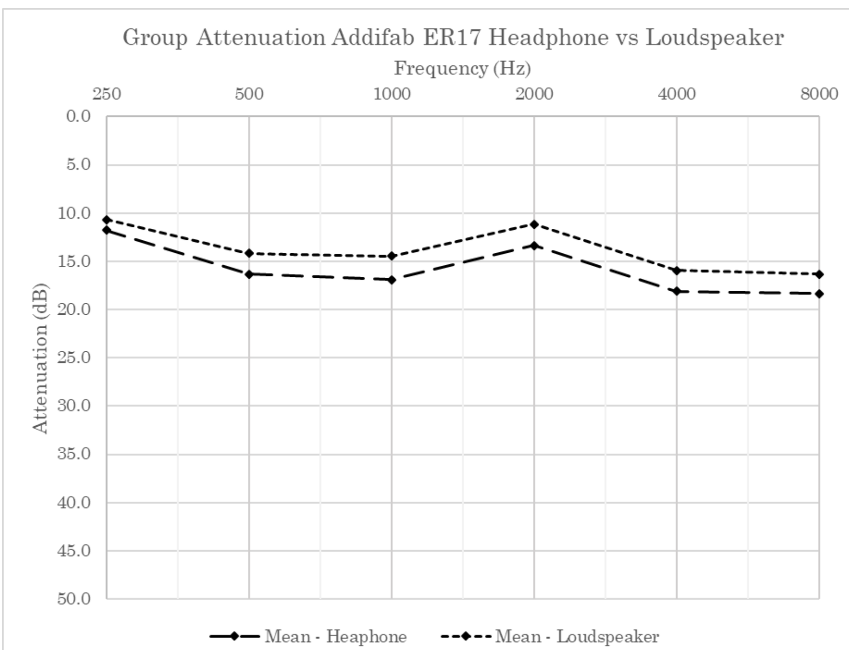

Figure 3: Like-for like Test variation between headphone and loudspeaker

Variation

Table 4 shows the variation from the manufacturer specification of the HML, SNR, APV and Mean attenuation (PSA) of the earplug. For comparison the variation in measured mean attenuation of the ear defender is also shown.

HML & SNR	**H**	**M**	**L**	**SNR**		
Earplug	-4.0	-6.0	-8.0	-6.0		
Frequency	**250.0**	**500.0**	**1000.0**	**2000.0**	**4000.0**	**8000.0**
APV 84 Earplug	-12.3	-9.3	-9.1	-5.5	-2.3	-4.2
Mean Attenuation - Earplug	-8.6	-3.7	-4.1	-3.7	1.3	-0.6
Mean Attenuation - Ear Defender	-12.5	-1.8	-21.4	-19.3	-26.4	-20.0

Table 4: Difference from Specification

The overall variation from specification for HML and SNR is around -6 dB, which is consistent with other studies, most notably a large scale study undertaken by HSE (2008). The test appears to give results which are comparable to those of other studies which indicates fitness for purpose.

Test-retest variation:

The test-retest variation was plotted in accordance with the methods used by Tufts *et al* to indicate reliability of results.

Figure 4 shows the equivalence of all individual test points at each frequency on scatterplots. The diagonal indicates exact correspondence between tests. Dashed lines on either side of the diagonal indicate the limits within which results agreed within 10 dB. This is in accordance with the procedure from Tufts *et al* (2011) and Berger (1984) which indicate that this is acceptable variation, taking into account variation in measurements of hearing threshold level.

While there are some outliers, notably at 8 kHz, these plots indicate that the majority of tests are reliable within the normal variation of measurements in hearing threshold level. As users were not trained in fitment, the outliers are again consistent with the variation seen in other studies (Berger, 2005, Witt, 2011).

Personal Attenuation Rating

The values of SNR, HML and APV are all based on cohort samples, so are not recommended to be used for individual user-fit testing as by definition they are derived using the subtraction of one standard deviation of the mean of a sample, and results for a single subject will therefore not be directly comparable as no standard deviation can be measured. While some studies have used a standard deviation obtained from a sample group to derive an individual SNR or HML value this adds to the potential measurement uncertainty. The above measures are also typically calculated down to 125 Hz, whereas the system under test measures down to 250 Hz, leading to some potential for error.

The Personal Attenuation Rating (PAR) stated by Michael (1999) is a means of comparing personal sound attenuation values to other single number values such as NRR and SNR, and has been used in a number of studies of fit-testing as a rating value. It can be directly subtracted from an A-weighted sound pressure level to predict a person's individual noise exposure when protection is worn. A binaural PAR calculates the poorest protection in each ear at each test frequency. This gives the most appropriate overall prediction as it takes into account the lowest level of protection received by the individual.

The mean PAR was calculated for the earplug tests with headphones as 15.6dB, compared to an SNR of 17 dB. The mean Binaural PAR was calculated at 15.3 dB.

This mean calculation does not take into account the variation of the sample, and individual PARs were calculated between 5.1 dB and 22.7 dB, which is consistent with the individual variation in PAR shown by Michael (1999).

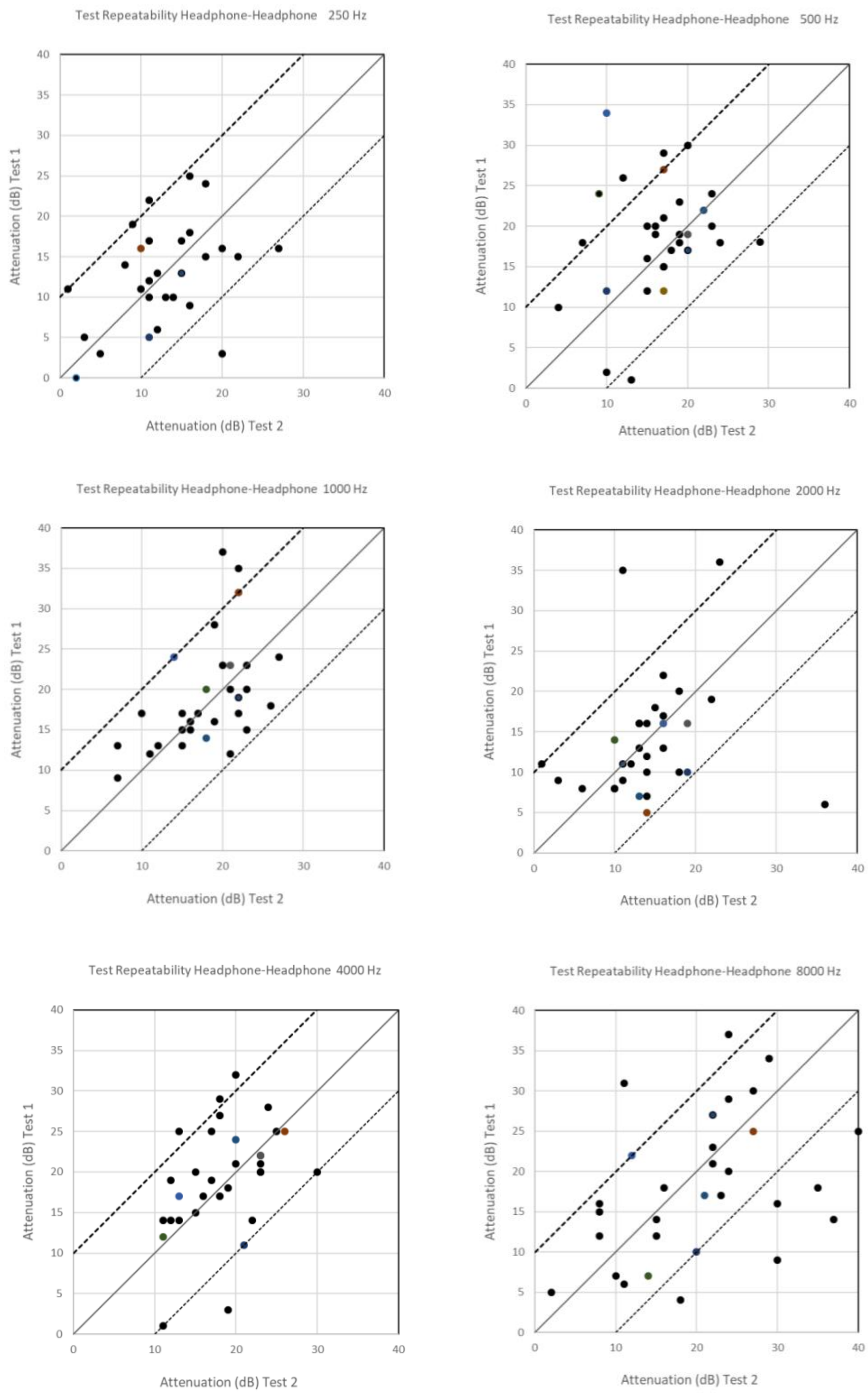

Figure 4. Scatterplots of attenuation in repeated tests at each tone frequency. The diagonal indicates exact correspondence between tests. Dashed lines on either side of the diagonal indicate the limits within which results agreed within 10 dB.

Ear Defender test

While the test appeared to show good reliability between the headphone test and the direct field loudspeaker test, the tests conducted on ear defenders demonstrated significantly larger variation from the manufacturer's stated performance than the tests on earplugs.

Results from the tests for the over-ear HPD compared to manufacturer specification are shown in figure 5.

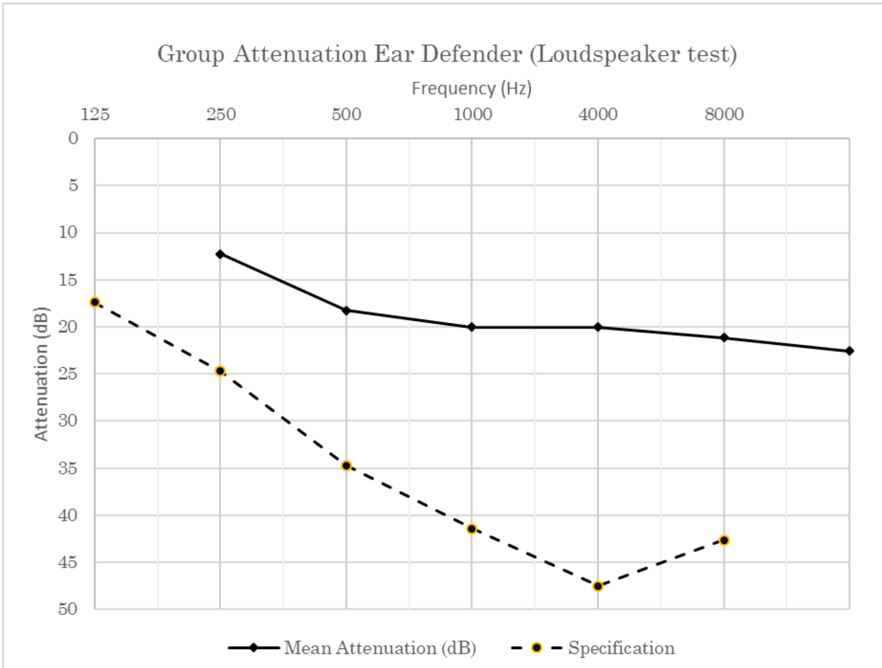

Figure 5 – Mean and standard deviation of measured attenuation vs specification

This is a significant variation from the specification and therefore the test cannot at this stage be considered for use with over-ear HPDs.

As a reduced sample size was available, results could be affected by variation in the sample. The high level of protection nominally offered by the HPDs could also be an issue with this test if the tone presentation was not sufficiently high. The lack of a diffuse field could also have had an effect on the results, and this requires further investigation. At this stage the test using direct field loudspeaker placement cannot be considered verifiable for use with over-ear HPDs.

4. Conclusion

The tests demonstrated attenuation values which although below manufacturer specifications track the performance of the HPD, and indicate that attenuation is occurring in an appropriately reliable manner.

Overall it is considered that the system under test gives an appropriate indication of the Personal Sound Attenuation which would be received by a particular user. ANSI 2008 suggests that testing using inexperienced user fit is a more reliable method in terms of between laboratory repeatability, and gives a more realistic interpretation of actual performance although the overall variation can be quite high.

The results indicate a reduction of performance in real world, inexperienced fit situations with a mean reduction of -6dB and a wide standard deviation. This is in accordance to results from several other studies (HSE 2008, Berger 2005, Witt 2011). The system operates within similar parameters to other fit test systems using circumaural headphones or audiometers.

Use of individual attenuation values for each band, or if a single number rating is required a Personal Attenuation Rating (Michaels, 1999) would be a more appropriate measure. The PSA (attenuation at each frequency) would be generally comparable to the published Group Attenuation value, while the PAR is comparable to the SNR which is published by many manufacturers. Users should be guided that normal performance could be expected to be around 6 dB below specification.

Shultz (2011) demonstrated that the level of variation in performance can be significantly reduced with user training, and a further study is recommended to investigate whether this is the case with this test system. It is suggested that with appropriate training and monitoring this test could potentially match the reliability of the REAT test for group attenuation specified in ISO 4869-5:2006.

5. References

Berger E, 1984. Assessment of the performance of Hearing Protectors for hearing conservation purposes. *Noise & Vibration Control International Worldwide* 15, pp75-81.

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Witt B. 2007. Putting the Personal Back into PPE: Hearing Protector Effectiveness. Occupational Health and Safety, June 2007, pp 90-94

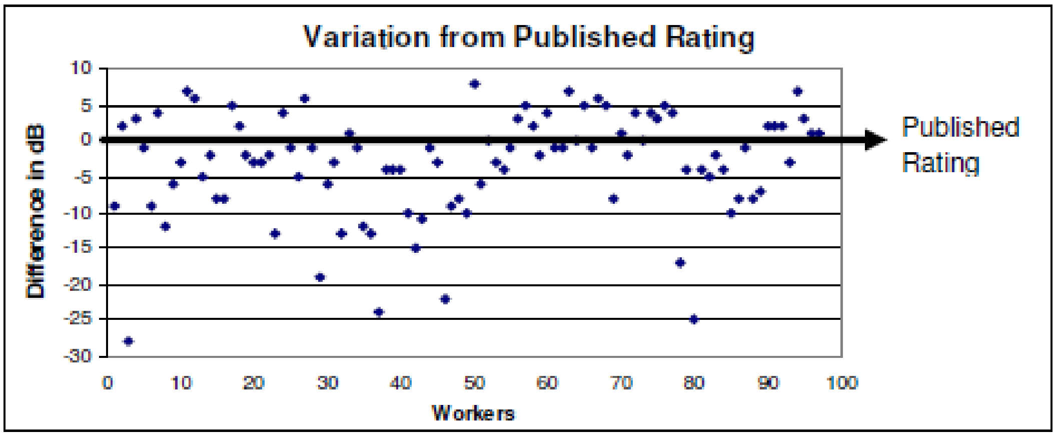
Michael, K (1999) Measurement of Insert Type Hearing Protector Attenuation on the End-User: A Practical Alternative to relying on the NRR.

APPENDIX A

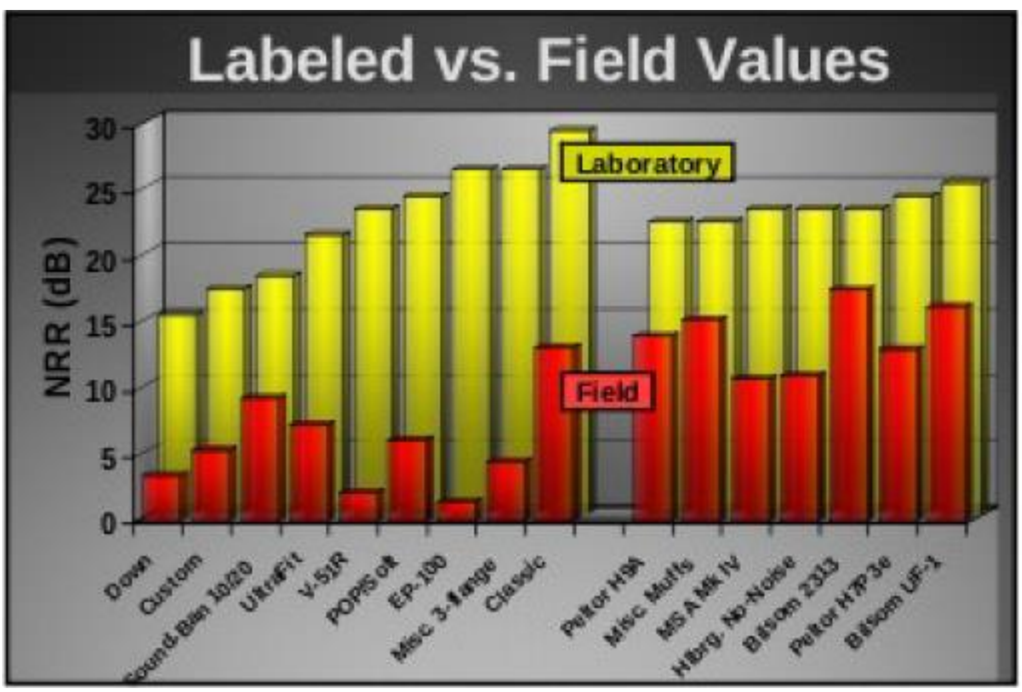
Key results from other studies:

1. Variation in actual (field) attenuation from published specification, using Microphone in real Ear method (MIRE) from Witt (2011) p3.

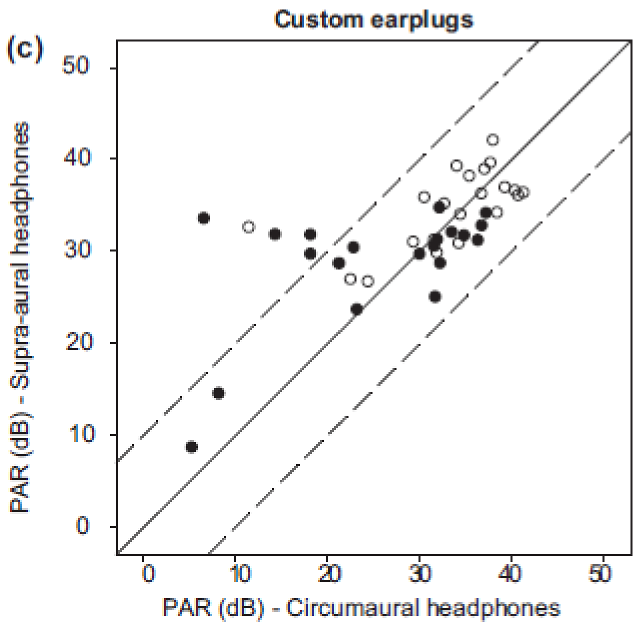
Figure 1 – Field attenuation results from 100 workers wearing earplug of their choice. Each dot represents one worker, and the difference between their field attenuation, and the published attenuation for their chosen earplug.



2. Variation between specified and field measured values for a range of different systems (Berger E, from INRS 2008, p28)

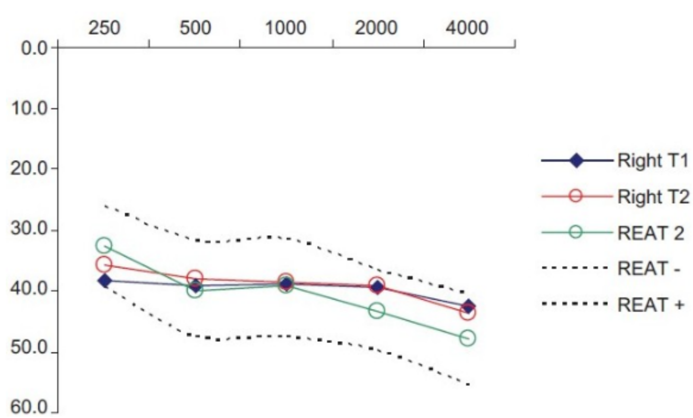


3. Scatterplots of the Personal Attenuation Rating (equivalent to PSA) for custom Earplugs, tested using Supra-aural and Circumaural headphones, with fitment training and monitoring provided. (Tufts et al, p735)



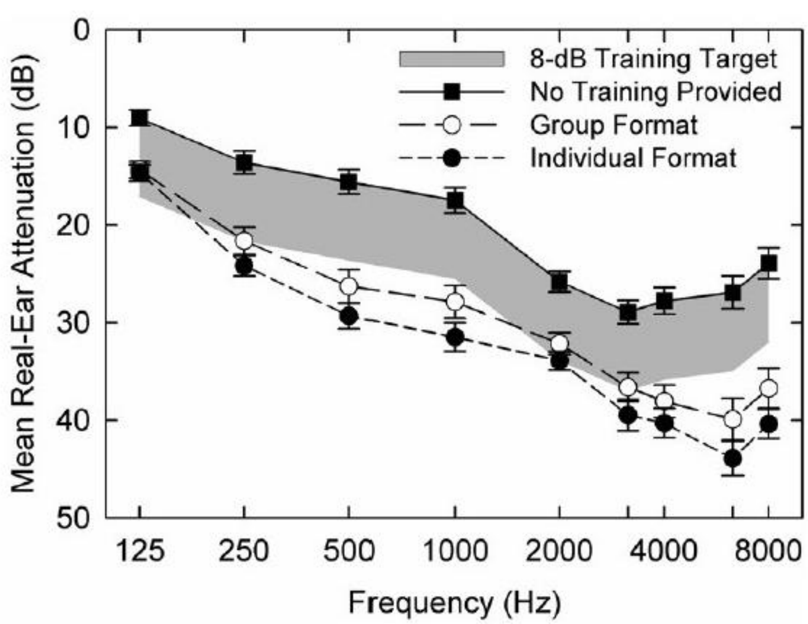
4. Mean and standard deviation of two trials for Loudness Balance (a similar approach to REAT). From Tufts *et al,* 2011

Figure 1: Right ear loudness balance means for 2 trials, T1 and T2) plotted with REAT mean and the mean ± 1 S.D. [From Larson's review of Vermiglio.[10] Used with permission]

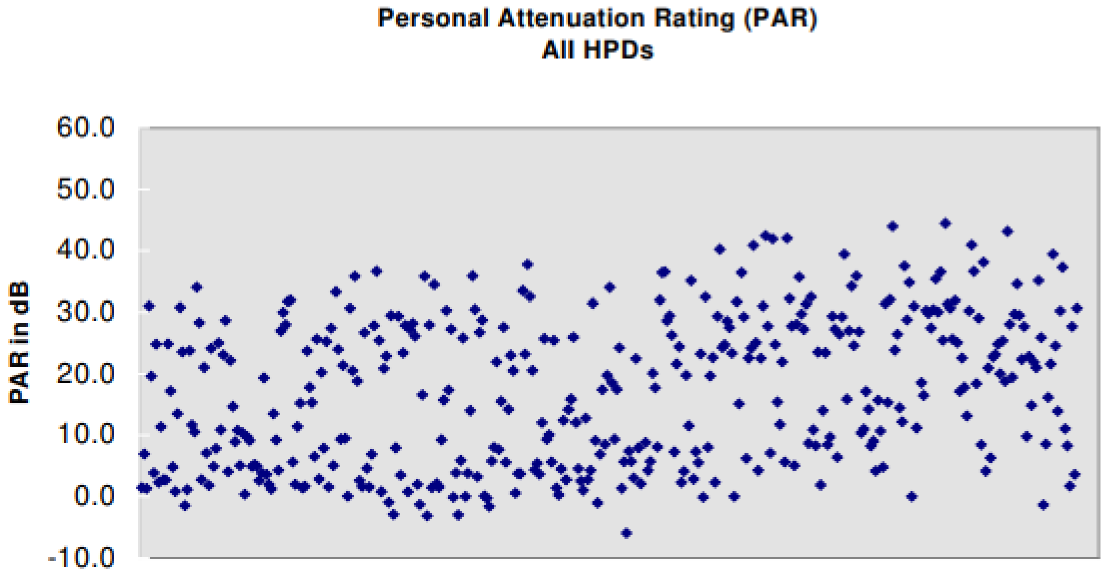


5. Mean (dotted line) of initial individual attenuation results (open circles) compared to mean (solid line) of post-training attenuation results for those individuals (filled triangles). From Tufts *et al* 2011.

6. Mean binaural REAT data and standard errors for participants receiving no training, individual training and small group training, irrespective of the HPD group. An overlay of 8 dB is included for assessment of training effectiveness. Joseph *et al,* reproduced from Tufts et al, 2011.



7. Personal Attenuation Ratings for individual HPDs from Michael (1999). Mean value 12 dB, Standard deviation 11.2dB.



APPENDIX B – Calibration Certificates

Campbell Associates Ltd
5b Chelmsford Road Industrial Estate
GREAT DUNMOW, CM6 1HD, England
www.campbell-associates.co.uk
info@campbell-associates.co.uk
Phone 01371 871030 Facsimile 01371879106

CALIBRATION

0789

Certificate number: U31149

Certificate of Calibration and Conformance

Test object:	**Sound Calibrator**
Manufacturer:	**Brüel and Kjær**
Type:	**4231**
Serial no:	**3006275**
Customer:	Solent University
Address:	East Park Terrace, Southampton, Hampshire. SO14 0YN.
Contact Person:	Lawrence Yule.

Measurement Results:	Level	Level Stability	Frequency	Frequency Stability	Distortion
1:	93.97 dB	0.01 dB	999.98 Hz	0.00 %	0.30 %
2:	93.97 dB	0.01 dB	999.98 Hz	0.00 %	0.32 %
3:	93.97 dB	0.01 dB	999.98 Hz	0.00 %	0.31 %
Result (Average):	**93.97 dB**	**0.01 dB**	**999.98 Hz**	**0.00 %**	**0.31 %**
Expanded Uncertainty:	0.10 dB	0.02 dB	1.00 Hz	0.01 %	0.10 %
Degree of Freedom:	>100	>100	>100	>100	>100
Coverage Factor:	2.00	2.00	2.00	2.00	2.00

The stated level is relative to 20µPa. The level is traceable to National Standards.
The stated level is valid at reference conditions. The following correction factors have been applied during the measurement: Pressure: 0.0008 dB/kPa Temperature: 0.0015 dB/°C Relative humidity: 0.001 dB/%RH Load volume : 0.0003 dB/mm3
The reported expanded uncertainty of measurements is based on a standard uncertainty multiplied by the coverage factor of k=2, providing a level of confidence of approximately 95%. Where the degrees of freedom are insufficient to maintain this confidence level, the coverage factor is increased to maintain this confidence level. The uncertainty has been determined in accordance with UKAS requirements.
Records: K:\C A\Calibration\Nor-1504\Nor-1018 CalCal\2019\BNK4231_3006275_M1.nmf

Environmental conditions:	Pressure:	Temperature:	Relative humidity:
Reference conditions:	101.325 kPa	23.0 °C	50 %RH
Measurement conditions:	99.682 ± 0.041 kPa	23.5 ± 0.2 °C	34.1 ± 0.8 %RH

Date received for calibration:	26/02/2019
Date of calibration:	05/03/2019
Date of issue:	05/03/2019
Engineer	Michael Tickner
Supervisor	Darren Batten TechIOA

This certificate is issued in accordance with the laboratory accreditation requirements of the United Kingdom Accreditation Service. It provides traceablity of measurement to recognised national standards, and to the units of measurement realised at an accredited national physical laboratory or other recognised standards laboratories. This certificate may not be reproduced other than in full without the prior written approval of the issuing laboratory.

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Campbell Associates Ltd
5b Chelmsford Road Industrial Estate
GREAT DUNMOW, Essex, GB-CM6 1HD
www.campbell-associates.co.uk
Phone 01371 871030 Facsimile 01371879106

Certificate of Calibration and Conformance

CALIBRATION 0789

Certificate No.: U31151

Test object:	**Sound Level Meter, BS EN IEC 61672-1:2003 Class 1 (Precision)**
Manufacturer:	**Brüel and Kjær**
Type:	**2250**
Serial no:	**2644983**
Customer:	**Solent University**
Address:	**East Park Terrace, Southampton, Hampshire. SO14 0YN.**
Contact Person:	**Lawrence Yule.**

Method :
Calibration has been performed as set out in CA Technical Procedures TP01 & 02 as appropriate. These are based on the procedures for periodic verification set out in BS EN IEC 61672-3:2006. Results and conformance statement are overleaf and detailed results are in the attached Test Report.

	Producer:	Type:	Serial No:	Certificate number
Microphone	Brüel & Kjær	4189	2638744	31150
Calibrator*	Brüel and Kjær	4231	3006275	U31149
Preamplifier	Brüel & Kjær	ZC0032	12322	Included

Additional items that also have been submitted for verification

Wind shield	None
Attenuator	None
Extension cable	None

These items have been taken into account wherever appropriate.

Environmental conditions:	Pressure:	Temperature:	Relative humidity:
Reference conditions:	101.325 kPa	23.0 °C	50 %RH
Measurement conditions:	99.72 ±0.01kPa	23.2 ±0.2°C	35.1 ±2%RH

Date received :	26/02/2019
Date of calibration:	05/03/2019
Date of issue:	05/03/2019

Engineer

Michael Tickner

Supervisor

Darren Batten TechIOA