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MILITARY LOW FLYING AND HEARING - GOOD PRACTICE GUIDELINES FOR THE ASSESSMENT OF AUDITORY EFFECTS IN THE OVERFLOWN POPULATION

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ABSTRACT
The recent literature contains a number of reports of apparent hearing loss allegedly due to exposure to the noise of low flying military aircraft. In one such study, the high-frequency hearing of children living in regions of Germany subject to military low flying has been compared to that of peer groups living in other parts of the country not subject to low altitude overflights. When the full extent of measurement uncertainties and systematic measurement constraints are taken into account, such data cannot be regarded as showing statistically significant differences between subject groups. This paper considers the extent of measurement uncertainties in high-frequency audiometry and the particular difficulties associated with audiometric field-work with children, leading to the presentation of proposals for good-practice guidelines for improved measurement techniques in field studies.

1 - INTRODUCTION AND HISTORICAL PERSPECTIVE
This paper addresses the subject of field and laboratory studies of auditory effects, in particular high frequency hearing acuity, in members of populations living in areas subjected to fast-jet low flying. Our interest in this subject was heightened when, in 1997, in the course of a sponsored research project on military aircraft noise signatures, we were asked to review and analyse reports [1] alleging permanent hearing loss at high frequencies in young children living in areas of Germany where, prior to 1990, military low flying took place. In the German studies, lead by Hartmut Ising, the high-frequency hearing, at frequencies of up to 16 kHz, of young children and teenagers in various regions of Germany was investigated, using field measurements made in mobile audiological laboratories or in their schools.
There was considerable interest in high frequency audiometry (HFA) in the 1960s, with the widespread expectation that early warning of noise induced hearing loss at conventional frequencies could be detected by examination of high frequency hearing acuity, offering the chance of avoidance of severe damage [2]. A number of researchers suggested that fast rise-time noises, such as pistol shots, would particularly be likely to produce hearing loss at high frequencies, long before it became apparent at normal frequencies. Commonly used audiometric earphones did not have the extended frequency response needed for audiometry up to 16 kHz and HFA work in the 60/70s was undertaken using either quasi-free field presentation or by a close coupled transducer. With the advent of hifi supra-aural headphones in the late 70s, researchers were able to extend the range of monaurally presented audiometric testing to HF. The attenuation of external noise of these headphones was poor and, typically, the transducers were installed in large volume circumaural ear defenders to provide noise exclusion, with absorbent foam to control high frequency modes.

2 - DEVELOPMENT OF ISO RETSPL FOR HIGH FREQUENCIES
Only in recent years has agreement been reached on "normal" hearing at high frequencies. The enormous range of hearing levels at 10kHz upwards is apparent, even for nominally non-exposed young adults, in recent studies by Han and Poulsen [3] and Richter [4], whose work has led to the publication of ISO TR/389-5 [5]. Using the Sennheiser HDA200 circumaural earphone, Han and Poulsen found a standard

deviation of 16.8 dB (range 72 dB) at 16kHz for 62 ears. Richter found a similar pattern (sd 16.6 dB, range 65 dB at 16 kHz).

3 - MEASUREMENT UNCERTAINTIES

Stelmachowicz [6], in a comprehensive and instructive paper, identifies three sources of uncertainty for high frequency audiometry − a) calibration variance − involving possibly both random errors and systematic errors associated with the repeatability of audiometric earphone calibration procedures, b) subjective variance − the number of trials, the slope of the psychometric function, the psychophysical procedure selected for the audiometric testing, the consistency of the subject's attention and their personal criterion for audibility − which may change from test to test or with frequency, and c) fitting variance − the variability in sound level presented to the subject's ear arising from the placement of the headphone on or over the subject's ear.

We have examined, assessed and quantified the likely magnitude of these three sources of uncertainty. Of specific interest in this context are the particular difficulties associated with children as new test subjects at high frequencies and the need for realistic simulation of the headphone/ear interaction when investigating headphone placement effects.

In many recent HFA studies a Sennheiser HDA200 audiometric earphone has been used. This comprises a high fidelity audio earphone capsule mounted in a Peltor H7 circumaural earmuff, with absorbent foam to control HF modes. Using an IEC 318 flat plate coupler, errors of placement of some 0.5 cm off-centre will result in a variation of the order of not more than 2 dB, even at 16 kHz. However, if repeated fitting measurements are made on one well-established type of manikin, much larger variations in high frequency sound level can occur, of the order of ± 6 −10 dB above 6 kHz. Measurements on another well-known type of head and torso simulator indicated only small variations in level, of similar magnitude to those observed for the IEC 318 coupler. On this manikin, the artificial pinnas were large and stiff, constraining any lateral movement of the headphone. The fitting variance observed with a manikin is largely determined by the design of the manikin head and ear simulator. Combined fitting variance and subjective variance may be assessed by repeated measurements on one subject. Separating the two elements is not easy.

On a young child's head, a heavy circumaural headphone could easily slip, possibly affecting the test signal level at high frequencies. This would also adversely affect the attenuation provided by the circumaural headphones, increasing the chance of masking or disruption from the task of listening.

Regarding audiometric techniques and subject training, although the choice of technique may not be so important at normal frequencies, the use of purely an ascending threshold presentation at HF gives the subject little chance to familiarise with what is an unusual acoustic signal. Based upon our own experimental work using the preferred Bekesy presentation, a repeatability range of ± 5-8 dB is typical for a "naïve subject" child of between 6 and 10 years at high frequencies.

To these three sources of variance identified by Stelmachowicz, we would add a further factor, related to a) and b) but capable of separate treatment − namely the choice of step size. Jerlvall and Arlinger [7] have shown that a 5 dB step size can give as reliable results as a 2 dB step size. However, some studies have used steps of 7 to 10 dB, severely limiting one's ability to make judgements about individuals as compared to a larger population. It is necessary to take account of step size by the inclusion of a term representing this additional source of uncertainty in the estimate of overall measurement uncertainty when judgements of statistical significance are made. We would call this term "resolution or rounding" variance.

A further potential source of difficulty in comparing absolute high frequency hearing levels in young children is the dependence of hearing level at these high frequencies on the geometry of the ear canal and concha [8], which might be presumed to yield systematic differences between children of different ages due to differences in ear canal resonance frequencies.

4 - DYNAMIC RANGE LIMITATIONS

Because of the huge range in hearing at HF, there can be severe dynamic range problems. Zero dB HL at 16 kHz for the Sennheiser HDA200 is 56 dB SPL (referenced to the IEC 318 coupler) and one can expect to find "normal" subjects with thresholds approaching 100dB SPL. Subjects with HF hearing loss will have even higher thresholds. Some studies have reported subjects' observations of extraneous sub-harmonics at high presentation levels, confounding reliable threshold determination, and safety and ethics issues about exposure levels must be considered. Thus, dynamic range limitations may constitute a fifth source of measurement uncertainty.

Although the determination of high frequency hearing thresholds is unlikely to be directly affected by background noise when using a circumaural headphone, indirect masking by mid frequency background noise may adversely affect the reliability of measurements. In a noisy environment, one way to tackle masking is to test well above normal threshold and to identify those who apparently have elevated thresholds. We estimate that to measure down to minus 10 dB HL at mid frequencies when using typical ear defender HFA headphones on a child, one would be looking for a room noise not exceeding 15 dB SPL at any time.

In the case of the HFA studies carried out in Germany, background noise limitations prevented any hearing level measurements being made below +10 dB HL, or even +20 dB HL for some of the groups of children tested. That is to say, the minimum level of test signal presented to the children being tested was set prior to test, dependent on the background noise encountered in the test room, to +10 dB HL or +20 dB HL according to the conditions pertaining at the time. In the 1995 screening tests reported by Ising, measurements were started at 30 dB SPL "to save time". Screening out those subjects who have real elevated thresholds is a reasonable experimental technique, but it is vital that the level of any extraneous and unwanted masking noise at the subject's ear is known. Otherwise, the data collected by such means will comprise an unknown mix of real elevated thresholds and non-elevated thresholds masked by the instantaneous external noise.

5 - A COMMENTARY ON THE GERMAN HFA STUDY

As a first stage in the development of a high quality database for children's hearing at high frequencies, we tested sixteen children, none of whom were known to have hearing defects, in our laboratory, using a computer-controlled precision Bekesy technique and the HDA200 headphones. Not surprisingly perhaps, when the mean HLs of our test subjects are compared with the data from Han and Poulsen, Richter and the ISO RETSPL, we find a high degree of comparability. Furthermore, the inter-subject variance found in our limited study matches the frequency-dependent variance observed in these studies.

Ising [1] describes low altitude overflight noise as impulsive noise, although the rise-times of such transient events are typically around 0.5 s, an order of magnitude or two slower than those of pistols, firecrackers or even some children's toys. Ising offers a comparison between the hearing levels of children born in 1989 and 1991 as evidence of hearing damage at high frequencies caused by low altitude military jet aircraft overflights up to 1990 (the minimum altitude for flights was raised, post-unification, in Germany to 300 metres in 1990). The Table below shows Ising's data compared to the Richter/Han and Poulsen data, and our data for the group of "Salford" children. All of the mean HLs reported by Ising are elevated relative to 0 dB HL, typically 17 −25 dB at 1 kHz, 21 −26 dB at 4 kHz. As described above, we have established that this is directly attributable to the experimental techniques employed by Ising to take account of background noise.

Frequency	1 kHz		4 kHz		12.5 kHz		14 kHz		15 kHz		16 kHz	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Han and Poulsen	−1	4	1	7	0	8	2	12			6	17
Richter	0	3	−1	4	−1	6	1	9			1	17
Salford	−3	4	−1	6	1	10	−5	7			−10	9
Ising 4 yr	25	14	26	12	33	12			31	11		
Ising 6 yr/150m	18	12	21	10	30	11			29	10		
Ising 6 yr/150m 75m	17	11	22	12	32	11			21	12		
Ising 6 yr/75m target	21	12	21	11	35	11			33	11		

Table 1: A comparison of four studies: Han and Poulsen/Richter − young adults, Salford and Ising − children.

Surprisingly high standard deviations are also reported by Ising for all subject groups (eg a mean of 21 dB HL and sd of 12 dB for 55 children at 1 kHz). Given that the minimum measured HL would have been +10 dB HL (or perhaps, for some subjects, +20 dB HL), this suggests a highly skewed data set with a compressed lower range and an enormous upper range, due to either very poor hearing in some subjects (in all four groups), the coalition of data using different starting levels, or lack of control in the audiometric testing procedure.

A high minimum measurable HL has been simulated for our source data, resulting, not unexpectedly, in a greatly reduced (apparent) variance rather than an increased variance, so there must be other factors influencing the Ising data. The presence of such large variance in the data make it very difficult to compare with any degree of reliability the relative hearing acuity of different groups of children.

6 - THE DEVELOPMENT OF GOOD-PRACTICE GUIDELINES

The following paragraphs address the key issues for good practice in field HFA studies.

Firstly, and obviously, it is important, to screen subjects, particularly children, for any prior history of ear infection or hearing problems. This can reduce the potential subject pool size considerably, as Ising found.

Secondly, regarding the audiometric technique to be employed, it is important that subjects, particularly children, should become completely familiar with the sound of the test signals to which they are expected to respond. High frequency test tones are unusual in nature, being quite unlike anything heard in everyday life, whereas a steadily "beeping" tone at middle frequencies can be related to everyday noises, for example computers and telephones used in the home. Sub-harmonic extraneous sounds, reported by some subjects, must be eliminated if they have a physical external origin.

Our experience of high frequency audiometric testing of young children suggests that a balance between familiarisation sessions and overall length of testing must be achieved, perhaps by limiting the number of test frequencies, if early onset of fatigue is to be avoided.

Notwithstanding the possible difficulty associated with achieving the necessary degree of sound insulation in field experiments, we believe it is essential that a reliable determination of absolute threshold is made, rather than merely screening at +10, 20 or even 30 dB HL. If we wish to test the assertion that high frequency hearing is damaged before loss at normal frequencies is detected, subjects with elevated high frequency thresholds but with non-elevated normal frequency thresholds will be of particular interest. Screening at +20 or +30 dB will not yield the data required for this issue to be examined.

The uncontrolled and highly variable nature of the background noise environment in a field site such as a school can mean that, even with an ear-defender headphone, masking can occur (as Ising found). A better knowledge of the noise level at the subject's ear, or outside the ear-defender headphone as a minimum, during the presentation of audiometric test signals would be highly advantageous. Although there may be some instrumentation signal-to-noise problems at middle frequencies, at high audiometric frequencies there should be no difficulty. Recent advances in miniature microphone technology make this technique worthy of consideration for investigative field studies where masking noise may be a factor. We suggest that real-time monitoring of the room and at-ear sound levels during audiometric testing would greatly assist in eliminating this source of uncertainty in field data.

Finally, in order to establish a causal relationship, some knowledge of the historical exposure of subjects to specific low-flying events is necessary.

7 - CONCLUSIONS

Recent studies by several researchers have yielded consistent information for the high frequency hearing of young adults. A wide range of hearing acuity is observed. Analysis of the sources of measurement uncertainty in HFA has identified the need for realistic simulation of the headphone/ear interaction and the importance of the inclusion of step width as a source of uncertainty when large values of step size are used. Serious experimental deficiencies can result from dynamic range limitations when background noise is not controlled sufficiently.

It has been established that experimental design limitations and inadequate treatment of measurement uncertainties render allegations made in the recent literature of high frequency hearing loss in children from military low altitude flying in Germany unfounded.

It is important in field studies that efforts are made to determine high frequency hearing acuity more reliably than has been the case in recent studies. Absolute and masked threshold data must be separable and one step towards this could be the monitoring of the instantaneous noise level at the ear of the subject during audiometric testing. This and other issues are addressed in the formulation of good-practice guidelines.

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