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SUBJECTIVE NOISE ASSESSMENT USING BINAURAL HEADPHONE PRESENTATION

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INTRODUCTION

Subjective reactions to any given sound or noise can only be predicted from physical measurements of that sound or noise under a very limited range of circumstances. For example, all other things being equal, the average reported aversiveness or annoyance response to road traffic noise increases with average noise level yet individual responses depend very much on other factors such as a history of change in exposure, the nature of the road traffic, the distance from the road, and many individual psychological attitudes and characteristics. When we consider subjective reaction to sounds with greater information content, such as speech or music, the number of additional factors which influence response becomes very large indeed. While considerable efforts have been made to develop physical descriptors that correlate with average subjective reactions, there will probably always be a requirement to measure actual reactions from real sounds from time-to-time. Recorded sounds are often used as a substitute for the real sound and, in this case, the problems usually revolve around the reproduction technique and listening environment for the most appropriate simulation of the real sound.

VEHICLE INTERIOR NOISE

Subjective assessment using binaural headphone presentation has become a useful alternative to test track appraisal in the field of vehicle interior noise. The sound of the engine and running gear and any aerodynamic noise make an important contribution to the way in which potential customers feel about any car they are considering purchasing, and this is reflected in the efforts made by the manufacturers to produce an "acceptable" sound. Tests have shown that the overall 'A' weighted noise level is not the most important factor in determining the acceptability of the noise of a car running along the road.

The first stage in determining vehicle interior noise acceptability is necessarily a road test in which the interior noise for different driving conditions can be assessed. However, until more is known about the subtle effects which make a car sound pleasant or unpleasant, the application of laboratory based subjective tests is twofold. Firstly, a program of research can be carried out to determine the factors which contribute to the quality of the noise and, secondly, laboratory based tests and demonstrations can allow manufacturers to appraise the effects of modifications or new designs without the relative inconvenience of road trials. Recorded sounds allow direct A-B blind comparisons which are not possible with road trials and test track appraisal.

As was discussed in the introduction, one important factor in the design of subjective acoustics experiments is the method used for both the recording and the playback of the stimulus. Initial trials were carried out with a single microphone using high quality analogue recording equipment. On the recording side, this technique was fairly limited since fairly low recording levels had to be used in order to obtain enough headroom to accommodate the high transient levels which occur as the car passed over an irregularity in the road surface. This resulted in unacceptably high levels of background tape noise on reproduction at the correct presentation level. Playback was through a tetrahedral array of wide bandwidth loudspeakers, normally used for the assessment of the performance of industrial hearing protectors. This type of presentation was judged to be unrealistic due to the 'one dimensional' feel of the sound, and a lack of source localisation cues. The recent availability of high quality digital audio recorders has eliminated the background noise problem, but not the source identification problem.

The sound of a car travelling along a road is made up of a number of major noise sources in addition to the engine and gearbox. The high frequency portion of the road/wheel noise comes from the window adjacent to the position of the observer and wind noise from points on the exterior of the car where turbulence is set up. The low frequency portion of the road/wheel noise comes from the underneath of the car and any rear axle noise from the rear. The engine and gearbox noise appears to come from approximately straight ahead although any body panels or interior fittings resonating in sympathy will change the apparent direction of this noise source. In addition, the car body will have numerous modal resonances which will drastically alter the spectra inside from those expected outside the passenger compartment. In summary, the two dimensional sound field has many components and should therefore be presented as such.

BINAURAL PRESENTATION

There are two methods of accurately presenting a two dimensional sound field to a listener positioned in the centre of that field. The first is to use a multiphonic array of at least two microphones, depending on the accuracy required, and a corresponding number of appropriately orientated loudspeakers for playback. The second method is to make the recording at the ear positions with a suitable dummy in the observer position, and then to replay these recordings through headphones such that the listener is in acoustically the same position as that occupied by the dummy when the recordings were made. There are, however, a number of problems with this simpler approach, some of which have immediate solutions and some of which do not.

Localisation

The single ear has a certain amount of directional hearing capability at high frequencies, controlled by the shape and size of the pinna and entrance to the auditory meatus. Clearly, the position of a recording microphone is fairly critical for this directionality effect to be reproduced accurately. For this reason, developmental work carried out at ISVR has used the Knowles Electronics Mannikin for Acoustic Research (KEMAR) for recording purposes (Figure 1). This mannikin, fitted with Zwislocki open ear simulators and Bruel & Kjaer half inch microphones at the ear drum positions, provides an average male or female standard reference recording microphone position for this work. The use of this mannikin does however introduce further problems in the form of the external ear canal resonance.

The Bruel & Kjaer Head and Torso Simulator type 4128 uses a similar type of open ear simulator, whereas the HEAD acoustics AACHEN head uses a microphone reference position just 4mm inside the ear canal entrance. It is not known at present to what extent high frequency localisation effects are compromised by using a non–eardrum position microphone in the dummy head, although miniature microphone recordings at the entrance to the ear canal on real ears produce apparently good results.

The External Ear Canal Resonance

The amplitude response of an open ear canal located in a uniform diffuse sound field exhibits a resonance which has a peak of approximately 15dB at 2.7KHz. The shape and size of this resonance varies according to the shape and size of the ear canal in question and the Zwislocki open ear simulator used in the KEMAR mannikin has been designed to represent the average ear. Hence, any recordings made using the microphone at the eardrum position automatically contain this resonance. In order to present these recordings in such a way as to acoustically recreate the same sound field as was present during the recording process, this ear canal resonance must be extracted from the recordings before or during playback, allowing the listener's own ear canal resonance to operate instead.

Frequency Equalisation

Frequency equalisation must be carried out in such a way as to ensure that the sound which is presented to an experimental test subject is the same as that which was 'heard' by the mannikin when the recording was performed. There are two ways to set up the necessary equalisation characteristic. The first is to carry out frequency analysis over a long sample of the recorded material, both as it was recorded and as it plays back through the headphones to be used for the experimental presentation to the eardrum microphones of the mannikin. The difference in frequency response between the two measurements of the same sample gives the required characteristics for the equalisation curve. This curve can then be set up on an adjustable equaliser and the stimulus material re-recorded through it onto a second tape recorder. In this way the ear canal resonance is removed from the signal and any deficiencies in the frequency response of the headphones is automatically removed. A simpler method of carrying out both these operations is to play 'pink' noise through the headphones to the eardrum microphones of the mannikin and to adjust the curve on the equaliser to obtain a flat frequency response on a frequency analyser. The stimulus material can then be re-recorded in the same way to obtain an acoustically correct presentation.

Possible Errors Introduced by Frequency Equalisation Standardisation of Ear Canal Resonance

The frequency equalisation is carried out such that the mannikin listening, through the headphones, to the equalised stimulus material 'hears' the same sound that it 'heard' when the recording was carried out. As was mentioned above, the mannikin provides an *average* open ear canal and so any equalisation carried out for this *average* ear canal will not be exactly correct for the ears of the test subject. Clearly it would be much too cumbersome to carry out separate equalisation for each individual test subject and given the variation in resonance at different points along the ear canal(1) it would also be very difficult, even using appropriate probe microphone techniques. It should also be noted that analogue equalisers have limitations in respect of phase response although this can be overcome (in theory) by using digital filters with the latest available technology.

Directional Effects Provided by Ear Canal and Pinna

One of the reasons for using the mannikin for the binaural recording was to include the effects of the pinna and ear canal in the reconstruction of the directional response of the single ear. When the test subject listens to the recordings played back following equalisation he/she is effectively listening with the pinna and ear canal of the mannikin rather than those which he/she is used to. This is thought to constitute only a small weakness in the presentation method and it is possible that individuals can "learn" to extract the locational information contained in sound from the standard ear, and to use it in the same way as they would their own.

Coupling of Headphones to Ear Canal

An important element in the accuracy of the required frequency response of the headphones is the way they couple to the ear canal. This affects the low frequency portion of the response in particular. The coupling is affected both by the size of head and hence the headphone tension and the way the pinna is compressed against the material of the 'phone. Again, this can cause inaccuracies since the equalisation is carried out on the mannikin which will be slightly different to each individual subject.

PROBLEMS WITH HEADPHONE PRESENTATION

It has been accepted when carrying out subjective tests using this presentation method that small inaccuracies do exist but it is considered essential that more important elements of the methodology are given serious consideration before the fine details.

Head Movement vs Head-Locked Image

An important element of the localisation process, in which the origin of sounds can be identified, is the ability of the listener to move his head. This gives major cues which identify whether a sound emanating from a particular place in the two dimensional sound field has its location in front of or behind the listener. It also gives important cues as to the location of a sound on the vertical axis. Whilst these aspects are not considered to be important from the point of view of comparison of the relative acceptability of different sounds, as recorded under similar conditions, investigations need to be carried out to determine how this effect detracts from the realism of the presentation method.

Isolation

Whilst headphone presentation is central to this presentation method, it leads to a certain sense of isolation exemplified by the lack of any external reference stimulus against which to compare the sound in question. All the research done at ISVR has been carried out using closed back headphones, in order to obtain the best possible frequency response, and this has been found to exaggerate the problem.

Sensory Deprivation

For interior vehicle noise in particular, the sound of a car running along a road is always associated with the feeling of the vibration which necessarily accompanies it and the sense of motion generated by visual cues. The 'noise only' form of presentation causes a certain amount of sensory deprivation causing the illusion, for some listeners, that the stimulus material is too heavily loaded with low frequency sound or even in some cases that it does not even sound like a car! Further investigation needs to be carried out to establish whether this feeling can be overcome by the use of some kind of associated vibration and/or visual stimulus. In addition to this, the visual impact of a type of car can have serious implications for how the noise is assessed and this should also be investigated.

RESULTS AND CONCLUSIONS

A number of detailed comparisons have been made at ISVR between track test appraisals and binaural headphone listening simulations over a range of vehicles and operating conditions.

Tests of three types of car at different engine speeds using the same piece of road for the recordings and for the field tests showed good correlation (Figure 2). Rank order and curve shape is preserved although correlation is better at the higher engine speeds due to the unrealistic nature of the way the lower speeds were presented (i.e. long periods of ti me at low constant road speed). Most importantly, it should be noted that the car obtaining the lowest subjective scale value (i.e. least annoying) did not have the lowest dB(A) sound pressure level both for the field and for the laboratory presentation methods.

Experienced vehicle interior noise appraisal engineers noted some subjective deficiencies of the binaural recordings yet produced better correlations between laboratory and track noise ratings than naive subjects who tended to be less critical of the technique. These findings should be interpreted as demonstrating that great care needs to be taken when making and presenting binaural recordings if they are to stand comparison with the real thing under critical scrutiny, yet there is considerable potential for the simulation technique to provide valid and meaningful results.

REFERENCE

(1) B W Lawton. "A survey of the sound field within the occluded ear canal". *Proceedings of the Institute of Acoustics Autumn Conference, Windermere, 1979.*

Figure 1 KEMAR Manikin

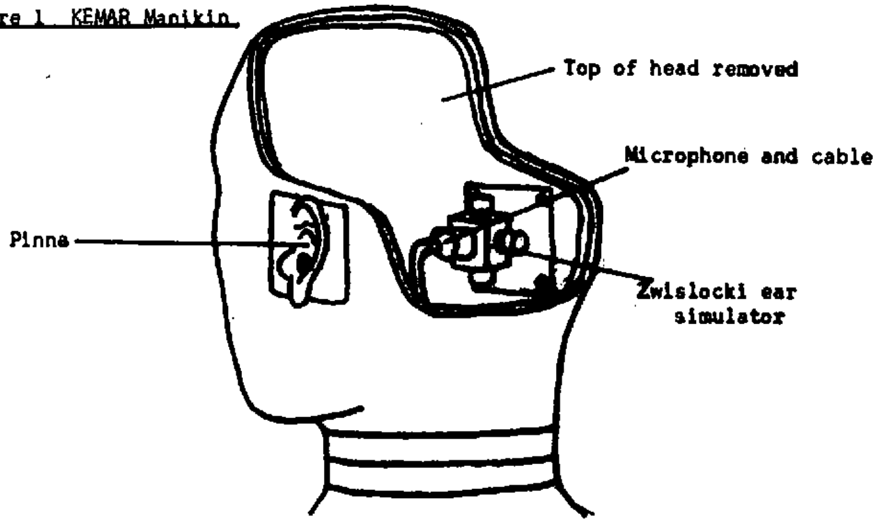

Figure 2 Lab-Field Comparisons