HUMAN FACTORS AFFECTING THE ACOUSTIC MEASUREMENT OF ROOMS
Philip Newell Acoustics consultant, Moaña, Spain (philiprnevell@gmail.com)
Keith Holland ISVR, University of Southampton, UK
Soledad Torres-Guijarro Universidad de Vigo, Spain
Julius Newell Electroacoustics consultant, Blackburn, UK
David Santos Domínguez Universidad de Vigo, Spain

ABSTRACT

Many sound systems are set up and equalised using measurements of the frequency response of the loudspeaker/room combination at one or more microphone positions. The results of these measurements, and the consequent applied equalisation, are dependent on the positioning of the microphones and the specific method used to adjust the equalisers. This paper investigates the variability in the frequency response measurements and equaliser settings that may occur when different people carry out what is ostensibly the same process. The results from both laboratory experiments and computer simulations are presented, and conclusions are drawn.

1 INTRODUCTION

In the near future, various standards covering the targets and methods for the equalisation of loudspeaker systems in rooms for the cinema and television industries will be being considered for renewal. Some of these are probably now out-dated and the methods of calibration are somewhat antiquated. However, some aspects of the poor repeatability of calibration results may well be carried over into the newer standards unless they can be clearly highlighted as being sources of possible, or even probable, errors. The studies being presented here also have a wider-ranging field of application, into the area of loudspeaker-in-room calibration in general.

Many different microphone techniques are used in the current methods of 'room' calibration. Most frequently there would be a single, fixed microphone, usually positioned close to a point which is deemed to be representative of a place where any critical listeners would sit. Another variation, also using a single microphone, is to slowly move it about, by hand, over a region considered to be of importance; such as the working area behind a mixing console. These movements, often involving some degree of walking around, would also involve side to side, up and down, and forward and backward motions. In many cinema rooms, techniques employing multiple microphones are also frequently used, and the outputs are then multiplexed, or mathematically averaged in post processing, to hopefully give a better average over the area of interest. No rigorously specified positioning instructions exist, and probably nor could they, because there are too many differing circumstances to which they must apply. All such placements are therefore subject to human variability in terms of people's opinions and their interpretations of the 'rules'.

In all of the above cases, pink noise is usually used as the source, and the measurements are either done in 'real time', or the microphone output(s) can be recorded over a period of two minutes or so, with the recordings being used for subsequent post processing by FFT or other means.

The purpose of the experiments described in this paper was to assess the degree to which the people carrying out such measurements could inadvertently introduce unhelpful variability into these proceedings, which are, in themselves, already rather delicate.
2 VARIABILITY IN HUMAN IMPLEMENTATION OF A GIVEN EQUALISATION TASK

In the 'Salon de Actos', a multi-purpose theatre in the Telecommunication Engineering School at Vigo University, Spain (shown in Figure 1), a self-powered loudspeaker (Digital Audio Systems 'Hailey') was set up on stage, close to where the removable cinema screen would normally be mounted. The loudspeaker was of a frequency range adequate for meeting the current cinema requirements of a spectrum to match ISO 2969 (the so-called X-curve). During the experiments, the output never exceeded 98 dBC at a distance of 1 metre. The signal to the loudspeaker was derived from a pink-noise source via a one-third octave graphic equaliser (Alesis MEQ 230). The output of the equaliser was also fed to a recording device for future analysis and assessment. At a chosen position, about two-thirds of the way into the audience area and slightly off centre, a measuring microphone (B&K 4190) was mounted on a stand, pointed towards the loudspeaker and connected to a one-third-octave spectrum analyser which could be viewed in real time. This measurement system is not unlike those which are still frequently used to perform 'calibrations' in many rooms for recording, mixing and entertainment purposes.

![Figure 1 The 'Salon de Actos', multi-purpose theatre in the Telecommunication Engineering School at Vigo University, Spain used for the tests](image)

Ten people were asked to complete four tests consecutively. All the people involved had some prior experience of such methods of equalisation. Four were from the Telecommunication Engineering School of Vigo University, and six from the recording studio or live sound industries. For Test 1, the equaliser was initially set to its flat position and the participants were asked to adjust the equaliser to show a response on the analyser that yielded a reading of flat ±3 dB, using the minimum amount of equalisation. The equaliser was then re-set to flat by the person supervising the procedure. For Test 2, each participant was asked to repeat the previous exercise, only this time to within a
tolerance of only ±2 dB. For Test 3, after again re-setting the equaliser to flat, each person was asked to repeat the equalisation to the ±3 dB tolerance. In effect, this was a repeat of Test 1.

For Test 4, each participant was given a microphone, a stand and a laser measuring device. Then, instead of using the previous, fixed microphone, they were asked to place the microphone at a position about two thirds of the distance to the back of the theatre, on the centre line, at a height of no more that 1.25 metres. This is typical of the way that not only cinemas, but also many music venues are currently still calibrated, despite all the known caveats. After the equaliser had been returned to its flat setting, each person in turn was asked to repeat the calibration to the ±3 dB tolerance band. Only one participant at a time was allowed to be in the room whilst a microphone was in its chosen position, and on completion of each test the microphone and stand were returned to a storage position before the next person entered. This was to ensure that nobody saw the position in which anybody else had placed the microphone. Each person had therefore to interpret the positioning rules according to their own judgement. This mirrors what usually takes place in real alignment situations. Very rarely indeed are the measuring positions tightly defined.

Figure 2 shows the overlaid positions of the equaliser control settings for each of the ten subjects after their first attempts at the ±3 dB tolerance adjustments (Test 1). Figure 3 shows the overlaid positions for the ±2 dB tolerance adjustments (Test 2). Figure 4 shows the positions for the second attempts at ±3 dB (Test 3), and Figure 5 shows the equaliser positions after Test 4 had been completed. The plots shown were made from photographs taken of the graphic equaliser once each participant had concluded each adjustment procedure to their satisfaction.

![Figure 2 Equaliser settings for ten subjects: Test 1, ±3 dB tolerance, fixed microphone](image)

A visual inspection of Figures 2 and 4 (from Tests 1 and 3) reveals that not one of the participants arrived at the same equaliser settings in their two attempts at achieving the same ±3 dB equalisation target. No two of the twenty curves are alike, despite the pairs of tests having been done within 20 minutes of each other and with the fixed microphone. No environmental explanation could be found for this variability, as the ventilation system was turned off and the temperature of the room remained at around 23°C throughout the tests. The summer weather at the time was generally stable during the two consecutive days in which the experiments were carried out.
Figure 3 Equaliser settings for ten subjects: Test 2, ±2 dB tolerance, fixed microphone

Figure 4 Equaliser settings for ten subjects: Test 3, ±3 dB tolerance, fixed microphone
Comparing these two figures also shows that less equalisation was applied during the second attempt, which took place after the more gruelling attempts at achieving the ±2 dB tolerance limits (Test 2). Perhaps the whole exercise seemed to be easier by Test 3. Indeed, Test 2 took an average of about four times as long to complete than the other three tests. Tightening the tolerance limits was far more demanding of the people doing the equalisation. Perhaps by Test 3, the people were becoming more familiar with how the room was responding, or even how the equaliser controls were interacting. Nevertheless, for whatever reason, the tendency was for less equalisation to be applied during Test 3 than had been applied during Test 1.

In general, the equaliser settings for Tests 1 and 3 can be seen to be (other than for a very few exceptions) within the range of -7 to +5 dB from 62 Hz to 6.2 kHz. By comparison, however, the results for Test 2 show that a much wider range of equalisation needed to be applied to get the response to within the tighter, ±2 dB limits. Equalisation ranging from typically -10 to +10 dB was frequently used - a range of 20 dB. This is 8 dB more of equalisation range that had been used to achieve only 2 dB less of tolerance range. The implications of this are significant, and will be discussed in the Sections 4 and 7.

3 VARIABILITY IN THE INTERPRETATION OF INSTRUCTIONS

It became clear during the carrying out of Tests 1, 2 and 3 that the request to use 'the minimum of equalisation' meant different things to different people. The approach of some of the subjects was simply to deal with the frequency regions where the initial response was found to be out of limits. Once all the frequency bands were inside the limits, they made no further adjustments. Some of the other subjects adjusted a greater number of frequency bands, but attempted to minimise the deviation from '0' of the equaliser control settings. Still others attempted to obtain the smoothest response on the analyser display. What had seemed to be a simple instruction gave rise to quite different interpretations. All of the approaches can, in one way or another, justifiably be deemed to be applying the minimum of equalisation.
Figure 5 shows the results from Test 4, in which every participant set their own microphone position. As with the equaliser adjustments, no two microphone positions coincided. In fact, two of the participants disobeyed the instructions given to them as to where to place the microphones because they did not agree that the instructions were correct (i.e. that the requested microphone position was not the best place to make such a measurement from). They began to place the microphone well away from the intended region, and had obviously failed to understand that the were participating in an experiment, and not trying to calibrate the room. Nevertheless, the three people overseeing the experiment decided not to argue the point, as this was probably another valid example of what really happens in practice. Interestingly, though, it was not evident from Figure 5 that any of the equalisation settings was particularly out of the range of the rest. The dissenting participants had not produced any unduly wayward results. So, is the precise microphone position that important? Nothing in Test 4 suggested any significantly greater variability in the applied equalisation levels due to microphone position alone.

It is obvious from the comparisons of Figures 2, 4 and 5 that, except below 100 Hz, there is little difference in the overall range of equalisation used to bring the response to within the ±3 dB tolerance limits. On the other hand, when comparing Figure 5 with Figures 2 and 4, it is also evident that the spread of the applied equalisation in terms of frequency is much broader. This is a good indication that there may well be, as is often cited, benefits in the use of spacial-averaging techniques when doing this type of measurement. Nevertheless, as mentioned in Section 1, the choice of the positions for the various microphones involved still remains a question for the individual people carrying out the tests to decide upon themselves. Evidence from other recent tests, within the cinema industry, suggest that some very significant disagreements can be reached, even amongst experienced professionals, when it comes to the question of where best to position the measuring microphones for the purpose of calibrating loudspeakers in large rooms.

Somewhat perversely, the spread of microphone positions that occurred in Test 4 was the result of the people all being asked to put the microphone in what would have hopefully been roughly the same position.

4 EFFECT OF IN-ROOM TOLERANCE LIMITS ON THE DIRECT SOUND

Figure 6 shows the response of the loudspeaker use in these experiments, measured in a large, hemi-anechoic chamber. It can be seen that the spectrum is relatively flat, other than for the obvious floor-reflexion dips. However, the differently equalised responses of the loudspeaker, especially after the ±2 dB adjustments had been made, would have rendered the direct output highly irregular in terms of the frequency balance from one case to another. In effect, every different equalisation setting applied by each person would have considerably changed the spectrum of the sound emanating from the loudspeaker; in some cases to an alarming degree. The impact on the integrity of the direct sound would have been much less if the tolerance limits had been ±3 dB. This type of equalisation can lead to highly coloured sound, despite the apparent, in-room, quasi steady-state response appearing to be reasonably smooth when measured in one-third octaves [1].
A severe conflict appears to be arising, here, between the desirability of having a smooth spectral response in the steady-state character of the room, and the need for maintaining a sonically uncoloured source. Significant colouration in the source cannot possibly give rise to a natural sound deep into the room, no matter how acceptably flat the steady-state response in that position may appear. It is impossible for a coloured source to become uncoloured by its passage across a room. It is also impossible for differently coloured sources to lead to the compatible perception of the deep-into-the-room responses. If different technicians with different interpretations and different manipulations of the equaliser controls give rise to differences in the direct sounds of the same loudspeaker systems, then those technicians, themselves, are a source of incompatibility in the perception of the same source material from room-to-room.

Figure 7 show the changes in equaliser settings for the two attempts of each person at the fixed microphone, ±3 dB tolerance adjustments (Tests 1 and 3). Bearing in mind that these pairs of tests were carried out within less than 30 minutes of each other, on stable equipment and in stable conditions, the results can only be considered to be worrying if serious calibration work relies on such procedures.
Figure 7 Change in equaliser settings for ten subjects: Test 1 to Test 3, ±3 dB tolerance, fixed microphone

Figure 8a) Test 1 Subjects 9 & 10

Figure 8b) Test 2 Subjects 2 & 7

Figure 8c) Test 3 Subjects 7 & 10

Figure 8d) Test 4 Subjects 7 & 9

Figure 8 A selection of comparisons of equaliser settings
Figures 8 a) to d) show the degree of difference between some of the individual adjustments found in each test. (Test 1, subjects 9 and 10; Test 2, subjects 2 and 7; Test 3, subjects 7 and 10; Test 4, subjects 7 and 9). This degree of difference in equalisation will undoubtedly lead to very different sounds from the loudspeakers, no matter whether heard from close to, or from deep into the rooms.

5 Calibration of Surround Loudspeakers and Related Problems

Cinema surround loudspeakers are usually distributed along the side walls and rear wall of the room and the calibration of these brings with it further problems in addition to the 'human related' problems described above. Each surround signal channel (eg side left) is usually used to drive a number of surround loudspeakers in parallel, so the sound field in the room is subject to interference between the sound from the individual loudspeakers. This interference gives rise to very complicated, frequency dependent spacial variations in sound level. To investigate this, a computer simulation of the sound field in a room, based on an image model, was set up. The simulated room was 15m long by 11m wide by 4.5m high, the reference microphone position was 10m from the front wall, at 1.2m high on the centre line of the room. Figure 9a shows the simulated sound pressure level in third octave bands at the reference microphone position when 5 surround loudspeakers are operated simultaneously. The surround loudspeakers are placed along the side wall spaced 2m apart from 6m to 14m from the front wall. Figure 9b is as Figure 9a but for 5 different microphone positions placed 0.1m apart from 9.8m to 10.2m from the front wall. It can be seen that the combined output of the 5 surround loudspeakers gives rise to level differences of up to 7 dB between microphone positions at mid and high frequencies. Clearly, the calibration of arrays of surround loudspeakers cannot be reliably carried out using in room measurements, except at low frequencies. Furthermore, it is totally unreasonable to expect the calibration technicians to conform to positions which would have to be accurate to only a few centimetres between one visit and another.

The computer model can also be utilised to investigate the sensitivity of the calibration of the front loudspeakers to microphone position. Figure 10a shows the simulated sound pressure level in response to the output from the left front loudspeaker (on front wall, 2m left of centre) at 5 microphone positions spaced 0.75m apart from 1.5m to the left to 1.5m to the right of the reference position, to simulate measurements at adjacent seats. Figure 10b is as Figure 10a but for 5 microphone heights spaced 0.1m apart from 0.2m below to 0.2m above the reference position. Considering the variations seen in these plots, it is difficult to justify how any of these results at these relatively close positions could be considered to be representative of the sound in this part of the room, let alone that in the room as a whole.

Vol. 34, Pt. 4. 2012
Listening tests have shown that the nature of the sound barely changes when moving between such seat positions, so there is no apparent motive for using different equalisations other than as a result of different microphone locations having been chosen for the measurements. All of the microphone positions simulated are well within the range of places chosen by different people doing this sort of calibration.

![Figure 10a Simulated sound pressure level from the left front loudspeaker at 5 microphone positions spaced 0.75m apart from 1.5m to the left to 1.5m to the right of the reference position](image)

![Figure 10b As Figure 10a but for 5 microphone heights spaced 0.1m apart from 0.2m below to 0.2m above the reference position](image)

6 CONCLUSIONS

a) It is clear from the tests reported in this paper that there are variables involved in the equalisation of room/loudspeaker combinations that stem from both the individual interpretations and executions of the instructions given to the technicians.

b) The meaning of 'use the minimum equalisation' was interpreted not only in terms of amplitude, but also in terms of frequency, and even a combination of both. Within the groupings of people who were largely interpreting the instructions reasonably similarly, the way that they carried out those instructions still led to an undesirable degree of variability in their final control-settings. The overall degree of similarity between the results of the ten people carrying out the 3 tests to the same tolerance margins was disappointing. No two of the 30 results corresponded with each other. Neither were any of the results the same when the participants attempted to equalise the response to within the ±2 dB tolerance limits.

c) When people were asked to position a microphone according to a standard set of instructions, there were not only differences in their ideas of what those instructions implied, but there were also dissenters who blatantly refused to comply, due, no doubt, to the predominance of their own ideas of what those instructions should have been. In the opinions and experiences of the authors, this probably reflects what actually occurs in the field.

d) Part of the problem is that the whole concept of 'room' calibration by such methods is seriously flawed. Old ideas that the similar, smoothed, steady state responses of the rooms will somehow indicate similar sounding loudspeaker/room combinations are no longer supportable, yet they still prevail in the concepts behind many standard techniques of measurement. When rooms are measured at arbitrary positions and with arbitrary microphone techniques, they have no hope whatsoever of being 'tuned' to sound equal. All of the choices are subject to arbitrary variability because it is left to individual persons, or perhaps small groups of people, to decide upon the placement of the microphones; and very often this is done without those involved being fully conversant with the ramifications of their decisions.

e) Measurements lumping together the direct sound, the early reflexions, the late reflexions, the resonances and the reverberation are almost chaotic in their degree of complexity. It is unlikely that any two people sent to measure the same room would arrive at the same result, and not even

Vol. 34. Pt. 4. 2012
within ±1 dB, *at the very best!* Nothing even approaching this degree of similarity can be seen in the results presented here, despite the fact that they were carried out in an auditorium that was acoustically well-controlled. In any case, this type of far-reverberant-field measurement gives little indication of true sound quality. The approach is far too simplistic for any serious calibration process. As explained in Section 4, colouring the direct sound is absolutely contrary to the concept of achieving compatibility from one room to another, and the indications from the results published here seem to suggest that each person will introduce their own variations on this theme.

f) As an aside to the original goal of this study, it can clearly be seen from a comparison of Test 2 with Tests 1 or 3 that 8 dB more equalisation range was used to achieve only ±1 dB narrower limits in the two-thirds-distance response. In a way, this result is quite ironic, because, whilst it is unlikely that the change in the global, far-reverberant-field limits between ±3 dB and ±2 dB could be expected to significantly 'improve' the overall sound quality (that is to say, little timbral difference could be expected), the degree of extra equalisation of the direct signal that would be necessary to force the response into the tighter limits would almost certainly give rise to a far more coloured, and less natural, general sound characteristic. In terms of sound 'quality', the effect would probably be significantly negative, as colouration would actually be increased, not decreased, so the motives for tightening limits in this way must be seen to be very questionable indeed. In any case, the degree of repeatability achieved was not very encouraging in terms of reliable calibration. In the light of this human inconsistency, one must wonder how many times such changes from one calibration visit to another have been attributed to 'equipment drift', when in fact, no drift had occurred. Modern equipment drifts very little, but what has been shown in this paper is that not only different engineers and technicians, but also the same people at different times, have great difficulty in repeating equalisation settings, even with fixed equipment and stable conditions!

g) The potential for serious calibration differences due to microphone positioning inconsistencies is particularly evident when measuring multiple loudspeaker arrays, such as are frequently used for surround loudspeakers.

h) A more modern and more scientifically justifiable philosophy would be to concentrate more effort into achieving better consistency between the outputs from the sources. This is something which can be done in a manner which is not only much less subject to human vagaries, but also various other types of variations, as well. Equalising a loudspeaker system from deep within a room is a highly inaccurate standardisation technique which can do great damage to the integrity of the direct sound, as has clearly been shown in these tests. The un-equalisable non-minimum phase characteristics of several aspects of the room acoustics will give rise to adjustments that lead to both unnatural sounds and strange relationships between the percussive and sustained sounds. The question of how to accurately measure a loudspeaker response in a room is not easy to answer. Nevertheless, whichever way a measurement is carried out in a normal room, there will be a human being making judgements about how it should be done. This puts an extra variable on top of an already complicated situation.

7 REFERENCE
