THE RELATIONSHIP BETWEEN SUBJECTIVE AND OBJECTIVE RESPONSE DIFFERENCES AT DIFFERENT HEIGHTS ABOVE CINEMA SEATING

Philip Newell — Acoustics Consultant, Moaña, Spain (philiprnewell@gmail.com)
David Santos-Domínguez — Universidade de Vigo, Spain
Keith Holland — ISVR, University of Southampton, UK
Soledad Torres-Guijarro — Universidade de Vigo, Spain
Sergio Castro — Reflexion Arts, Vigo, Spain

ABSTRACT

It has been customary to perform the calibration of the loudspeaker responses in cinemas with the measuring microphones placed at, or near, the height of the ears of the seated audience, in the belief that this would best represent the sound as actually heard, but the motives for doing this would appear to have been based on anecdotal evidence more than from specific testing. In the light of the fact that the cinema industry is currently looking at reassessing the whole subject of theatre calibration, this paper reports on a pilot study to investigate at which height the calibration microphones should be placed in order to best represent the most realistically-perceived sound quality.

1 INTRODUCTION

Traditional thinking has implied that in order to best represent the sound heard by the audience in a cinema, the measuring microphones should be placed at or near the height of the ears of an average, seated, member of the audience. However, two ears and a brain do not detect sound in the same manner as a measuring microphone and an analyser. The ear is very sensitive to the directions and the times of arrival of the different components of a sound, whereas a microphone combines all of the individual characteristics of a sound field as a simple series of pressure fluctuations. It was also customary at the time when many of the current cinema-calibration practices were first defined (c. 1980), to believe that the frequency spectrum measured in the theatre in one-third-octave bands was the predominant factor in determining the response similarity from room to room. We now know that there are many other factors concerned with the audible similarity and 'fidelity' of sound reproduction, and evidence has been accumulating to suggest that the pressure-response measured close to the seat-backs in a cinema theatre may not, in fact, be the most representative way to calibrate the loudspeaker systems.

Close to the seating is a zone where the response is significantly disturbed compared to what would be measured a metre higher, but preliminary tests indicated that the difference as heard by a person when either seated or standing was only minimal. It therefore followed that if, during the loudspeaker-channel calibration process, equalisation was carried out via reference to microphones placed close to the seat backs, the locally-measured disturbances might lead the technicians to make adjustments to the responses which did not correspond with the local perception of the sound. That is to say, changes would be made to the direct-sound responses which would only serve to introduce colouration, instead of *reducing* any response errors, due to the technicians or auto-calibration systems trying to 'correct' what was, effectively, an inconsequential problem.

2 THE EXPERIMENTS

A series of tests were performed in the multi-purpose theatre in the Telecommunication Engineering School at Vigo University, in Spain (shown in Figure 1). Microphones were positioned at heights of 4 cm, 20 cm, 40 cm, 60 cm, 80 cm. 100 cm and 120 cm above the backs of two different seats. One seat was towards the rear of centre of the seating area, displaced one seat to the right of the centre line. The other seat was towards the front of centre, four seats to the left of the centre line. A loudspeaker (JBL Cabaret Series Model 4612) was mounted on a stand on the front platform, well ahead of the projection screen and at a height which would represent an angle similar to that of a loudspeaker mounted half-way up the screen when viewed from the test seats. The loudspeaker can be seen in Figure 1, and the seats at the measurement positions can be seen with the tables extended (although they were stowed away during the tests).

Figure 1: The multi-purpose theatre in the Telecommunication Engineering School at Vigo University, showing the loudspeaker on the stage, and the measurement positions – which are the seats with the tables unfolded

The seating in the auditorium was on a stepped floor, with a moderate angle of rake, but not as steep as stadium seating. The degree to which the extremes of seating rake could make much difference to the results is something for a further experiment, but it seemed reasonable to do the initial tests with an intermediate rake. Much of the existing literature applying to the absorption due to seats in concert halls involved the sound sources being at a much lower relative height than is normally the case in cinemas, where the loudspeakers tend to be mounted well above the front rows of seats and the sound strikes the audience at a much steeper (and variable) angle than that from a concert platform. The seats in the room under test, here, were upholstered, with quite a soft padding.

The decision to use a relatively compact sound-source was intended to avoid introducing additional variables which might be associated with the positional differences of any interaction between the separated drivers in a larger loudspeaker system. The object of the test was to assess only the differences due to the rows of seats, and not those due to listening at the limits of a loudspeaker coverage pattern or due to multiple-driver cancellation. Indeed, during the set up of the experiment, listening in the front rows, on the edge of the loudspeaker's horn directivity pattern, clear differences in the pink noise could be heard between the standing and sitting positions, which were by no means as pronounced in the area of principal coverage. It was important to the experiment that this type of variable should not compound those resulting from the seats themselves.

For the measurement part of these tests, a B&K 4190 measuring microphone was mounted on a stand at different heights above the seat backs. Figure 2 shows the microphone in the lowest position measured. Pink noise was reproduced via the loudspeaker system at a sound-pressure level confirmed to be well above the background noise, and the response at each height in each seat position was recorded. Although the analysis would be carried out at a later date, a visual check of the response was made before each measurement was concluded. During previous experiments, the decay time of the room had been measured as:-

63 Hz - 1.05 s
125 Hz - 0.76 s
250 Hz - 0.79 s
500 Hz - 0.73 s
1000 Hz - 0.63 s
2000 Hz - 0.70 s
4000 Hz - 0.69 s
8000 Hz - 0.55 s

Figure 2: The measuring microphone positioned 4 cm above a seat back

The subjective part of the test involved listeners being asked, one by one, to listen to a soundtrack containing dialogue, effects and music, in each of the two measurement locations, both when seated and when standing. They were each given a sheet of paper on which to write any comments about any perceived differences in the sound. The listeners were mostly students, but they were not screened for hearing acuity as the object of the tests was only to look for differences in the character of the sounds. There was no quantification involved. The programme material was played back at a level consistent with what was deemed to be natural for a film being shown in the theatre, although the soundtrack was presented without picture. A mixed, mono signal was used, because the principle, most critical sounds in cinemas tend to come from the centre-front channel. Furthermore, cinema loudspeaker channels are calibrated one at a time. Tests in stereo or multi-channel would have involved totally separate experiments.

3 RESULTS OF THE MEASUREMENTS

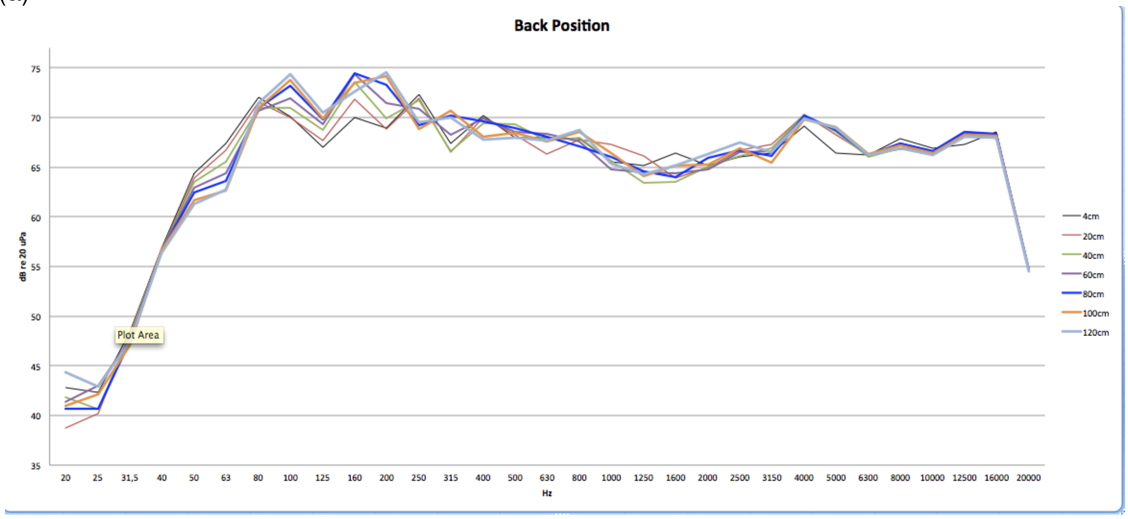
The results of the measurements above the rearmost of the two seats are shown in Figure 3(a). Other than for the position 4 cm above the seat back, the responses conform reasonably well above 500 Hz. Indeed, the responses at the 80, 100 and 120 cm heights generally correspond well at all frequencies, but below 500 Hz the responses can be seen to fall with the height, at least down to 80Hz, below which they exceed the measured levels at the higher positions until converging, again, around 40 Hz, where the loudspeaker response rolls off. A somewhat similar effect was reported by Gedemer, albeit with a higher ‘crossover’ frequency [1]. By contrast, Figure 3(b) shows the results of the measurement at the foremost of the two seats. Again, above 500 Hz there is good correlation between the measurements at different heights, with only the position closest to the seat-back showing much deviation, but the degree of differences in the 40 Hz to 200 Hz band is clearly greater when measured at 40 cm and below, compared to the rear position.

4 RESULTS OF THE LISTENING TEST

The comments from the twenty people taking part in the listening tests were sometimes quite difficult to interpret, but this would appear to be due to them struggling to describe the small changes in the sound character. Indeed, many of the comments were simply that they could not hear any obvious differences at all between the seated and standing positions. There were several comments that there was a greater sense of reverberation when standing, and that there was a sensation that there were more low frequencies in the music, but nobody commented on any meaningful differences in the sound of the dialogue. There were also some comments about the sound being clearer when seated, but this could be associated with the other comments about there being more reverberation when standing.

Other than the above comments, there was little in common between the opinions of the listeners, and there were at least a few contradictory statements regarding whether there was greater clarity when seated or when standing, although when using subjective terminology, such things are to be expected. Nevertheless, notwithstanding some of the vagueness, the only distinct tendencies were to hear more low frequencies and more reverberation when standing.

(a)



(b)

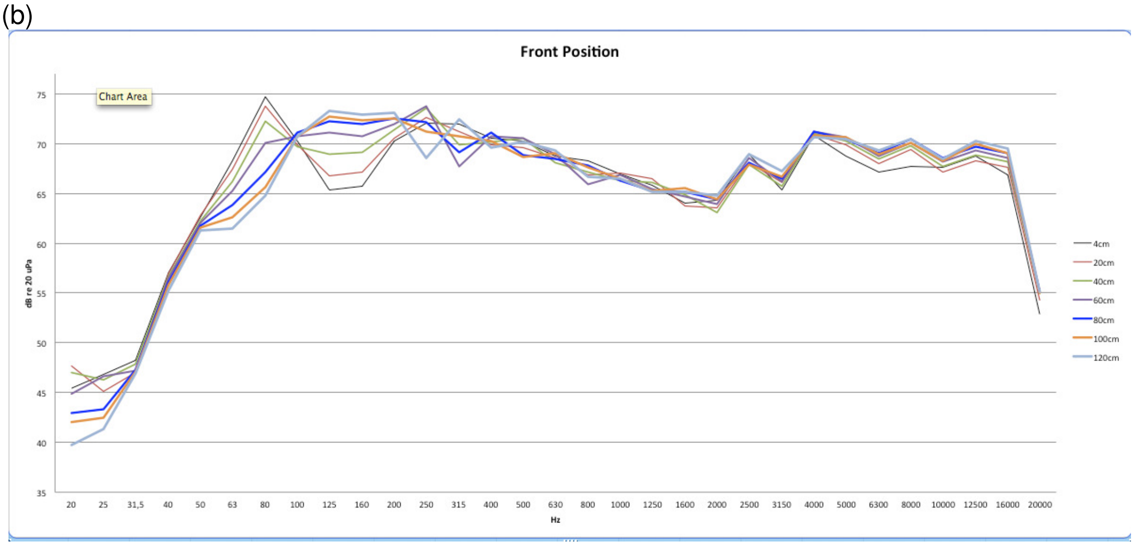


Figure 3 (a): The responses measured in one-third-octave bands above the rearmost of the two seats. The thinner lines are the lower positions. A distinct increase in the upper low-frequencies can be seen between the 4 and 40 cm positions, but with little change above that height
(b): The responses measured in one-third-octave bands above the foremost of the two seats. The thinner lines are the lower positions. A greater deviation in the low frequencies can be seen between the 4 and 40 cm positions than was evident at the rear position, shown in (a)

5 DISCUSSION OF RESULTS

The most obvious difference that can be seen in the measurements at the two different seats is the degree to which the low-frequency responses vary at different microphone heights, especially at and below 40 cm; as can be seen by comparing Figure 3 (a) with Figure 3(b). The only apparent explanation for this is the change in the angle of incidence of the wavefront as it strikes the seating. At the heights closer to the seats, the steeper angle of incidence seems to give rise to greater attenuation of the frequencies in the octave from approximately 100 to 200 Hz, but *reduced* attenuation (or perhaps a resonance or a reflective-boundary boost) below about 80 Hz. This finding would indicate the need for a future experiment involving raising the loudspeaker angle whilst measuring at the same seat.

As mentioned earlier, during the setting-up of the experiment, the authors were in agreement that the sound in the very front rows of seats changed significantly between the seated and the standing positions, but this was mainly a high-frequency effect due to the seat rows being at the vertical-directivity limits of the horn. However, there was no apparent reason why lower frequencies should change due to directivity effects because the drivers were of small diameter and horizontally paired. In fact, at the two measured positions, the high frequencies do not show any noticeable losses between the front and rear test-seats which could be attributed to directivity issues, at least not above the 3 kHz crossover frequency. Although there is some evidence of directivity issues or multiple-driver interference for about an octave below that frequency, there is nothing in this band which noticeably changes with the measurement height, so it would not be likely to influence any audible differences between the standing versus seated differences.

The subjective and objective results correlate quite well inasmuch as there were more, overall low-frequencies evident when standing. However, nobody made any significant comment about preferring the sound in one (vertical) position more than in the other. After finishing their tests, the last ten listeners were asked if they had any preferences regarding listening position, but most of the comments in which any preference was expressed related to the front or rear *seat* positions, and not the standing versus seated positions.

6 FURTHER QUESTIONS

Many questions remain for further study. It would be interesting to know what was responsible for the 'crossover' frequency between the augmented and attenuated responses closer to the seats at low frequencies, and whether it would be affected by the material from which the seats were made, the relative heights of the seat backs in front and behind (such as with flat or stepped seating) or the presence (or otherwise) of a seated audience. In addition, measuring in an arc at a fixed distance from the sound source would show if the horizontal angle of incidence also affects the response characteristics close to the seats if the vertical angle of incidence remained the same.

As mentioned in Section 5, the changes which may be due to the vertical angle of incidence of the sound could indicate the need for a future experiment involving raising the loudspeaker whilst measuring at the same seat, in order to study the effect on the low-frequency response. In this aspect, the situation in most cinemas is significantly different from that in a concert hall because, in the latter case, the sources of sounds are multiple and distributed. The audience also tends to look down on to the stage, so the sources are relatively low. Conversely, the principal sound sources in a cinema are usually mounted much higher, and they are usually compact, with well-defined directivity characteristics. Much work has been done on the 'seat dip' effect in concert halls, but little literature can be found relating to the acoustic disturbances arising from the seating in typical cinema installations.

The question being asked to the listeners for the tests being reported here was intentionally simple, but there is still the consideration as to whether different questions presented to the listening subjects could reveal any more insight. It would also be interesting to repeat the tests using separate, specialist and lay listeners. However, as nobody reported any major differences in the sounds at different heights, it may be likely that any detailed differences derived from such work could be swamped by the other variables to a degree that they had no practical relevance. What is more, the 'better, clearer sound' reported by some participants in the standing or seated positions are differences which probably cannot be corrected by equalisation, and, as such, are outside the scope of this study.

7 CONCLUSIONS

Whilst these tests were carried out in some very limited conditions, and were very empirical, the results do give some indication of additional work which may need to be done on a more extensive basis if the question of at what height to make measurements for loudspeaker calibration is to be clarified. Some of the basic variables are outlined below, but the number of possible combinations which may affect the situation from room to room is very great.

(i) Height at which measurement is made
(ii) Seating rake angle – from flat to stadium
(iii) Height of loudspeakers relative to the seats
(iv) Type of seats
(v) Height of seat backs
(vi) Effect of audience in the seats and the presence of many heads
(vii) Direction of sound incidence (front/side/ rear/overhead)
(viii) Loudspeaker directivity with respect to the area to be covered.
(ix) Specialist or lay audience
(x) Any combination of the above

Although only a few of the above variables were dealt with in these tests, from the results being reported here it is evident that the height at which the response measurement is made has a considerable influence on the observed spectrum, though perhaps somewhat less of an effect on the audibly-perceived spectrum. If this is the case, there would seem to be no motive for calibrating the rooms with microphones at close distances from the seat backs if those locations proved to be less representative of the general response of the loudspeakers. That is to say, if a disturbance was measured but not perceived to be relevant to the enjoyment of a soundtrack, it would be better to measure in places less affected by the seats, as equalisation applied solely to compensate for the seating disturbances would tend to disturb the perceptually important, direct sound from the loudspeakers, and add needless colouration. It has previously been shown that the direct sound arrives intact before the disturbances due to the seats take effect [2].

As the results were rather similar to each other above the 60 cm height, the implication is that the increasing differences as the seat-backs are approached are due to the response disturbance given rise to by the seats themselves. Sixty centimetres above the seat backs would therefore seem to be a minimum height for making measurements if they were to be free of the effect of the presence of the seats.

Regarding items (ii) and (iii), above, the objective results of the test reveal that the angle of incidence at which the sound strikes the seats may be important, as it appears to affect both the frequency and the amplitude of the disturbances. This result seem to indicate that, whilst much more work needs to be done, the disturbance close to each seat may be particular to that location, in which case, it would seem to be unwise to make equalisation corrections to the source of the sound, which would be general for all locations. Consequently, if the measuring microphones were positioned 60 cm or more above the seat-backs, there would be a greater probability of measuring the more general sound being radiated by the loudspeaker, without the unknowable variations which could be due to the proximity of the seating and the variable presence of the audience. We do not know that the measurements at the (empty) seat backs are relevant if the human beings sitting in the seats change the situation significantly. No literature was found relating to this phenomenon when the sources of sound were mounted relatively high, as in cinemas.

The main conclusion of this work is that if there was no listener-preference between the sounds at different heights, there would seem to be little point in making calibration measurements in an acoustically-disturbed zone closer to the seats. This would be especially so in cases where the new trend towards auto-calibration is to be relied upon, and where ‘mindless’ equalisation would take place.

8 REFERENCES

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