THE EFFECT OF VISUAL STIMULI ON THE PERCEPTION OF 'NATURAL' LOUDNESS AND EQUALISATION

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ABSTRACT

In the world of audio for picture, the two must combine well to create a believable reality. It has long been known that the visual and audible stimuli are to some degree affected by each other; however, the ways in which these variables interact has not been particularly well documented. This paper presents the results of several controlled experiments, which have dealt with some of the separate variables; individually, and also in various combinations. These experiments relate to the problems of compatibility between cinema and domestic reproduction of audio-visual programmes, and also the compatibility between the different mixing environments, themselves. The need for multi-format mixing rooms has been with us for many years, but the practical realisation of such rooms has not enjoyed much success; principally for lack of a fuller understanding of the subjects under discussion in this paper.

1 INTRODUCTION

A series of tests were conducted in 2007, on a relatively informal basis, which culminated in a paper which was presented at Reproduced Sound 23 [1]. The reason for the experiments was to try to determine some of the factors which seem to make it very difficult to achieve mix-compatibility between cinema soundtracks which have been variously made in large and small dubbing theatres, despite the fact that all the rooms have been similarly aligned to tight specifications at the mixing positions. The concept of 'universal' mixing rooms has been a Holy Grail of the multi-media industries for many years, but 'blockbuster' films still, almost invariably, need to be mixed in large, expensive rooms if good compatibility of the perception of the soundtrack is to be maintained in large, public-performance cinemas.

Tests are still being planned to investigate further the effects of large and small room acoustics on the compatibility of mixes, as described in Section 10, but the majority of the work which is reported in this paper relates more to the impact which the image size, distance and brilliance may have on the perception of when a sound balance and overall level are deemed to be most 'correct' in audio-visual terms.

The first test in the series was carried out in a 5.1 television mixing room, of very low decay time, at the voice-over and dialogue replacement studios of Sodinor, in Vigo, Spain. This room, in fact, was the same room that had been used for some of the less formal tests which were carried out for the previous paper [1], so some direct comparison was possible

2 EFFECT OF THE PRESENCE OR ABSENCE OF IMAGE, AND OF SCREEN SIZE, ON 'NATURAL' SPL

A test was devised to investigate the effect on desired sound levels, with and without image, and with screens of two different sizes. Eighteen people took part in this test, all of whom were between 17 and 35 years of age. They were mainly musicians, both male and female, drawn from a music school near to the studio where the test was being carried out. None of them were informed about the reason for the test, or what it would involve, and they were only given brief instructions prior to each individual part of the test. The participants adjusted the fader levels themselves, and an operator conducting the test read the levels from a data screen and noted the values for each participant.

Two video monitors were set in front of the listening seat at a distance of about 1.5 metres from the ears of the participants. The signal source was stereo, and the loudspeakers were mounted in the front wall, about 30 centimetres behind the front planes of the screens. The participants were asked to enter the room and to listen to an action sequence from a film soundtrack, without image, and to imagine that they were listening to a radio drama. They were then asked to adjust a fader such that they were comfortable with the sound level in terms of their own enjoyment of the programme. The people were tested individually, from small groups, and when each person had completed the test, they were then asked, one by one, and in the same order, to repeat the test, only this time they would also see the image on a 10 inch video monitor. The whole process was then repeated once more with a 31 inch video monitor.

At first glance, the results appeared to be chaotic, although what was noticeable was the very wide range of SPLs that the participants individually considered to be normal. When no image was presented, a range of over 25 dB was observed between the person selecting the highest level (around 96 dB(C) at the listening position) and the person selecting the lowest level. With the 10 inch monitor the range increased to over 27 dB, and with the 31 inch monitor to over 28 dB. After much deliberation, the results of two of the participants were excluded from the analysis. They were wildly anomalous, although in opposite directions. On the overall range of SPLs they did not significantly affect the results, but when the relative levels were assessed, the variability range reduced considerably without their inclusion. They were the only two participants asking for differences of over 10 dB between the viewing of the larger and the smaller screens (one person in each direction).

When the other 16 results (shown in Table 1) were averaged, they showed that the participants had asked for 1.1 dB more level when no image was present, compared to when watching the smaller screen. When the larger screen was being viewed, the mean level considered to be most enjoyable was 5.7 dB higher than that when viewing the smaller screen, (and therefore 4.6 dB higher than when listening with no image).

Despite the programme material being different, the experimenter being different, and the participants being different, the difference of about 5 dB between the preferred sound levels when watching the screens of different sizes were in keeping with the findings of a previous experiment [1] carried out one year previously, where an approximately 4 dB difference was encountered. The findings would therefore appear to be reasonably robust, and indicate that the there is a tendency for people to expect more sound level to accompany a larger screen, compared to a smaller screen, when the viewing distance is the same.

Table 1 Results: Effect of the Presence or Absence of Image, and of Screen Size, on 'Natural' SPL

NAME	No image	10 inch screen	31 inch screen
Ana	-14.5	-15.0	-12.7
Dario	-14.0	-14.9	-15.0
Sandra	-22.9	-27.4	-28.0
Paula	-6.1	-3.2	+0.7
Alex	-14.0	-8.8	-12.2
Martinho	+2.4	+0.4	-0.1
Edu	0.0	-1.0	-0.1
Júlio	-2.7	-9.9	-11.7
Carlos	-19.6	-17.6	-18.5
Manuel	-16.9	-15.0	-9.7
Luis	-14.0	-15.0	-15.7
Pablo F.	-11.9	-11.7	-13.5
Sandra	-16.7	-10.7	-11.8
Javier	-14.3	-17.1	-12.8
Rubén	-23.3	-21.5	-26.2
Xulia	-16.4	-17.2	-12.6
VARIATION RANGE	25.6 dB	27.8 dB	28.7 dB
Mean difference relative to 10 inch screen	+1.1 dB	0.0 dB	+5.7 dB

2.1 Screen size with dialogue, only.

A few weeks after the previous tests were carried out, a similar test was undertaken with 21 participants, using the same room and equipment as above, but this time the soundtrack was dialogue-only, albeit with background noises. In order to try to investigate the subject without the complication of whether lip-reading could affect the results, a foreign language version was used, in which the persons on film were not originally speaking the language of the soundtrack used in the tests (an interview carried out in Tienemann Square, with voice-over). The results showed that the participants were again asking for more level with the larger screen, but this time only an average of about 1 dB more. It is still under investigation whether this could be due to the limited bandwidth of the voices, or if the relationship of dialogue to screen size is somehow different to that of music and effects.

3 EFFECT OF THE DISTANCE FROM SOURCE ON THE 'NATURAL' SPL

Two different tests were carried out to determine the effect of screen size on the 'natural' SPL. In the first test, a single screen was used, and the participants set their 'natural' sound levels whilst sitting on stools, positioned at various distances from the screen. In the second test, the seating position was fixed, but different sized screens were used at different distances from the seating position. The screen sizes and distances were chosen to maintain the same angle of vision.

The first test, carried out in the hemi-anechoic chamber at the University of Vigo, employed a video monitor and a loudspeaker, both located in a corner of the chamber, as shown in Figure 1, with a series of stools at determined distances from the screen. The participants were asked to set, via a remote control, what they considered to be the most normal (for each of them) sound level at each of the distances. The operator noted the level settings remotely. Twelve of the students from the Department of Telecommunications took part in the test, and the results are shown in Table 2. (The results for one participant were discounted due to gross inconsistency.) These tests were carried out in a room of very low decay time in order to avoid the influence of a critical distance, where the room reverberation could complicate the analysis of the fall-off with distance. The mean values of the results are shown in Table 3, and it can be seen that they indicate a considerable reduction of the SPL with distance. However, when the best fit straight lines to the individual curves were averaged, there was an indication that the participants were asking for only about 1 dB SPL less as the distance increased from 1 metre to 5 metres. Nevertheless, both interpretations show a reduction of the desired sound level with distance, which is consistent with the findings of the experiment carried out for the previous paper [1], in which an approximately 4 dB fall-off was noted.

Figure 1 Experimental Setup for First Test at the University of Vigo

Table 2 Results: Effect of the Distance From Source on the 'Natural' SPL dB(C)

	d (m)			
Listener	**1**	**2**	**3**	**5**
1	81,8	81,7	82,9	82,5
2	67,1	62,7	62,1	64,9
3	70,9	66,5	65,5	66,1
4	75,2	74,0	76,2	77,9
5	76,3	78,1	78,0	75,9
6	77,4	75,8	73,2	71,5
7	77,4	77,3	75,5	79,2
9	73,9	74,0	69,3	72,9
10	77,4	73,0	72,3	73,6
11	69,1	69,5	70,4	71,5
12	52,4	60,2	62,1	58,9

Table 3 Mean Values of Data From Table 2

Distance	SPL dB(C)
1m	72.6
2m	72.0
3m	71.6
5m	65.6

The second test of this pair was also carried out in a room with a very low decay time, but in this case it was a sound control room. The screens were progressively larger at greater distances from the seating position of the participants, in order to maintain a constant viewing angle at the listening position, from the screen edges, as shown in Figure 2. The screen sizes, distances, and the chosen SPLs are annotated in Table 4 from which it can be seen that there was a tendency for the participants to ask for more sound level as the distance (and screen size) increased.

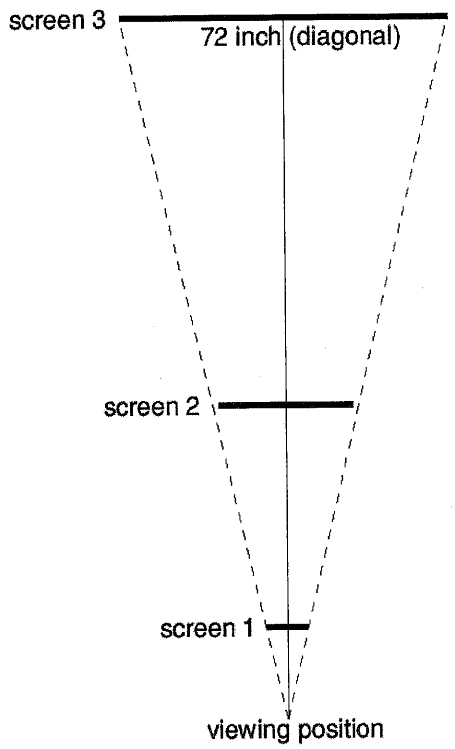

Figure 2 Layout of Screens in Room with Very Low Decay Time

Table 4 Results: Effect of Screen Size and Distance on 'Natural' SPL: Constant Viewing Angle

Screen Size	Distance	Mean SPL change (dB)
14 inches	0.5 m	0.0
29 inches	1.7 m	2.0
72 inches	3.8 m	3.7

The pair of tests described in this section were intended to show if the distance to the screen, or the perceived size of the screen, were the dominant factors in eliciting any changes in the preferred sound pressure levels. Obviously, keeping the screen size constant, whilst increasing the distance from the viewer/listener, will make the image appear smaller. However, it was not known to what degree the brain could compensate for this effect, or even whether it would 'expect' less level when viewing the same object from greater distances. The apparent size differences could be correlated with the effects of the actual size differences described in Section 1 of this paper.

From the results of the two tests it can be seen that when the screen size remains constant, the tendency is for the viewers to expect a lower sound level as the apparently shrinking image recedes into the distance. Conversely, if the screen size increases as the distance increases, and the viewing angle remains constant, the tendency is for the viewers to expect a higher sound level.

4 EFFECT OF SCREEN SIZE ON LOW AND HIGH FREQUENCY EQUALISATION

During the first of the experiments referred to in Section 2, it had been noted that some participants commented about the 'unnatural', or 'excessive' levels of low frequencies when watching the smaller screen. This had also been noticed during the tests carried out the previous year. It was not entirely clear whether people were simply unused to hearing strong low frequency sounds from small televisions, or whether they were simply reacting to the fact that, in nature, small objects do not produce high levels of low frequencies. In other words, were we dealing with something learned, or something innate?

At the University of Southampton, a test was carried out in the listening room of the ISVR, in which two video monitors were installed, one of 7 inches and another of 42 inches, along with a pair of loudspeakers for reproducing the soundtrack. Both monitors were widescreen format (16:9) and positioned the same distance from the listening/viewing seat. When each participant entered the chamber (making the tests one at a time) the bass and treble controls on the amplifier feeding the loudspeakers were set at minimum. Viewing first the smaller monitor, the participants were asked to increase the bass and treble levels until they were satisfied that the equalisation was 'natural'. A DVD of an action film with a 2-channel soundtrack was used as a programme source, and after adjustment of the equalisation, the experimenter noted the positions of the controls before they were re-set to minimum. The test was then repeated with the image displayed on the larger screen. The object of the test was to determine whether more, or less, or even the same level of low and high frequencies was considered to be most appropriate for each different screen size.

The results are shown in Table 5, from which it can be seen that the screen size appears to have had very little influence on the amount of high frequencies that were deemed to be natural for realistic viewing. (The mean control setting changed from only 5.7 to 5.8, which was well within the range of error of the test.) By contrast, the effect of the image size on the appropriateness of the low frequency response was very noticeable, with the larger screen calling for a mean setting of 7.6, compared to 5.6 from the smaller screen. At 60 Hz, this difference in the control settings represents a change of about 4 dB.

This finding is interesting, because it suggests that if levels are decreased in smaller rooms, then the reduced sensitivity of the ear to the low frequencies will at least act in the same direction as the desirable equalisation.

Table 5 Results: Effect of Screen Size on Low and High Frequency Equalisation

Subject number	Small Screen Bass	Small Screen Treble	Large Screen Bass	Large Screen Treble
1	3	4	5	5
2	3	5	6	7
3	6	6	7	5
4	4	6	8	7
5	7	6	7	6
6	6	3	7	5
7	8	5	9	3
8	6	7	9	6
9	7	9	10	8
MEAN	5.6	5.7	7.6	5.8

5 THE EFFECT OF IMAGE INTENSITY ON THE 'NATURAL' SOUND PRESSURE LEVEL

In the large mixing room at Cinemar Films, a test was carried out using a 35 mm film projector, with a high intensity short-arc lamp, and also a video projector. Each projector was used in turn, in conjunction with an 8 metre screen at a 7 metre viewing distance. In each case, the programme material was the same, but the video projection was much less luminous than the film projection. The participants were each asked, in turn, to enter the room, sit at the mixing position, then adjust a fader on the mixing console to give what they considered to be an appropriate sound level. The participants first viewed the video image, and were then asked to leave the room. After a break, they were then asked to re-enter the room and repeat the test, but this time whilst viewing the much brighter 35 mm projection.

Contrary to what had been indicated in some earlier experiments [1], the results of this test showed no difference in the chosen level versus the image intensity. In fact, not only did the average of the findings show no significant difference, but neither did the results of the individual participants show much variation. What was noteworthy, however, was the fact that all the participants selected levels between 15 and 25 dB below the standard level at which the film would normally be exhibited. When questioned about their choice, some participants commented that they thought that the general soundtrack levels in cinemas were too high. The relevance of these comments will be assessed in later sections of this paper.

6 OBSERVATIONS

During the tests described in Section 2, the operator was worried about the great range (over 25 dB) of levels selected by the different listeners. However, the test described in Section 3, carried out entirely independently in Vigo University, exhibited the same order of difference (around 25 dB). It seems to be clear that the general public have a very wide range of opinions about what level is comfortable for each of them, but it is interesting to note that almost nobody chose levels as high as in standard cinema reproduction. Not even in the tests carried out in the dubbing theatre at Cinemar Films, as described in the previous section, did anybody push the fader up to what would be anything even approaching the normal cinema levels. Modern-day cinema soundtracks, it seems, are loud by almost anybody's standards.

During these tests, two owner/operators of cinema chains were contacted, and were asked about whether playback levels for public performances were always maintained at the Dolby reference levels. Both of them replied that for performances where lots of children were present, the reference level was usually used, but for more 'mature' audiences the level was often reduced to avoid complaints. The sound level reduction was more common in the smaller cinemas than in the larger ones. This revelation was consistent with the results encountered during some of the experiments carried out for this paper, and the proposal in Section 8.

Various interesting comments were also noted during the tests carried out in a 5.1 mixing room for television, with a very low decay time, used for the tests described in Section 2. One participant complained of pressure on the ears; a very common comment when people enter an anechoic chamber for the first time (they confuse the lack of ambience with the pressure-induced loss of hearing acuity when travelling in pressurised aircraft). Another listener (Edu) said that he was used to listening to the television, at home, with a large sub-woofer, and that he needed to use a high level in the test to compensate for the lack of bass. (The experimenters thought that there was plenty of bass from the monitor loudspeakers in use, which responded to well below 40 Hz.) Yet another participant, when asked to make up his mind about the fader levels, replied that he always watched the television at home with the remote control in his hand, so that he could adjust the sound levels during the programmes, to be more dynamic. Comments were also heard about the separation of the stereo loudspeakers being too wide for the small screen, though no such comment was made during the large-screen or no-screen presentations. Some of these comments suggest that many people are very accustomed to listening in their own home environments in highly personalised ways.

7 SUMMARY OF FINDINGS

It is clear from the above tests that larger screens at greater distances demand more sound level than smaller screens at shorter distances. However, it is hard to classify the differences if several variables change at the same time, such as the viewing angle, screen size, and the nature of the soundtrack.

In commercial cinemas, the audience in the front rows receives considerably more SPL than the people in the back rows, but experience has shown that the sensation of 'reality' is not unduly different. The front rows of the audience also experience a much larger picture, extending over a viewing angle of perhaps 100 degrees or more, whilst the people at the rear view the screen with a subtended angle of maybe only 30 degrees, or less. The SPL differences seem to be relatively consistent with the distance and viewing-angle differences, and so the sense of realism can be maintained.

[In mixing/dubbing theatres, it is customary to locate the decision-making position about two-thirds of the distance from the screen to the back wall, and to maintain a viewing angle between 40 and 50 degrees. This is a reasonable best-compromise position for representing the entire audience.]

From the information gleaned from the experiments reported in this paper, the evidence suggests that, in general, the perception of a larger screen, in absolute terms, tends to require a higher accompanying sound level if a realistic audio/visual combination is to be achieved. Given the standard alignment of cinema rooms and mixing rooms of all sizes, in terms of level and equalisation, it suggests that films which are mixed in small rooms will not tend to be mixed as loud as those mixed in significantly larger rooms, because the perception of what is the appropriate sound level will change according to screen size. This seems to be contrary to the concept of the single, standard setting for all mixing rooms being a means of achieving mix compatibility from room to room. It would appear from the findings here reported that a progressive reduction in monitor level should be applied to mixing rooms as size decreases, and that the widely used 85 dB(C) reference level is probably most suited to a screen distance of around 12 metres (see next section), as typically used in rooms of 18 to 20 metres, front to back.

8 A LEVEL VERSUS SCREEN SIZE / DISTANCE CURVE

In a previous paper [1], reference was made to the existence of a possible curve of screen distance against SPL for a natural perception of the sound and image. Work done by one of the authors (Beusch, and his associates), after many experiments, has led to the equation:

$$L_p = 85 - 10\log\left(\frac{12}{W}\right) - 2\log\left(\frac{W}{12}\right) \quad \text{dB(C)},$$

in which the screen width - '12' (metres) - is an experimentally-based reference width, chosen as being the screen width for which the 85 dB(C) Dolby calibration level is considered (by Beusch) to be most appropriate. (For a 50 degree viewing angle, the screen width and distance would be approximately equal.) As examples, this equation would give:

W(m)	Level dB(C)
12	85.0
10	84.4
6	82.6
3	80.2
1	76.4
0.68	75.0

Other test reports in this paper tend to suggest that the one-metre figure is reasonable.

Applying the equation to widths (and therefore also distances for a 50 degree viewing angle) greater than 12 metres would give the following results:

W(m)	Level dB(C)
15	85.8
18	86.4
21	86.9

A plot of the curve is shown in Figure 3.

However, it may not be wise to increase the levels beyond the 85 dB(C) calibration level in cinemas (as opposed to mixing theatres) for several reasons:

1) Cinema levels are already, in many cases, considered to be too loud by the general public.

2) The more than 6 dB extra level required between the 12 metre and 21 metre distances/widths (4 dB, or so, for the distance increase and 2 dB from the equation) would call for over four times the power rating of the loudspeakers and amplifiers. This would mean a considerable increase in the cost of the equipment (more relevant in cinemas than mixing theatres) if reliability and thermal compression problems were to be avoided. At these power levels, the 2 dB from the equation could be worth avoiding.

3) In addition, the distortion would be likely to increase disproportionately to the benefit, even if the loudspeakers and amplifiers were up-rated, due to the increased air non-linearity which would be associated with the SPLs in the proximity of the mid-range diaphragms, (which for these levels would almost certainly have to be horn loaded). The distortion would not only be higher in the throats of the horns, but would also continue to increase as the propagating waves had a greater distance to travel whilst still in the non-linear propagation region of SPLs [2,3]. This problem is less relevant in a mixing theatre because if it becomes apparent it can still easily be dealt with.

Nevertheless, increasing the reference level beyond 85 dB(C) in the larger mixing theatres would tend to discourage the directors and mixing personnel from making excessively hot mixes, which can be incompatible with their reproduction in smaller theatres. If the proposed curve is realistic, then if all rooms are calibrated to the same reference level, there should be a natural tendency to mix at higher levels in very large mixing theatres, and at lower levels in smaller mixing theatres.

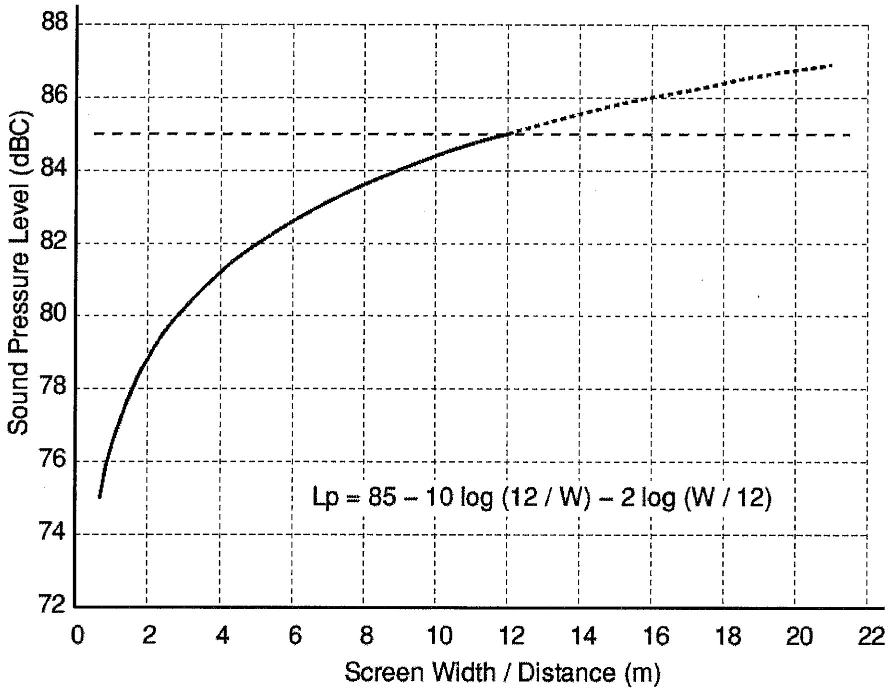

Figure 3 Proposed Level vs Screen Size / Distance Curve

9 THE DYNAMICS DILEMMA

Despite the apparent practicality of the curve proposed in Section 8, there is an associated problem related to the overall dynamics of a mix. In the precursor to this paper [1], it was noted that the larger screens supported not only a higher maximum, tolerable programme level, but also a higher dynamic range, due to the minimum tolerable programme level being relatively independent of screen size.

Clearly, if the minimum programme levels are adjusted to be just audible above the theatre noise-floors, which in general are independent of room sizes, then when a soundtrack which had been mixed in a large room was adjusted downwards to be more compatible in a smaller room, the lower levels of the programme (quiet dialogue, for example) could tend to be lost in the ambient noise. Conversely, a mix made in a smaller room, with a lower dynamic range due to the lower calibration level, may not exploit the full dynamic range available in the larger theatre.

Many re-recording mixers (soundtrack mixers) have reported that when forced to change rooms in the course of a mix, they can spend more time re-adjusting the dynamics than any other aspect of the mix. It has been suggested that dynamics control devices, linked to the 85 db(C) reference level, could enable the automatic compensation of dynamic range with room size, but, despite being doable, it introduces an entire new level of complexity to the overall process.

10 EFFECT OF ROOM SIZE ON LOW-FREQUENCY BALANCE JUDGEMENTS

As a large screen will obviously not fit into a small room, it is difficult to separate the electro-acoustic, low frequency room effects from the screen size question. A further study was undertaken (and which will be investigated in more depth in the coming months) to try to understand more about the influence of room size on the transient/steady-state balances within a mix.

A very dry, highly transient bass drum, and a very resonant bass guitar were recorded separately. These recordings were convolved with the impulse responses captured from large and small Dolby mixing theatres. One of the authors (Castro), an experienced sound mixer, was asked to make different bass-drum/bass-guitar mixes of the treated and untreated instruments, without knowing how the sounds had been processed, or why. The mixes were made from an entirely artistic viewpoint, as would be the case with the mixing of a soundtrack.

As expected, the resonant-sounding bass guitar was much less affected in its tonality by the room acoustics than was the very dry bass drum. However, after mixing the bass drum and bass guitar recordings with another, unprocessed guitar, to provide a reference context, up to 4 dB of difference was noted in the chosen, appropriate levels between the bass drum and bass guitar. The equalisation for the conformity with the standard room response was clearly affecting the transient and more resonant components of the low frequency instruments in quite different ways.

It would still seem to be that mixing to a tight standard, in rooms of different sizes, and with different screen sizes, continues to be fraught with complicated variables.

11 CONCLUSIONS

Despite the fact that many interacting variables have been discussed in the preceeding text, some of the findings can be generalised, at least as tendencies.

1) At a **fixed distance**, as the screen size increases, the sound level necessary for a realistic combination of sound and vision also increases.

2) For a **fixed screen size**, as the distance from the viewer increases, the sound level necessary for a realistic combination of sound and vision decreases.

3) For a **fixed viewing angle**, where the screen size increases as the distance from the viewer increases, the sound level necessary for a realistic combination of sound and vision also increases.

4) For a **fixed sound level**, as the screen size increases, the amount of low frequencies necessary for a realistic combination of sound and vision also increases.

5) The **brightness** of the image, alone, has not been found to have a significant effect on the desired sound level.

6) A **curve** has been suggested, relating the viewing distance to the sound level (for a 50 degree viewing angle - reasonably typical for mixing theatres) to maintain the optimum balance between sound and vision.

7) The natural, supportable **dynamic range** increases as the screen size increases.

8) The **low frequency responses** of typical large and small mixing rooms can give rise to differences in the perception of the transient and resonant characteristics of the bass sounds if modal activity is not adequately suppressed.

12 ACKNOWLEDGEMENT

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