Multichannel level alignment, part II: The influence of signals and loudspeaker placement

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Abstract

The correct level alignment of multichannel reproduction systems is critical to the quality of the reproduction. This, the second paper discusses the results of two experiments employing the nine test signals discussed in paper I. Experiments employing the method of adjustment have been conducted in two standard listening rooms, considering both the symmetrical and asymmetrical loudspeaker set-ups. It is found that the calibration signal does not play a major role in the level alignment of multichannel systems whilst source distance is quite a dominating factor.

1 Introduction

This work forms part of the studies of the Eureka 1653 Medusa (Multichannel Enhancement of Domestic User Stereo Applications) project. The Medusa project is a 3.5 years joint research project with the following partners: British Broadcasting Corporation, The Music Department of the University of Surrey, Nokia Research Centre, Genelec Oy, and Bang & Olufsen A/S.

The purpose of the project is to examine the variables of the domestic multichannel sound system, with and without picture, to carry out the essential optimisation leading to consumer end products. These products will combine the requirements of multichannel reproduction together with the less complex modes of reproduction, such as stereo and mono. These, of necessity, will involve linked studies of programme production and perceptual elements, leading to a single optimised approach to domestic reproduction.

This is the second paper in a series dealing with level calibration of five channel sound systems. The first paper (Suokuisma et al [10]) discusses the generation of the calibration signal that form the basis for the experiments reported in the present paper.

The purpose of the relative level calibration is to ensure that the spatial properties of the programme material are reproduced, as closely as possible, in accordance with the intentions of the programme maker. This is well known for two-channel systems intended for reproduction of stereophonic signals. The main requirements for such systems is 1) that the reproduction level at the listening position is identical for both loudspeakers for the same applied signal and 2) that the listener is positioned on the line of symmetry such that the signals from the two loudspeakers arrive at the listening position simultaneously. This will ensure the optimum reproduction of the spatial properties of the programme material.

The importance of relative level alignment of multichannel sound systems has been recognised by the film industry for a long time, and today quite elaborate measurement schemes exist to ensure that cinema reproduction systems fulfil the requirements. Various schemes have also been established for domestic systems, however, not in a standardised form. Bech [1] has shown that the calibration signal can have a significant influence on the relative level calibration for a system including three separate front channels and one surround channel (3/1 system). It was further shown that the observed differences in level calibration lead to significant differences in the quality of reproduction of spatial information and overall quality for standard film material.

Bech [1] suggested that a number of factors, in addition to the signal, could have an influence on the relative level calibration: the acoustical and physical characteristics of the reproduction room, the reproduction system, and the number of separate channels.

The purpose of the experiments that are reported in this paper has been for a five channel system, to investigate the influence of the calibration signal, the reproduction room, and the position of the loudspeakers. The influence of the overall reproduction level, the directivity characteristics of the individual loudspeakers, and low frequency extension will be the subject of forthcoming papers.

2 Physical conditions

2.1 Listening rooms

Two standard listening rooms were employed for these experiments, that of Nokia Research Center (NRC) and Bang and Olufsen (B&O). The details of both these rooms are illustrated in table 1 and figures 1-2.

The NRC room has been designed in accordance with ITU-R BS 1116 [6] and meets the recommendation in all respects with the exception that the room is 0.5m wider that required. The room is symmetrical and contains no furnishings, other than the equipment under test and a television (see figure 3).

The B&O room is designed to meet the IEC 268-13 recommendation [3]. The walls are brick and both the floor and ceiling are wooden. The ceiling has been designed as a slit resonator to act as a part of the low-frequency absorption area. The floor is partially carpeted and the room is furnished with a number of chairs, bookshelves and tables, as might be found in a typical domestic environment.

The reverberation time characteristics of both rooms are presented in figure 4.

2.2 Loudspeakers & listening positions

The 2-way active, waveguide design Genelec 1030A type loudspeaker was selected for the purpose providing a 50-20kHz ±2 dB bandwidth. The difference in passband response between units is less than 0.5 dB. The directivity characteristic of these loudspeakers is illustrated in figures 5-6.

In all cases the speakers were placed at a height of 105cm, measured to the speaker's axis. This was considered to coincide with the mean ear height of listeners.

For experiment 1 the listening position was situated at the geometrical centre of the room in both sites and the speaker radius was specified as two meters at 0°, ±30°, ±110°, as illustrated in figure 1. In practice this ensured that all speakers at more than 1m from any backwall. This set-up is idealised and in accordance with ITU-R BS 775-1 [5].

For experiment 2, performed at NRC only, an asymmetric set-up was employed. The listening position was shifted 1m left of the room geometric centre and speakers were placed at 0°, ±30°, ±110°. Also, in this experiment the speaker radius was not constant for all channels, as shown in figure 2. In this set-up the influence of the asymmetrical speaker distances and the room loading on the loudspeakers will be evident. For all experiments the loudspeakers were rendered invisible to the subject by means of a visually opaque, but acoustically transparent curtain.

2.3 Signals

A total of nine signals were tested in these experiments, the development of which has previously been discussed in the first paper of this series [10]. The characteristics of these signals are presented in table 2.

The signals were digitally stored on a hard disc based recording system and played back via a 20 bit digital-to-analogue sampling rate of 44.1 kHz with low-pass filtering at 20 kHz (see also figure 7).

2.4 Level setting of reference channel

The aim of this task was to align the level of the reference, centre channel to an equal output sound pressure level in accordance with ITU-R BS 1116 [6], this level is defined as 78 dB SPL (A-weighted, slow). To achieve this a Brüel and Kjær (B&K) 4134 pressure microphone was placed, upward facing, at the centre of the listening position at ear height (1.05m), without the listener's presence. This was connected via a B&K 2609 microphone amplifier to a B&K 2144 analyser with the 7638 loudness module.

Having aligned all signals to the 78 dB SPL (A-weighted, slow) output level, it was noticed that the perceived loudness of these signals was not equal and that the output level was quite uncomfortably high for test purposes, particularly with the psychoacoustically shaped signals. It was also found that due to the high energy content of certain signals at high frequencies, there was a risk of electrical clipping in the reproduction chain.

Following a few iterations it was found that a suitable means of alignment would be to align the centre channel level for equal loudness for all signals in accordance to the Zwicker diffuse field method, as specified within ISO 532 [4]. A level of 20 Sones was found both to provide a comfortable listening condition and allow for sufficient headroom (> 6 dB) in the reproduction system to avoid clipping (see table 3). This method of level alignment was employed at both sites.

3 Experimental procedure and evaluation

3.1 Listeners

Six expert listeners from the B&O team and five from Nokia were employed for these tests. All listeners have long experience in these types of subjective tests, have normal hearing (less that 15 dB deviation for normal) and generally have an interest in music or listening.

3.2 Test duration

Each experiment was completed within a period of two weeks. The test was broken up into 6 blocks each taking approximately 15-20 minutes. To minimise fatigue on the listeners, a maximum of 2-3 block were tested per day.

3.3 Test procedure

A single subject participated in each session and was asked to adjust the level of an individual channel to be subjectively equal to that of the centre channel. A method of adjustment [2] paradigm was employed where the subject was free to switch between the centre channel and the channel to be adjusted. The B&O set-up allowed the subject to make the adjustments in fixed steps of approximately 0.25 dB and at Nokia the subject was provided with a fader for continuous adjustment. The accuracy of the fader was < 0.3 dB. The initial level of the channel was randomly set in the range of +2-6 dB or -2-6 dB. This ensured that the initial level difference between the centre and variable channel was clearly perceivable. The subject was instructed to be facing forward during the entire session.

In the main experiment each subject adjusted the levels of the left front and the left surround channels for three signals in one session. The distribution of signals between session was random for each subject and the experiment was repeated once.

In the control experiment each subjects adjusted the levels of the front left and right channels and the left and right surround channels for B_weighted pink noise only. This experiment was also repeated once.

3.4 Familiarisation and training experiment

Listeners were put through a three stage procedure for listening tests, consisting of

- a familiarisation and training session
- a training experiment
- the main experiment

At the initial stage listener were provided with oral and written instructions (see appendix). They were presented with all the signals under consideration, and allowed to consider the task in hand. The use of the switching system was illustrated and listeners were allowed to test the system.

The training experiment is intended to have two functions: 1) train the listener for the task and further familiarise them with the test system and procedure, 2) test for listener reliability. This experiment consisted of a subset of the main experiment with all test signals employed with only the left channel. This data is not employed in the analysis presented in this paper.

3.5 Objective measurements

In order to facilitate the analysis of the subjective data, a set of measurements were performed that would allow for the detailed study of objective measures of the sound field. To ensure that these measurements were as generic as possible, impulse responses (IR) where collected for each of the reproduction channels at 9 points in the horizontal plane, as illustrated in figure 8. The microphone spacing was chosen as 18 cm as this associates well with the average separation between the ears. In addition, the central microphone position was also employed, as during calibration. Having collected IR's, it is possible to calculate a broad range of objective responses by convolving the IR with the original test signals and applying calibration data. This method was considered more convenient and flexible than making all measurements.

In addition, to provide a true estimate of the response at the ear a single set of head and torso simulator (B&K HATS) IR measurements was made for each reproduction channel at the listener position. This data was stored for later analysis and correlation to subjective data.

4 Results and discussion

4.1 Control experiment

The results reported by Bech [1] indicated that the calibration of a symmetrical set-up (identical loudspeakers positioned symmetrically in the room) was identical for the front left and right hand channels and for the surround left and right hand channels. This was used to reduce the experimental effort in the main experiment as only the channels on left hand side of the set-up were adjusted. However, it was decided to verify the symmetry in a control experiment employing only B-weighted pink noise. The physical conditions, the loudspeaker and listener set-up, the level setting, the subjects, and the test procedure were as described above.

The results were analysed using a type III sum of squares GLM procedure with the fixed factors CHANNEL, SITE, PERSON and the interactions between CHANNEL*SITE and CHANNEL*PERSON. Note that PERSON is nested within SITE as two different groups of subjects were employed. The distribution of the residuals was tested and found to be Gaussian in accordance with the statistical requirements. The results showed that all main factors and the interaction between CHANNEL & PERSON were significant ($p < 0.01$). The results for both test sites can thus be summarized as shown in figure 9.

The results show that the assumption of full symmetry is confirmed, that is the adjusted levels for front left and right hand channels and surround left and right hand channels are not significantly different in either of the two rooms.

A number of other observations, such as a general level difference between the test sites will be discussed under the main experiment.

4.2 Experiment 1

4.2.1 Level data

The data were analysed using a type III sum of squares GLM procedure to perform a covariate analysis of variance (ANCOVA) with the fixed factors CHANNEL, SIGNAL, SITE, and PERSON plus two- and three-way interactions. It is noted that PERSON is nested within SITE (see table 4). The residuals were checked and found to be normally distributed in accordance with the assumptions. The results showed that all main factors and two-way interactions except CHANNEL*SIGNAL were significant ($p < 0.05$). The results of the experiment can thus be summarised by the two-way interactions SIGNAL*SITE and CHANNEL*SITE which are shown in figures 10 and 11. It is noted that SEQUENCE was not significant ($F = 1.75$, $p = 18.8\%$). This indicate that the listeners are consistent over time in their ratings.

The results for NRC shows that there is no significant influence of the SIGNAL, however, for B&O there are significant differences between the signals.

A more detailed analysis of the B&O results, shown in figure 12, shows that the differences between the signals depend on the channel. The results indicate that the low levels for signals 6 & 7 in the surround channels is the main reason for the significant signal effect for B&O. This is confirmed by an analysis of the data without signals 6 & 7 which result in a non-significant signal effect. The low level in the surround channel for B&O is also the reason for the significant interaction between CHANNEL*SITE as seen in figure 11. The main difference between the results for the NRC and B&O test results is also seen to be due to signals 6 & 7 in the left surround channel.

One of the drawbacks of the MOA procedure is that the initial level is known to be able to influence the final value adjusted to. To prevent this the initial levels were randomised as described previously. The initial levels were also distributed evenly between positive and negative values to prevent any influence from an asymmetrical distribution.

To test the influence of the initial level an analysis were made of the B&O data with the initial level as co-variable. The results showed that there was a significant effect of the initial level and that the inclusion of the covariate, reduced the error variance by 16%. The main change was that CHANNEL became non-significant, however, the differences between the signals were still caused by the low adjusted values for signals 6 & 7 in the surround channel, as discussed above. At present there is no plausible explanation for the deviating results for signals 6 & 7. The forthcomming analysis of the objective measures could possibly contribute to a further clarification.

The data in figure 10 can be compared to the results of the control experiment as discussed in section 4.0 for signal 9 and the results reported in Bech [1] for signals 3 and 9.

The data are compared in table 6 and it is seen that there is an excellent agreement between the control experiment and experiment 1 for both test sites. The two experiments were conducted separated in time so this indicates that the experimental repeatability is quite good.
The agreement between the results from Bech [1] and experiment 1 is rather poor. The centre loudspeaker in Bech was positioned below the television set and this would influence the HF response at the listening position. However, this effect would be fairly limited for signal 3 due to its limited bandwidth. The directivity characteristics of the loudspeaker used in Bech and the present set-up are also different and the influence of this factor is the subject in a forthcoming paper. So at present no plausible explanation for the observed differences can be provided.

Robinson and Whittle [9] examined the loudness of band limited (less than a critical band) noise as a function of angle of incidence compared to a fixed reference channel in the front. The subjects (16 – 20) were asked to match the loudness of the noise to that of the centre channel using a MOA procedure. They conducted the experiment in a free field for the horizontal, the transverse (frontal), and the median planes. The results for the horizontal plane are shown in figure 13 as a function of centre frequency for the noise band for angles of incidence corresponding to a front channel and a surround channel.

The Robinson & Whittle [9] results are for band limited noise and they should only be related to the present data set with caution. Their results for the direction corresponding to the front-left loudspeaker, indicate that it will be adjusted to a level lower than the front reference loudspeaker independent of the frequency range. This is in qualitative agreement with the results shown in figure 10. Their results for the direction corresponding to the surround channel indicate that the adjusted level depends on the spectrum of the calibration signal. Signals with the main energy below 5 kHz are seen to have positive calibration levels whereas lower levels are seen for signals with the main energy above 5 kHz.

The present set of calibration signal can be divided into two groups: one including signals with little spectral energy above 5 – 6 kHz (1 – 3) and another where the signals have a significant energy above 6 kHz. Robinson & Whittle results indicate that signals in the first group should result in calibration levels higher than the reference channel. This is not in agreement with the results shown in figure 9, except for signal 1 for Nokia.

Ratliff [8], using the same paradigm as Robinson & Whittle [9], examined loudness calibration in the horizontal plane for octave bands of pink noise, centred on 230 Hz, 2 kHz, and 7 kHz. Ratliff employed 8 subjects and conducted the experiment under reverberant (average T = 0.35 s) conditions and the results are shown in Table 5 together with the data from B&O and Nokia for the pink noise signal.

Firstly, it is noted that there is no agreement between Ratliff’s and Robinson & Whittle’s results. This indicates that the acoustic environment have a significant influence on the calibration. Secondly, it is noted that the B&O result for the left-surround is in agreement with Ratliff’s results for the two LF octaves.

The data and discussion thus suggests the following:

1. In general, there is little influence of the calibration signal,
2. The interaction between the acoustic environment and the signal could influence the calibration,
3. Subjects can make quite accurate loudness matches between the channels. Typical

standard deviations are in the range of 0.4 – 0.6 dB,

4.2.2 Response time data

The experimental procedure also included a recording of the time needed for calibrating a given channel. The time is defined as the time interval from start of presentation of the signal to the subject reports that the calibration is finished.

The time data were analysed for each test site individually using an ANOVA model including the fixed factors CHANNEL, PERSON, and SIGNAL plus two-way interactions. The residuals were checked for normality.

The results showed that there were no significant main factors (except Person), however, the tendency is that the surround channel takes slightly more time to adjust. There was also a difference between the Nokia and B&O as the B&O subjects on average used 100 s. for the calibration compared to the Nokia team's 59 s.

The conclusion is that calibration time is not a measure that can be used to characterise the calibration signals.

4.3 Experiment 2

4.3.1 Level data

The data was initially checked to meet the ANOVA assumptions for independence, homogeneity of variance, normally distributed residuals. These assumptions were not breached.

A type III sum of squares GLM procedure was employed to perform the covariate analysis of variance (ANCOVA) with factors: SIGNAL, CHANNEL, PERSON and SEQUENCE (covariate). A full factorial analysis was performed and main, two- and three-way interaction were considered. The model was found to be significant at a level of $F = 18.735$, $p < 0.00$ (see table 7).

The reproduction sequence (SEQUENCE) was again found to be insignificant in this experiment ($F = 1.703$, $p <= 0.19$). This is an indication that the listeners have become familiar and consistent with this task.

The two-way interaction CHANNEL*PERSON is found to be the second most significant factor at a level of $F = 14.299$, $p < 0.00$. This is understandable as PERSON is also a factor ($F = 7.551$, $p < 0.00$) and implies that people judge the channel levels differently, which is understandable. The other two-way interaction PERSON*SIGNAL is found to be a factor, also implying that listeners judge the levels differently as a function of the test signal.

SIGNAL is also found to be marginally significant on the ANCOVA tables at a level of $F = 4.264$, $p < 0.00$. However, in figure 14, this is less apparent. To clarify this issue, a powerful post hock test (Scheffé) was employed to find where the difference occurs. The finding was that only signal 1 is significantly different from signals 3-5 at a level of $p < 0.12 - 0.64$. At this point the cause of this difference has not been considered, but will be discussed in later reports.

The dominating factor in this experiment is that of CHANNEL ($F = 929.445$, $p < 0.00$). This is also clearly the case from figure 15. Upon closer inspection it would appear that there is some relationship between the calibration levels and the distance of the listener from the source. A simple Pearson correlation was performed between these two factors, the results of which can be seen in table 8 and figure 17. An 87 % correlation is found ($p < 0.01$), which is quite surprising. Figure 16 illustrate the SIGNAL*CHANNEL data.

Let us consider for a moment an idealised point sound source in a free and diffuse field. It is a well know fact that in both these environments the sound varies as a function of distance in accordance with Eq. 1, where *ldiff* is the level difference (dB), between two measuring points in space separated by a distance *rdiff* (m) and x is a weighting factor. In the free field x = 20 whilst in the ideal diffuse field, x = 0. This leads to a ~ 6 dB and 0 dB decay in level as a doubling in distance, respectively. As these two acoustic environments rarely occur in practice, it can be stated that the acoustic environments under test here lies somewhere between these two ideals. In an attempt to better understand the subjective data, we tested if it could fit Eq. 1. At this point it was assumed that the differences between signal were insignificant. The mean result was that if x = 8.5 (with a standard deviation of 0.3 excluding outliers), a level attenuation of ~ 2.55 dB per doubling of distance is found for this room (Eq. 2).

$$ldiff = x(\log_{10}(rdiff)) \qquad \text{Eq. 1}$$

$$ldiff \approx 8.5\log(rdiff) \qquad \text{Eq. 2}$$

This is a rather intriguing finding as it suggests that listeners are essentially just making a calibration based upon the source distance in a room, within the limits of the reproduction set-up tested.

The data and discussion thus suggests the following:

1. Generally the calibration signal has little influence on the calibration level,
2. Loudspeaker distance has a very dominating affect on the subjective level calibration,
3. The loudspeaker/room interaction does not appear have a dominating effect,
4. Subjects can quite accurately match levels between the channels with a standard deviations < 0.4 dB.

4.3.2 Response time data

Response time data was also recorded for this task and analysed employing a type IV sum of squares ANCOVA (due to a few missing data points). No new information was to be found from this data, as concluded in section 5.2.2.

5 Conclusions

This experiment has tested by the method of adjustment, the subjective multichannel level calibration with a range of signals. The experiments considered two cases 1) a symmetrical set-up and 2) an asymmetrical set-up with identical loudspeakers (in terms of bandwidth and directivity). Tests were performed in two standard listening rooms with trained listening panels.

Based upon the results of two subjective experiments, the following conclusions can be drawn:

1. There is a strong indication that for identical loudspeakers and idealised room acoustics, that the calibration signal characteristics are not significant
2. For the asymmetrical case, listeners are performing a level calibration based principally upon distance from the loudspeaker, which is a function of the room acoustics
3. Listeners in general are capable of very accurate level alignment

6 Further work

To improve upon the quality of subjective results its has been considered that the two alternative forced choice (2AFC) paradigm [7] would be more suitable than the presently employed method of adjustment [2]. Further to the current work it is considered of interest to study the effects of reproduction bandwidth and loudspeaker directivity employing similar test procedures to those presented. A further study is also to be made considering the relationship between objective measures and the subjective data.

7 Acknowledgements

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8 References

[1] Bech S., Calibration of relative level differences of a domestic multichannel sound reproduction system, J. Audio Eng. Soc., vol. 46, pp 304 – 313, April 1998.

[2] Cardozo B. L., Adjusting the method of adjustment: SD vs DL, J. Acoustical Society of America, 37(5), May 1965.

[3] IEC Recommendation 268-13, “Sound system equipment - Part 13: Listening tests on loudspeakers”, International Electrotechnical Commission, Geneva, Switzerland (1985)

[4] ISO Standard 532, Acoustics - Method for calculating loudness level, International Organisation for Standardisation, 1975.

[5] ITU-R Recommendation BS 775-1, Multichannel stereophonic sound system with and without accompanying picture, Geneva, 1994.

[6] ITU-R Recommendation BS.1116, Methods for the subjective assessment of small impairments in audio systems including multichannel sound systems, Geneva, 1994.

[7] Levitt H., Transformed up-down methods in psychoacoustics, J. Acoustical Society of America, 49(2), 467, 1971.

[8] Ratliff P. A., Properties of hearing related to quadraphonic reproduction, British Broadcasting Corporation, Research Department, report BBC RD 1974/38, 1974.

[9] Robinson, D. W., Whittle, L. S., “The loudness of directional sound fields”, Acustica, vol 10, (1960), pp 74 - 80

[10] Suokuisma P., Zacharov N., Bech S., Multichannel level alignment, part I: Signals and methods, presented at the 105th Convention of the Audio Engineering Society, September 1998

Figures

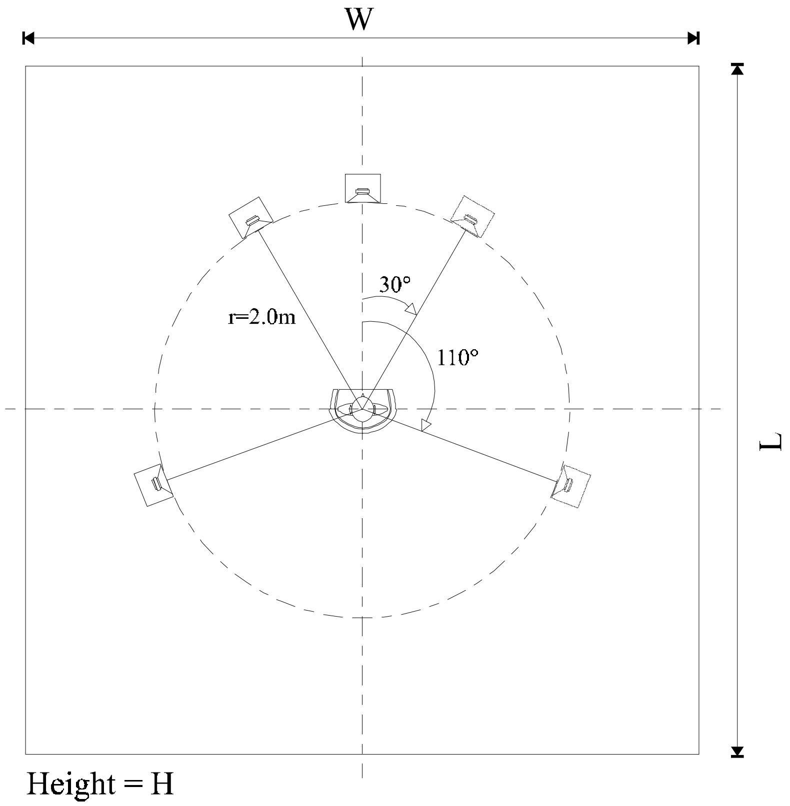

Figure 1. NRC & B&O listening room set-ups (experiment 1)

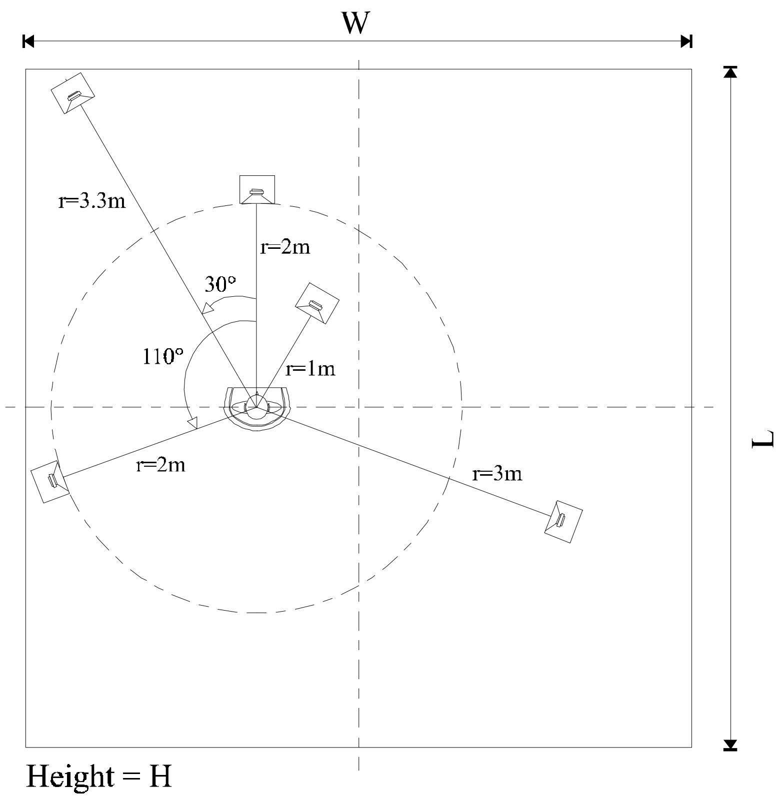

Figure 2 NRC listening room set-up (experiment 2)

	NRC listening room	B&O listening room
Volume, (m^3)	129.7	82.9
Height, H (m)	3.00	2.65
Width, W (m)	6.50	5.03
Length, L (m)	6.65	6.03
Floor area (m^2)	43.2	30.3
Background noise level (dB SPL, A-weighted, fast)	< 30	< 35

Table 1. Summary of listening room characteristics

Figure 3 HATS measurement set-up at NRC

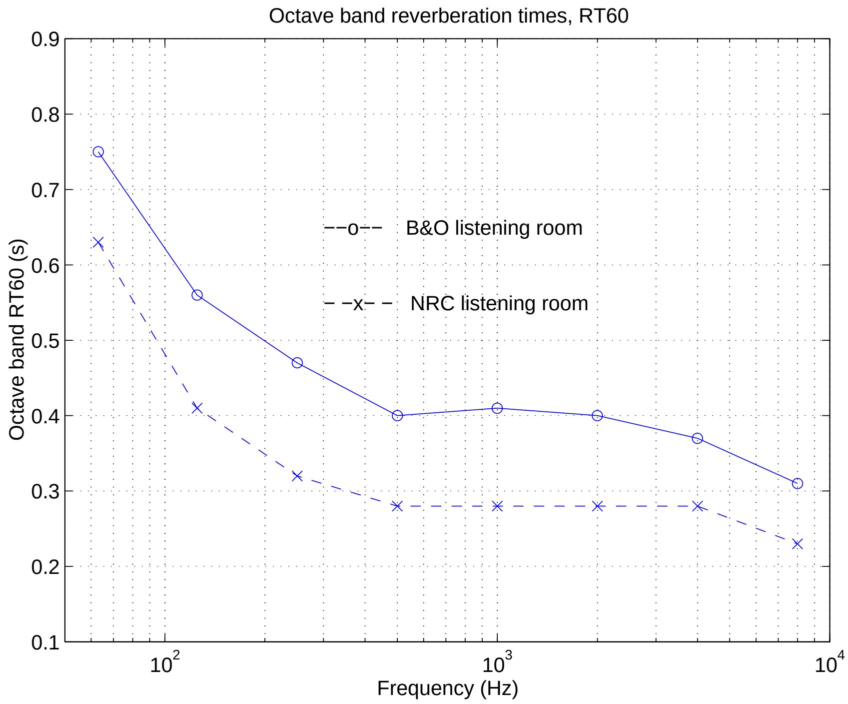

Figure 4 NRC and B&O listening room reverberation times (RT60) as a function of one-octaves.

Signal name	**High pass filter characteristics**	**Low pass filter characteristics**	**Comments**
	Hz , dB/Oct.	**Hz , dB/Oct.**	
1.	700, 12	700, 6	Commercially available signal
2.	250, 6	500, 6	A signal
3.	500, 18	2k, 18	Commercially available signal
4.			Zwicker constant specific loudness according to ISO 532 (diffuse field)
5.			Zwicker constant specific loudness according to ISO 532 (free field)
6.			Constant specific loudness according to Moore
7.			Uniform excitation noise according to Zwicker
8.			Pink noise
9.			B-weighted pink noise

Table 2 Characteristics of test signals

Signal name	Diffuse field loudness	SPL's at NRC		SPL's at B&O	
	Sones (±0.5)	Linear, Slow	A-weighted, slow	Linear, Slow	A-weighted, slow
1.	20	68.7	67.1	67.2	66.5
2.	20	70.6	65.4	70.0	65.1
3.	20	70.8	69.2	69.5	69.0
4.	20	68.7	64.8	70.8	63.5
5.	20	68.3	64.0	72.9	65.8
6.	20	69.7	65.7	71.4	66.5
7.	20	66.2	64.0	65.2	63.8
8.	20	66.9	63.9	67.0	62.9
9.	20	66.8	64.0	65.5	63.6

Table 3 Center channel loudness alignment for the experiment 1, NRC and B&O. Measured at the listening position.

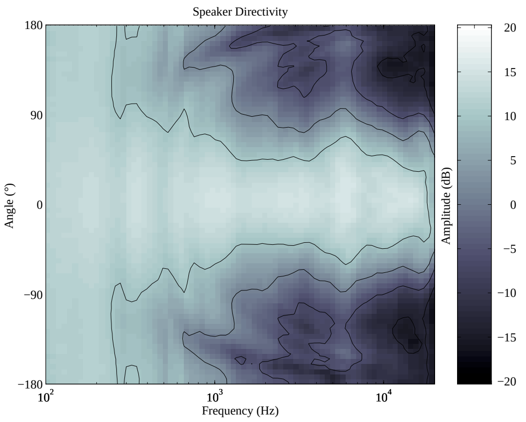

Figure 5 Genelec 1030A directivity response (horizontal plane)

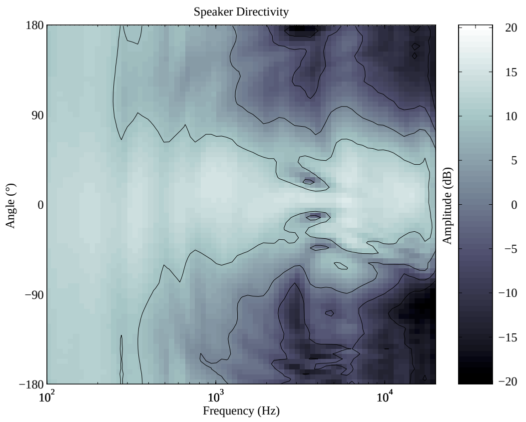

Figure 6 Genelec 1030A directivity response (vertical plane)

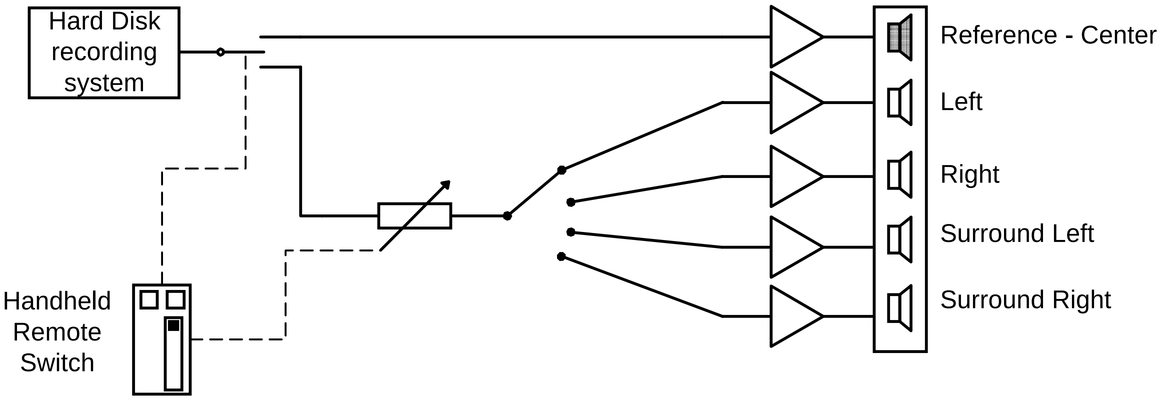

Figure 7 *Block diagram of electrical set-up.*

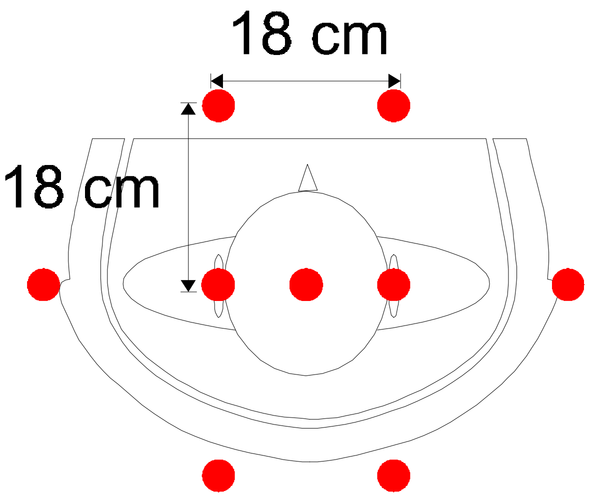

Figure 8. *Objective measurement grid showing the positions of the measuring points.*

Tests of Between-Subjects Effects

Dependent Variable: LDIFF

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Corrected Model	149.289[b]	198	.754	2.097	.000	415.206	1.000
Intercept	3.239E-02	1	3.239E-02	.090	.764	.090	.060
SEQUENCE	.629	1	.629	1.749	.188	1.749	.260
CHANNEL	1.597	1	1.597	4.441	.036	4.441	.555
SIGNAL	9.456	8	1.182	3.287	.002	26.299	.970
SITE	11.072	1	11.072	30.793	.000	30.793	1.000
PERSON(SITE)	31.324	9	3.480	9.680	.000	87.120	1.000
CHANNEL * SIGNAL	2.051	8	.256	.713	.680	5.705	.326
CHANNEL * SITE	2.490	1	2.490	6.925	.009	6.925	.745
SIGNAL * SITE	6.622	8	.828	2.302	.022	18.418	.872
CHANNEL * PERSON(SITE)	7.497	9	.833	2.317	.017	20.851	.903
PERSON * SIGNAL(SITE)	43.739	72	.607	1.690	.002	121.648	1.000
CHANNEL * SIGNAL * SITE	3.766	8	.471	1.309	.241	10.473	.591
CHANNEL * PERSON * SIGNAL(SITE)	22.223	72	.309	.858	.771	61.808	.952
Error	70.113	195	.360				
Total	232.699	394					
Corrected Total	219.402	393					

a. Computed using alpha = .05

b. R Squared = .680 (Adjusted R Squared = .356)

Table 4 ANCOVA tables for experiment 1

Channel	Ratliff	B&O	Nokia
Front-left	0.3 dB (230 Hz)	-0.35 dB	0 dB
Front-left	0.6 dB (2 kHz)		
Front-left	0.75 dB (7 kHz)		
Left-surround	-0.55 dB (230 Hz)	-0.33 dB	0 dB
Left-surround	-0.4 dB (2 kHz)		
Left-surround	0.5 dB (7 kHz)		

Table 5 Comparison between Ratliff's results and the present. The 95% confidence intervals for Ratliff's data are approximately ± 0.4 dB and ± 0.3 dB for the present data. The B&O and Nokia results are the average of the front-left and left-surround channels as the channels are not significantly different for this signal.

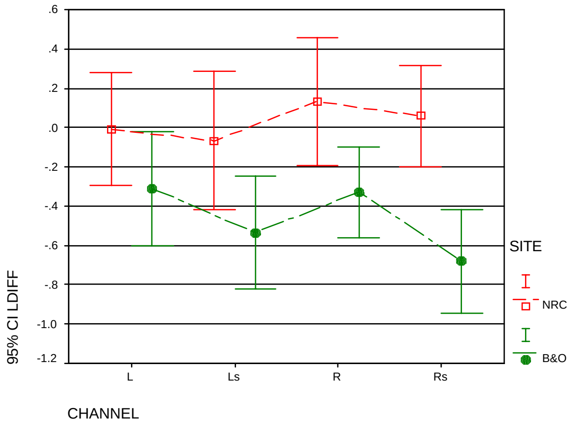

Figure 9 Results of control experiments for both test sites. Shown are mean values for the adjusted level (LDIFF) averaged across subjects. Also shown are 95% confidence intervals

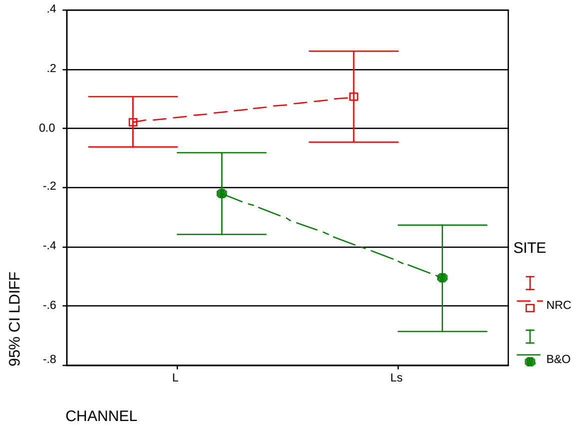

*Figure 11 Channel*Site results from experiment 1. . Shown are mean values for the adjusted level (LDIFF) averaged across subjects and signal. Also shown are 95% confidence intervals*

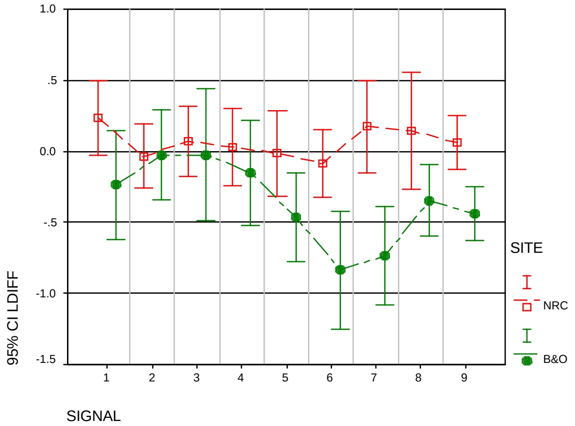

*Figure 10 Signal*Site results from experiment1. Shown are mean values for the adjusted level (LDIFF) averaged across subjects and channels. Also shown are 95% confidence intervals .*

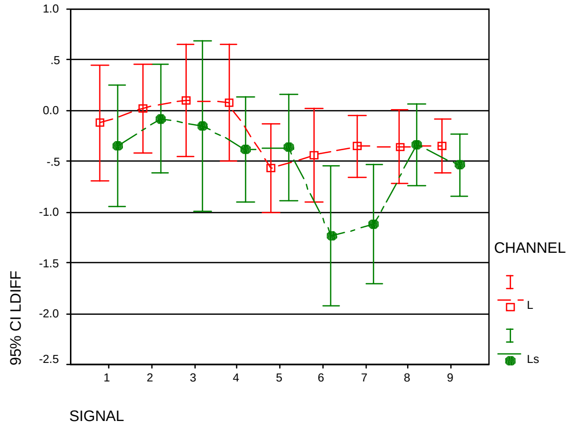

*Figure 12 Channel*Signal for B&O results. . Shown are mean values for the adjusted level (LDIFF) averaged across subjects. Also shown are 95% confidence intervals*

Channel	Experiment	Signal #	B&O site	NRC site
L	Control	9	-0.31 ± 0.1	0.08 ± 0.24
L	Experiment 1l	9	-0.35 ± 0.41	0.08 ±0.26
L	Bech [1]	9	0.95 ± 0.41	---
Ls	Control	9	-0.54 ± 0.1	0.04 ± 0.24
Ls	Experiment 1	9	-0.54 ± 0.1	0.04 ± 0.26
Ls	Bech [1]	9	-2.90 ± 0.41	---
L	Experiment 1	3	0.1 ± 0.41	---
L	Bech [1]	3	-1.45 ± 0.41	---
Ls	Experiment 1	3	-0.15 ± 0.41	---
Ls	Bech [1]	3	-3.70 ± 0.41	---

Table 6 Comparison of ADTT, these and control experiments for signals 3 and 9. 95% Confidence intervals have been indicated.

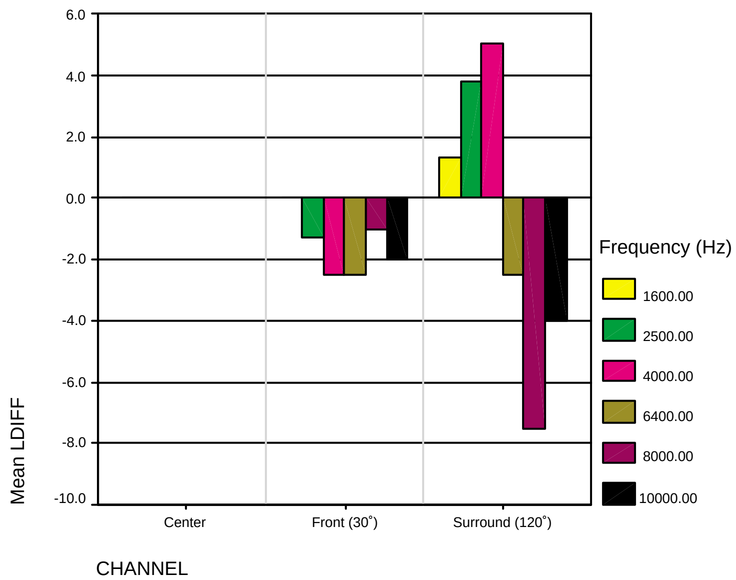

Figure 13 Results from Robinson and Whittle [9].

Tests of Between-Subjects Effects

Dependent Variable: LDIFF

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Corrected Model	1333.760[b]	180	7.410	18.735	.000	3372.255	1.000
Intercept	1.880	1	1.880	4.754	.031	4.754	.583
SEQUENCE	.674	1	.674	1.703	.194	1.703	.255
CHANNEL	1102.814	3	367.605	929.445	.000	2788.336	1.000
PERSON	11.946	4	2.986	7.551	.000	30.203	.997
SIGNAL	13.490	8	1.686	4.263	.000	34.108	.994
CHANNEL * PERSON	67.862	12	5.655	14.299	.000	171.582	1.000
CHANNEL * SIGNAL	13.368	24	.557	1.408	.108	33.799	.932
PERSON * SIGNAL	26.436	32	.826	2.089	.001	66.841	.999
CHANNEL * PERSON * SIGNAL	33.338	96	.347	.878	.759	84.291	.978
Error	70.796	179	.396				
Total	1421.980	360					
Corrected Total	1404.556	359					

a. Computed using alpha = .05

b. R Squared = .950 (Adjusted R Squared = .899)

Table 7 ANCOVA tables for experiment 2

Correlations

		LDIFF	DISTANCE
Pearson Correlation	LDIFF	1.000	.872**
	DISTANCE	.872**	1.000
Sig. (2-tailed)	LDIFF	.	.000
	DISTANCE	.000	.
N	LDIFF	360	360
	DISTANCE	360	360

**. Correlation is significant at the 0.01 level (2-tailed).

Table 8 Correlation analysis between the factors loudspeaker distance and the subjectively adjusted level (LDIFF).

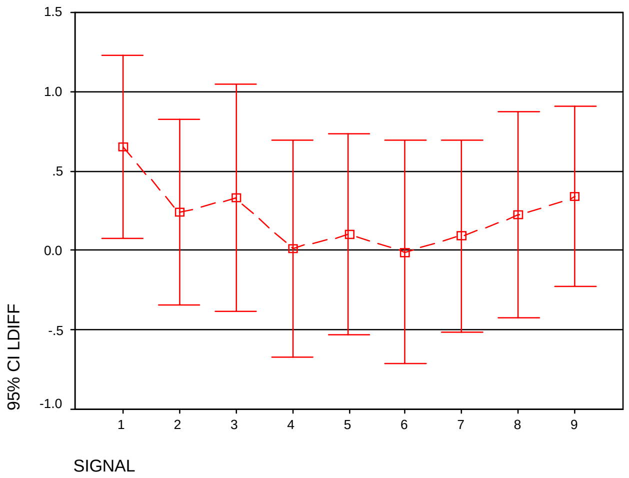

Figure 14 Signal results from experiment 2. Shown are mean values for the adjusted level (LDIFF) averaged across subjects and channels. Also shown are 95% confidence intervals

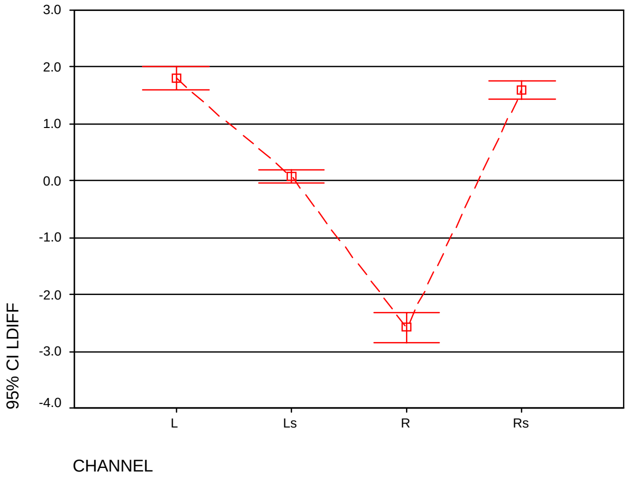

Figure 15 Channel results from experiment 2. . Shown are mean values for the adjusted level (LDIFF) averaged across subjects and signals. Also shown are 95% confidence intervals

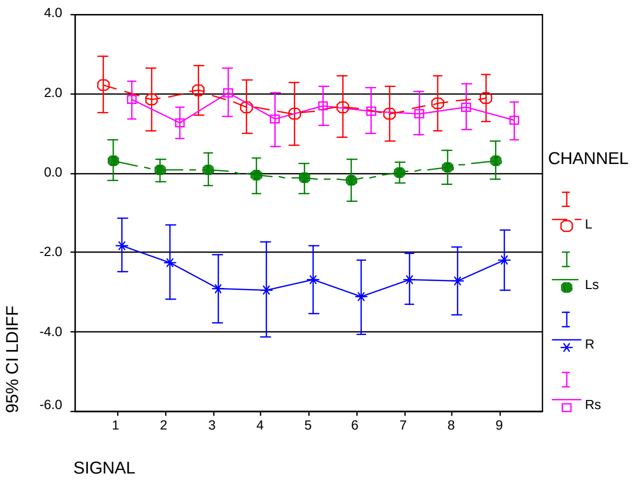

*Figure 16 Signal*Channel results from experiment 2. Shown are mean values for the adjusted level (LDIFF) averaged across subjects. Also shown are 95% confidence intervals*

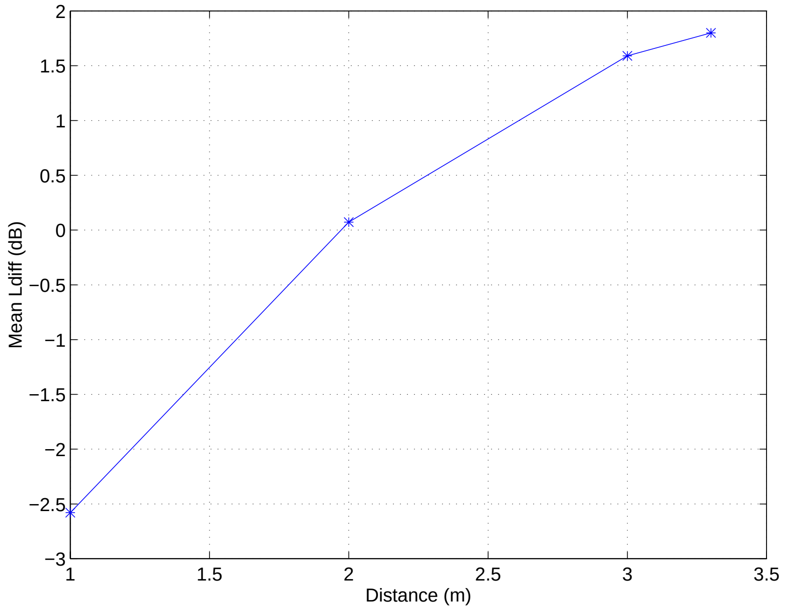

Figure 17 Plot on mean subjective alignment levels (LDIFF) against speaker distance (m)

Appendix 1. Example of instructions to listeners (NRC)

Dear listener

You have been asked to take part in a loudness alignment task for multichannel audio systems.

Your task is to adjust the level of the test channel until you are happy that both channels sound equally loud.

For this task you will be asked to compare two sounds. The reference sound is always the centre channel. You can freely switch between the reference and the test channel, which may come from different directions. You will be able to change the level of the test channel using the fader on the screen. When you have done this, the level of the test fader will be noted. You will then be asked to repeat this procedure for several times for different set-up. You have an unlimited time to do this alignment. So just take it easy and only grade the signal when you are happy they are equally loud.

You will be asked to grade 36 samples in total, which will be broken into 6 session. This should take some 3 or so hours to complete
Remember that there are no correct answers in these tests, so just set the level such that the test and reference signals sound equally loud.

During the course of the session you are asked to remain seated at the centre of the room, and to keep you head facing forward.

You are asked not to discuss the your views on the different noise signals with other listening panel members during the test, though you may do so during the induction and training phase.
Before a test, please ensure that you have not recently been exposed to high sound pressure levels (e.g. a ZZ Top gig). Please inform us if you have had any trouble with you hearing or if you have a cold or the flue. Before a test please ensure that you ears are clean and free from wax, and that you are not hungover.

Good luck and have fun.