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**NRCC-38814**

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June 1994

A version of this document is published in / Une version de ce document se trouve dans:  
Proceedings Sabine Centennial Symposium, Cambridge, Mass., U.S.A. June 01,  
1994, pp. 271-274

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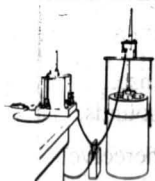


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## WALLACE CLEMENT SABINE CENTENNIAL SYMPOSIUM

CAMBRIDGE, MASSACHUSETTS, USA

5 TO 7 JUNE, 1994



# A SUBJECTIVE EVALUATION OF NEW ACOUSTIC MEASURES IN CONCERT HALLS USING BINAURAL SIMULATION

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## 1. INTRODUCTION

About a hundred years have passed since Sabine proposed his measure of reverberation time as a predictor of the acoustic quality of a concert hall. Since then, as a result of extensive research and our ability to make increasingly precise acoustical measurements, researchers have proposed many other objective measures as predictors of a concert hall's acoustic quality. In this paper, a series of experiments were conducted to evaluate the suitability of several acoustical measures as predictors of subjective judgements. Subjects were asked to rank binaurally reproduced sound fields in terms of reverberance, clarity, loudness, envelopment, treble, bass, apparent source width, and overall preference. The binaural impulse responses were measured in several North American concert halls and were chosen so as to cover as broad a range as possible with respect to RT60, EDT, C80, G, IACC and LF values. The results of these tests were then correlated with the various objective measures on an octave band basis to find the best predictor of each subjective parameter. The relative importance of the various subjective parameters to the overall preference of these sound fields was also examined.

## 2. EXPERIMENTAL PROCEDURE

The subjective experiments were conducted using a binaural simulator system. The value of this experimental approach has been demonstrated in a past study [1] and the validity of the present system for use in this type of study has been demonstrated in previous work by the authors [2]. A detailed description of the present system is given in [3].

Sound fields were produced by convolving anechoic music with binaural impulse responses measured using a Brüel and Kjær Type 4128 Head and Torso Simulator. A 15 second passage of Mozart's, "Le Nozze di Figaro" was used for the tests. The resultant sound fields were played back to listeners over a pair of loudspeakers.

The subjective testing was in the form of double-blind paired comparison tests. A computer provided random playback of pairs of sound fields. The stimulus was played repeatedly by the computer allowing subjects to switch back and forth between the two sound fields for as long as they required in order to make their decision. The subjects' responses were automatically recorded by the computer. Unlike the study by Schroeder, Gottlob, and Siebrasse, subjects in the present study were not asked to simply identify which sound field they preferred. Rather, in this study, subjects conducted eight separate sets of listening tests and were asked to rank the sound fields in terms of reverberance, clarity, loudness, envelopment, treble, bass, apparent source width, and overall preference. This list of parameters was based on the one used by Barron in his subjective study of eleven British concert halls [4]. Prior to each test, a description of the parameter under test was read to the subject (see Figure 1).

Ten subjects participated in each of the eight experiments. All of the subjects had previous experience in critical listening tests and almost all had extensive musical training. To ensure that they fully understood their task, subjects were given a brief training sequence prior to each test.

<i>Loudness:</i>	The relative strength or loudness of the sound.
<i>Reverberance:</i>	The degree of perceived reverberation in a temporal sense. The blending of one sound into subsequent following sounds.
<i>Clarity:</i>	The clarity or definition of the sound. Your ability to perceive musical detail. The degree to which notes are separated in time.
<i>Envelopment:</i>	The sense of being immersed or surrounded by it rather than it appearing to come from a particular point on the stage. The sense of being part of the sound rather than observing it.
<i>Apparent Source Width:</i>	The perceived width of the sound.
<i>Treble:</i>	The relative strength of the treble or high frequency sounds relative to mid-frequency sounds.
<i>Bass:</i>	The relative strength of the bass or low frequency sounds relative to mid-frequency sounds.
<i>Overall Impression:</i>	Which sound do you prefer?

Figure 1: Descriptions of the eight subjective parameters used in the study.

A preliminary study was carried out prior to the final study. The purpose of this preliminary study was to verify that the process would provide meaningful results and to identify any procedural issues in the experiments. Eight sound fields were used in the preliminary study and two more were added to the final study so as to more thoroughly cover the ranges of all the objective parameters. The results shown here are from the preliminary study. The results of the final study including a complete analysis will be given at the presentation.

3. RESULTS

Sound fields were chosen from a large database of measurements made in North American concert halls. Since the main goal of the study was to evaluate various objective measures as predictors of subjective opinion, sound fields were chosen to encompass as much of the full ranges of each of the objective measures as possible. The objective measures of interest were; RT60, EDT, C80, G, LF, and IACC. Therefore, ten sound fields were chosen such that the full range (as found in actual concert halls) of each of these objective parameters would be included.

3.1 Loudness

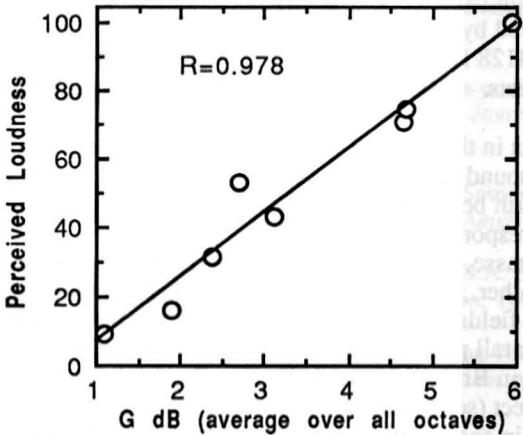


Figure 2: Perceived loudness versus G, averaged from 125Hz to 4kHz

The results from the loudness experiment are given in Figure 2. The figure shows the ranking of perceived loudness versus the measured values of  $G$ . The values of  $G$  consist of the average of the octave bands from 125Hz to 4kHz. Clearly there is a very strong correlation ( $R=0.978$ ) between the subjective and objective results. If however, the abscissa of Figure 2 is replaced with the average value of  $G$  measured across the octave bands from 250Hz to 2kHz, then the correlation is even higher ( $R=0.987$ ). This suggests that, while a broadband measure of  $G$  performs very well as a predictor of loudness, a better predictor might be obtained by excluding certain frequency bands. It should be noted that the vertical axis does not have any units.

### 3.2 Reverberance

Figure 3 shows the reverberance perceived by the listeners versus the early decay time, EDT, of the sound fields. There is good agreement ( $R=0.931$ ) between the objective and subjective results and therefore it appears that a measure of EDT (averaged over all octaves) is a reasonable predictor of reverberance. If the 4kHz octave band is excluded from the measure of EDT, a somewhat better correlation can be obtained ( $R=0.954$ ).

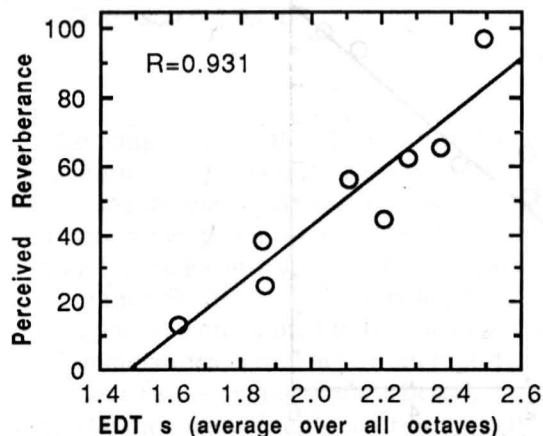


Figure 3: Perceived reverberance versus EDT.

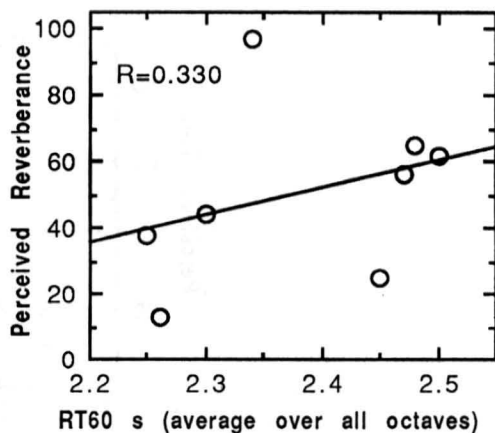


Figure 4: Perceived reverberance versus RT60.

Figure 4 shows the perceived reverberance plotted against the measured values of RT60. It can be seen that the correlation is very low in this case ( $R=0.330$ ). Part of this poor correlation can be explained by the rather small range of RT60's included in the preliminary experiment. The final experiment includes additional sound fields to expand the range. Regardless of this however, it is clear that EDT performs far better than RT60 as a predictor of perceived reverberance.

### 3.3 Clarity

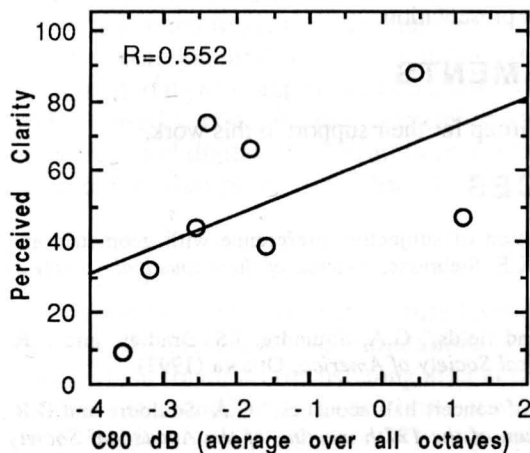


Figure 5: Perceived clarity versus C80 averaged over all octave bands.

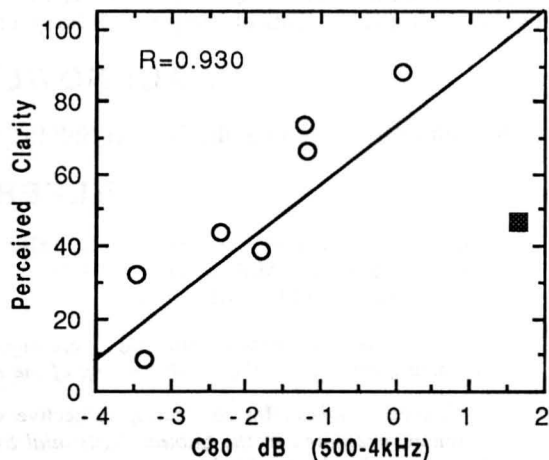


Figure 6: Perceived clarity versus C80 averaged from 500Hz to 4kHz.

Figure 5 shows the perceived degree of clarity plotted against C80 averaged over the 125Hz to 4kHz octave bands. In this case we see that the correlation is not very strong ( $R=0.552$ ). However, if only the octave bands from 500Hz to 4kHz are used in measuring C80, the correlation increases ( $R=0.602$ ). This is shown in Figure 6. It seems reasonable that the lower octave bands may not contribute to a listener's perception of clarity.

There is one sound field which seems to be an outlier (indicated by the black square). When this data point is excluded, the correlation increases significantly ( $R=0.930$ ). An examination of the impulse response for this sound field revealed two very strong reflections. Although both reflections arrive within 80ms of the direct sound, it may be that they are in some way reducing the perceived clarity.

### 3.4 Treble

Figure 7 shows the perceived level of treble frequencies versus the average high-frequency (2kHz and 4kHz) values of G. The results show that the high-frequency values of G act as a reasonable predictor of the amount of treble perceived by a listener.

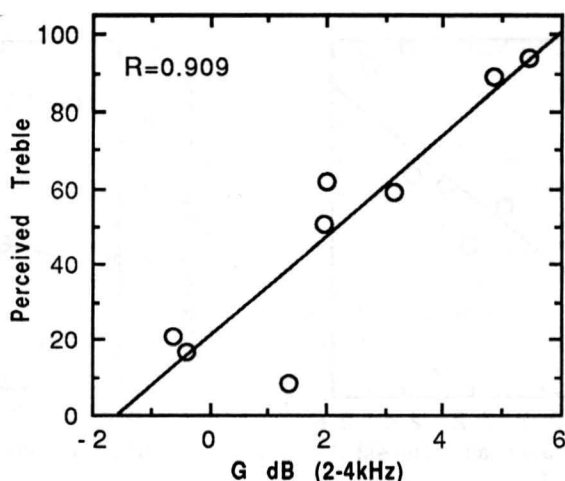


Figure 7: Perceived treble versus values of G averaged from 2kHz to 4kHz.

## 4. SUMMARY

A series of subjective experiments have been conducted to evaluate various objective measures as predictors of subjective opinion. The results of the preliminary study indicate that a broadband measure of G performs well as a predictor of loudness. Also, the broadband measure of EDT is a good predictor of perceived reverberance. Improved correlation between objective and subjective results can be obtained for some parameters if certain frequency bands are excluded from the measurements. The results from the full study and a complete statistical analysis will be given in the presentation.

## ACKNOWLEDGMENTS

The authors are grateful to the Concert Hall Research Group for their support in this work.

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