**Megaron**
https://megaron.yildiz.edu.tr - https://megaronjournal.com
DOI: https://doi.org/10.14744/megaron.2023.23080

Article

# Optimization of the room acoustics parameters values depending on auditory sensitivity distinctions

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## ARTICLE INFO

*Article history*
Received: 13 May 2023
Revised: 04 June 2023
Accepted: 06 June 2023

**Key words:**
Auditory comfort; auditory sensitivity distinctions; conference halls; room acoustics

## ABSTRACT

Elderly individuals may experience hearing difficulties for various reasons. The most common of these is age-related hearing loss called presbycusis. Due to these changes in auditory sensitivity, it is difficult to hear and understand speech at certain frequencies. Due to the acoustic design based on the auditory sensitivity of the younger ear, elderly listeners may have hearing difficulties, especially in conference rooms without a sound system. The objective of this research is to provide acoustic comfort conditions in conference halls that can be suitable for all listeners. In this context, new optimum reverberation times were determined for three different age groups to eliminate the negative effects of auditory sensitivity distinctions on speech intelligibility. The obtained results were compared to the reference values determined for the objective room acoustics parameters in various standards (ISO, DIN, JIS, etc.) for young and elderly listeners. A 3000 m3 (volume) conference hall was chosen as an example to support the research with a listening test and a survey. Following the completion of the listening test studies for a receiver point located approximately in the center of the hall, the data were analyzed in a statistical program. Based on these evaluations, it seems evident that the subjective and objective data overlap and that the intelligibility values can be improved by applying the new reverberation times determined by the study's method to the halls. It is thought that the research will make significant contributions to the improvement of acoustic comfort in conference rooms.

**Cite this article as:** Şentürk H, Akdağ N. Optimization of the room acoustics parameters values depending on auditory sensitivity distinctions. Megaron 2023;18(2):172–183.

## INTRODUCTION

Various standards have been developed as a result of the studies that were carried out so far to evaluate the listeners' acoustic comfort in conference halls. The DIN standard, (German Institute of Standardization, 2005) which was first published in 1968 by the Deutsches Institut für Normung, is one of these. In the standard titled "Acoustic quality in small- and middle-sized rooms," the acoustic criteria required for the spaces used in daily life are summarized and made available as a basic resource for planning and design. A hall's acoustic quality indicates its suitability for a particular acoustic performance, such as speech communication or musical performance. In this context,

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the rooms were divided into two categories, A and B, in the version of the standard published in 2004. Category A includes areas where acoustic comfort is provided in terms of intended room use (speaking - music) over average and longer distances, as a result of the adjustment of the reverberation time and directivity of the sound source. Category B, on the other hand, specifies the criteria for appropriate absorption regulation in situations where short-distance speech communication is crucial. The five usage types determined for Category A are labeled as A1-A5. It is recommended that music (A1), speech/presentation (A2), education/communication (A3), education/special communication (A4), and sports (A5) functions should be evaluated separately. Room types in this category are as follows; conference and meeting rooms, courts, training and seminar rooms, group rooms in children's daycare facilities and elderly care centers, religious venues, ball and festival halls, gymnasiums, and indoor pools. A4 usage type states that in cases where improved conditions are needed in terms of speech intelligibility, the reverberation time given for A2 and A3 usage types (education/communication) can be reduced by up to 20%. A4 "special" use, in particular, aims to meet the needs of people with hearing impairments (Nocke, 2018). As a result, various formulas have been created to determine the required reverberation times in rooms. Ttarget (target reverberation time) varies depending on the size of the room and the type of use. The headlines of the International Organization for Standardization (ISO) standards, which include various evaluations in terms of room acoustics criteria, were also examined as a literature source within the scope of the study. The primary one is the ISO 7029 standard, (International Organization for Standardization, 2017) titled "Acoustics-Statistical distribution of hearing thresholds related to age and gender," which examines age-related changes in auditory sensitivity. The standard describes the expected mean values of hearing thresholds and the method developed to calculate the statistical distribution around this mean. This calculation is possible for frequencies in the 125-8000 Hz range. (Kurakata&Mizunami, 2005) To establish the standard, a comprehensive study and an additional formula study were carried out by various researchers. (Robinson&Sutton, 1978; Shipton,1979). As individuals age, their sense of hearing gradually changes in various aspects. One of the most obvious effects of aging is an increase in hearing threshold. This is more noticeable at higher frequencies than at lower frequencies. In aging societies, there is a need for accessible designs that can be used by as many people as possible, including the elderly. (Kurakata&Sagawa,2008). For this purpose, the standard ISO/TR 22411 has been developed. The standard titled "Ergonomics data and guidelines for the application of ISO/IEC Guide 71 to products and services to address the needs of older persons and persons with disabilities" provides various guidelines to use in practice by addressing ergonomics data in the ISO/IEC 71 guide and the needs of people with disabilities (International Organization for Standardization, 2008; International Organization for Standardization, 2014). It is intended to guide the accessible design of products, services, and environments by providing ergonomics data on people's sensory, physical, and cognitive abilities. One of the topics examined in this context is the hearing capacity of people of various ages. The Japanese Industrial Standard (JIS) titled "The standards for auditory and visual functions in the guidelines for the elderly and people with disabilities" (Japan Standard Association, 2011) was used in the development of the international standard. Based on the importance of frequency, sound pressure level, and time-dependent changes in the perception of auditory signals, it was proposed by the Association for Electric Home Appliances in 2002 to adjust the frequency and time model. (Japan Standard Association, 2002) At the same time, various studies on sound levels have been conducted taking into account the effect of declining hearing due to aging, background noise, and individual differences. Afterward, different studies were carried out to develop auditory signals that can be heard easily by both young and elderly people, and the JIS S 0014 standard. (Japan Standard Association, 2013) was established as a result. In this context, hearing ability in the presence of background noise was measured for old and young individuals. As a result of the experimental research, it was confirmed that when the sound level reaches a certain value, elderly individuals perceive the sound as loud as young people. (Sato,2006). The majority of JIS guidelines are based on research done in collaboration with the National Institute of Technology and Evaluation. There is another standard for speech intelligibility (STI) calculations, which is a different room acoustics parameter. The standard BS EN 60268 has been published with the title of "Sound System Equipment Part 16: Objective Rating of Speech Intelligibility by Speech Transmission Index." (British Standards Institution, 2011). The purpose of this document is to standardize the STI methodology in a more comprehensive, clear, and complete approach. A new method for the estimation of the auditory masking effect is presented. The standard also includes explanations about age-related hearing loss and its effect on speech intelligibility. In determining the reference values of the room acoustics parameters evaluated within the scope of this study, the standards mentioned in this section were used and comparative analyzes were carried out.

## METHODOLOGY

With longer life expectancies, the proportion of elderly people in the adult population is increasing. Although it is incorrect to label older people as disabled, it is well known that the natural aging process causes a variety of physiological changes in people (Figure 1), including different types of hearing loss.

People with hearing difficulties may not be able to hear the auditory signal due to the frequency of the signal, the effect of background noise (including echoes), fast speech, and reduced volume. (Stephanidis 2009, 3-3)

Hearing loss can cause cognitive confusion and negatively impact people's quality of life. According to statistical research, one out of every ten people have a significant hearing impairment. (Newell & Gregor, 1997) Figure 2 illustrates the ISO 7029 graphs that were generated by calculating hearing threshold deviations based on the listener's age and frequency parameters.

Hearing threshold change is defined as "the expected mean value of hearing thresholds for a given age relative to the average threshold of an 18-year-old listener." For example, for 90% of 70 years old to hear a 2000 Hz signal as well as 18-year-old adults, the signal must be at least 30 decibels louder. Hearing thresholds in ISO 7029 standards are given in separate charts for male and female listeners of different ages (Figure 2). Based on these findings, the following steps were taken to evaluate auditory comfort in conference halls for listeners with varying auditory sensitivities.

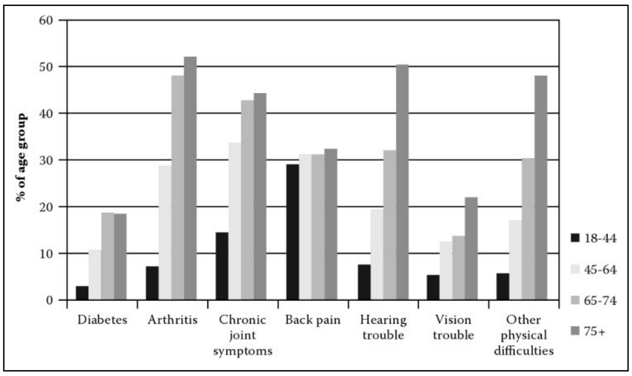


**Figure 1**. Physical disabilities as function of age (Stephanidis 2009, 3-3).

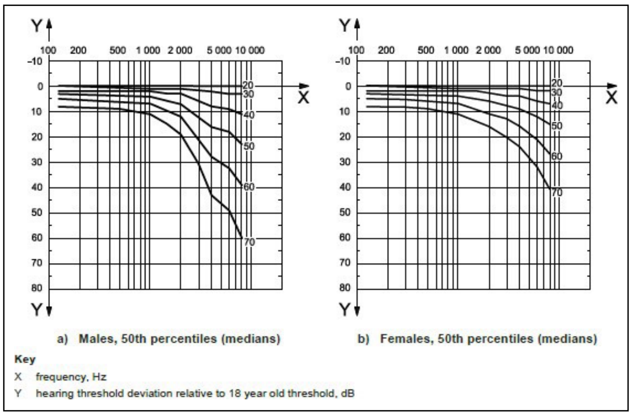


**Figure 2**. Hearing threshold as function of age-50$^{th}$ percentiles (ISO 7029).

- Determining the parameters for the research (such as listeners room, etc.) based on the literature and standards.
- Conducting studies through the simulation program to evaluate different halls with reference to predetermined criteria
- Evaluation of the results obtained by considering the auditory sensitivity distinctions
- Explanation of the method to be used to improve intelligibility values and application of the new reverberation times (that obtained as a result of this method) to the hall
- Performing an auralization study in a selected hall and completing listening tests with participants of various ages to support the simulation data with fieldwork
- Comparison of subjective and objective data with statistical analysis

**Determining the Parameters and Standards to be Used in the Research**

The following figure summarizes the studies conducted in this context.

**Simulation Studies**

The room acoustics parameters shown in Figure 3 were calculated in the Odeon simulation program for various receiver points in three different halls of 1000, 3000, and 5000 m$^3$ size. The criteria and standards specified in Figure 3 were used to determine the reference values. The studies were primarily conducted according to the values

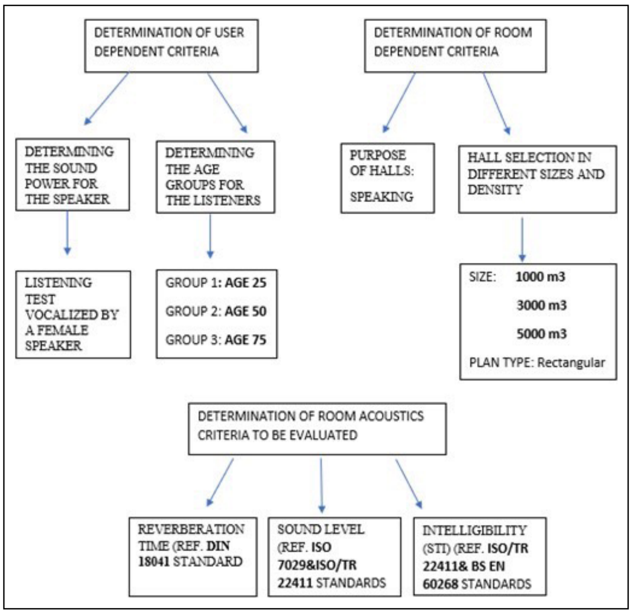


**Figure 3**. Parameters and standards evaluated within the scope of the research.

determined for the young ear, and the auditory comfort conditions of different age groups were examined in these conditions. European scale was used to determine the dimensions of the conference halls. (Rettinger 1988, 160) Table 1 shows the width, length, and height values calculated for the halls, and the locations of the receiver points are given in Figure 4 additionally.

The equation determined in the DIN 18041 standard for "classrooms and seminar rooms, group rooms in kindergartens and nursing homes, conference, and meeting rooms" was used to determine the reverberation times in halls depending on frequency. Accordingly, the reverberation time is calculated as (Ttarget) = 0.32 lg V-0.17. Depending on the room size, the mid-frequency reverberation times determined for speech are 0.79 s for a 1000 $m^3$ hall; 0.94 s for a 3000 $m^3$ hall, and 1.01 s for a 5000 $m^3$ hall. Afterward, the graph given in the DIN standard was used to determine the frequency-dependent distribution of target reverberation times. Table 2 shows the optimum values calculated for the halls by multiplying the coefficients in the graph with the mid-frequency reverberation times.

As a result of the background noise description research, it was decided to use the NC25 curve in all halls. (Schroeder vd., 2007; Bradley, 2002; Barron, 2009). The BB93_NORMAL_NATURAL file in the Odeon simulation program is used for the sound level parameter, which is the average of the sound levels of male and female speakers. (Odeon Application Note, 2014).

### Evaluation of Simulation Results by Considering Auditory Sensitivity Distinctions

The standards mentioned in Chart 1 were used in the evaluation of the results obtained through the simulation program for conference rooms of different sizes. For this purpose, as a starting point, sound levels should be arranged according to the auditory sensitivity distinctions determined in ISO 7029 for the age groups (25, 50, and 75) to be evaluated. Male listeners have more hearing loss than female listeners, especially at certain frequencies. For this reason, changes in hearing thresholds expressed as "values not exceeded in 50% of male listeners" in the standard were taken into account. The results were analyzed in terms of "Sound Level" and "Intelligibility (STI)" parameters.

### Sound Level

Vocal effort is defined as the A-weighted speech level that occurs 1 m in front of the speaker's mouth (International Organization for Standardization, 2003). As a result of the examination of the ISO/TR 22411 standard and various studies in the literature, it has been concluded that a minimum speech sound level of 50 dBA is needed for both young and elderly listeners (Sato vd., 2011; Akdağ, 1995).

**Table 1.** Room specifications for three different halls

| Hall Number | V ($m^3$) | Height (m) | Width (m) | Length (m) | Number of listeners |
|---|---|---|---|---|---|
| I | 1000 | 6 | 10.14 | 16.22 | 143 |
| II | 3000 | 8.65 | 14.45 | 23.10 | 320 |
| III | 5000 | 10 | 16.7 | 26.7 | 480 |

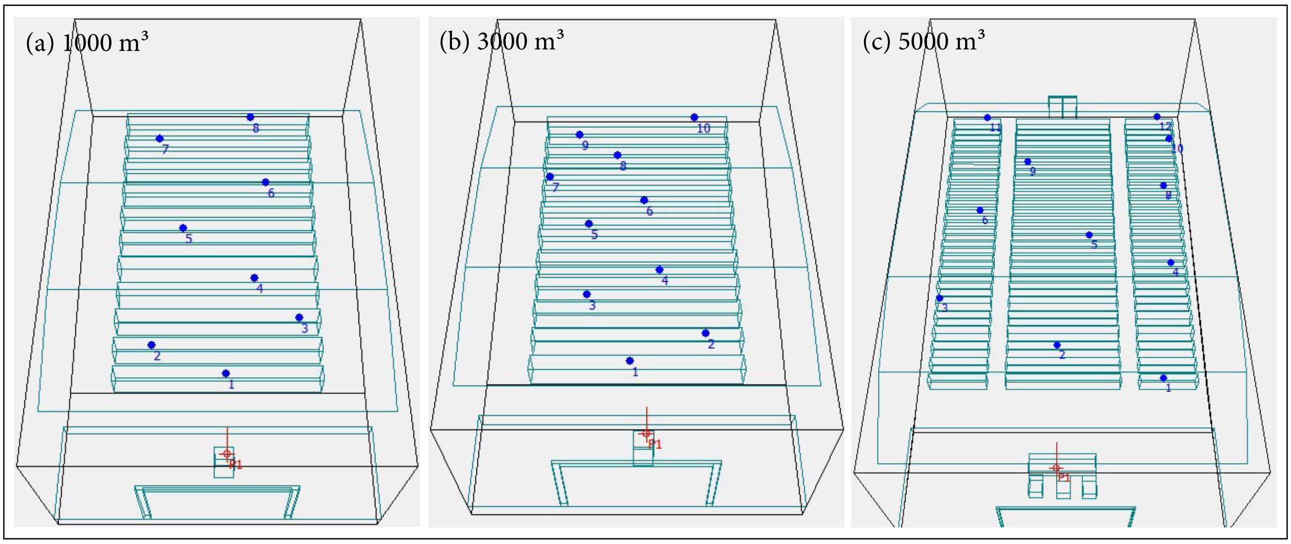


**Figure 4**. Sample images indicating the placement of source and receiver points in the acoustic simulation program.

**Table 2.** Optimum reverberation times for speech based on hall size

| V ($m^3$) | Frequency (Hz) | 125 | 250 | 500 | 1000 | 2000 | 4000 |
|---|---|---|---|---|---|---|---|
| 1000 | Topt. (s) | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 |
| | T30 opt. max | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
| | T30 opt. min | 0.54 | 0.60 | 0.60 | 0.60 | 0.60 | 0.50 |
| 3000 | Topt. (s) | 0.94 | 0.94 | 0.94 | 0.94 | 0.94 | 0.94 |
| | T30 opt. max | 1.13 | 1.13 | 1.13 | 1.13 | 1.13 | 1.13 |
| | T30 opt. min | 0.65 | 0.70 | 0.70 | 0.70 | 0.70 | 0.60 |
| 5000 | Topt. (s) | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 |
| | T30 opt. max | 1.21 | 1.21 | 1.21 | 1.21 | 1.21 | 1.21 |
| | T30 opt. min | 0.70 | 0.76 | 0.76 | 0.76 | 0.76 | 0.65 |

**Intelligibility (STI)**

The "adequate intelligibility" tables prepared for "young listeners and people with hearing loss over the age of 60" in the ISO/TR 22411 standard were used in the evaluation of speech intelligibility (Table 3).

According to Table 3, the STI parameter should be at least 0.6 to provide adequate speech intelligibility. Table 4 presents an analysis of the results obtained from the calculations completed for three different halls in this context. During the calculations made in the Odeon program, which is used for simulation studies, the speaker's volume is adjusted according to the auditory sensitivity of different age groups. While making these arrangements, both sound levels and background noise levels should be reduced at the same rate using the average hearing loss values specified in the ISO 7029 standard. Since the distinction between background noise and sound level is taken into account in STI (speech intelligibility) calculations, there is no change in STI results for different age groups, since both values decrease at the same rate. Table 4 shows the reduced values of sound levels reaching different receiver points after the adjustment for age-related differences in auditory sensitivity.

When the results are examined; it is seen that the acceptable intelligibility values are provided at all receiver points in the 1000 $m^3$ hall. When the results are examined in terms of sound level, it is observed that sufficient sound levels cannot be achieved, particularly for the audience in certain age groups. Since it will be possible for the speaker to raise her/his voice only to a certain level in rooms that do not have a sound system; hearing difficulties will be noticed especially for elderly individuals who experience decreases of up to 30–40 dB in hearing thresholds at high frequencies. As a result, sound systems are recommended in halls larger than 1000 $m^3$. Studies done to increase intelligibility (STI) values were explained in the next section.

**Determination of New Reverberation Times to Increase Intelligibility in Conference Halls**

To increase the intelligibility values to the desired levels, the method in a doctoral thesis was implemented. (Akdağ, 1995) The method in the thesis was developed on the assumption that speech sounds are masking each other like background noise. For this reason, it was concluded that the 2000 Hz frequency, (French&Steinberg, 1947) which is considered the most important frequency in the intelligibility of speech in the literature, should not be masked by the sounds at lower frequencies. A formula was developed based on the assumption that new optimum reverberation times should be calculated to prevent masking (Figure 5).

Accordingly, the following equation was used to determine the reverberation times:

$60/T60= b(1,2,3,4,5)-(b5-B)/0.070$

T60=Reverberation time b(1,2,3,4,5)= Total sound levels at each frequency

**Table 3.** The relationship between intelligibility degree and STI for normal hearing young and hearing-impaired elderly persons

| STI Label Category | Normal Listeners (Standartd STI) | Older Listeners PTA = 15 dB | Older Listeners PTA = 20 dB | Older Listeners PTA = 30 dB |
|---|---|---|---|---|
| Bad - Poor | 0.30 | 0.42 | 0.47 | 0.51 |
| Poor - Fair | 0.45 | 0.57 | 0.62 | 0.66 |
| Fair - Good | 0.60 | 0.72 | Cannot be achieved | Cannot be achieved |
| Good - Excellent | 0.75 | Cannot be achieved | Cannot be achieved | Cannot be achieved |

**Table 4.** Calculation results using the reverberation time given in the DIN standard for three different halls

| | | Parameters | | | |
|---|---|---|---|---|---|
| | | STI | Sound pressure level (dBA) | | |
| V(m³) | Receiver No: | | 25 years | 50 years | 75 years |
| 1000 | 1 | 0.73 | 60.4 | 56.8 | 45.7 |
| | 2 | 0.66 | 58.9 | 55.3 | 44.0 |
| | 3 | 0.70 | 59.2 | 55.6 | 44.3 |
| | 4 | 0.66 | 58.2 | 54.5 | 43.3 |
| | 5 | 0.65 | 57.8 | 54.2 | 42.9 |
| | 6 | 0.66 | 57.6 | 53.9 | 42.6 |
| | 7 | 0.66 | 57.1 | 53.5 | 42.2 |
| | 8 | 0.69 | 57.6 | 54.0 | 42.7 |
| 3000 | 1 | 0.65 | 58.3 | 54.6 | 43.1 |
| | 2 | 0.64 | 55.1 | 51.4 | 40.1 |
| | 3 | 0.59 | 53.1 | 49.4 | 38.0 |
| | 4 | 0.60 | 51.5 | 47.8 | 36.4 |
| | 5 | 0.56 | 51.7 | 48.0 | 36.6 |
| | 6 | 0.59 | 51.3 | 47.6 | 36.2 |
| | 7 | 0.60 | 52.0 | 48.3 | 37.1 |
| | 8 | 0.60 | 51.1 | 47.4 | 36.0 |
| | 9 | 0.61 | 50.4 | 46.7 | 35.4 |
| | 10 | 0.61 | 51.8 | 48.1 | 36.7 |
| 5000 | 1 | 0.63 | 53.1 | 49.4 | 38.2 |
| | 2 | 0.63 | 53.1 | 49.4 | 38.0 |
| | 3 | 0.57 | 51.4 | 47.7 | 36.3 |
| | 4 | 0.55 | 51.2 | 47.5 | 36.1 |
| | 5 | 0.56 | 51.9 | 48.1 | 36.7 |
| | 6 | 0.56 | 51.8 | 48.0 | 36.6 |
| | 7 | 0.57 | 51.6 | 47.9 | 36.5 |
| | 8 | 0.57 | 51.6 | 47.9 | 36.5 |
| | 9 | 0.58 | 51.7 | 47.9 | 36.5 |
| | 10 | 0.55 | 51.1 | 47.4 | 36.2 |
| | 11 | 0.58 | 51.2 | 47.5 | 36.3 |
| | 12 | 0.61 | 51.8 | 48.0 | 36.7 |

Target value provided; Target value not provided

b5-B= The level distinctions required between frequencies to avoid masking, it is calculated over the frequency-dependent distributions of speech and background noise at the same level (Table 5).

Since the study focused on different age groups, total sound levels were arranged according to decreases in hearing thresholds, and different reverberation times were calculated for listeners aged 25-50-75. In Table 6, the frequencies that need to be intervened are framed.

Curves were created for three different halls depending on their size to compare the new optimum reverberation times that were calculated for three age groups with the target range given for speech in the DIN standard (Figures 6-8). To determine the target range; target values calculated

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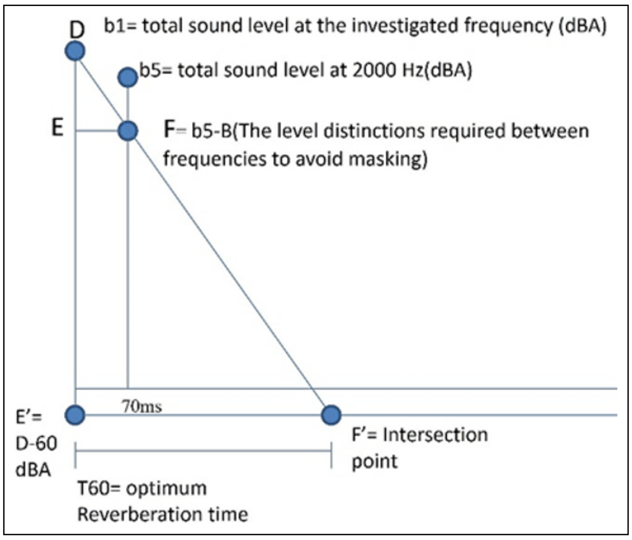


**Figure 5**. Illustrative explanation of the method.

b1' = the total sound level at 125 Hz.

b2' = the total sound level at 250 Hz.

b3' = the total sound level at 500 Hz.

b4'= the total sound level at 1000 Hz.

b5 and b5' = represent the total sound level at 2000 Hz.

It has been accepted that the sounds follow each other with an average of 70 milliseconds time intervals.

according to the formula given in the standard are multiplied with the limit values in the reference curve. For the 1000 $m^3$ hall, 0.79 s reverberation time was multiplied by the coefficients. According to the study's methodology, the curves in red represent the new reverberation times that were determined by considering deviations in the hearing threshold mentioned in ISO 7029 for listeners of various ages.

To determine the target range in the DIN standard for the 3000 $m^3$ hall, the 0.94 s reverberation time was multiplied by the coefficients in the table.

To determine the target range in the DIN standard for the 5000 $m^3$ hall, the 1.01 s reverberation time was multiplied by the coefficients in the table.

When the reverberation time parameter is evaluated in terms of the DIN standard, it is seen that the new reverberation times determined for the 25 age group are within the range given in the standard, while the reverberation times calculated for the 50 and 75 age group are below the curve at some frequencies. Therefore, it is advised to provide shorter reverberation times for certain frequencies in conference halls. Intelligibility values were improved at different receiver points for all age groups by applying the newly calculated optimum reverberation times to the halls (Table 7).

**Table 5.** The sound level separations that must be found to avoid masking

| | |
|---|---|
| Level distinction required for 2000 Hz not to be masked by 125 Hz | 0.6 dBA |
| Level distinction required for 2000 Hz not to be masked by 250 Hz | 1.3 dBA |
| Level distinction required for 2000 Hz not to be masked by 500 Hz | 1.8 dBA |
| Level distinction required for 2000 Hz not to be masked by 1000 Hz | 2.6 dBA |
| Level distinction required for 2000 Hz not to be masked by 2000 Hz | 4.5 dBA |

**Table 6.** Optimum reverberation times calculated according to the auditory sensitivity of different age groups

| V ($m^3$) | Frequency (Hz) | 125 | 250 | 500 | 1000 | 2000 | 4000 |
|---|---|---|---|---|---|---|---|
| 1000 | Reverberation time: | | | | | | |
| | Calculated for 25 years | 0.80 | 0.80 | 0.65 | 0.65 | 0.80 | 0.80 |
| | Calculated for 50 years | 0.80 | 0.60 | 0.55 | 0.65 | 0.80 | 0.80 |
| | Calculated for 75 years | 0.50 | 0.40 | 0.40 | 0.40 | 0.80 | 0.80 |
| 3000 | Calculated for 25 years | 0.90 | 0.85 | 0.70 | 0.80 | 0.90 | 0.90 |
| | Calculated for 50 years | 0.90 | 0.65 | 0.55 | 0.70 | 0.90 | 0.90 |
| | Calculated for 75 years | 0.45 | 0.40 | 0.40 | 0.45 | 0.90 | 0.90 |
| 5000 | Calculated for 25 years | 0.95 | 0.95 | 0.70 | 0.70 | 0.95 | 0.95 |
| | Calculated for 50 years | 0.90 | 0.70 | 0.60 | 0.65 | 0.95 | 0.95 |
| | Calculated for 75 years | 0.45 | 0.45 | 0.40 | 0.40 | 0.95 | 0.95 |

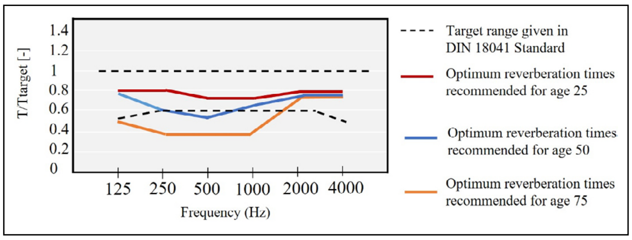


**Figure 6**. Comparison of the recommended optimum reverberation times (according to the age of 25, 50, and 75) with the target range given in DIN 18041 standard for the 1000 m³ hall.

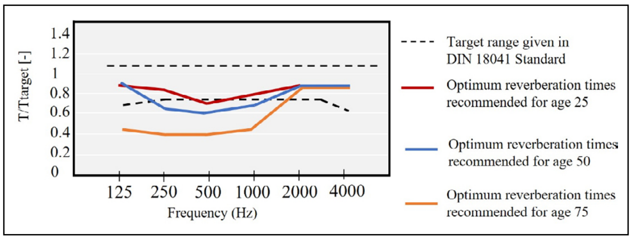


**Figure 7**. Comparison of the recommended optimum reverberation times (according to the age of 25, 50, and 75) with the target range given in DIN 18041 standard for the 3000 m³ hall.

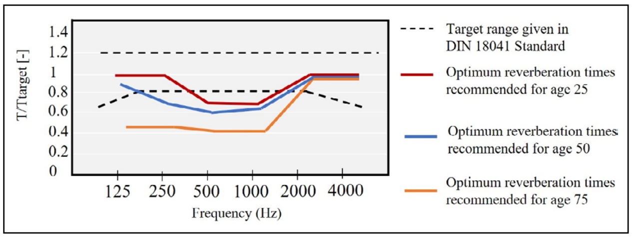


**Figure 8**. Comparison of the recommended optimum reverberation times (according to the age of 25, 50, and 75) with the target range given in DIN 18041 standard for the 5000 m³ hall.

**Questionnaire and Listening Test Studies**

To compare the objective results obtained through the simulation program with subjective data, a listening test and questionnaire study were conducted with participants at various ages. In this context, it was decided to examine the 3000 m³ hall to make a general assessment. Among the new optimum reverberation times determined in the study, the values calculated based on the auditory sensitivity of the 50 age group (which is considered the average listener age) are thought to provide suitable conditions for all listeners. As a result, these values were used in the auralization study conducted in the Odeon simulation program for the listening test. Receiver point 5, located in the middle of the hall, was taken as a reference. The sound recording used in the study was recorded in the anechoic room of TUBITAK UME laboratories by a female speaker, using meaningless words (Ilgurel & Akdag, 2017). The record contains 52 words in total. Two recordings were presented to the audience. The first recording was prepared by applying the target reverberation times specified in the DIN standard to the hall (current condition), and the second recording was prepared using the new optimum reverberation times determined within the scope of the study (improved condition). The recordings were presented to the participants in a quiet environment through headphones and they were instructed to only listen to the each recording once and to write down the words they heard on paper. The volume of the recording was increased until the participants stated that they could hear. After the test, they were asked to answer a short questionnaire. The questionnaire includes questions about age, gender and hearing status, as well as questions about the sound level and intelligibility of the recording. The listening test and survey were completed mostly in 20 min and a total of 82 participants took part in the study. The average age of the participants, that include 54 women and 28 men, is 46. The results obtained by the questionnaire and listening test were analyzed in the SPSS statistical program. With the recording generated by applying the reverberation time specified for the 3000 m³ conference hall in the DIN standard to the room, an average intelligibility value of 0.60 was achieved among the audience. For the receiver point taken as a reference for the listening test, this value was calculated as 0.56 in previous studies done with the simulation program. Within the scope of the study, the average intelligibility value increased to 0.70 according to the results of the second recording (obtained by applying the optimum reverberation times calculated by considering the auditory sensitivity of the 50 age group) to the hall. In the studies conducted for the same receiver point in the simulation program, this value was calculated as 0.61. In the comment section of the questionnaire, many participants stated that they heard the words better in the second recording. Following that, the participants were divided into four groups to evaluate the results based on age. The values calculated for the 50-year-old group were chosen as the optimum condition according to the age groups examined through simulation, because it is difficult to provide in the simulation setting since the reverberation times required for the older group are very low. However, for the participants of the listening test and survey in which these optimum conditions were examined, more groups were evaluated since there was no specific age restriction. The age ranges of the participants are 18–25 in the first group (11 people), 25–50 in the second group (32 people), 50–75 in the third group (35 people), and 75 and over in the fourth group (4 people). Table 8 lists the intelligibility values obtained under current and improved conditions for all age groups as a result of the listening test.

Within the scope of the questionnaire, the listeners evaluated

**Table 7.** Results of three different hall's simulation studies using new calculated reverberation times

| V($m^3$) | Receiver No: | Intelligibility (STI) | | |
|---|---|---|---|---|
| | | STI values when $T_{30}$ taken by age 25 | STI values when $T_{30}$ taken by age 50 | STI values when $T_{30}$ taken by age 75 |
| 1000 | 1 | 0.74 | 0.75 | 0.79 |
| | 2 | 0.68 | 0.69 | 0.72 |
| | 3 | 0.71 | 0.72 | 0.75 |
| | 4 | 0.68 | 0.68 | 0.71 |
| | 5 | 0.66 | 0.67 | 0.69 |
| | 6 | 0.67 | 0.68 | 0.70 |
| | 7 | 0.67 | 0.68 | 0.70 |
| | 8 | 0.70 | 0.71 | 0.73 |
| 3000 | 1 | 0.68 | 0.71 | 0.74 |
| | 2 | 0.67 | 0.69 | 0.71 |
| | 3 | 0.62 | 0.64 | 0.65 |
| | 4 | 0.63 | 0.65 | 0.66 |
| | 5 | 0.58 | 0.61 | 0.62 |
| | 6 | 0.61 | 0.63 | 0.64 |
| | 7 | 0.62 | 0.63 | 0.64 |
| | 8 | 0.63 | 0.64 | 0.65 |
| | 9 | 0.62 | 0.63 | 0.64 |
| | 10 | 0.62 | 0.64 | 0.65 |
| 5000 | 1 | 0.65 | 0.66 | 0.69 |
| | 2 | 0.64 | 0.66 | 0.69 |
| | 3 | 0.60 | 0.62 | 0.63 |
| | 4 | 0.58 | 0.60 | 0.61 |
| | 5 | 0.58 | 0.60 | 0.61 |
| | 6 | 0.58 | 0.60 | 0.61 |
| | 7 | 0.60 | 0.61 | 0.62 |
| | 8 | 0.60 | 0.61 | 0.62 |
| | 9 | 0.61 | 0.62 | 0.63 |
| | 10 | 0.57 | 0.57 | 0.60 |
| | 11 | 0.60 | 0.61 | 0.62 |
| | 12 | 0.62 | 0.63 | 0.64 |

Target range provided; Target range not provided.

the sound level of the recording and the intelligibility of the words. Participants were asked to mark one of the options "Poor," "Adequate," "Good," "Very Good," or "Excellent" for both parameters.

The answers given by the participants were categorized and classified according to the number of people and age groups (Figure 9).

## CONCLUSION

In halls where auditory perception is significant, auditory sensitivity distinctions between listeners must be taken into account in the acoustic design process to provide suitable auditory conditions for all listeners. When reference reverberation time values based on the auditory sensitivity of young people (18–25 years old) in the acoustic literature

**Table 8.** Comparison of intelligibility values for current condition and improved condition

| Group Name | Age Range | Average Intelligibility in Current Condition<br>T30 Avg. 0,94 | Average Intelligibility in Improved Condition<br>T30 Avg. 0,72 |
|---|---|---|---|
| Group 1 | 18-25 | 0,65 | 0,75 |
| Group 2 | 25-50 | 0,63 | 0,73 |
| Group 3 | 50-75 | 0,56 | 0,68 |
| Group 4 | 75 + | 0,53 | 0,67 |
| GENERAL | 18-87 | 0,60 | 0,70 |

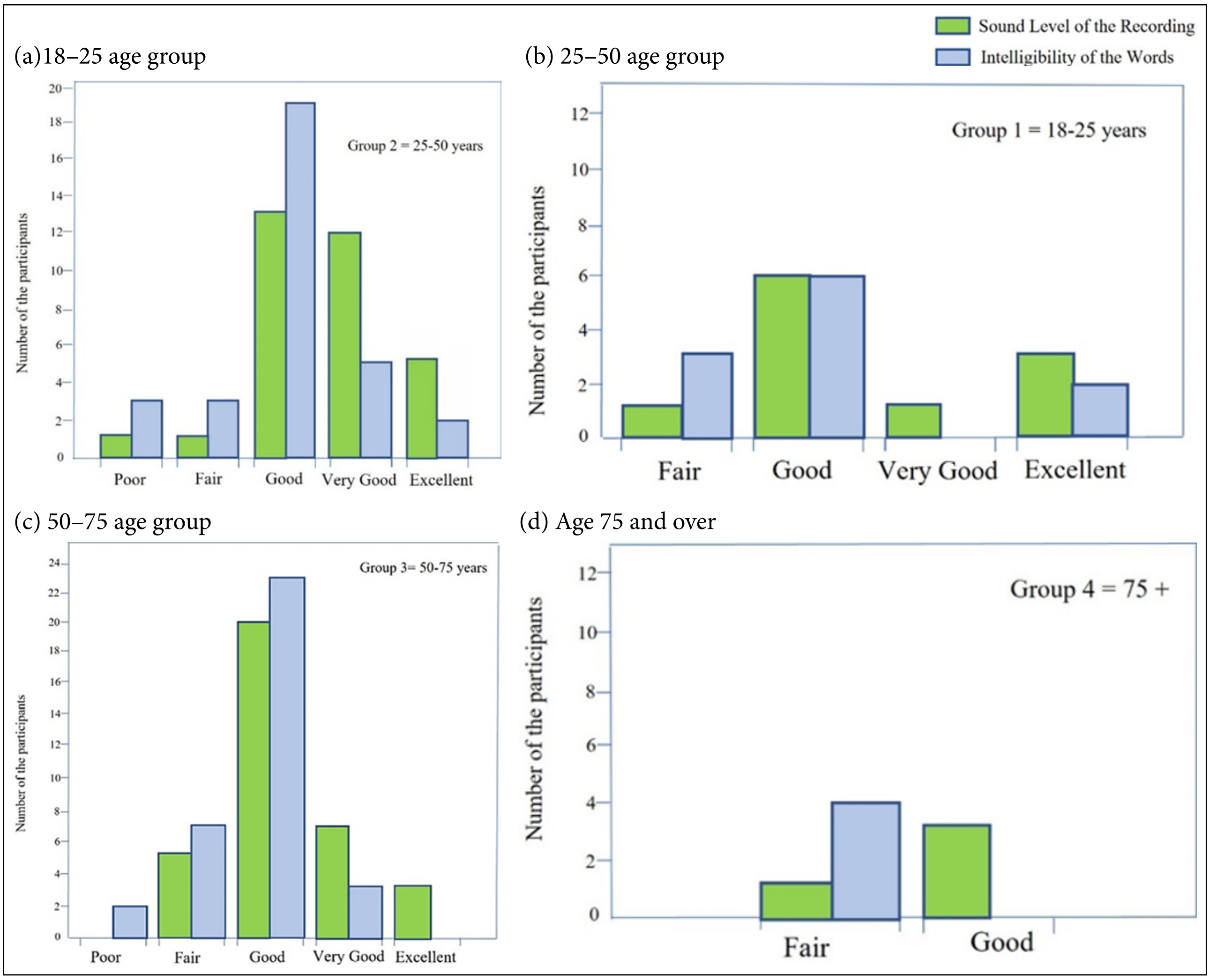


**Figure 9**. Evaluation of the sound level of the recording and the intelligibility of the words by participants in different age groups.

were applied to the halls, it was found that the adequate intelligibility for older listeners could not be fully achieved in the conference halls evaluated within the scope of the study. To ensure the optimization, acoustic evaluations were made with simulation and listening tests for the 25, 50, and 75 age groups under the conditions determined for the 50 age group, and it was observed that intelligibility increased for all age groups. The intelligibility values increased by around 20%, according to the average of the listening test findings. As a result of all the evaluations, it was determined that the subjective and objective data overlap with each other and that following the acoustic design specifications defined in the study (shorter reverberation times compared to DIN standard, calculated by considering age-related auditory sensitivity distinctions) could increase the intelligibility values of the majority of listeners. It is thought that this study, which was carried out for conference halls with certain sizes and proportions, should also be carried out for halls of different functions, shapes, and sizes, to determine the optimum conditions that would be suitable for all audiences.

**ACKNOWLEDGMENTS:** We would like to thank everyone who participated in the listening tests, especially Prof. Dr. Ayşe Erdem Aknesil and Yıldız Technical University academics. We also thank Assoc. Prof. Dr. M. Nuri İlgürel for the recording used in the listening test studies.

- This article is based on the PhD Dissertation entitled as "An Approach for Evaluating the Impact of Age on the Acoustic Design of Halls" by Hazal Şentürk and continues under the supervision of Prof. Dr. Neşe Yüğrük Akdağ at Yildiz Technical University, Department of Architecture in 2023.

**ETHICS:** There are no ethical issues with the publication of this manuscript.

**PEER-REVIEW:** Externally peer-reviewed.

**CONFLICT OF INTEREST:** The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**FINANCIAL DISCLOSURE:** The authors declared that this study has received no financial support.

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