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Reverberation perception in Spanish cathedrals

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ABSTRACT

Listening tests based on paired comparisons have been employed to investigate the subjective perception of the acoustic environment in highly reverberant large spaces. Seven cathedrals in the southern half of Spain have been included in the survey, thereby covering a wide range of reverberation-time values from 4.32 s in Murcia cathedral to 8.96 s in Cadiz cathedral at mid-frequencies. These cathedrals present a common architectural typology, known as the "Spanish style", which allows similar source-receiver points to be selected when comparisons are made between two different cathedrals. The tests were carried out in the listening room of the Acoustics Laboratory of the Applied Physics II Department of the School of Architecture of the University of Seville. Several types of anechoic sound signals (choral pieces, extracts of Baroque instrumental music, and a speech) were auralised with the impulse responses measured in the cathedrals to be used in the tests. Such

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auralisations were reproduced through headphones, thereby ensuring that all audio signals were perceived at the same level during each test. The results indicated the existence of a threshold, whose value depends on the type of stimulus, from which the objective reverberation differences are subjectively remain almost indistinguishable to the listener.

Keywords: Cathedral acoustics, listening test, auralisation
I-INCE Classification of Subject Number: 79

1. INTRODUCTION

Worship places, especially cathedrals, are complex buildings, resulting from a collective and prolonged effort with combinations of different architectural styles and multiple rehabilitations and additions of other volumes. This characteristic is common to all European cathedrals.

The propagation of sound in churches, has been the object of study of several research groups across many countries with a great variety of contributions, such as the analysis of the sound field as a function of distance to the source [1,2], acoustic measures relating to ecclesial furniture [3], the influence of occupation [4], the relationship between acoustics and liturgical uses [5,6], and the use of simulation techniques with different purposes [7,8]. In these large reverberant spaces, room impulse responses (RIRs) [9] and parametric and sensory evaluation need to be tuned to meet for the major values of reverberation times in relation to concert halls and auditoriums [10]. In recent decades, the acoustic study of cathedrals has become an object of multidisciplinary interest, and hence certain pieces of research have been produced on emblematic European historic cathedrals, such as St. Paul's in London [11], St. Peter's in Rome [12], and Notre Dame in Paris [13].

The possible sound messages also vary widely through a liturgical service, from the spoken word to organ music and congregational singing. Likewise, churches are the natural places where sacred music, both choral and instrumental, should be performed and, in particular cathedrals very often host orchestral music concerts. In addition, good speech intelligibility in Catholic churches became imperative after the liturgical reforms of the Second Ecumenical Council of the Vatican. Nevertheless, there are only a few studies concerning the preferential listening conditions of the congregation-audience in these sacred spaces: Carvalho [14] employed a group of subjects who attended live music performances in different churches; Desarnaulds [15] and Meyer [16] collected the judgments given by members of several parish communities on the acoustics of their churches, and obtained curves of optimal reverberation times as a function of room volume; and Martellotta [17] used laboratory methods based on loudspeaker reproduction with crosstalk cancellation, of anechoic materials convolved with measured impulse responses in order to understand the relations between subjective preference and the architectural and acoustic aspects observed in a group of Italian Catholic churches. This latter author [18] also presented research aimed at investigating the possible dependence of JNDs for the centre time and clarity as a function of reverberation time, and took into account the particular case of large reverberant enclosures. Postma and Katz [19] presented the results of a subjective listening test which compared simulated and measured binaural auralisations for the calibrated geometrical acoustic models of the Cathedral of Notre Dame.

This paper presents and discusses the results of a listening test carried out through the laboratory method in order to investigate the subjective perception of the acoustic environment in highly reverberant large spaces and the influence of various types of

sound stimuli on this perspective. Evaluations of seven cathedrals in the southern half of Spain have been included in the survey.

2. DESCRIPTION OF THE CATHEDRALS

Spanish architectural heritage involves all the various cultures that have converged in its many regions: Roman architecture, the construction of masterpieces of Al-Andalus architecture, Gothic architecture, and Renaissance and Baroque architecture of the Christian period provide the main monuments in the country.

Cathedrals are complex buildings resulting from a collective and prolonged effort. These historic yet fully alive buildings exert a cultural projection towards their interior, with a remarkable accumulation of assets, and also towards the exterior surroundings, as spatial references of the cities which shape their urbanism.

The construction process of the Cathedral of Cadiz (CA) lasted for 116 years, and involved a combination of different architectural styles: Baroque and Rococo in the interior, and Neoclassicism in the façade and the two towers. Its shoreline location affects the stone used in its construction and has caused it to slowly crumble.

The mosque at Cordoba was the result of a series of extensions and modifications that were carried out during the time of the emirs. Its construction started with the demolition of an old Visigoth church in the year 785. The last extension of the mosque, in the late 10th century, delimited the area of the building as 179 metres long by 128 metres wide. In 1236, the Great mosque was consecrated as a Christian church. In the 16th century, the construction of the Renaissance cathedral began within the mosque. In this building there are more than eight hundred columns of jasper, marble, and granite. The cathedral-mosque of Cordoba (CO) was declared a World Heritage Site in 1984.

The construction of the Cathedral of Jaen (JA) began in 1249 atop the ruins of the ancient mosque of the city. The temple was damaged and rebuilt on numerous occasions during the following five centuries, which led to the existence of various architectural styles. The new renaissance cathedral was built between 1540 and 1724, and it is considered the masterpiece of the Spanish architect Andrés de Vandelvira.

The construction process of the Cathedral of Malaga (MA) started in 1528, where the Great Mosque of the city once existed. The temple is considered one of the jewels of the Renaissance in Andalusia, mainly designed by Diego de Siloé and Andrés de Vandelvira. The façade, unlike the rest of the building, is in the Baroque style, and, despite having been initially designed with two towers, the south tower remains unfinished to this day.

The construction process of the Cathedral of Murcia (MU) began at the end of the 14th century, and ended with the raising of the Gate of Apostles (transept on the south side) in 1488. In its history, it has suffered additions: the chapel of Velez, (15th century); the bell-tower (16th and 17th centuries); and the new main façade (18th century), which unifies various artistic styles. After the fire of 1854, the cathedral required a new Neo-Gothic altarpiece and a great organ for the choir.

The Gothic Cathedral of Seville (SE) was also built in the 15th century on the site of an ancient mosque. In 1987, it was declared a World Heritage Site by UNESCO. In dimensions, it is the third largest Christian church in the world after St. Peter's cathedral in Rome and St. Paul's cathedral in London.

The first stone of the Cathedral of Toledo (TO) was placed in 1226, and, in 1493, with the closing of the last vaults, this great construction was concluded. The temple has a clear French influence, due to the Gallic origin of its first architect. During the 16th to 18th centuries, various work activities were carried out, in accordance with the new styles. Its large retrochoir is of remarkable beauty.

Acoustically, cathedrals are complex buildings, characterised by side chapels, vaults and domes, whose enormous volumes and constructive solutions and finishing materials give them a highly reverberant character that, a priori, is not recommendable for liturgical practice nor for cultural activities, although it is suitable for organ music and Gregorian chants. Table 1 summarises the main data that broadly describes the geometry of each temple and also its architectural style. The seven cathedrals under study correspond, to the so-called "Spanish style" [20] in which the choir is located in the middle of the central nave. In this distribution, the space is organised through the sequence altar-faithful-choir-retrochoir-faithful. This subdivision of the space determines the acoustic behaviour of these spaces.

Table 1. *General data of the studied cathedrals.*

Cathedral	ID	Architectural Style	Volume (m^3)	L×W (m×m)	Heights* (m)	Description	T_{30m} (s)	Group
Cadiz	CA	Baroque, rococo c. XVIII–c. XIX	70,000	85×60	29/19/46	3 naves. 16 lateral chapels Choir in the central nave	8.96	G3
Cordoba	CO	Renaissance c. XVI	22,114 (134,700)	60×40	26/-/35	Cathedral inside the Mosque Choir in the central nave	4.51	G1
Jaen	JA	Renaissance c. XVI - c. XVIII	85,100	85×60	31/31/47	3 naves. 18 lateral chapels Choir in the central nave	8.05	G3
Malaga	MA	Renaissance c. XVI - c. XVIII	118,500	98×52	37/34/39	3 naves. 15 lateral chapels Choir in the central nave	6.89	G2
Murcia	MU	Late Gothic (c. XIV-c. XVI)	50.000	84×51	22.5/16.5/32	3 naves. 22 lateral chapels Choir in the central nave	4.32	G1
Seville	SE	Late Gothic c. XV – c. XVI	215,000	116×76	35/34/40	5 naves. 18 lateral chapels Choir in the central nave	4.68	G1
Toledo	TO	Gothic (c. XIII-c. XV)	125,000	120×60	31/19-12/31	5 naves. 15 lateral chapels Choir in the central nave	6.12	G2

*Height of the central nave / Height of the lateral naves / Maximum height of the temple.

In general, the same materials are used in the construction of the seven cathedrals studied, although, in each case, specific peculiarities do appear. Different types of stone are commonly used in walls, columns and vaults; marble tiles are used as flooring and in some parts of the pillars; wood is used in all the choirs, altarpieces, organs and doors and, exceptionally, in the beams beneath the flat ceiling of the Cathedral-Mosque of Cordoba; and finally, certain chapels and vaults are finished in plaster. Pulpits and canopies vary in material (marble, wood, or ormolu), height, and shape. The main furniture consists of wooden pews, upholstered seats, and plastic chairs located throughout the congregation area. The decoration mainly consists of textiles, wooden or marble altarpieces, and paintings. There are notable differences in the distribution of these elements from one temple to another. Figure 1 shows an interior view of the seven temples described.

3. EXPERIMENTAL METHODS

Experimental measurements were carried out by following the procedure established in the standard [10] and specific guidelines [9, 21]. The process of generation, acquisition, and analysis of the acoustic signal was performed by using commercial software platforms. All Room Impulse Responses (RIR) were obtained from sine-swept signals, in which the scanning frequency increases exponentially with time.

One of the tasks contemplated in the investigation is the accomplishment of anechoic records of musical pieces composed in and for the cathedrals throughout their history, interpreted by the Baroque Orchestra of Seville (OBS). This milestone has been carried out in the Anechoic Chamber of the National Centre for Means of Protection of

Figure 1. *Interior view of the seven cathedrals studied.*

Seville, of the National Institute of Health and Safety at Work (INSST). The procedure takes place in a first stage by recording a video and audio of the interpretation of the pieces at the headquarters of the OBS in the Monastery of La Cartuja, with all the musicians playing. Subsequently, the recording in the anechoic chamber is performed with each musician individually. To achieve synchronisation in the musical piece of the various musicians, each player visualizes the recorded video of the rehearsal and listens to its sound signal by means of headphones [22] (see Figures 3a and 3b).

Each soloist is recorded on different tracks that are then synchronised and equalised by the specialised REAPER software in a single signal with wav format (mono, 48 kHz, 16 bits). The auralisations that are presented have been carried out with Matlab, convolving the measured binaural impulse responses. In this case, a similar source-receiver combination has been chosen for each of the 7 cathedrals so that the results would be comparable: the source is placed at the main altar and the receiver located in the pew zone, facing the main altar. The following anechoic signals are presented with the same acoustic level in each pair of cathedrals to be compared:

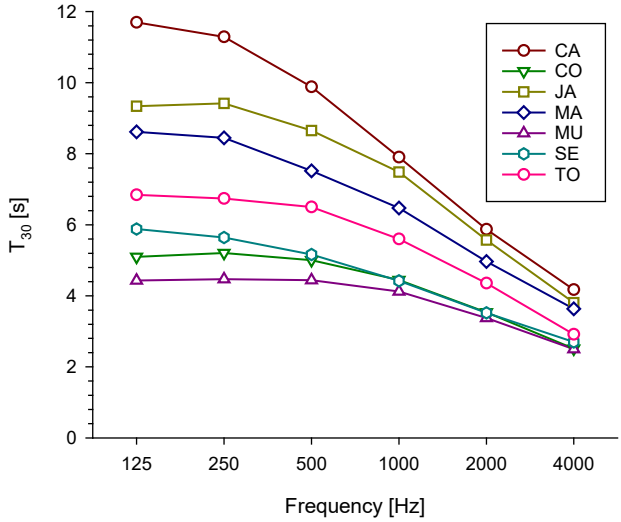

Figure. 2. *Spatially averaged values of the reverberation time, measured when the sound source is located at the high altar, on the symmetry axes of the cathedrals.*

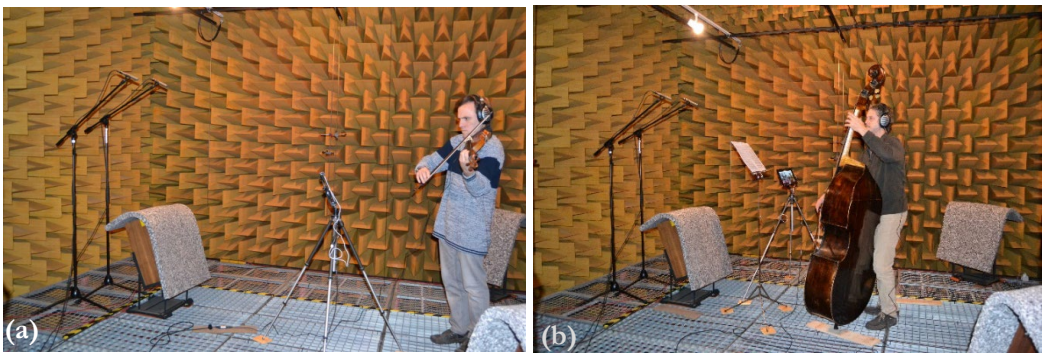

Figure 3. *(a) and (b) Musicians of the Baroque Orchestra of Seville in the anechoic chamber.*

- An excerpt from a choral interpretation of Alleluia by Randall Thompson.
- Two instrumental pieces, interpreted by the Baroque Orchestra of Seville: extract of the Sonata for flute, by Felipe Lluch; and extract of the Sonata VI Re-minor bass violin from Francisco Manalt.
- Two locutions in Spanish (with female and male voices) from a biblical passage.

4. LISTENING TESTS

As far as possible, the recommendations for the surveys collected in the publications of the International Telecommunication Union (ITU) [23] have been followed. With the idea of minimizing the variables that can affect the listener, the signals of each cathedral are at an equivalent distance to the sound source and all have the same perceived volume. The voice signals are in Spanish, the native language of the respondents. In the case of choral music, the only non-native word corresponds to "Alleluia", which is widely known. The concept of reverberation is explained to all subjects, although 100% of the respondents were already familiar with this concept. The survey method corresponds to a pairwise comparison of reverberation signals that are 25 seconds long. The subjects are aware of the fact that some paired samples may be exactly the same. When the qualification of the reverberation is necessary, numerical scales are chosen as opposed to explanatory scales in order to prevent listeners from understanding the qualifications differently.

The questionnaire was completed by 30 people, 16 women and 14 men all without hearing defects and aged between 18 and 63 years old. They are mostly students and lecturers. Some have music studies, and most have no knowledge of acoustics (Table 2).

The tests were carried out in the listening room of the Acoustics Laboratory of the Applied Physics II Department of the School of Architecture of the University of Seville (Figure 4). The room, semi-anechoic, has a low background noise, with an average mid-reverberation time of 0.3 seconds. The auralisations were reproduced through hi-fi / professional headphones SENNHEISER-HD600, which presented an adequate frequency response between 100 to 20,000 Hz, thus ensuring that all audio signals were perceived at the same level during each test (see Figure 4).

The virtual recreations, obtained under the same aforementioned conditions, correspond to the cathedrals of Cadiz, Cordoba, Jaen, Malaga, Murcia, Seville, and Toledo. For the subjective statistical analysis, the cathedrals have been classified into the following three groups according to the measured values of the mid-reverberation times. Group 1: $0s<T_{30m}\leq 5s$; Group 2: $5s<T_{30m}\leq 7s$; Group 3: $T_{30m}>7s$ (last column of Table 1).

The survey aims to ascertain the perception of the reverberation existing in Spanish cathedrals. To this end, a questionnaire organised into three sections has been

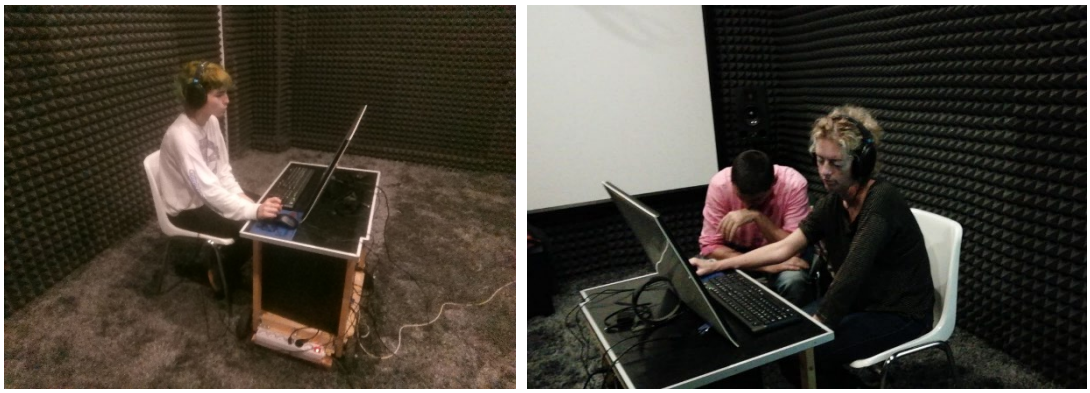

Figure 4. *Subjects during the survey.*

designed. In order not to exhaust the listener, a brief break between completing Sections 2 and 3 is suggested.

In the first section, the listener is asked about personal aspects: gender, age, profession, whether he/she has musical training, and whether he/she has a background in acoustics (Table 2).

Table 2*. Section 1: Summary of participants' information.*

Gender	Age	Profession	Musical education	Knowledge of Acoustics
Male: 14	≤ 35 years: 22	University lecturer: 8	Yes: 10	Yes: 13
Female: 16	> 35 years: 8	Student: 19	No: 20	No: 17
		Pedagogue: 1		
		Researcher: 2		

In order to cover the results of the seven Spanish cathedrals under study, three models of the same survey have been devised with different combinations of cathedrals. Each model has been answered by 10 people. The layout of each survey, in addition to the aforementioned Section 1, includes Section 2 as follows: the first 5 questions involve pairs of auralisations that correspond to two cathedrals of groups 1 and 3 (see Table 1) with 5 different types of sound stimuli for each pair of cathedrals (1 choral piece, 2 pieces of music, 1 female voice, 1 male voice); the subsequent 5 questions correspond to pairs of auralisations of two cathedrals of groups 2 and 3 with the same pattern of previous stimuli; and the last 5 questions correspond to the same cathedral of group 1, or 2, or 3, respectively, with the same 5 previous stimuli.

In all cases, the sound recordings are heard sequentially to enable the comparison of each pair and to provide an indication of: which recording seems to be more reverberant; whether they are equally reverberant; or whether the participant does not know/does not answer (Table 3).

Table 3*. Section 2*

Section 2 consists of a total of 15 questions. For each pair of stimuli presented to you, you must indicate which stimulus is more reverberant in each case.					
		A	B	Equal	DK/NA
Pair 1	Which stimulus seems to you to be more reverberant?	☐	☐	☐	☐

In Section 3 (Table 4), after hearing two reference sound stimuli, corresponding to "null reverberation" and "maximum reverberation", auralisations of 2 musical pieces, 1 female voice, 1 male voice, and 1 choral piece is presented to the listener corresponding to two cathedrals from the various groups in order to assess reverberation, intelligibility,

and overall acoustic quality of the sound field of the cathedral (all on a scale from 1 to 10).

***Table 4**. Section 3*

Section 3 consists of a total of 26 questions (13 for each cathedral). In all cases, "1" corresponds to the lowest value and "10" to the maximum value in the given scale and the rest of values for the intermediate cases.												
Music		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DK/NA**
1	How reverberant does the space seem to you?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2	How would you rate the space acoustics for instrumental music?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Speech		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DK/NA**
1	How reverberant does the space seem to you?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2	Can you clearly distinguish the message from the spoken phrase?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
3	How would you rate the acoustics of this space for the speech?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Choral		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**DK/NA**
1	How reverberant does the space seem to you?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2	Can distinguish between the voices of the choral performance?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
3	How would you rate the acoustics of this space for choral music?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

The listener has no information about which of the spaces corresponds to each stimulus. The level of reproduction is adjusted so that not only is it sufficient for the correct performance of the test, but the listener is also in the comfort zone. This level cannot be modified during the survey. Each sound stimulus can be heard only once, without the possibility of repetition. The approximate duration of the complete perception survey is 30 minutes.

5. RESULT ANALYSES

5.1 Section 2

The fundamental aim of Section 2 of the perception questionnaire is to study the correlation that exists between the objective parameter T_{30m} measured in the cathedrals and the estimation of the subjective perception of the reverberation by the listeners. To this end, the statistical analysis is based on the number of hits or recognitions that listeners indicate of the cathedrals according to their reverberation times.

By means of Pearson's non-parametric chi-square test carried out by the SPSS software [24], it has been found that the degree of recognition of the most reverberant cathedral is independent of gender in all spaces regardless of the type of musical or oral stimulus. It is also independent of age and of the existence of knowledge of acoustics, however, the analysis does reveal that there is dependency on the possession of music education when perceiving the first instrumental piece.

The recognition of the most reverberant cathedral, taking into account all pairs of cathedrals or coincidence for their comparison, shows that it depends on female and male vocal stimulus and more weakly on the choral and the first instrumental piece, whereby the biggest discrepancies are observed with the second instrumental piece.

When the recognition of the most reverberant cathedral is analysed for the set of pairs of groups 1 and 3, the results are only significant in Seville-Cadiz: 88% of listeners

can distinguish the most reverberant of the pair, and the second instrumental piece is the piece that most often causes confusion. For the comparison of the signals corresponding to cathedrals of groups 2 and 3, only the results of the Malaga-Cadiz pair are significant, where 78% of the listeners can distinguish the most reverberant of the pair, and the second instrumental piece is again the piece that most often causes confusion. In the recognition of the coincident signals, 60% of the listeners have indicated this in the Cathedral of Murcia, where again the second instrumental piece is the piece that presents the most confusion.

5.2 Section 3

First, the results are presented that were obtained together with the basic statistical analysis based on numerical ratings. In all questions, the order corresponds to the instrumental piece of sonata for flute, the sonata for violin and basso continuo, the female voice, the masculine voice, and finally the choral piece. The variables introduced corresponding to each question (see Table 4) have acronyms: REV for reverberation, INST for the instrumental character, SPE for the spoken word, FE for female sex, MA for male sex, ACU for the acoustic evaluation, and CUN for the capacity of understanding. Figure 5 shows the average values and standard deviations for each variable and in all cathedrals. Cathedrals have been put into order from the shortest to the longest reverberation times. Although the standard deviations vary between 1.5 and 2.5, for the evaluation of the uncertainty in the qualification, the use of the standard error is more suitable, which would stand at a value of less than 0.5 in all cases.

When analysing the results of reverberation, we can observe that all listeners identify the most reverberant cathedral for all stimuli; however, in the remaining cathedrals there is no equality between objective and subjective reverberation. Curiously, the Cathedral of Toledo, with intermediate reverberation times (G2) is chosen by the respondents as the least reverberant in 4 of the 5 stimuli. It seems, therefore, that in this study, values between 4 and 7 seconds for the reverberation time render the sensation of reverberation indistinguishable for listeners. In addition, the perception of reverberation in all cathedrals is less for instrumental pieces than for those spoken pieces, and the reverberation of a female voice is perceived greater than that of the male voice. The reverberation of the three pieces of music is similar in each cathedral.

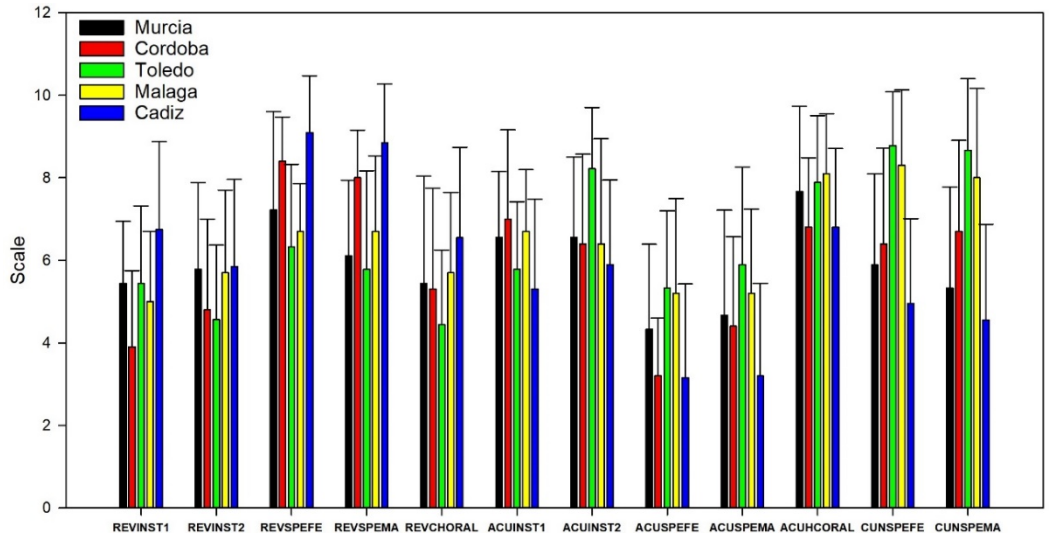

Figure 5. *Qualification of the signals in each cathedral: REV for reverberation, INST for the instrumental character, SPE for the voice, FE for female, MA for male, ACU for acoustic evaluation, and CUN for the capacity of understanding.*

The evaluation of the acoustics again allows all listeners to qualify the Cathedral of Cadiz as the worst rated for all stimuli. The rating varies depending on the pieces, without any consensus at a global level. However, when it is assessed according to the spoken word, the order is uniform. Again the Cathedral of Toledo is recognised as having the best acoustic rate for the spoken word, followed by Malaga, Murcia, Cordoba, and Cadiz. In each cathedral, the acoustics of the instrumental pieces on the one hand, and those of female and male voices on the other hand, are valued in a similar way.

Finally, when studying the comprehension of the oral message, the qualification pattern is repeated for both the female and male voice and the order of preference is very similar to the evaluation of acoustics with a permutation between the cathedrals of Murcia and Cordoba.

In the absence of normality, non-parametric tests study whether, in the various cathedrals, listeners evaluate reverberation, acoustics, and the capacity to understand the voice for the different types of pieces in the same way. To this end, the Kruskal-Wallis H test has been used through the asymptotic significance or the Mann-Whitney U test with the exact significance.

Listeners evaluate the reverberation not only of the sonata for violin and basso continuo in the same way in the various cathedrals, but also of the choral piece. In the remaining cases, the evaluation is dependent on the cathedral analysed. For the evaluation of acoustics, the independence of the enclosure occurs only for the instrumental pieces and the choral piece. In the case of understanding the vocal message, both the female and male cases are totally dependent on the corresponding cathedral.

For each cathedral, we also study whether listeners evaluate the reverberation and acoustics in the musical pieces, (instrumentals and choral) in the same way. This evaluation is then also studied for the set of all five pieces, and finally we study whether listeners evaluate the acoustic reverberation and the comprehension of the oral message for female and male voice signals in the same way.

In general, for the analysed cathedrals, the listeners consider that the variable rating of the reverberation behaves in the same way in all three types of music. For the qualification of acoustics, only Murcia and Toledo behave differently. When the analysis incorporates the five pieces, the reverberation is scored differently in Cadiz and Cordoba. For the acoustic evaluation, however, differs across all cathedrals. Finally, when only the spoken signals are studied, there is a total unanimity of qualification criteria for reverberation, acoustic evaluation, and understanding of the sound message.

6. CONCLUSIONS

Listening tests based on paired comparisons have been employed to investigate the subjective perception of the acoustic environment in highly reverberant large spaces. Seven "Spanish style" cathedrals in the southern half of Spain have been included, covering a wide range of reverberation-time values, from 4.4 s to 8.96 s, at mid-frequencies. The tests were carried out in the listening room of the Acoustics Laboratory of the Applied Physics II Department of the School of Architecture of the University of Seville. Several types of anechoic sound signals (choral pieces, extracts of Baroque instrumental music, and a speech) were auralised with the impulse responses measured in the cathedrals to be used in the tests. Such auralisations were reproduced through headphones, thereby ensuring that all audio signals were perceived at the same level during each test.

The degree of recognition of reverberation in cathedrals is independent of gender in all spaces whatever the type of musical or oral stimuli; it is also independent of age, and of whether the listener has a background in acoustics. The recognition in the most

reverberant cathedral, taking into account all the pairs of cathedrals, shows that it depends on the male and female vocal stimuli and more weakly on the choral piece and on the first instrumental piece, whereby the greatest discrepancies are observed with the second instrumental piece.

When rating reverberation, all listeners identify the most reverberant cathedral for all pieces. However, in the remaining cathedrals, there is no equality between objective and subjective reverberation. Values of between 4 and 7 seconds render the sensation of reverberation indistinguishable for listeners.

The perception of reverberation in all cathedrals is less for instrumental pieces than for those spoken pieces for each cathedral, and the reverberation of the female voice is greater than the male voice. The reverberation of the three pieces of music remains similar in all cathedrals. The participants evaluate the reverberation not only of the sonata for violin and basso continuo in the same way in the different cathedrals, but also the choral piece. In the rest of the cases, the evaluation is dependent on the cathedral analysed. For the acoustic evaluation, the independence of the enclosure occurs only for instrumental pieces and choral music. Furthermore, for the understanding of the vocal message, both female and male cases remain totally dependent on the corresponding cathedral.

The evaluation of acoustics allows all listeners to rate the Cathedral of Cadiz as the one with the most unfavourable acoustics for all the stimuli. The rating varies depending on the pieces, without any consensus at a global level. However, when it is assessed according to the spoken word, the order is uniform. In each cathedral, the acoustics of the instrumental pieces on the one hand and those of female and male voices on the other, are valued in a similar way.

Finally, when studying the comprehension of the oral message, the qualification pattern is repeated for the female and for the male voice, and the order of preference is very similar to that of the evaluation of acoustics. In general, for the cathedrals analysed, listeners indicate that reverberation behaves in the same way in the three types of music. The qualification of acoustics behaves differently only in Murcia and Toledo.

When the analysis incorporates the five pieces, the reverberation is scored differently in Cadiz and Cordoba. The acoustic evaluation, however, differs across all cathedrals. When only the spoken signals are studied, there is a total unanimity of qualification criteria for reverberation, acoustic evaluation, and the understanding of the sound message.

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