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THE SUBJECTIVE INVESTIGATION OF ACOUSTIC PERCEPTION OF MUSICIANS: A PROPOSED METHOD FOR INTERPRETATION OF RESULTS

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ABSTRACT
The paper focuses on the acoustic perception of musicians playing on a stage or in an orchestra pit. The subjective survey tool is a questionnaire, the aim of which is to obtain the 'priority classification' of acoustical attributes describing the acoustics of these spaces. The subjective data were collected by means of a list of subjective attributes; musicians were asked to rank them in order of importance.
The work is focused in assessing the more effective method for data analysis to obtain a reliable interpretation of musicians acoustical attributes priority. In particular, the investigation to choose the most suitable method consists in the application and comparison of two analysis methodologies, the "Condorcet method" and the "Borda count".
The outcome is then the identification of the most important acoustical attributes for the musicians and the assessment of the resolution of their perception. This is a fundamental issue in order to obtain reliable conclusions; the identification of the most important and understood acoustical attributes is, in fact, necessary to carry out a trustworthy subjective survey aimed to a reliable correlation with objective measurements.

INTRODUCTION
This paper deals with the comparison of data elaboration methodologies in order to assess the acoustic perception of musicians. In particular, a preference score was asked to professional musicians with the aim to rank, in order of importance, the most significant acoustical attributes during the music playing. Two professional orchestras, the RAI National Orchestra which plays on the stage of a large concert hall, the "Lingotto" Auditorium in Turin, and the "Teatro Regio" Orchestra which plays in the orchestra pit of the "Teatro Regio" in Turin, participated in the survey. A questionnaire was used to collect the subjective data and interviews were administered to the musicians in order to better interpret the data. The survey consists of a wider research dealing with the musicians' acoustic perception having the final target to find reliable correlation between subjective and objective data [1].

In the field of this topic previous works can be cited, but not yet universal conclusions were achieved. In particular, referring to the identification of the most important acoustical attributes for musicians, A. C. Gade, in 1989, after an interview survey among professional musicians [2], obtained the following relevant subjective aspects in musicians' judgement on room acoustic conditions: 'Reverberance', 'Support', 'Timbre', 'Dynamics', 'Hearing others'', 'Hearing oneself', 'Time delay'. Moreover, based on the subject averaged data corresponding to one "orchestra judgement" for each hall, he found that musicians judge the acoustics primarily in two dimensions: the first is closely connected to all the mentioned aspects except 'Timbre', which comprises the second dimension. The first dimension, associated with an overall quality judgement, was governed by aspects related to early energy when orchestra players are familiar with the halls.

Another study was carried out in 2002 by J. Sanders, Marshall & Day Acoustics [3] that, by means of the correlation between the subjective parameters with ‘Overall Acoustic Impression’, yields to the identification of the better correlated parameters and ordered them in order of significance. The ‘Support’ was considered the most significant acoustical attribute for music playing, followed by the ‘Balance’, the ‘Ensemble’, the ‘Reverberance’, the ‘Visual Impression’ and the ‘Clarity’. A similar approach was used by the Authors in a previous work [4] that yields to slightly different results: ‘Ensemble’ was in Authors’ case the most significant acoustical attribute for musicians, ‘Support’ the second one, followed by ‘Clarity and ‘Dynamics’.

Another paper by L. L. Beranek *et al.* [5] is interesting because it dealt with the ranking of acoustical attributes, even if in a different context: 21 famous directors were asked to rate the acoustics of known opera houses on a scale that had five scores from “poor” to “one of the best”.

The questionnaire used for the present work is a second release after a previous one used in a pilot study as reported in [4]. It is made up of three parts, after an introduction of the topic and the instruction about the filling in. The first part holds the questions about acoustic assessment of the performance space, the second part deals with a ranking list of ten acoustical attributes, where the musicians were asked to number them in order of importance from 1 (the most important) to 10 (the less important), the third part holds open questions with the purpose to check the answers of the other parts.

The questionnaire was anonymous and there were not questions to collect data for the musicians profile description, with the exception of the information concerning the played musical instrument. In this paper only the second part of the questionnaire is analyzed.

Taking into account the previous indications, the acoustical subjective attributes inserted in the list of the second part of the questionnaire were ‘Clarity’ (CLA), ‘Reverberance’ (REV), ‘Ensemble’ (ENS), ‘Dynamics’ (DYN), ‘Sound Envelopment’ (SENV), ‘Sound Strength’ (SS), ‘Tempo’ (TMP), ‘Own Instrument Perception’ (OIP), ‘Tonal Balance’ (TB), ‘Timbre’ (TBR). The musicians were asked, hence, to give a priority order of these acoustical attributes.

ANALYSIS METHODS

In this section two well-known counting methods for subjective data elaboration, giving as results priority classifications, are applied and compared, the “Borda count” [6] and the Condorcet method [7]. These methods were developed at the Science Academy of France with electoral aims and have applications in several fields to process data in which each “voter” declares a preference order of candidates.

Description of methods

The Borda count is named for Jean-Charles de Borda (1733-1799). The method transforms the ranking provided by each voter, given n candidates to choose, into a numerical representation assigning n points to the candidate placed as first, $n-1$ to the second and so on, down to one point to the candidate placed as last. The overall ranking is obtained adding up the points received by each candidate.

The Condorcet method is named for Marquis de Condorcet (1743-1794). Votes are counted by pitting every candidate against every other candidate in a series of imaginary one-on-one contests. The winner of each pairing is the candidate preferred by a majority of voters. When all possible pairings of candidates have been considered, if one candidate beats every other candidate in these contests then he is declared the ‘Condorcet winner’. If this condition is not verified there is no Condorcet winner; then a further criterion must be introduced to find the winner of the election; however in the considered case it was sufficient to notice a draw condition, so the present paper does not deal with such criterion. In order to find the overall ranking, it is necessary to reiterate the algorithm taking away at each iteration the winner determined in the previous iteration.

It would be noticed that the Condorcet method can even drive to contradictions, in fact the principle of the pairs choice can provide distortions because the winner can depend by the order of the pairing; for this reason the Borda count was preferred to Condorcet method by the French

Science Academy. In the present paper, the concept of uncertainty for the considered ordinal data is introduced to choose between the two counting methods, as that one giving a lower uncertainty.

Uncertainty evaluation

In the context of subjective evaluations, at the moment, there are no generally accepted procedures for uncertainty evaluation; the main norm for uncertainty calculation, the ISO GUM [8], does not consider subjective data. Moreover, often the subjective data, as in the presented cases, are few, due to a practical difficulty of replicating the tests. In order to overcome these limits, the Authors propose the use of the statistical method of *bootstrap*, introduced in 1979 by Bradley Efron [9], as a computer-based method for estimating the statistical distribution of a parameter evaluated using a small experimental sample. The method depends on the notion of *bootstrap sample*: being *n* the number of data of the original experimental sample, a bootstrap sample is obtained by *n* extractions with re-draw of the data contained in the original sample. According to the theory proposed by Efron, bootstrap samples simulate samples taken from the same population of the original experimental sample, so, when their number is sufficient, it is possible to perform on the bootstrap samples the calculation of the population parameters.

APPLICATION AND COMPARISON OF THE METHODS

Using the software *MATLAB*®, the Borda count and the Condorcet method were applied to experimental cases, in order to find the more adequate analysis methodology.

With respect to the administrated questionnaires, some of them were not correspondent to the requirements. A part of them were recovered, e.g. when the classification was not given to all the attributes, in a way to give an equal weight to each musician. For the RAI Orchestra a total of 46 questionnaires were distributed, 44 were considered for the analyses, and among these, 29 were as requested and 15 were recovered. For the Teatro Regio Orchestra a total of 46 questionnaires were distributed, 41 were considered and, among these, 33 were as requested and 8 were recovered.

The first case study: the RAI National Orchestra on the “Lingotto” Auditorium stage

Firstly the Borda count was used on data from the judgements of the RAI National Orchestra, getting the overall ranking shown in Table I, where the scores were obtained averaging on the number of musicians, so that the results of different orchestras are also numerically comparable. Afterwards, the bootstrap (100 extractions of bootstrap samples as suggested by Efron [9]), was applied to assess the standard deviation associated with the Borda count. Since, within the scope of this paper, the null hypothesis of normal distribution is generally not refused, the uncertainty value, at the confidence level of 95%, was calculated as two times the relevant standard deviation.

Table I.- Overall ranking obtained with the Borda count for the RAI National Orchestra

	CLA	ENS	OIP	DYN	REV	TBR	TB	SS	TMP	SENV
Totals	7.5	6.7	6.0	5.6	5.4	5.2	5.0	4.8	4.4	4.3
Position	I	II	III	IV	V	VI	VII	VIII	IX	X

The Condorcet method was then applied to the same data, getting another overall ranking shown in Table II. It is possible to observe that the first three positions are equal to that obtained by the Borda count, while REV and DYN positions are inverted, moreover it is possible to state that Condorcet method is not able to resolve positions down of the V. In order to assess the uncertainty associated with the Condorcet method, the same bootstrap samples used for the Borda count, are considered. It must be noticed that the results given by the Condorcet method are poorer, being the information only a sequence, without indication of a mean score. In this case every result has a resolution of 1 over *n*, while the resolution for the Borda count is more than 1 over the number of voting persons, hence the latter is generally more efficient than the Condorcet method. However, to obtain better results with the Condorcet method a weighted Borda ranking was added to the Condorcet analysis to get a better resolution, but it was not sufficient, as can be seen hereafter.

Figure 1 compares the results obtained from the two methods. For the Borda count, it is possible to notice groups of more or less compatible attributes, for which a real difference cannot be set, e.g. a first group containing CLA and ENS, a second group containing REV, DYN and OIP, and a third group including SENV, SS, TMP, TB, and TBR, can be identified. More accurate analysis could be done, taking into account also the compatibility among all acoustical attributes, e.g. OIP can be considered as compatible both with the first group and with other attributes. In this way the misleading conclusion of attributing a real difference to ex-aequo conditions could be avoided. On the other hand, looking to the results of r method, it is evident that a larger uncertainty is present; in this case, it is even difficult to get a rank order among acoustical attributes having very different scores, as CLA and REV.

Table II.- Overall ranking obtained with the Condorcet method for the RAI National Orchestra

	CLA	ENS	OIP	REV	DYN	SENV	SS	TMP	TB	TBR
Position	I	II	III	IV	V	V	V	V	V	V

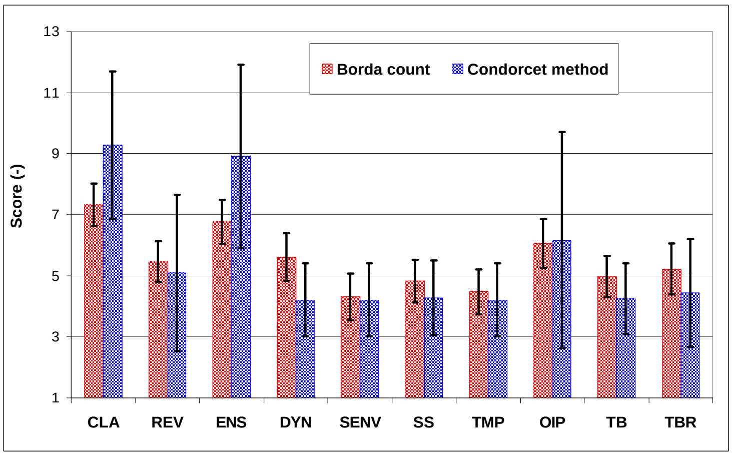

Figure 1.- Comparison of the Borda count and the Condorcet method from RAI National Orchestra preference order, with uncertainty bands.

The uncertainty bands are wider for the Condorcet method, therefore the Borda count is considered better for evaluating a ranking order.

The second case study: the "Teatro Regio" Orchestra in the "Teatro Regio" pit

On the basis of what previously observed, the Borda count was used to analyze the "Teatro Regio" dataset and the bootstrap statistical method was applied to assess the uncertainty associated with this counting method. Table III shows the overall ranking, where the scores were normalized on the number of musicians. Figure 2 shows the results obtained in the case the "Teatro Regio" Orchestra compared with the RAI National Orchestra.

Table III.- Overall ranking obtained with the Borda count for the "Teatro Regio" Orchestra.

	ENS	CLA	TMP	DYN	TBR	OIP	TB	SENV	SS	REV
Totals	8.0	7.2	6.5	5.7	5.3	5.1	4.9	4.6	4.3	3.5
Position	I	II	III	IV	V	VI	VII	VIII	IX	X

The comparison is meaningful only if the uncertainty bands assigned to each evaluation are taken into account, as previously discussed. In this way, in fact, it is clear that the judgments on 'Clarity', 'Dynamics', 'Sound Envelopment', 'Tonal Balance' and 'Timbre' have not significant differences; on the other hand, for 'Sound Strength' and 'Own Instrument Perception' differences are slightly higher, but always not significant, while for 'Reverberance', 'Ensemble' and 'Tempo' differences are really significant.

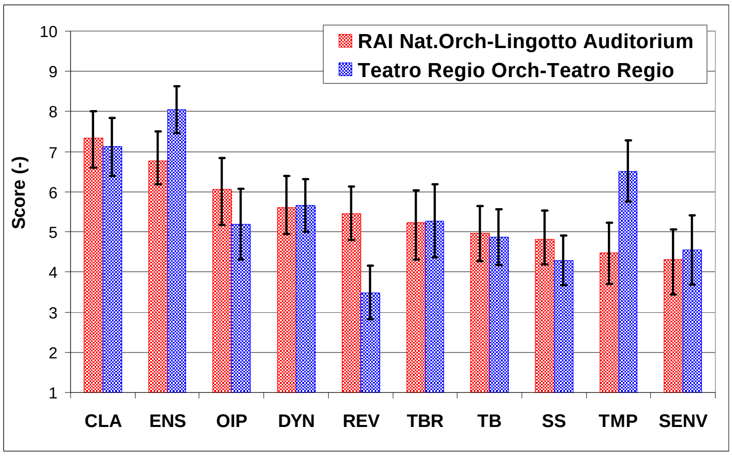

Figure 2.- Comparison with Borda count of the RAI National Orchestra and “Teatro Regio” Orchestra preference order, with uncertainty bands.

DISCUSSION

From the comparison of the two classifications for the RAI National Orchestra and “Teatro Regio” Orchestra, obtained applying the Borda count, as shown in Figure 2, a good accordance exists for the importance assumed for most of the acoustical subjective attributes. ‘Clarity’ and ‘Ensemble’ are the most important aspects, even though ‘Ensemble’ for the “Teatro Regio” Orchestra is much more important than for the RAI National Orchestra. ‘Dynamics’, ‘Timbre’, ‘Tonal Balance’, ‘Sound Strength’ and ‘Sound Envelopment’ have lower priority. On the other hand, ‘Own Instrument Perception’, ‘Reverberance’ and ‘Tempo’ have different importance for the two Orchestras. The first aspect is much more important for the RAI National Orchestra and can be placed together with ‘Clarity’ and ‘Ensemble’, while for the Teatro Regio Orchestra is in secondary position and can be associated with the other attributes.

It is particularly interesting to notice that ‘Reverberance’ has very different scores for the two situations; for the RAI Orchestra is associated with the secondary group, for the ‘Teatro Regio’ Orchestra it can be stated that it takes part of a third separate group, whose importance is inferior to all the other aspects. As far as the attribute ‘Tempo’ is concerned, it can be associated to the second group for the RAI Orchestra, while the ‘Teatro Regio’ Orchestra placed it in the first position together with ‘Clarity’ and ‘Ensemble’.

An attempt to interpret the results can be made considering some information obtained from the interviews with the musicians of the “Teatro Regio” Orchestra and taking into account the different role and performance type concerning the two orchestras. In the case of the orchestra in the pit, probably the synchronism with the singers and some difficulties to see the director, due to the unfavourable disposition of the orchestra in the pit, can explain the notable importance given to some aspects bond with the precision of the execution. The ‘Ensemble’ and the ‘Tempo’ are, in fact, more important for the “Teatro Regio” Orchestra than for the RAI National Orchestra.

On the other hand the different relevance given to the reverberation needs furthers statements. In the pit, the reverberation seems more difficult to be perceived as an important feature of the space, instead on the stage, where the orchestra performance is more relevant, the quality of the hall, given from feature as the reverberation time, can explain the more importance given to this attribute from the musicians.

CONCLUSIONS

A comparison of two data elaboration methods was carried out on subjective scores from two different orchestras about the importance of ten acoustical attributes. The methods adopted were that of Borda and Condorcet, applied on preference priority order of acoustical attributes given by the RAI National Orchestra, playing on the stage of the “Lingotto” Auditorium, and the “Teatro Regio” Orchestra playing in the pit of the “Teatro Regio”.

The Borda count is the more efficient method in order to give reliable results and a better interpretation of the results. The comparison of the different ranking order obtained for the two orchestras can be explained considering some information from the interviews administered to the musicians of the "Teatro Regio" Orchestra and taking into account the different situations for the musicians on the stage and in the pit.

As general result, 'Clarity' and 'Ensemble' are the most important attributes for both the orchestras, followed by 'Dynamics', 'Timbre', 'Tonal Balance', 'Sound Strength' and 'Sound Envelopment', that are shown to be at the same level of importance. Due to the different situations of performance some exceptions have been found. In particular, the orchestra playing in the pit is more concerned with acoustical attributes bond with aspects like the 'Ensemble' and the 'Tempo', placed with 'Clarity' in the same group of importance, probably for more difficulties of synchronism with the singer and to hear each other; on the other hand, 'Reverberance' results the least important aspect. For the orchestra playing on the stage, 'Own Instrument Perception' becomes as important as 'Clarity' and 'Ensemble', while 'Reverberance' can be grouped together with 'Dynamics', 'Timbre', 'Tonal Balance', 'Sound Strength', 'Tempo' and 'Sound Envelopment', probably due to a greatest interest for the quality of the music performance which needs reverberation.

Finally, in order to better understand the results of this work, while the meaning of most of the ten attributes can be easily comprehended by the readers, it is worth to explain the significance of the attribute 'Clarity', as interpreted by musicians. It was described in the questionnaire as the 'capacity to distinct, in a clear way, the music articulation'. As stated from the interviews 'Clarity' has been interpreted as the good articulation of the music played by the orchestra. From this analysis the 'Clarity' is one of the main aspects for the correct performance.

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