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Conference paper | Published version
This version is available at https://doi.org/10.14279/depositonce-8676

Schärer Kalkandjiev, Z.; Weinzierl, Stefan (2018): An Instrument for Measuring the Perception of Room Acoustics from the Perspective of Musicians: The Stage Acoustic Quality Inventory (STAQI). In: Fortschritte der Akustik - DAGA 2018 : 44. Jahrestagung für Akustik, 19.-22. März 2018 in München. Berlin: Deutsche Gesellschaft für Akustik e.V., 2018. pp. 1747–1750.

An Instrument for Measuring the Perception of Room Acoustics from the Perspective of Musicians: The Stage Acoustic Quality Inventory (STAQI)

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Introduction

The sound of a concert hall can be characterised either by technical measurements of room impulse responses and room acoustical parameters [1] or by psychological measurements aiming at perceptual evaluations with questionnaires. In order to cover all relevant facets of room acoustical perception, these questionnaires have to be well-designed.

Some recent attempts were made to develop a comprehensive and empirically substantiated catalogue of perceptual attributes describing the different dimensions of room acoustical impression from the audience perspective [2, 3]. Musicians, however, have a different perspective than the audience since they are not passive listeners but actively produce the sound and interact both with other musicians and with the room acoustical environment [4, 5]. It is thus not the same aspects that play a role for their perception and they often use a very distinct vocabulary to describe them [6].

In an interview study with performers of classical music, the aspects 'reverberance', 'support', 'timbre', 'dynamics', 'hearing each other' and 'time delay' were named by the musicians as important room acoustical properties [7]. 'Making harmony', i.e. the blending of instruments, was described as essential aspect in an interview with chamber musicians [8]. In other questionnaire studies conducted with musicians, further aspects were added to the items suggested in [7] by the researches, among others: 'hearing oneself', 'ease of ensemble', 'clarity', 'balance', 'warmth' and 'overall acoustic impression (OAI)' [9, 10, 11, 12, 13]. The importance of the questionnaire attributes was investigated by correlating their ratings with the ratings of the 'OAI'. This showed that 'support', 'hearing others/ensemble playing' and 'reverberance' were relevant for the quality judgments of concert halls by musicians [11, 12, 13]. Based on several studies conducted with orchestras, an extensive list of room acoustical aspects that should be taken into account when conducting questionnaire studies with musicians was proposed in [14].

Using attributes defined by researchers in questionnaires involves two potential problems: Firstly, the items might not be relevant for the participants or important ones might be overlooked. Secondly, the participants might misinterpret the meaning of the items. We therefore developed the Stage Acoustic Quality Inventory (STAQI) as a psychological measurement instrument for the perceptual evaluation of room acoustical environments by musicians. It is intended to serve as a questionnaire with items that are relevant for and can be well understood by musicians. The development of the STAQI involved two parts that are outlined in the following sections.

Elicitation of attributes

The first part of the study was dedicated to the elicitation of terms that are commonly used by musicians to describe room acoustics. Two experiments were conducted in a fully anechoic chamber: The participants of the first experiment were solo players of six standard orchestral instruments covering different registers: violin, cello, oboe, bassoon, trumpet and trombone. The second experiment was conducted with a string quartet and a trumpet quartet. In both experiments, the players were recorded with microphones (Sennheiser MKE 1 for soloists and Sennheiser MKE 40 for ensembles) attached directly to the instruments. The recordings were used as input signal for the simulation of six room acoustical environments by means of dynamic binaural synthesis. The auralisations were presented to the musicians via extraaural headphones (AKG K1000) while only the room response and not the direct sound was simulated since the musicians heard their instruments directly in the anechoic chamber. The simulated rooms were based on computer models of six typical concert venues for Western classical music: two chamber music halls, two concert halls, a baroque church and an opera (see Figure 1). The receivers in the computer models were placed at a frontal and central stage position and the sources were arranged at positions typical for the respective instrument relative to each receiver. Binaural room impulse responses were generated as described in [5] and [15], using sources with the directivity of the instruments played in the experiments [16, 17].

The method used for eliciting room acoustical attributes in these experiments was the repertory grid technique (RGT). In this qualitative procedure, pairs of elements were randomly drawn from the stimulus pool of six simulated rooms and the test subjects were asked to play excerpts of two self-chosen pieces with different musical character in both of them. They were then asked to describe differences and similarities between the two concert spaces with respect to room acoustical properties. In case of the solo musicians, the experimenter directly notated the attributes (including positive and negative poles) named by the performers. In case of the ensemble musicians, a group discussion among the players took place before they agreed on certain terms that they all regarded as suitable to characterise the rooms. This procedure was repeated until all 15 combinations of stimulus pairs had been presented to the musicians. The RGT experiments resulted in 145 terms that could be reduced to a list of 65 German attributes describing room acoustics from the perspective of musicians after eliminating identical and obviously redundant terms.

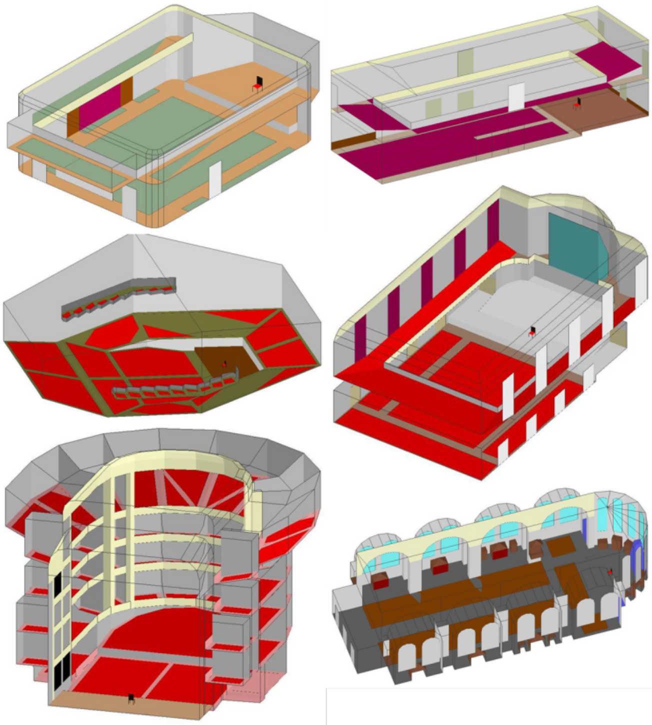

Figure 1: Computer models of six typical concert venues for Western classical music used for the dynamic binaural simulation in the RGT experiments with solo and ensemble musicians. Clockwise from bottom left: Opera, concert hall 1, chamber hall 1, chamber hall 2, concert hall 2, baroque church.

Questionnaire development

The number of terms resulting from the RGT procedure was too large to be used in a questionnaire. Furthermore, the correct understanding of the attributes needed to be validated by a second group of musicians. For this purpose, an online-study was conducted with 240 professional musicians and singers (153 male, 85 female, 2 without assignment; average age: 44 years; average experience: 23 years) performing in orchestras (63%), as soloists (13%), in chamber ensembles (12%), choirs (10%) or big bands (2%) and playing 21 different instruments. In the first part of the questionnaire the musicians were asked to select at least 20 from the list of 65 terms that they regarded as relevant for the description of a room acoustical surrounding. In the second part they were asked to rate the concert hall they had last played in using the chosen attributes.

Table 1 shows the attributes that were chosen by at least 50% of the participants. As recommended for the development of psychological scales [18], the rating data of these 22 items were analysed in two steps using the MPlus 7 Software Package [19]. First, an exploratory factor analysis (EFA) with robust maximum likelihood (MLR) estimation and orthogonal CF-varimax rotation was conducted to determine the basic factor structure of the data. Here, missing values were estimated by means of regression imputation [20] using demographic data and the ratings of those two items showing the highest correlation with the item in question as predictors. In a second step, the ratings were subjected to a confirmatory factor analyses (CFA) with MLR-estimation using the factor structure determined in the EFA. The aim was to confirm and assess the extracted body of terms as measurement instrument that can be generally used for the perceptual evaluation of stage acoustics and to understand the underlying perceptual dimensions.

Table 1: Room acoustical attributes regarded as relevant by at least 50% of the 240 participants in German and English (translated by four native-English speaking musicians).

1	Halligkeit: trocken – hallig	Reverberance: dry – reverberant	88.10%
2	Die Mitspieler hören: schlecht – gut	Hearing others: badly – well	87.30%
3	Sich selbst hören: schlecht – gut	Hearing oneself: badly – well	86.11%
4	Nachhall: wenig – viel	Amount of reverberation: little – a lot	78.57%
5	Dauer des Nachhalls: kurz – lang	Duration of reverberation: short – long	78.17%
6	Zusammenspiel: schwer – leicht	Ease of ensemble playing: difficult – easy	77.38%
7	Transparenz: schwammig – klar	Transparency: muddy – clear	71.03%
8	Eignung für Besetzung: ungeeignet – geeignet	Suitability: unsuitable – suitable	67.46%
9	Qualität: schlechte Akustik – gute Akustik	Quality: bad acoustics – good acoustics	67.06%
10	Klangfarbe: dumpf – brillant	Tone colour: dull – bright	67.06%
11	Tragfähigkeit: weniger tragend – tragend	Projection: does not carry – carries	62.30%
12	Mischung der Instrumente: breiig – transparent	Blending of instruments: soupy – transparent	59.52%
13	Charakter: studioartig – krichenartig	Character: studio-like – church-like	57.94%
14	Wohlbefinden: unangenehm – angenehm	Comfort: uncomfortable – comfortable	57.14%
15	Resonanz: wenig – viel	Resonance: little – a lot	56.35%
16	Raumgröße: klein – groß	Room size: small – large	55.95%
17	Spielgefühl: schlecht – gut	Feeling of playing: bad – good	54.37%
18	Basslastigkeit: weniger Bass – mehr Bass	Low end: bassy – not bassy	53.57%
19	Spielfreude: macht keine Freude – macht Freude	Enjoyment: not enjoyable – enjoyable	53.17%
20	Raumantwort: schluckend – verstärkend	Room response: dead – live	52.78%
21	Klangfarbe: matt – obertonreich	Tone colour: dull – rich in overtones	52.38%
22	Raumhöhe: niedrig – hoch	Room height: low – high	51.98%

The EFA yielded a 5-factor solution according to the Kaiser criterion and four items (no. 2, 3, 10 and 18, see Table 1) were eliminated due to minor loadings (<0.5). Surprisingly, two items with high relevance ratings, 'Hearing others' and 'Hearing oneself', did not contribute clearly to any of the EFA factors. The reason for this might be that the ratings on these two items were very diverse since they strongly depend on the own and the other instruments as well as the position on stage.

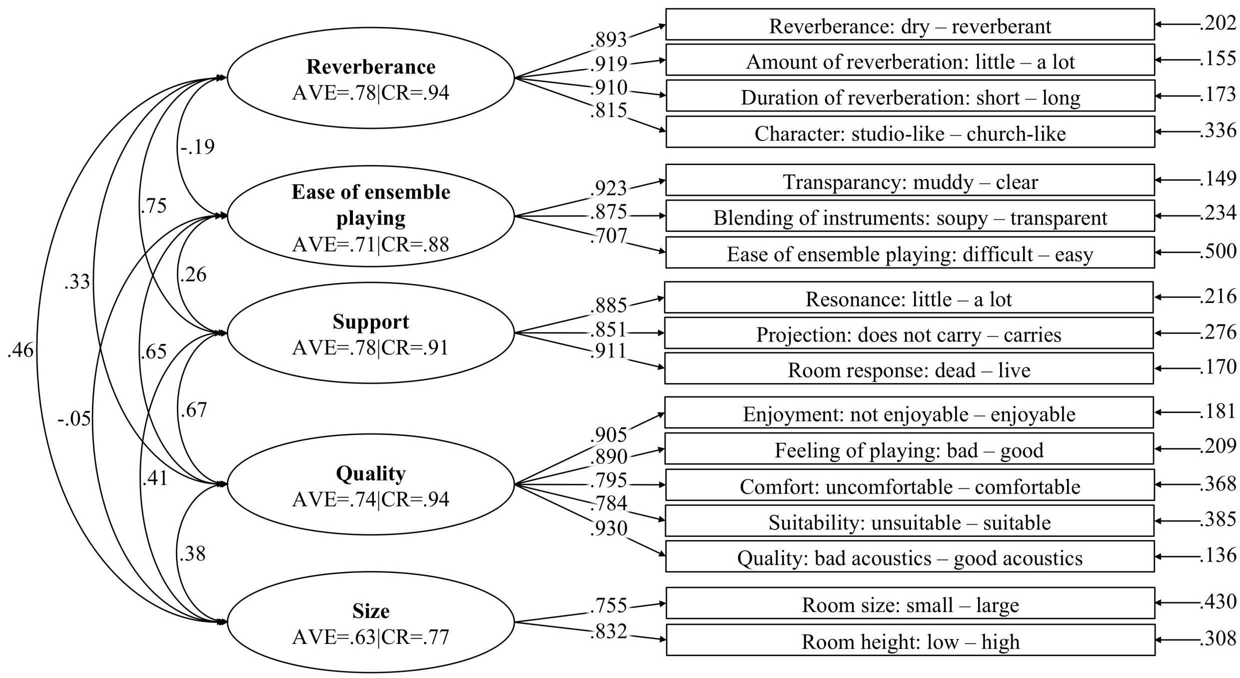

Figure 2: The Stage Acoustic Quality Inventory (STAQI) as measurement instrument. Far left arrows: correlations between factors; ovals: factor names with average variance explained (AVE) and congeneric reliability (CR); middle arrows: items loadings; boxes: items; far right arrows: item error variances.

The CFA led to a well fitting model with 17 items and five factors, which can be interpreted as *Reverberance, Ease of Ensemble Playing, Support, Quality* and *Size.* According to [21], the calculated fit indices were all above the respective threshold for a good fit ($\chi^2 = 157.341$, $df = 109$, $p < 0.01$; $RMSEA = 0.043$; $CFI = 0.967$; $SRMR = 0.064$). Figure 2 shows the factor measurement model with standardized item loadings and error variances for each item, correlations between factors, average variance explained (AVE) and congeneric reliability (CR) for each factor. The CR is a measure for the ability of a group of items to represent the meaning of a construct and was quite high for all five factors.

The first three items of the *Reverberance* factor in Figure 2 are similar to those found in audience questionnaires [3]. The fourth item (‘Character: studio-like – church-like’), however, is clearly musician-specific and strongly related to their practical experience. It is one of the items in the STAQI that accentuate the importance of a musician-orientated vocabulary. *Ease of ensemble playing* and *Support* have been named as important stage acoustical aspects in previous studies (see above). In this study they appear as constructs determined by several items each (see Figure 2), allowing for a more differentiated view on these properties. Apart from the item aimed at an overall evaluation (‘Quality: bad acoustics – good acoustics’), the *Quality* factor is determined by four items that are strongly focused on the subjective experience of the performers, again confirming the specificity of their vocabulary. Even though *Size* is not strictly speaking an acoustical property, the auditory extension of a concert space seems to be a crucial aspect for musicians.

Discussion and outlook

In this paper a psychological measurement instrument intended for the evaluation of stage acoustics by musicians was proposed. The use of comprehensive, relevant and understandable questionnaires is essential when it comes to investigating the perception of stage acoustics and the interrelation with physical parameters. A qualitative elicitation process with musicians in simulated acoustical environments yielded 65 attributes describing room acoustic qualities. These were proposed to a large group of musicians who rated their relevance and used them for a room acoustical evaluation. The result of an exploratory and confirmatory factor analysis with these ratings was a list of 17 items describing room acoustical properties with 5 underlying dimensions. The number of factors is remarkable since previous studies have revealed not more than two dimensions based on data collected from orchestra musicians [9]. These studies, however, used considerably less questionnaire items as well as a much lower variance in room acoustical conditions, which emphasises that the whole perceptual space needs to be covered by a questionnaire in order to collect meaningful data.

The quality inventory proposed in this paper will be verified by presenting an identical group of concert halls as stimuli to a sample of musicians to enable the computation of quality criteria characterising the consistency, difficulty and discrimination of the items. Furthermore, stage acoustical parameters can be developed in order to predict the items of the STAQI, enabling a more target-oriented design of room acoustical environments from the musicians’ perspective.

Acknowledgement

This research was funded by the German Research Foundation (DFG WE 4057/9-1). The authors wish to thank the musicians who participated in the experiments for their time and effort and they thank their colleague Dr. Steffen Lepa for his valuable advice on statistical issues.

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