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Impact of architectural variables on acoustic perception in concert halls

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A B S T R A C T

Acoustic perception in concert halls has been a topic of research of great interest over the last century. It has been studied through physical and subjective parameters. Nevertheless, a concert in an auditorium is a multi-sensorial experience; so that the acoustic perception may be influenced by other non-acoustical attributes. Therefore, the aim of the present study was to analyze whether architectural variables (visual component) affect acoustic perception in concert halls and quantify this influence. This analysis was carried out implementing the Semantic Differential method and differentiating among experts and non-experts users. A total of 310 subjects assessed *in situ* 17 concert halls. Results showed that acoustic perception was influenced by the visual component, and acoustic parameters had an influence on architecture as well. However, when separating both groups, it was found that experts were able to isolate acoustic variables from architecture when evaluating the sound quality of a venue.

1. Introduction

Acoustic perception in concert halls (opera houses, theatres and venues for classical music and orchestra performances) has been a topic of great interest for many years (Barron, 1988; Beranek, 1962; Cerdá, Giménez, Romero, Cibrián, & Miralles, 2009; Hidaka & Beranek, 2000). At a certain moment, it was thought that only one parameter was able to explain the acoustic quality of a music hall: the reverberation time (Sabine, 1922). However, later on, researchers came to realize that other physical parameters also influenced acoustic perception such as early decay time (Jordán, 1981); initial time delay gap (Fischetti, Hemim, & Jouhaneau, 1992); spatial impression (Schroeder, Atal, Sessler, & West, 1966); clarity factors (Reichardt, Abel Alim, & Schmidt, 1975); gain factor (Soulodre & John Bradley, 1995) and interaural cross-correlation (Ando, 1983); among others.

Some studies began to relate all these physical parameters to human response and the subjective evaluation they evoke in the listener: intimacy, enveloping sound, clarity, loudness, balance and warmth (Farina, 2001; Fischetti et al., 1992; Giménez, Cibrián, Cerdá, Girón, & Zamarreño, 2014; Soulodre & Bradley, 1995). This fostered the development of psychoacoustics, a new branch which studies acoustic subjective perception. Nevertheless, attending a concert in a music hall is a multi-sensorial experience (Beranek, 1962; Semidor & Barlet, 2000; Tokunaga, Okuie, & Terashima, 2013). This means that many variables may influence concertgoer perception besides acoustics; such as the visual component, temperature, lighting, comfort, or the architecture of the venue. In addition, attending a concert in an emblematic and prestigious auditorium may exert a power of positive suggestion on the audience, even if the acoustics are not excellent: "Acoustics are a bit disappointing but "La Scala" has a great atmosphere and this distracts from the objective perception of acoustics …. testimony of a conductor" (Hidaka & Beranek, 2000). Following this reasoning, a poor environment may cause a negative impact on acoustics perception, even if the sound quality of the concert hall is good.

In this line, several studies have analyzed the influence of non-acoustical parameters on users' assessments of auditoria (Beranek, 1962; Hawkes & Douglas, 1971; Semidor & Barlet, 2000). Other studies specifically examined the influence of the visual component in sound perception. Through photographs and sound recordings, Cabrera and collaborators (Cabrera, Nguyen & Ji, 2004), collected the assessments of two auditoria. They used variables previously defined by experts. The results showed that space perception in vision and audition differ because of the physical characteristics of

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light and sound, their different interactions with the physical environment, differences between the sensory organs of the two modalities, and differences in the neural processing and cognition of these modes. Tokunaga and collaborators (Tokunaga et al., 2013) conducted a similar study in which an auditorium was assessed through interior photographs and videos of playing music. The results showed significant relationships between the items "reverberance" and "ceiling height" and between "loudness" and "distance perspective". In another line, various authors analyzed the relationship between visual and auditive components for the purpose of identifying the optimum location of users in a room. Jeon and collaborators (Jeon, Kim, Cabrera, & Bassett, 2008) studied the relationship between both components in an auditorium. In their study, participants assessed first the visual dimension from photographs, and then the auditive dimension through recordings. The results showed a positive relationship between the visual and auditive component with greater impact of the auditive dimension on the choice of place. Then, Kawase (2013) in an experiment with professional and non professional musicians reached a different conclusion, identifying the visual factor as having a greater impact on the choice of location in the room, for both groups of individuals. The experience used the seat map of the hall to be assessed as stimulus and a questionnaire elaborated by the author beforehand. Platz and Kopiez (2012) also conducted a remarkable research. These authors performed a meta-analysis of 15 aggregated studies on audiovisual music perception in order to quantify the influence of the visual component on the evaluation of music performance. The authors concluded that the visual component was not a marginal phenomenon in music perception, but an important factor in the communication of meaning.

However, these works did not evaluate the interaction of both dimensions on a live performance. Furthermore, in most studies the questionnaires were built from concepts and expressions previously defined by experts, and these may not represent the conceptual scheme of the users themselves.

Thus, the main objective of the present proposal is to analyze the effect of architectural attributes on the acoustic assessment of concert halls in a real environment, previously identifying the affective significance of concepts defined by the users themselves.

On the other hand, many works have studied concertgoers' subjective responses through questionnaires and tests to evaluate the acoustic quality of music halls. Some of these experiences have analyzed for many years the response of expert users such as professional musicians, acousticians and conductors (Barron, 1988; Beranek, 1962; Farina, 2001; Hidaka & Beranek, 2000). Other studies focused on the response of non-expert users (Chiang & Wang, 2002; Semidor & Barlet, 2000); while other researchers have analyzed both collectives (Galiana, Llinares, & Page, 2012; Möller, Vehviläinen, Tishko, Wulfrank, & Rozanov, 2010). Besides, several studies proved that professional musicians respond in a different way to acoustic stimuli from non-musicians (Brandler & Rammsayer, 2003; Koelsch, Schröger & Tervaniemi, 1999; Kim & Belkin, 2002; Münte, Altenmüller, & Jäncke, 2002; Ohnishi et al., 2001). Ohnishi and collaborators (2001) examined the cerebral activity pattern associated with musical perception in musicians and non-musicians. While musicians showed a left dominant secondary auditory areas during a passive music listening task, the non-musicians demonstrated right dominant secondary auditory areas during the same task. The results indicated distinct neural activity in the auditory association areas. This fact revealed that the brain of both groups of subjects worked in a different way and therefore they presented differences in perception. Following this line, Koelsch et al. (1999) measured the brain activity of two different groups (musicians and non-musicians) in response to acoustic stimuli. Their study revealed that compared to non-musicians, musicians were superior in pre-attentively extracting more information out of musically relevant stimuli. Results also indicated that sensory memory mechanisms could be modulated by training. Münte et al. (2002) investigated plastic changes in the brain of professional musicians by using neuroimaging methods. The authors detected anatomical differences regarding the brain of non-musicians. Furthermore, the work carried out by Brandler and Rammsayer (2003) compared psychometric performance on different aspects of primary mental abilities in musicians and non-musicians. They found that while performance on verbal memory was reliably higher for the musicians, non-musicians performed significantly better in other fields. This fact confirmed that the brain of both groups of subjects worked in a different way. Kim and Belkin (2002) investigated how people (particularly non-music experts) perceive music. For the study, participants had to assess several classical musical pieces. They observed that this collective never used words related to formal features of music, rather using words indicating other features, most of which have not been considered in existing or proposed music Information Retrieval systems (IR). Therefore, these authors concluded that music IR research should be extended to consider needs other than finding known items, or items identified by formal characteristics, and that understanding music information needs of users should be prioritized. This fact links with the need to consider the mental scheme of the users (experts in a field or otherwise). As experts filter the information to assess, some of the parameters appreciated by non-experts may never be evaluated. These specific drawbacks can be offset by techniques such as the Semantic Differential method (SD).

SD is a tool that allows the subjective response of concepts to be measured. It was developed by Osgood, Suci, and Tannenbaum (1957) to analyze semantic structures and to quantify the affective meaning of things. This method studies product semantics by means of adjectives and expressions which reflect users' impressions and measures users' perception on a Likert scale. It is a standard procedure that assumes an underlying structure in the semantic evaluation of products which it analyses using principal components factor analysis (PCA).

In a previous work, Galiana et al. (2012) used this technique to study differences between experts and non experts' assessments of acoustic quality in concert halls. This study found significant differences in the affective response of both groups. In the present study, using the same concert halls, the authors include a further step by introducing the variables which reflect acoustic quality the set of architectural variables together and analyze their interaction.

In this line, some researchers have also used SD in order to investigate the interaction between visual and auditory information (Kuwano, Namba, Komatsu, Kato, & Hayashi, 2001; Tokunaga, Terashima, & Ishikawa, 2014). These works used assessment variables defined in prior studies or by experts. This approach has the limitation of not including the users' criteria, so that the concepts used may not correspond to the users' conceptual scheme. In this line, the present work applies SD in the field of concert halls, based on expressions from users themselves.

This paper aims to analyze the relation between acoustic and architectural variables in concert halls from a perceptual point of view. This analysis uses the SD method. The main contribution in comparison to previous studies is the joint analysis of acoustic and architectural variables from the initial stage, so that by identifying the users' conceptual structure both types of variables are taken into account. The analysis differentiates between experts and non-experts. This will enable us to determine whether the interaction between acoustics and architecture perception occurs in both groups, or whether the collective of experts is able to isolate acoustic perception from architecture.