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A laboratory study on the evaluation of soundscape

A. Ozcevik and Z. Yuksel Can

Yildiz Technical University, Faculty of Architecture, Yildiz Technical, University, Besiktas,
+90 34349 Istanbul, Turkey
asliozcevik@hotmail.com

This study is the second part of a research on a new approach for the evaluation of soundscape. In a previous paper, a field study of subjective evaluation through a survey form consisting of two parts (a questionnaire and a semantic differential test) was introduced. This part of the study aims to obtain proper data decided for using to assess if the subjective evaluation of soundscapes in laboratory environment is consistent with the data obtained from the field study. The research has three steps; preparing the recordings, calculating the sound quality metrics and realizing the laboratory study. The sound recordings are obtained by the soundwalk method at the previous areas. The original recordings, which lasted approximately 15 minutes, are edited to reduce the duration to 5 minutes to suit the laboratory tests. Sound quality metrics; loudness, sharpness, roughness and fluctuation strength, are chosen accordingly to both the pilot study and the soundscape literature. The laboratory study consisted of jury tests and listening tests. Data held from the laboratory study is statistically analyzed to attain the subjective evaluation of soundscapes. The information obtained from this study will be used in the next stage which is the comparative analysis between the field and the laboratory studies.

1 Introduction

Soundscape, as is used for urban noise, is basically a qualitative approach aiming to reach clues to improve the "sonic environment".

The aim of soundscape studies is to describe the global acoustic ambiences. Consequently it is suggested to realise the determinations, analysis, evaluations, applications and interventions about the sound environment according to the acoustical satisfaction of citizens. Several soundscape researches are developed to determine the sound sources and sound environments defined as satisfactory and needed to be preserved for acoustical identity; to introduce the sounds that have to be contended with; to define and standardize the intervention techniques, by using different methods. The review of these methods shows that soundscape studies are proceeding to technically analyzing the sound environments from merely documenting them.

Soundscape concept treats the sound environment as a multi-dimensional entity, based on the complex interaction between sound source, physical environment and human being. Derivations of objective and subjective data from field and laboratory studies, and attempts of correlating these data, are the common features of the soundscape studies. The flow diagram (Figure 1) held after a widespread examination of soundscape literature summarizes the main scheme of soundscape studies.

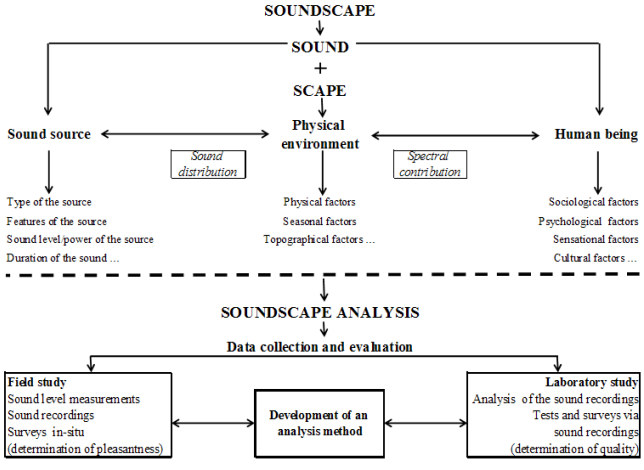


Figure 1. The complex interaction among sound source, physical environment and human being, at the soundscape researches

The review of the related literature shows that there are mainly three methods utilized to obtain subjective data; surveys at different types, interviews with citizens and various tests. Objective data used to be limited with sound level measurements and sound recordings is recently enlarged to cover the sound quality concept and the sound quality metrics.

This paper is about the second part of a wide-frame research aiming to develop a new approach for the evaluation of soundscape. In a previous paper, a field study of subjective evaluation through a survey form consisting of two parts (a questionnaire and a semantic differential test) and the objective data held from the area measurements achieved by soundwalk method (realized in four areas) was presented [1].

This part of the study aims to obtain proper data to be assessed if the subjective evaluation of soundscapes in laboratory environment is consistent with the data obtained from the field study. The research has three steps; preparing the recordings derived from the field study revealed at the previous areas, calculating the sound quality metrics (loudness, sharpness, roughness and fluctuation strength), and realizing the laboratory study (jury tests and listening tests).

2 Sound quality and the metrics

The term of 'sound quality', introduced in the 1980s, is defined as 'the adequacy of a sound in the context of a specific technical goal and/or task' [2].

Sound quality is not an inherent property of the sound. It is rather something that develops when listeners are exposed to the sound and judge it with respect to their desires and/or expectations in a given context.

Consequently, the usage of noise indicators such as SPL or L_{Aeq} is not sufficient to define the sound quality, in other words quantitative/objective data derived by the current indicators describing the sound environment is insufficient. Therefore psycho-acoustics and physical manner of the humans experiencing the sound environment are taken into consideration. It is thus expected to analyze how a person perceives a sound. In this way, the attributes of the sound that can be calculated and/or measured and the responses of the listener to the sound are considered respectively as the objective and subjective dimensions of the sound [3].

Sound quality metrics alias psycho-acoustic parameters/quantities, mostly improved by Zwicker [4], are defined as the mathematical model of sound perception. The applicability of these metrics in sound quality evaluation has been successfully proved. The metrics which are commonly used in the researches can be listed as; Zwicker loudness, sharpness, roughness, fluctuation strength, tone-to-noise ratio and prominence ratio. All metrics refer a specific attribute of the sound by a single scalar quantity; **loudness** is linearly proportional to SPL;

sharpness can be regarded as a measure of tone colour; **roughness** is governed by temporal variations of a sound and reaches a maximum for modulation frequencies around 70 Hz; **fluctuation strength** deals with the modulation frequencies around 4 Hz; **tone-to-noise ratio** regards if the pure tone is dominant or not; **prominence ratio** indicates the prominence of tonal components of the sound.

The subjective evaluation of sound quality is obtained by the jury and listening tests. Sound quality concept, is generally being used for stable/stationary signals e.g., in an industrial product, for mechanical sound sources. On the other hand the increased usage of sound quality concept for the evaluation of urban sound environment is observed in recently published and ongoing researches [5 - 17].

3 Laboratory study

The laboratory study has been carried out to investigate the subjective understanding of the areas including the subjects' evaluation of physical and psycho-acoustical perception of the records and the objective analysis of the records by utilizing the technically and statistically feasible software. Therefore, firstly the original sound recordings which lasted approximately 15 minutes and obtained by the soundwalk method at the previous areas (Beşiktaş and Ortaköy Pier Squares, Bağdat Street and Barbaros Boulevard), are edited to suit the laboratory tests. Then the sound quality metrics are calculated by using software, and finally jury and listening tests are realized by using the edited recordings. The appropriate and accurate re-organisation of the 15 minutes sound recordings is of utmost importance for the reliability and repeatability of the research. The issues which are considered and the steps of the re-organisation of the sound recordings are as follows;

- Short time average is preferred for the analysis of the fluctuating sound environment, instead of long time average.
- The usage of short time segments is preferred for laboratory tests instead of the original recordings (15 min), in order to avoid the subjects' distractions and to ensure the subjects' concentration.
- The hypothesis of the mentioned wide-frame research is that "soundscape quality may be judged depending on its components (keynotes, signals, soundmarks), and the perceptibility of the soundmark may be an important factor on the evaluation". Depending on this, two different 5 minutes' periods of each recording are decided to be utilized for the study; one is "**continuous 5 minutes' period**" which is selected according to the continuous segment having complete auditory data of sound environment, especially predicted soundmark/s of related urban area; the other is "**edited 5 minutes' period**" which is arranged by 'Wavepad Sound Editor' software considering the segments having only the predicted soundmark/s.
- Several pilot studies were actualized to inquire the attempt of using two different 5 minutes' periods. According to the findings of the pilot studies, it is realized that there is no differences between the subjective evaluations of two periods selected from the same sound environment, moreover, they are assessed as belonging to the same recordings by the subjects. Therefore, the "**edited 5 minutes' period**" is selected to analyze for both subjective and objective evaluations of the sound environments in laboratory study.
- Nine sound segments prepared through the division of the 15 minutes' period into 3 minutes with 1,5 minutes overlap by using 'Wavepad Sound Editor' software (0-3 min., 1.30-4.30 min., 3-6 min., 4.30-7.30 min., 6-9 min., 7.30-10.30 min., 9-12 min., 10.30-13.30 min., and 12-15 min.), are decided to be used separately for objective evaluations in order to verify if the edited 5 minutes' period reflects the whole recording.
- Instantaneous changes in sound level are decided to be evaluated due to the fact that the sound is fluctuating in time. In the laboratory study the objective evaluation is realised through statistical calculations depending on the relevant literature [17 - 19].

It is obvious that the "edited 5 minutes' samples has to be analyzed in order to confirm their quantitative and qualitative accuracy regarding the actual sound environment. Statistical calculations of the sound quality metrics for the edited 5 minutes' period, and the selection of nine sound segments each having 3 minutes' period utilized for the quantitative confirmation are explained in the following section. The comparative analysis between the on-site survey and the laboratory tests (jury and listening tests) realised for the qualitative confirmation will be presented in another paper.

The study areas L_{Aeq} levels of the edited 5 minutes' periods together with the average levels of nine sound segments each having 3 minutes' period and their standard deviations are given in Table 1. Data reported in Table shows that the L_{Aeq} levels of the edited 5 minutes' periods and the average levels of nine 3 minutes' periods are considerably close to each other.

Table 1. L_{Aeq} levels of the edited 5 minutes' periods and the average L_{Aeq} levels of nine sound segments each having 3 minutes' period with their standard deviations

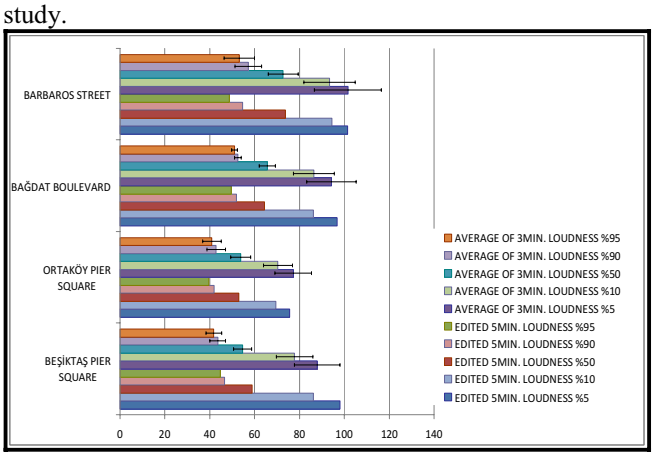
Study areas	L_{Aeq} levels		
	Edited 5min. period	**Average of nine 3min. periods**	**Std. dev. of 3min. periods**
Beşiktaş Pier Square	**84.85**	82.55	1.27
Ortaköy Pier Square	**84.19**	82.44	1.88
Bağdat Street	**83.96**	84.15	1.35
Barbaros Boulevard	**86.26**	85.86	2.15

3.1 Analyses of sound quality metrics

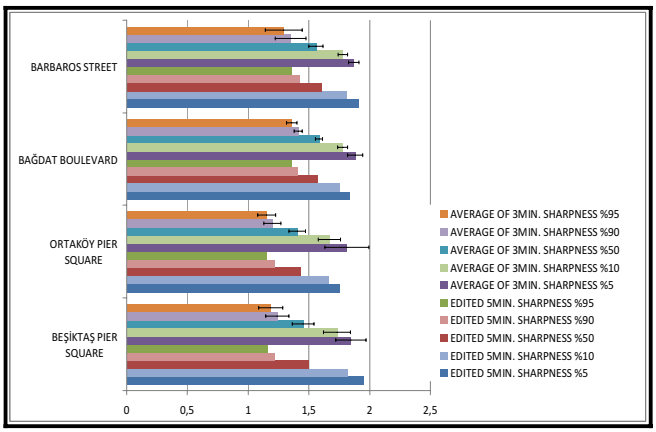
The edited 5 minutes' periods and the nine sound segments each having 3 minutes' period are transferred to sound quality software 'B&K PULSE Sound Quality', to determine the sound environment quality of the selected areas via the sound quality metrics. The instantaneous values of six sound quality metrics regarding to the edited sound recordings are calculated by the software; however, only four metrics (Zwicker loudness, sharpness, roughness and fluctuation strength) which refer significant results, are selected to be used for this study. The results of statistical calculations are also taken into consideration. The ratios used for these calculations are determined as %5 or %10, %50, and %90 or %95 which respectively imply the

exceptional events, the possible state and the continuous state.

Statistical values of the metrics which are calculated for the edited 5 minutes' period are compared with the average values for the nine 3 minutes' periods, concerning the areas. The graphs seen in Figure 1 shows that the values of the metrics for the edited 5 minutes' periods are in the standard deviations interval of the related metrics for the nine 3 minutes' periods meaning that the edited 5 minutes' period samples are quantitatively accurate. The statistical values of the metrics related to mentioned recordings are used in the study.



ZWICKER LOUDNESS



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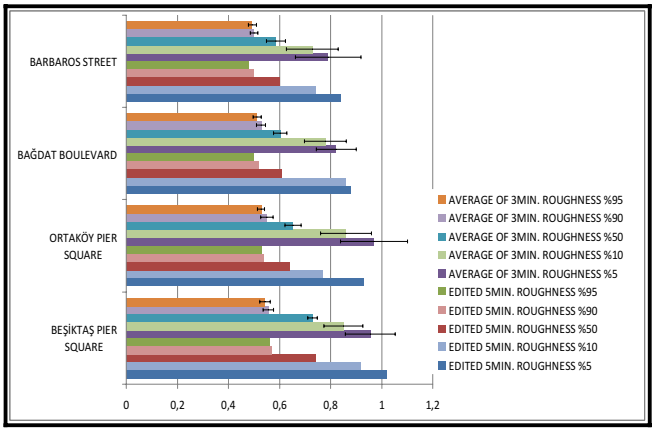
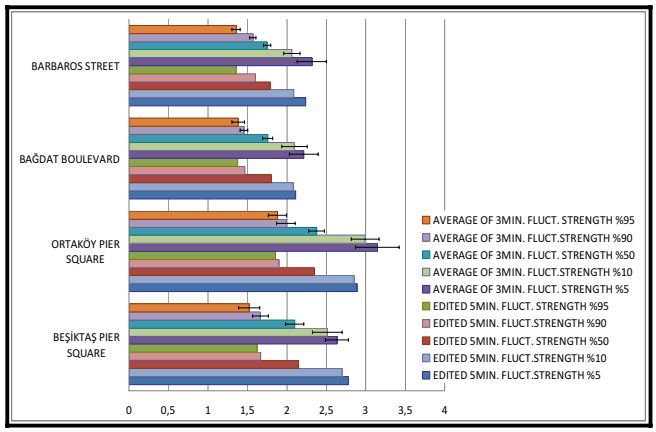


ROUGHNESS



FLUCTUATION STRENGTH

Figure 1. Graphs showing the statistical values of the sound quality metrics (Zwicker loudness, sharpness, roughness and fluctuation strength) calculated for the edited 5 minutes' period together with the average values for the nine 3 minutes' periods and their standard deviations, concerning the areas.

3.2 Jury and listening tests

30 subjects who don't have hearing bias, listened the edited 5 minutes' period samples of the areas at designated array; Bağdat Street – Beşiktaş Pier Square – Barbaros Boulevard – Ortaköy Pier Square, by using headphones with active noise control. No information about the recordings is given to the subjects; they are requested to do the listening and the jury tests. For each area, each of the tests is done under controlled conditions in order to achieve 120 subjective evaluations of the related sound environments. Consequently, the proper subjective data, displaying the qualitative accuracy of the edited 5 minutes' samples to be used in the laboratory study, is obtained.

Jury test: 30 pairs of adjectives listed in Table 2, which the selection procedure was explained in the previous paper [1], are utilized to examine the quality of sound environment in jury test.

Listening test: Subjects are asked to write down what they heard in free technique, and they are requested to explain the recording's area, to make estimation of the area and to define the sound sources.

4 Data analysis

Subjective data held from the laboratory study which is realized in four areas, is analyzed by using statistical software SPSS 18. Statistical reliability is calculated for each data on a percentage basis according to Cronbach's Alpha value which necessitates a percentage rate over %60, referring the reliability of data in interest. This value is %80 for the jury tests.

Variance analysis (valuing the Post Hoc Test after ANOVA test) is done with the data held from **jury test** in order to investigate the relation (the similarities and/or differences) between the evaluations of sound environments. Pairs of adjectives showing statistical significance are found by using the results of this analysis.

Table 2: Selected pairs of adjectives (EN and TR versions)

Pairs of adjectives	
EN version	**TR version**
Quiet – Loud	Sessiz / Gürültülü
Pleasant - Unpleasant	Memnuniyet Verici / Mem.Verici Değil
Comfortable - Disturbing	Rahatlatıcı / Rahatsız edici
Stressing – Relaxing	Stres Yaratıcı / Dinlendirici
Artificial – Natural	Yapay / Doğal
Calming - Agitating	Yatıştırıcı / Heyecanlandırıcı
Boring - Exciting	Sıkıcı / İlgi Çekici
Preferred - Not Preferred	Tercih Ederim / Tercih Etmem
Open – Enveloping	Açık / Sarmalayıcı
Harmonic - Discordant	Ahenkli / Ahenksiz
Soft - Hard	Yumuşak / Sert
Sharp – Not Sharp	Keskin / Keskin Değil
Crowded – Uncrowded	Kalabalık / Tenha
Organised – Disorganised	Düzenli / Düzensiz
Nearby – Far Away	Yakın Plan Ses / Uzak Plan Ses
Continuous -Discontinuous	Devamlı / Devamsız
Steady - Unsteady	Monoton / Değişken
Calming - Eventful	Sakin / Hareketli
Lively – Deserted	Yaşayan / Terk Edilmiş
Joyful – Empty	Neşeli / Durgun
Exciting – Gloomy	Coşturucu / İç Karartıcı
Weak - Strong	Zayıf / Güçlü
Soft - Loud	Yavaş / Hızlı
Dark -Light	Boğucu / Ferah
Muffled - Shrill	Boğuk / Net
Dull - Sharp	Donuk / Keskin
Light - Heavy	Hafif / Ağır
Smooth - Rough	Pürüzsüz / Pürüzlü
Unclear – Distinct	Karışık / Ayırtedilebilir
Common – Strange	Alışılmış / Farklı

According to the evaluation of this analysis; all pairs of adjectives; except 'Artificial – Natural', 'Calming – Agitating', 'Open – Enveloping', 'Nearby – Far away', 'Continuous – Discontinuous', 'Lively – Deserted', 'Weak – Strong', 'Muffled – Shrill', 'Dull – Sharp' and 'Common – Strange', denote significant statistical differences regarding selected sound environments. Considering the differences between the sound environments upon the pairs of adjectives, the sound environment of Ortaköy Pier Square, upon 12 pairs of adjectives which are 'Quiet – Loud', 'Pleasant – Unpleasant', 'Comfortable – Disturbing', 'Stressing – Relaxing', 'Preferred - Not Preferred', 'Soft – Hard', 'Organised – Disorganised', 'Soft – Loud', 'Dark – Light', 'Smooth – Rough', 'Unclear – Distinct' and 'Calming – Eventful', is evaluated as different due to the other environments.

The analyses of the texts held from **listening test**, are done regarding spatial evaluation, recognition of the function, assessment of the acoustical environment, determination of the sound sources, estimation of the area, definition of the soundmark/s, in conformity with the aim of this study. In this frame, the inferences based on the writings of subjects according to the areas can be listed as follows.

Beşiktaş Pier Square

- All subjects correctly defined the area as open and %73 of the subjects as along the front, %47 as pier, %30 as transportation area, %23 as transit crossing area.
- All subjects noted that there are many functions in the area. %73 of the subjects described the area as a commercial place.
- %53 of the subjects used the adjectives of 'crowded and eventful', %40 'noisy/loud', %20 'common', %13 'boring and disturbing' to assess the acoustical environment.
- All subjects defined voices, traffic noise and sound of the electronic ticketing of public transportation. %63 of the subjects defined sound of sales approach and ship/motor's siren, %57 siren and sound of wind, %27 sounds of gammon/teaspoon/cutlery.
- %77 of the subjects called the area as pier and %30 as bus stop, based on the voices, traffic noise and sound of the electronic ticketing of public transportation. %33 of the subjects called Beşiktaş Pier Square by its proper name by considering inter alia sound of sales approach, ship/motor's siren and siren.

Ortaköy Pier Square

- All subjects correctly defined the area as open and along the front. %17 of the subjects defined as square which is closed to traffic and including a playground and % 50 mentioned that there are some cafes and restaurants in the area.
- All subjects noted that there are many functions in the area and they described the area as a commercial place.
- %50 of the subjects used the adjective of 'crowded', %30 'calming', %20 'eventful and loud/noisy but not disturbing', %17 'comfortable-relaxing and unclear but light' to assess the acoustical environment.
- All subjects defined voices and ship/motor's siren. %60 of the subjects defined sound of sales approach, %53 sounds of children, %43 sounds of gammon/teaspoon/cutlery, %33 sounds of sea/wave and %27 music and sound of birds.
- %70 of the subjects called the area as pier and square, based on the voices, sound of sales approach and ship/motor noise. %37 of the subjects called Ortaköy Pier Square by its proper name.

Bağdat Street

- All subjects correctly defined the area as open and a street. %50 of the subjects mentioned that there are some cafes and restaurants in the area.
- All subjects noted that there are many functions in the area and they described the area as commercial place.
- %70 of the subjects used the adjectives of 'crowded-complex', %37 'noisy/loud but not disturbing', %27 'common', %23 'eventful-dynamic and burdensome but lively' to assess the acoustical environment.
- All subjects defined voices, traffic noise and music. %40 of the subjects defined sound of cutlery, %27 sound of children/baby, %7 sound of modified vehicles.
- All subjects called the area as street, based on the voices and traffic noise. %47 of the subjects called Bağdat Street by its proper name by considering inter alia music and sound of cutlery.

Barbaros Boulevard

- All subjects correctly defined the area as open and a street. %23 of the subjects as transportation artery.
- All subjects noted the area as transit crossing space and % 17 of the subjects as a space which has rarely pedestrian circulation.
- %70 of the subjects used the adjectives of 'noisy/loud', %47 'high attendence-complex', %27 'burdensome', %23

'eventful but boring' and %13 'common, dark and disturbing' to assess the acoustical environment.

- All subjects defined voices and traffic noise. %43 of the subjects defined sound of wind, %33 music, sounds of cat, and children/baby.
- All subjects called the area as street, based on densely traffic noise and %53 of the subjects as main street based on inter alia voices and sound of students; moreover, %17 called Barbaros Boulevard by its proper name.

5 Review

This study is the second part of a wide-frame research on a new approach for the evaluation of soundscape. In a previous paper, the field study part of the mentioned wide-frame research is presented. In this paper a proposal for the application and the evaluation of the laboratory study is developed in order to evaluate the soundscape upon the sound quality concept and the metrics. The procedure of the proposal can be summarized as follows;

- Editing the recordings to cover predicted soundmarks to 5 minutes' period.
- Preparing 3 minutes segments (with 1,5 minutes overlap) to confirm the quantitative values of edited 5 minutes' period by using statistical values of the sound quality metrics.
- Realizing jury and listening tests with sufficient number of subjects.
- Analyzing the subjective data by statistical software.

The information obtained from this part of the research is used in the next stage which is the comparative analysis between the field and the laboratory studies.

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