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Published in:
Noise & Health

Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Bjerre, L. C., Larsen, T. M., Sørensen, A. J., Santurette, S., & Jeong, C.-H. (2017). On-site and laboratory evaluations of soundscape quality in recreational urban spaces. *Noise & Health*, *19*(89), 183-192.

Noise & Health
A Bimonthly Inter-disciplinary International Journal

ORIGINAL ARTICLE

Year : 2017 | **Volume** : 19 | **Issue** : 89 | **Page** : 183-192

On-site and laboratory evaluations of soundscape quality in recreational urban spaces

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Date of Web Publication 14-Aug-2017

Abstract

Context: Regulations for quiet urban areas are typically based on sound level limits alone. However, the nonacoustic context may be crucial for subjective soundscape quality. **Aims:** This study aimed at comparing the role of sound level and nonacoustic context for subjective urban soundscape assessment in the presence of the full on-site context, the visual context only, and without context. **Materials and Methods:** Soundscape quality was evaluated for three recreational urban spaces by using four subjective attributes: loudness, acceptance, stressfulness, and comfort. The sound level was measured at each site and simultaneous sound recordings were obtained. Participants answered questionnaires either on site or during laboratory listening tests, in which the sound recordings were presented with or without each site's visual context consisting of two pictures. They rated the four subjective attributes along with their preference toward eight sound sources. **Results:** The sound level was found to be a good predictor of all subjective parameters in the laboratory, but not on site. Although all attributes were significantly correlated in the laboratory setting, they did not necessarily covary on site. Moreover, the availability of the visual context in the listening experiment had no significant effect on the ratings. The participants were overall more positive toward natural sound sources on site. **Conclusion:** The full immersion in the on-site nonacoustic context may be important when evaluating overall soundscape quality in urban recreational areas. Laboratory evaluations may not fully reflect how subjective loudness, acceptance, stressfulness, and comfort are affected by sound level.

Keywords: Acceptance, acoustic comfort, context effects, noise level, quiet areas, recreational areas, soundscape, stressfulness

How to cite this article:
Bjerre LC, Larsen TM, Sørensen A J, Santurette S, Jeong CH. On-site and laboratory evaluations of soundscape quality in recreational urban spaces. Noise Health 2017;19:183-92

How to cite this URL:
Bjerre LC, Larsen TM, Sørensen A J, Santurette S, Jeong CH. On-site and laboratory evaluations of soundscape quality in recreational urban spaces. Noise Health [serial online] 2017 [cited 2017 Aug 14];19:183-92. Available from: http://www.noiseandhealth.org/text.asp?2017/19/89/183/212950

Introduction

With increasing worldwide urbanization, larger cities result in a higher activity level and the distances from the city center to the land areas are extended. As a result, there is an increasing demand for green escape pits within urban spaces. These recreational urban spaces ought to have high quality to serve the purpose of a recharging urban oasis. Specifically, such areas should be free from noise annoyance. Therefore, requirements for quiet urban areas have been defined, typically based on sound level limits, with recommended limit values for the day–evening–night average sound level (L_{den}) being around 50 to 55 dB(A).[1],[2]

The sound level is typically related to how quiet or noisy an urban area is subjectively perceived. In a study focusing on quiet urban areas, it was found that levels above 55 dB(A) seldom obtained average scores corresponding to "quiet" or "very quiet."[3] At 60 dB(A) and above, another study found that only 20% of people perceived the acoustic quality as "good" or "very good."[2] Although quiet areas have been suggested to improve the wellbeing and recovering ability of people,[2] it is not necessarily easy to reach quiet sound levels due to increasing city sizes.[4] Moreover, sound barriers block the view toward recreational spaces and this decreased general visibility may negatively influence the acoustic perception.[5]

There is indeed some evidence that the nonacoustic context does affect sound-related comfort in urban areas. For instance, in central Hong Kong, only 24% of respondents considered the environment to be noisy for an average level of 64 dB(A) due to their low expectation of quiet city parks.[6] Overall, it is well-established that sound level alone does not determine acoustic quality[7],[8],[9],[10],[11],[12] and that quietness is not a core requirement for acoustic preferences outdoors.[13] Soundscapes thus have a wider meaning and the acoustic quality should be evaluated in addition to quietness[11],[12],[14] as human hearing is adaptable to contextual features.[7],[12],[13],[15] Although acoustic comfort is often the focus in soundscape studies,[4],[16],[17] its relationship with other subjective attributes, other modalities, and its influence on the overall perception of comfort remain to be more clearly defined.[12] In the context of urban park environments, acoustic comfort has been found to exert an influence on an individual's acceptability of the environment together with visual comfort and landscape features.[18] Consequently, the soundscape standard[11] emphasizes the role of full immersion in the acoustic environment. However, the exact effects of single nonacoustic factors, such as visual and thermal sensation, or the separation of feelings, are not yet characterized. The role of the visual context in particular has been widely studied. For instance, subjective evaluations of tranquillity were found to differ in a bimodal (audiovisual) information situation compared with a unimodal situation.[18] However, although in some cases there may be an improvement in comfort when visual information is added,[19] the use of visible vegetation as "noise screening" was rather found to increase sensitivity rather than tolerance to traffic noise.[20] Overall, the visual context is not negligible but the auditory modality seems more important than the visual modality when evaluating soundscapes, for example, for the overall appraisal of squares.[21]

Appraisal and differentiation of a given place may also largely depend on the combination of sound source types heard at that same place,[12],[19],[22],[23] and preferences for specific sound sources are linked to people's attitude toward and association with the source.[24] For instance, anthropogenic and mechanical sounds are typically considered slightly stressful,[17] with motorbikes, engines, construction work, campaigning vehicles, and karaoke restaurants often being classified as the least preferred sources,[25] and traffic sources as negatively impacting tranquillity.[26] In contrast, natural sound sources such as birds twittering, water rippling, insects/frogs, waves, wind chimes, and human voices typically result in positive attitudes.[9],[13],[15],[27] The perception and values imputed into different sound sources also varies with the context,[24],[28] such that reducing sound level from specific sound sources may not always result in high comfort, as the character of the sound also plays a role.[29]

The above findings suggest that the visual context and other nonacoustic environmental factors do affect sound-related comfort in urban spaces, as the standard for soundscapes articulates.[11] Furthermore, when studying soundscapes in an urban environment, on-site surveys may be more appropriate than laboratory experiments due to the difficulties in simulating complex acoustic situations and the interactions between sound and other visual, microclimatic, and sociocultural factors.[4],[10],[12],[28],[30],[31]

The present study investigated these aspects further by testing whether nonacoustic factors could outweigh the role of sound level in subjective soundscape assessment when the listeners are immersed in the full context of recreational urban spaces compared to laboratory settings. Specifically, the validity of using a limit value in terms of L_{Aeq} alone for defining a quiet urban space in the Nordic context of Copenhagen, Denmark, was investigated in terms of four subjective parameters: loudness, comfort, acceptance, and stressfulness. This was addressed by comparing on-site soundscape evaluation of three urban-space environments differing in noise level (on-site condition, OS) with laboratory listening test evaluations of the same acoustic environments. In the laboratory tests, the listening experiments were conducted either with access to the visual context of the real sites (visual context condition, VC), or without access to such context (no visual context condition, NC). Furthermore, the people's preferences toward different sound sources occurring in an urban recreational environment were investigated in these different conditions.

Materials and methods

Three sites

Three urban spaces with recreational purposes and different L_{den} were chosen for this study based on the noise map released by Geodatastyrelsen.[32] The spaces were chosen under the assumption that all occupants actively chose to stay in the urban area. Therefore, the positive perspective of soundscape quality was investigated, as suggested in an earlier study,[3] rather than annoyance, which was chosen in other acoustic investigations.[33] The three urban sites in the city of Copenhagen were chosen, so that each would represent different kinds of environmental context: a park, a square, and a bridge:

- *Park:* The park (Landbohøjskolens Have, [Figure 1]a and [Figure 1]b) is located in the area of Frederiksberg and classified to be a quiet urban area by the Municipality of Frederiksberg. The park is surrounded by a brick wall, and, therefore, there is no view of traffic from the park. It was chosen to represent a natural acoustic environment shielded from the surrounding traffic.

Figure 1: Pictures of the three urban spaces taken while occupants performed the evaluation. (a and b) Landbohøjskolens Have, park (site P). (c and d) Den Sorte Plads, square (site S). (e and f) Dronning Louises Bro, bridge (site B)

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- *Square:* The square area (Den Sorte Plads, [Figure 1]c and [Figure 1]d) is a newly renovated concrete square in the area of Nørrebro. It was chosen to represent an urban acoustic environment in Copenhagen with artificially added natural elements, such as planted trees and a water fountain, to meet the needs for a more comfortable space.
- *Bridge:* The bridge area (Dronning Louises Bro, [Figure 1]e and [Figure 1]f) is a bridge crossing Sortedams Lake and Peblinge Lake in Copenhagen with condensed traffic. It was chosen to represent an urban acoustic environment with heavy traffic and nature represented by the two lakes and sporadic trees in the area. Similar to in the square area, natural elements were added, but not specifically for the purpose of creating a recreational space. Instead, the area developed over time, as people started using and transforming the bridge into a recreational space.

The common factor for all places was that at the time of investigation they were being used for recreational purposes in the city and that they all had the presence of water. The square had a fountain, the park had a small lake with a fountain, and the bridge was situated between two lakes. Water was chosen as a sound parameter, as water was found to be effective to mask sounds from motorized transport and mechanical sounds,[34] and as it was of interest to examine whether the presence of water in these recreational urban spaces acted positively on people's perception. Benches and sculptures were also present at all three sites in this study. This was matched across sites as benches in combination with sculptures were found to increase the visitability of urban plazas.[35]

Measurements and recordings

Sound level measurements and sound sample recordings were obtained on site in the three urban spaces with a B&K 2250 (Brüel og Kjær, Nærum, Denmark) sound level meter positioned at a height of 1.5 m. L_{Aeq} was measured over 5 min at a representative spot for the occupants' experience at each site. L_{Aeq} was found to be preferable over L_{den} as a snapshot of the typical acoustic environment when the occupants performed the evaluation was needed. The participants were random visitors and users of the chosen areas, and the measurements and recordings took place during occupant peak flows. Thus, a weekday afternoon session in sunny weather in mid-June was chosen. All measurements and recordings were made under weather conditions of sunshine, an air temperature of 15°C, and reference 10-m wind speeds around 8 to 12 m/s. The recordings for later use in the listening experiments were made from three samples of 30 s for each site at random times.

Questionnaires

Twenty-two participants answered a questionnaire at each site, resulting in 66 participants in total for the on-site evaluation. The questionnaires investigated both quantitative and qualitative parameters and were answered in English or in a Danish translation.

The quantitative parameters attempted to decompose the overall acoustic comfort and challenge the psychoacoustic parameters used for soundscape assessment. They consisted of loudness, comfort, acceptance, and stressfulness, each of which was evaluated on both a 5-point verbal and an 11-point numerical scale according to ISO/TS 15666.[36] The 5-point verbal scale was used to check the consistency with the 11-point numerical scale. The 11-point numerical scales for loudness and stressfulness were bipolar scales around a neutral point with antonyms at each end of the scale: soft vs. loud and relaxing vs. stressful. For acceptance and comfort, positive scales were used, the lower anchor of the scales referring to the negation of the qualifiers: not acceptable vs. acceptable and not comfortable vs. comfortable. The bipolar scales were interpreted with threshold values of seven and three for "loud" and "soft", "stressful", and "relaxing", respectively. The terms "very loud" and "very stressful" were used at the threshold value of eight and "very soft" and "very relaxing" were used at the threshold value of two. The positive scales were interpreted with a threshold value of five or higher for either "acceptable" or "comfortable" and below five for "not acceptable" or "not comfortable". The extremes of "highly acceptable/comfortable" as well as "not at all acceptable/comfortable" were defined from threshold values of eight and two, respectively. All threshold values were chosen in accordance with Ref. [37].

The qualitative parameters were investigated through people's preference toward eight different sound sources that were possibly present on each site. The sounds were chosen on the basis of initial screenings. Some were generated by human activity, for example, motorized vehicles, air traffic, voices (nonamplified), bicycles, and music (amplified), whereas others were not generated by human activity, for example, birds twittering, water, and wind.[11] The participants were asked to evaluate their perception of these sound sources by marking a green happy smiley if they liked the sound and a red sad smiley if they disliked the sound. If the sound was not present or the participant was neutral toward it, a neutral/not relevant option was available.

Furthermore, the questionnaires asked about the occupants' motivation for being at the site, their age, gender, and whether they lived in Copenhagen, if so, for how long, and how long they expected to stay at the site. The whole questionnaire took approximately 5 min to fill in.

Listening experiments

The recorded sound samples were presented to a panel of participants in a laboratory listening experiment. The setup consisted of two KEF 107/2 reference loudspeakers placed at 2-m distance from the listener's ears in an IEC 268-13 standard listening room. As the recordings were made with a single microphone, the sound samples were played back in mono. The reverberation time of the room was flat at 0.4 s over all frequencies. Calibration was performed by measuring L_{Aeq} with a B&K 2250 sound level meter at ear position to match L_{Aeq} with the peak levels of the recordings.

In total, 24 participants took part in the listening experiments and were recruited from among an equal share of lay people and experts. Every participant was exposed to approximately 4 min of a sound sample from each site, consisting of repetitions of three 30-s recordings. Each person answered the same questionnaire survey as the on-site participants for all three sites, after listening to the sound sample for at least 30 s and while the remaining 3.5 min were played. The order of the presentation of the sound samples was randomized in each test.

The participants were divided into two groups. The first group listened to the samples without any visual context (NC, 12 participants). The second group listened to the sound samples with a visual context (VC, 12 participants). The VC group was shown two pictures from each site in size A4 shot the same day as the recordings were made [Figure 1].

Data analysis

For each quantitative attribute, a two-way analysis of variance (ANOVA) with location (P, S, or B) and context (OS, VC, or NC) as main factors was used to determine whether there were statistically significant differences between the responses under the different experimental conditions. To study specific group differences, *post hoc* multiple comparisons were then applied to the ANOVA output by using Tukey's honest significant difference criterion. Pearson correlation analyses were also performed to find relationships between the four quantitative attributes, with Bonferroni correction to account for multiple correlations. The correlations were obtained by pooling the data across all sites and context conditions. Correlations were also calculated separately for each context condition (OS, VC, and NC). For the OS evaluation of the qualitative attributes, a binomial test with a chance probability of 33.3% was used to estimate whether each sound source type was perceived as significantly positive or negative. A significance level of 5% was used in all analyses.

To find relations within and between the quantitative and qualitative attributes, an association mining procedure was used. The purpose of such a procedure is to find rules according to which one attribute leads to another and to find itemsets that frequently occur simultaneously. Every rule is composed of an itemset containing two items that can either be grouped or individual, such as $\{X,Y\} \rightarrow Z$, in which the itemset $\{X,Y\}$ leads to the item Z. The rules and itemsets were derived by using an a priori algorithm.[38] Two measures were used to evaluate the association rules: the support and the confidence. The support of an itemset is the percentage of occurrences of that itemset ($\{X,Y\}$ or Z), whereas the support for an association rule is the percentage of simultaneous occurrences of $\{X,Y\}$ and Z, $P(\{X,Y\},Z)$. The confidence for an association rule is the percentage of occurrences of $\{X,Y\}$ that also contains Z, $P(\{X,Y\}|Z)$. The input to the algorithm is a binarized matrix with the number 1 when an attribute was present. If any of the four quantitative attributes exceeded the threshold values described above, their corresponding attribute were marked by 1, otherwise by 0. For example, if the loudness was rated below three, an attribute called "soft" was marked with 1. Similarly, the responses to the preference toward sound sources were binarized such that, for example, a positive rating of birds twittering was marked by 1 in a "birds positive" attribute.

Results

Participant distribution and sound level

The average distribution of the participants is shown in [Table 1]. The measured L_{Aeq} values for each site were 51.8 dB(A) for P, 59.8 dB(A) for S, and 65.5 dB(A) for B.

		Participants	% Male	% Female	% Residents
On site	Total	66	58	42	68
	Park (P)	22	36	64	50
	Square (S)	22	82	18	86
	Bridge (B)	22	55	45	68
Listening room	Total	24	63	37	46
	VC	12	83	17	50
	NC	12	50	50	42

Table 1: Number of participants, gender distribution, and percentage of Copenhagen city residents for each on-site location and the listening-room experiments with (VC) and without (NC) visual context

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Quantitative attributes

As the ratings on the 5-point point verbal scale and the 11-point numerical scale were consistent, the 11-point numerical scale was used in the analysis. [Figure 2] shows the calculated means and corresponding standard errors of the participants' ratings on the 11-point numerical scale for the four quantitative attributes. The ANOVA revealed a significant main effect of location for all four attributes [loudness: $F(2,129) = 52.91$, $P < 0.001$; comfort: $F(2,129) = 48.37$, $P < 0.001$; stressfulness: $F(2,129) = 36.52$, $P < 0.001$; acceptance: $F(2,129) = 23.85$, $P < 0.001$]. The main effect of context was also significant for loudness [$F(2,129) = 6.71$, $P = 0.002$], comfort [$F(2,129) = 3.81$, $P = 0.025$], and acceptance [$F(2,129) = 3.66$, $P = 0.028$], but not for stressfulness [$F(2,129) = 0.42$, $P = 0.655$]. Moreover, the interaction between location and context was significant for all four attributes [loudness: $F(4,129) = 6.84$, $P < 0.001$; comfort: $F(4,129) = 4.43$, $P = 0.002$; stressfulness: $F(4,129) = 4.76$, $P = 0.001$; acceptance: $F(4,129) = 8.17$, $P < 0.001$].

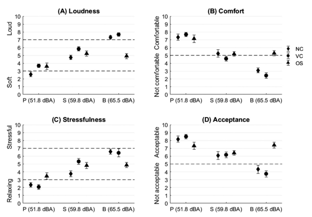

Figure 2: Mean ratings and standard errors for the park (P), square (S), and bridge (B). (a) Loudness, (b) Comfort, (c) Stressfulness, (d) Acceptance. L_{Aeq} values in dB(A) are indicated in brackets. *Dotted lines:* threshold values for attribute evaluation. *Diamonds:* laboratory without visual context (NC); *Circles:* laboratory with visual context (VC); *Triangles:* on site (OS)

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When comparing the ratings for the two locations with the lowest and highest L_{Aeq} (P and B, respectively), in the laboratory (VC and NC conditions), loudness and stressfulness were always significantly lower for P than for B, whereas comfort and acceptance were always significantly higher [$P < 0.001$ in all cases]. In contrast, in the OS condition the difference in ratings between the P and B sites was only significant for comfort ($P = 0.017$) but not for loudness ($P = 0.091$), acceptance ($P = 1.000$), or stressfulness ($P = 0.193$).

The *post hoc* analysis indicated that differences between the laboratory VC and NC ratings were never significant for any of the locations and parameters. Therefore, showing a visual representation of the different locations to the listeners in the laboratory did not affect their ratings. However, for the bridge, loudness was perceived as significantly lower on site than in the laboratory (OS vs. VC: $P < 0.001$; OS vs. NC: $P < 0.001$), whereas comfort was significantly higher (OS vs. VC: $P = 0.019$; OS vs. NC: $P < 0.001$), as well as acceptance (OS vs. VC: $P < 0.001$; OS vs. NC: $P < 0.001$). The differences for stressfulness were insignificant (OS vs. VC: $P = 0.166$; OS vs. NC: $P = 0.287$). For the park and square, there were no significant differences among the OS, VC, and NC ratings for any of the attributes. This suggests that the immersion of the listeners in the real environment at the bridge location affected their experience of the acoustic scene. Although still stressful to some extent, it was much more comfortable, acceptable, and less loud than when it was experienced out of context in the laboratory.

[Table 2] shows the calculated correlation coefficients across the four quantitative attributes. When grouping all context and location conditions in the correlation analysis (numbers without brackets in [Table 2]), there were strongly significant correlations between all four quantitative attributes. This means that a high perceived loudness corresponded to low comfort, low acceptance, and a high stress level. However, when performing the correlation analysis separately for each context condition, the correlations remained strongly significant in the VC and NC laboratory conditions ($P < 0.001$, not shown in [Table 2]), but not all OS attributes remained significantly correlated (numbers with brackets in [Table 2]). In contrast to the laboratory ratings, on-site ratings of loudness, acceptance, and stressfulness were no longer correlated. Finally, the significant correlations between comfort and all other attributes in all analyses suggest that people who feel comfortable in the urban sound environment also perceive the sounds as softer and more relaxing and are more accepting of the experienced acoustic environment.

	Loudness	Comfort	Acceptance	Stressfulness
Loud.		–0.699 (–0.544)	–0.599 (–0.366)	0.554 (0.243)
Comf.	<0.001 (<0.001)		0.746 (0.577)	–0.665 (–0.446)
Accept.	<0.001 (0.060)	<0.001 (<0.001)		0.524 (–0.139)
Stress.	<0.001 (1.000)	<0.001 (0.004)	<0.001 (1.000)	

Table 2: Pearson correlation coefficients across the four quantitative attributes (above diagonal) and corresponding Bonferroni corrected P values (below diagonal). *Values without brackets:* correlation analysis across all conditions. *Values in brackets:* correlation analysis across on-site conditions only

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Qualitative attributes

[Figure 3] shows the participant's preferences toward different sound sources. The figure shows the ratings for the "liked" (left panel) and "disliked" (right panel) markings. Therefore, it both indicates whether the different sound sources were present and the sound sources were preferred. By using a binomial test, for the OS ratings (darkest bars in [Figure 3]), a given sound source could be considered significantly positively or negatively rated for scores above 44%. By using this analysis, water, human voices, wind, birds twittering, and bicycles gave rise to a significantly positive attitude, whereas motorized vehicles led to a significantly negative attitude. All natural sound sources were thus most commonly stated as likeable, whereas motorized vehicles and air traffic were the most disliked source types among most participants, which concurs with previous studies.[24],[25] The fact that sample sizes differed between groups limits the interpretation of a direct statistical comparison of scores between the OS, VS, and NC conditions (for the VC and NC groups, a score of 66% is required for statistical significance). Despite this, there was a clear trend for OS scores to be higher than both laboratory scores for the most liked and disliked sound sources. This may indicate that the context not only helped the participants identify the different sound sources, but also affected their attitude toward the sources, enhancing their positive or negative experiences of these sources, as suggested earlier.[24]

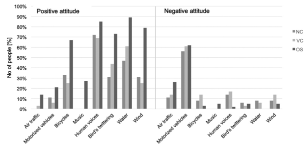

Figure 3: Percentage of people having a positive and negative attitude, respectively, toward anthropogenic and natural sound sources, for the three context conditions: OS, VC, and NC. The remaining percentage of people having a neutral attitude is not shown

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Association mining and frequent itemsets

Association mining was used to cluster ratings and statistical attributes into rules. By using the association mining, a confidence level of 100% resulted in five rules for the OS group as shown in [Table 3] (top). With a support of 45%, it resulted in "acceptance" if the participants lived in Copenhagen, found voices positive, and rated the soundscape as "comfortable." With a support of 35%, it resulted in "high acceptance" if the participants were socially motivated and rated human voices positively. Moreover, with a support of 41%, it resulted in "high acceptance" if the participants rated sounds from wind, voices, or water positively in all possible combinations. For all five association rules, the same rules were searched for in the listening experiments, but were only found with a support of 22% or less than 20%.

Association rules	OS	VC	NC
(resident; voices+; comfortable) → acceptable	45	22	<20
(social motivation; voices+) → highly acceptable	35	—	—
(wind+; voices+) → highly acceptable	41	<20	<20
(water+; voices+) → highly acceptable	41	<20	<20
(wind+; water+) → highly acceptable	41	<20	<20

Frequent itemsets	OS	VC	NC
social motivation & voices+ & acceptable	65	—	—
wind+ & voices+ & water+ & acceptable	64	22	<20
comfortable & wind+ & water+	56	28	<20
comfortable & wind+ & water+ & voices+	52	22	<20

Table 3: Association rules with a confidence of 100% and frequent itemsets with their corresponding support (in %). Association rules and frequent itemsets had the greatest support on site (OS) compared to listening experiments with (VC) and without (NC) visual context. "+" indicates a qualitative attribute rated positively.

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Four frequent itemsets were found with a support greater than 50% on site [Table 3], bottom]. The itemsets only had significant importance for the OS group. The first itemset of "social motivation," voices rated positively, and "acceptable" yielded a support of 65%. The itemset of wind rated positively, water rated positively, voices rated positively, and "acceptable" resulted in a support of 64%. The itemset of "comfortable," wind rated positively, and water rated positively yielded a support of 56%. The itemset of the three last mentioned parameters together with voices rated positively occurred with a support of 52%.

Discussion

The results indicate that sound level in terms of L_{Aeq} is not always sufficient to define the on-site soundscape experience in recreational urban spaces. In the listening experiment, a higher L_{Aeq} always led to higher loudness and stressfulness ratings, as well as lower acceptance and comfort ratings, when comparing the two sites with the lowest and highest sound levels. Therefore, L_{Aeq} is probably a good predictor of how people in an out-of-context laboratory experiment rate the loudness, comfort, acceptance, and stressfulness of the soundscape. However, this is not the case for real situations: on site, the influence of level on these four attributes was much reduced. This indicates that, when the full environmental context is available to the listeners, the sound level alone, as estimated by L_{Aeq}, is not sufficient to determine the subjective experience of the acoustic scene in terms of loudness, acceptance, or stressfulness. Thus, in real situations, the sound level seems to be a good predictor of the experienced comfort but not of the whole subjective experience of the acoustic environment. This further suggests that loudness, acceptance, and stressfulness are influenced greatly by context-related nonacoustical factors, such as the atmosphere and ambience at the specific location.

The role of L_{Aeq} for acoustic comfort was previously found to be dominant only below a certain sound level. Specifically, it was found that subjective evaluations of acoustic comfort generally showed a clear relationship with the mean L_{Aeq} below a certain location-specific sound pressure level,[4] estimated at 73 dB(A). Above this level, the evaluations became unpredictable. Consistently with these findings, the relatively high sound level at the bridge site in the present study might have distorted people's subjective evaluations. However, this lack of a dominant role of level on subjective soundscape evaluations already occurred at a lower equivalent level of 65.5 dB(A) in this study.

No difference was found in the ratings of the four quantitative attributes with and without visual context in the listening experiment. Therefore, the visualization of the scene through pictures did not affect the perception of the acoustic environment in the laboratory. The sparse information in a two-dimensional image may, thus, not have been sufficient to mimic the full environment, and it remains possible that a more realistic visual immersion could produce an effect.

Furthermore, there were no significant context effects on the ratings of the four quantitative parameters for the park or the square. In contrast, the immersion in the environment changed the perception of the acoustic environment significantly for the bridge site. Although the stress level remained the same independent of context, the bridge soundscape was rated as more comfortable, more acceptable, and softer on site than in the listening experiment. The bridge has a very complex auditory scene with many unexpected variations in the stimuli (e.g., constant change in traffic and human flows), demanding a high degree of cognitive filtration process from the participants. This may result in a stressful perception of the soundscape that is not context dependent. However, other nonacoustical parameters, such as visibility and thermal conditions, may have impacted the acceptance, comfort, and loudness in a more positive way on site. For instance, visual and auditory aspects have been found to interact as esthetic comfort factors.[4] Specifically, the most important factors influencing outdoor comfort were temperature, sunshine, and brightness, the second most important factors being sound level and view, and the third most important being humidity and wind.[4] Therefore, brightness may have been weighted heavier than sound level by our on-site participants. In the present study, the pleasant view over the lakes at the bridge site and the higher sky-view factor, and thus increased brightness, compared with the other two sites, may have influenced the acoustic perception of the site in a positive way. This is also supported by an earlier study suggesting that a more urban context resulted in a more contaminated auditory judgment.[39]

There are several other qualities about the bridge site that could be related to a relatively higher acceptance and comfort compared to the other sites. In contrast to the square and the park, the bridge provides a large visual and acoustic field in the city, with a view extent of 1.5 km over the lakes in each direction perpendicular to the bridge. The long sights and the contrast to the denser city on both ends of the bridge might have influenced the occupants' perception. It was earlier suggested that visibility is a resource that affects visitor enjoyment in natural parks.[5] That same resource might be valid for the case of a dense city that opens up, as is the case for the present bridge site. The function of the bridge site also changes over time and it was not originally planned as a recreational area. In such a popular urban space, the sounds are created as a democratic process and the people seem more acceptable toward them. This might be due to the social factor of taking part in the city's pulse as indicated in Ref. [12].

However, the fact that the bridge was still perceived as stressful with the full context calls for an awareness of the health issues related to a stressful environment and a thorough discussion of the purpose of urban recreational areas. The people in Nordic countries use the urban recreational areas a few hours during the day. However, there is evidence that exposure to high sound pressure levels in homes is related to risk of cancer and cardiovascular diseases.[40] Health effects of exposure to high sound pressure levels in urban spaces remain to be investigated but may be worth keeping in mind when municipal policies aim to make people spend more time outdoors,[41] such that acceptance and stressfulness may be important to consider. In the present study, the questionnaire focused on the sound-related stressfulness but some respondents still might have answered "stressful" because of the linguistic meaning of the word "stress" as a diagnosis to humans. Stressful could also be perceived relatively to the respondents themselves. One way to avoid this potential confound could be to ask two stress-related questions: "How stressful/relaxed do you feel?" and "How stressful/relaxing do you think the sounds are?"

Concerning the participants' preferences toward different sound sources [Figure 3], the OS results are especially noteworthy. Generally, there was a more positive attitude toward the sound sources on site compared to the VC and NC experimental conditions. This indicates that the on-site participants were better at identifying and distinguishing the different sound sources, which is likely to result from the complex visual and auditory environmental situation. An extended cognitive tolerance when the cause of the stimulus is known and understood may have contributed to the present observations.[42]Here, natural sound sources clearly created a positive attitude, whereas there was a general negative attitude toward motorized vehicles and air traffic. According to the frequent itemsets, the elements which mostly positively influenced perception were wind, water, and voices, all natural sounds. These sound sources were rated positively together with answers indicating acceptability and comfort. This result indicates that natural sources have a positive influence on people's perception of the sound environment. The two obtained frequent itemsets were more common on site than in the listening experiment, which may indicate that the perception of natural sounds is also influenced by other human senses such as feeling the ambiance and smelling the nature. In the association mining, it was found that, with a confidence of 100%, a positive attitude toward wind and water led to high acceptance, which also indicates that wind in vegetation and water can be used to make people more accepting toward an urban space. This concurs with previous results according to which streams and waves from lakes were the most effective natural sounds to mask urban noises.[34]

Another association rule showed that social motivation and positive attitude toward voices led to high acceptance. This result indicates that people who like to be around other occupants (i.e., with social motivation) and enjoy the presence of other people's voices are more acceptable toward high sound levels. Thus, a great part of the acceptance of urban sounds may be linked to the social aspect of being in the urban space. This is consistent with an audiovisual study of acoustic comfort in which the appearance of humans was found to increase the score of sounds originating from humans compared with those without the appearance of humans, suggesting that expecting the presence of humans increases tolerance towards their production of sound.[16]

Overall, the present investigation provides indications that sound level alone cannot fully account for sound comfort in urban spaces and that other contextual factors influence our perception of soundscapes. Although laboratory experiments remain useful to perform evaluations with carefully controlled conditions and to isolate separate factors, these findings concur with the suggestion that on-site surveys are more appropriate than laboratory listening tests for realistic subjective acoustic evaluation.[4] They suggest that, when designing urban spaces for the purpose of making them comfortable, acceptable, quiet, and not stressful, other factors than sound level limits should be taken into consideration. For instance, it is likely that certain sound maskers, such as wind, water, and bird twittering, can help improve soundscape quality in urban spaces by implementing trees, bushes, and water.

Conclusions

On-site and laboratory evaluations of soundscape quality were carried out in three urban recreational spaces. In the listening experiments, the measured L_{Aeq} was a good predictor of loudness, comfort, acceptance, and stressfulness. However, on site, there was no consistent relationship between the measured sound level and these four subjective attributes. It is likely that the visual environment and the atmosphere had a great influence on the on-site ratings.

There was no statistical evidence that the visual context in the listening experiments affected the ratings of the four subjective attributes or the preferences toward different sound sources. The ratings from the site with the highest L_{Aeq} showed that the acoustic environment was perceived as stressful but as significantly softer, more comfortable, and more acceptable on site than in the laboratory experiments. The physical urban typology around this bridge site, including a long view, increased brightness, and increased visibility, possibly contributed these more positive on-site ratings.

Natural sound sources such as water, wind, and birds twittering, together with culture-related sounds from human voices and bicycles, generally created a positive perception of the sound environment on site, whereas motorized vehicles were perceived negatively.

Overall, the results confirm earlier findings that the sound level alone is a poor indicator for assessing acoustic comfort of recreational urban spaces, as the nonacoustic context plays an important role. Urban designers should thus be careful when designing urban spaces on the basis of laboratory listening experiments alone. In addition, the results suggest that acceptance and stressfulness ought to be considered in recreational urban escape pits in addition to acoustic comfort, as the acoustic environment might be comfortable and acceptable but still perceived as loud and induce stress. Moreover, sound maskers such as nature and culture-related sounds are preferred sounds that may be used as maskers in urban soundscapes to increase their positive perception.

Finally, urban recreational spaces are typically used temporarily, and visitors have the opportunity to leave at any time. Therefore, soundscape quality is a momentary positive state of mind that is very important to aim for to attract more visitors, please citizens, and achieve a higher urban quality.

Acknowledgements

The authors would like to thank and all participants in the study and Brüel & Kjær for lending equipment.

Financial support and sponsorship

This work was supported by the Technical University of Denmark.

Conflicts of interest

There are no conflicts of interest.

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Source of Support: None, **Conflict of Interest:** None

DOI: 10.4103/nah.NAH_109_16

Figures

[Figure 1], [Figure 2], [Figure 3]

Tables

[Table 1], [Table 2], [Table 3]

ISSN: Print -1463-1741, Online - 1998-4030