Noise as a Stress Factor on Humans in Urban Environments in Summer and Winter

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Summary
With an increasing population in urban areas an increase of man-made influences on the environment like noise, particulate matter or temperature fluctuation can be expected. As a consequence, negative effects on the health of humans can be anticipated due to the rise of stress factors. To examine the influence of different stressors, an interdisciplinary research group has been formed to undertake acoustic measurements in certain areas in the city of Aachen, while interviews were simultaneously conducted to assess the perceived influence of the public. Intermediate results from measurements and interviews of two campaigns, one in winter and one in summer 2014, will be presented and compared. The compliance of classical A-weighted equivalent noise level and psychoacoustic time-variant loudness at sensitive receiver positions with the actual perception of the interview partners will be discussed.

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1. Introduction

The rise of metropolitan areas is a consequence of the human population moving into urban city parts. Thus, habitants are more and more exposed to human-induced influences of the environment that underlies constant change due to changing demands on infrastructure, entertainment, shopping, relaxation, etc. [1].

In this paper, an attempt to capture the variety of these physical influences as they occur on-site is described. A combined measurement and interview-based study has been designed to simultaneously gather data representing physical parameters on the one hand, and perceived stress on humans on the other hand. The combination of those two data sets build the foundation for comprehensive research on correlation, i.e. through modelling and statistical analysis. In order to learn if physical parameters in a natural environment are perceived accordingly we undertook joint measurements in a medium-sized European city (Aachen, Germany). At present, data of two campaigns during summer and winter have been collected. There are current studies which indicate that noise is a serious stress factor for humans in urban environments [2]. Results of the stress factor comparison in summer and winter are presented concerning acoustic parameters and perceived parameters such as annoyance, stress, loudness and discomfort.

2. Data collection

In 2014, during winter season in February and during summer season in July, two campaigns were conducted. The city of Aachen was chosen as a pilot study location, a fairly large town with a total of 240,000 inhabitants. At the rather lively surroundings of the *Elisenbrunnen*, a half-open neoclassical building framing a geothermal spring of sulphurous hot water, five distinct positions were selected as starting points for simultaneous measurements and interviews. The research design follows the principle of a user-centered data acquisition, where objectively measured data is compared against answers from interview partners (e.g. perceived loudness) at the same location[2] [3].

2.1 Acoustic measurements

Time series of physical sound pressure levels were captured on a mobile device using a calibrated omnidirectional microphone. From sound pressure time series, the classical A-weighted sound pressure level for any given period, where data were recorded, is determined resulting in the well-known L_{EQ} in $dB(A)$ from ISO 226. Also, the psychoacoustic evaluation of *time-variant Loudness* in the unit *sone* and the *N5 percentile* as described in ISO-532 B (*Zwicker* algorithm) has been performed, which is known to be closer to actual noise perception and can result for instance in a better prediction of annoyance evoked by noise [4–6]. Further psychoacoustic parameters have not been considered so far, since most of them require stationary sounds which are normally not present in urban scenarios. In addition to acoustic measurements, a set of physical parameters was also measured. Further information was gathered by a quasi-permanent station [7]. Background data from permanent survey stations maintained by the municipality were also included to guarantee compatibility with long-term measurements.

2.2 Questionnaire survey

The second fundamental data source is the data set from a mixed method interview study with on-site users (city visitors or dwellers in a wide age range). The main goal of the interview-based questionnaire was to investigate perceptions of the public with respect to the acoustic parameters that were measured simultaneously. Besides physical influences (concerning stress, comfort and other) demographic data (e.g. the gender, age, social and living situation, occupation) were noted to create user profiles on the long run. The underlying idea was to preserve the possibility of extracting significant intersections among the set of samples that are likely (or not likely) to develop a certain emphasis on one or more stress factors under examination. This, however, has not yet been carried out and will be investigated at a later point in time.
The survey included the following sections (with some examples):

1. Demographic data (gender, age, etc.)
2. Outdoor habits and private activities
3. Reason for site visit
4. Perception of comfort
   a. Overall comfort (health, stress)
   b. Influence of climate
   c. Influence of acoustic environment
5. Feedback and suggestions for the particular location (proposed changes)

In total, N=340 dwellers participated (152 in winter season, and 188 during summer season). In the end, 267 samples could be linked with acoustic measurement data, while the rest had to be excluded due to unmatched circumstances (inappropriate distance from measurement setup or partly uncovered recording during the poll). The interview covered 40 questions, which could be answered by 5- or 6-point Likert scale, respectively. For each evaluation, scales with five options were presented, giving the interviewees the possibility to choose a value between extreme negative or positive, a tendency to negative/positive as well as a neutral element.

3. Statistical analysis

With the data acquired, a variety of different parameters were subject to evaluation. Regarding the diverse background of the multiple stressors, a comprehensive analysis based on multivariate statistics may reveal common factors that correlate with the perceived influences of the environment in a positive or negative manner[3]. A first approach was to generalize the entire survey results for a certain location and isolate physical stress factors that result from comparison with single individual

[2] For further information on the campaign, details can be taken from [8]

[3] Since the undertaking of the described project is still in a phase of field experiments, this goal will be pursued in a later stage.

Table I. Example items of acoustical questions (1 = min, 5 = max.)

Acoustical questions: How do you perceive the acoustic environment at this very location? I perceive the location as …					
Loud or quiet?	loud	rather loud	neutral	rather quiet	quiet
Pleasant or discomforting?	discomforting	rather discomforting	neutral	rather pleasant	pleasant
Annoying or not annoying?	annoying	rather annoying	neutral	rather not annoying	not annoying
Relaxing or stressful?	stressful	rather stressful	neutral	rather relaxing	relaxing
Scale	5	4	3	2	1

perception fields, like noise, heat/cold stress and particulate matter [7], [8]. Looking at the acoustic domain, the evaluation of the present sound field with respect to actual perception of the public showed good accordance, i.e. a louder area was also perceived as such when comparing with noise level or loudness. Now, the distinct examination of particular places within the *Elisengarten* will be dropped to some degree and the more general idea of a location-independent investigation will be discussed, maintaining the separate data sets from summer and winter. In other words, the hypothesis is made that the only influence on acoustic comfort is based on differences between winter season and summer season. For this purpose, the sound pressure time series during every single interview was analyzed and A-weighted equivalent noise level as well as time-variant loudness were calculated. The resulting single value numbers for each interview were matched with the answers to the questions of Table I. The Figures 1-4 show the diagrams of the four questions posed (Table I) presenting both winter (blue crosses) and summer (red circles) in one plot. In each of the figures, the left hand side diagram shows the related energetic sound pressure level using classical A-weighting in decibel on the abscissa (from now referred to as 'noise level') and the right hand side diagram displays the same answers with the abscissa scaling of psychoacoustic loudness evaluation in *sone* (from now referred to as 'loudness'), respectively. For all figures, the total number of answers for the particular response option is given under the left plot only, while the first row is indicating the winter results and the second row is indicating the summer values. For now, there has been no attempt to cope with the outliers, however to some extend odd physical values could be further investigated if one listens to the associated sound sample.

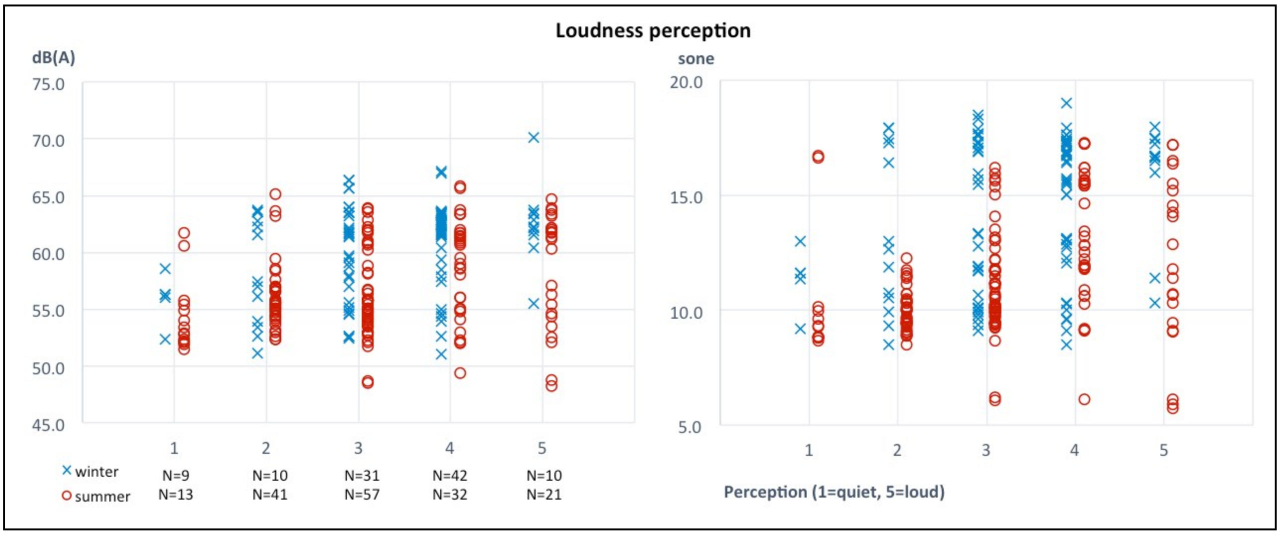

Figure 1: Loudness perception vs. noise levels in dB(A) (left) and psychoacoustic time-variant loudness (right)

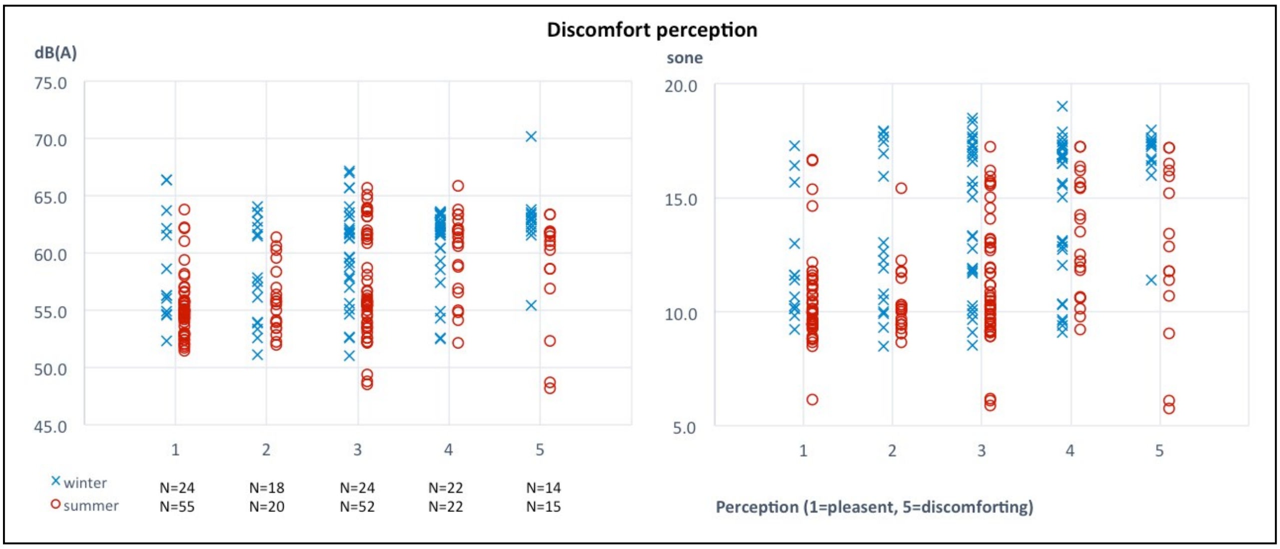

Figure 2: Discomfort perception vs. noise levels in dB(A) (left) and psychoacoustic time-variant loudness (right)

4. Summer vs. winter

The overall research question was, if perception and physical measured data in a natural environment can be evaluated together and if they might be affected by other environmental influences (e.g. thermal comfort, wind stress etc.).

Also it was unclear if the psychophysical accordance (perception data and measured noise level in dB(A)) differs with extreme weather conditions like winter and summer. In order to determine the match, Spearman correlations were run. In the winter campaign, only small and mostly non-significant relations between loudness perception and measured noise level were found – except that the sound level correlated significantly with the perception according to annoyance ($r = .2$; $p<.02$). In the summer campaign, the picture was completely different. dB(A) values showed significant correlations with the perceptions of loudness ($r=.24$; $p<.001$), discomfort ($r=.27$; $p<.000$), annoyance ($r=.16$; $p<.05$) and perceived stress ($r=.25$; $p<.001$). Similar values were found for the time-variant loudness (sone) and perceptions. In the following sections we report on the descriptive outcomes in the respective perception dimensions, focusing on the individual distribution of evaluations.

4.1 Loudness perception

In Figure 1, the loudness perception of the public is shown as a function of acoustic evaluation for all evaluations conducted. The distribution of the results has a tendency to higher perceived loudness with a maximum of 27% of participants (N=42 answers) on 'rather loud' and 21% (N=31) on the neutral position in the winter campaign. For the noise level, a normal distribution can be interpreted

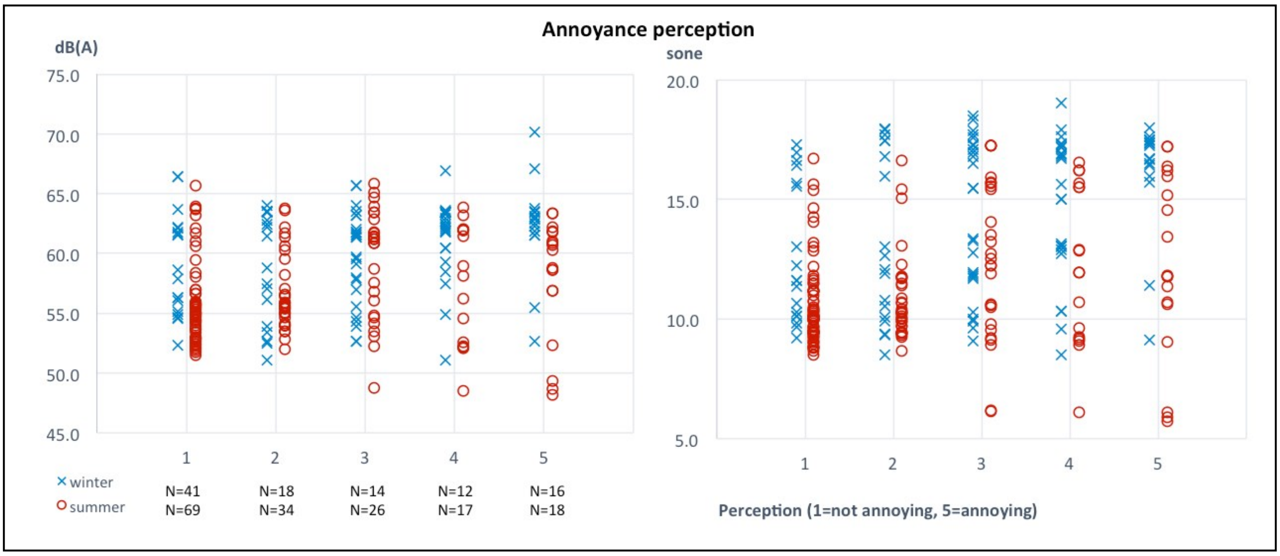

Figure 3: Annoyance perception vs. noise levels in dB(A) (left) and psychoacoustic time-variant loudness (right)

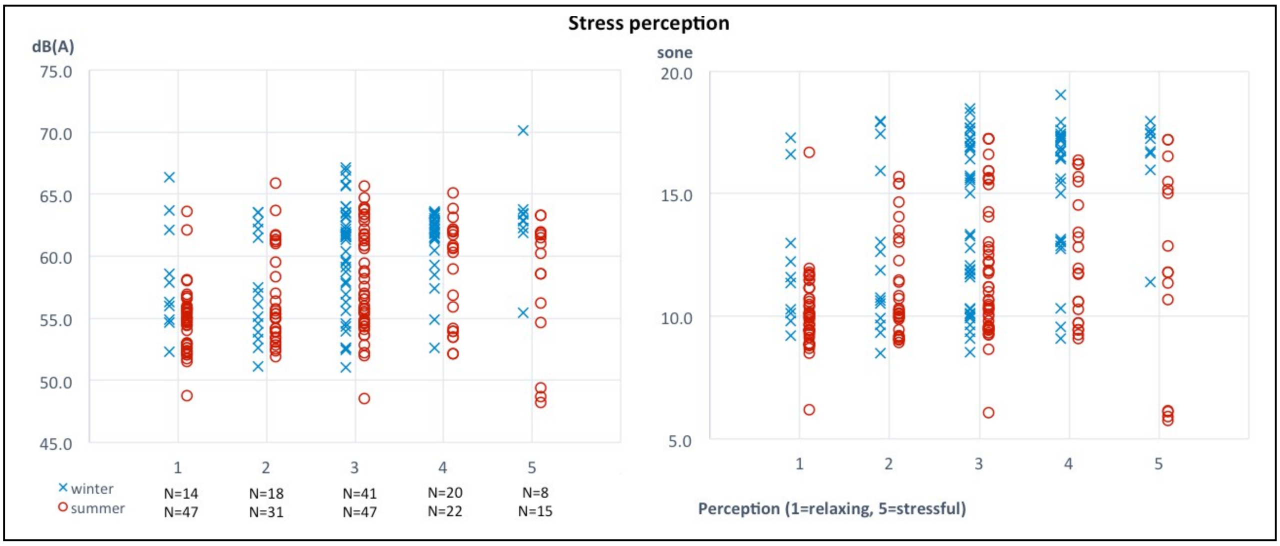

Figure 4: Stress perception vs. noise levels in dB(A) (left) and psychoacoustic time-variant loudness (right)

for the summer data, the winter data is more spread especially for the neutral option and the tendencies towards positive and negative perception of loudness. Remarkably, the extreme negative answer 'loud environment' covers the entire range of measured values indicating that these answers are not identifiable by acoustic measures. In addition, the loudness evaluation shows a movement towards two clearly separable areas that evidently do not agree with the expected normal distribution. For the moment, the reason can only be guessed, but the assumption can be made that the examination of loudness perception using the entire dataset without further separation of other influences is not valid.

4.2 Discomfort perception

Figure 2 depicts the evaluation from the question, if the acoustic environment is perceived as pleasant or uncomfortable. Here, the highest total number of N=24 (13%) can be found both on the option 'pleasant' as well as 'neutral' in winter season. As well, numbers of N=55 (29% of the samples, judging on the option 'pleasant') and N=52 (28% selecting the option 'neutral') are found in summer season. Interestingly the results in summer are following a rather strong tendency in the low noise level range for a pleasing sound field and during winter, in contrast, a strong density of responses during high levels for a discomforting acoustic environment. The in-between numbers do not draw a clear picture, however the neutral option is covering almost the entire measured range of physical values. For the opposite case, both high discomfort during summer and high pleasantness during winter appear scattered. Outcomes corroborate seasonal influences on user's perceptions and different psychological thresholds of pleasantness. Thus, a general state of comfort in summer might influence the interviewee to answer more positively and more negatively in winter. The investigation of this problem has to consider other factors that influence the biased responses reflected in these cases.

4.2 Annoyance perception

Figure 3 depicts the perceived annoyance by the public. A first observation regards the high number of participants in both seasons that evaluate the perceived annoyance of environmental noise as very low. The great majority (28% of the samples, N=41) for the winter season and even 36% (N=69) for the summer season respond to the annoyance induced by noise with complete denial. This is particularly interesting, because compared to perceived discomfort, the neutral option is not accentuated in terms of the total number of responses. A similar attitude to annoyance can be extracted from the diagrams that point in the same direction as discomfort perception. Again, the positive responses accumulate during summer season at lower noise levels resulting in a meaningful distribution, and spread rapidly towards negative. During winter season, the extreme negative appear denser despite the fact, that the total number of results is low. As already detected in loudness perception (Figure 1), two distinct areas can be observed in the psychoacoustic loudness evaluation scale.

4.2 Stress perception

A final analysis regards the accordance of loudness and stress perceptions (Figure 4). As can be seen there, the perception of noise induced stress does not portray a clear tendency, since almost every answer-option appears over the entire range of measurement data. Except for the summer season, where a high number (24% of the samples, N=47) judged the ambient noise as 'extremely stressful' and the same amount (25%, N=47) as 'neutral'. In winter season, the maximum number (28%, N=41) is found with the selection of 'neutral'. However, the positive replies in summer season are in compliance with the measured low noise levels, whereas the broad distribution of the neutral responses indicate the majority of users perceive the acoustic environment as neither 'stressful' nor 'relaxing', which also applies for winter season.

5. Conclusions

In this paper, we report on a first approach in which we captured the perception of ambient noise in an urban environment. During winter and summer time, the noise was psychophysically (dB(A), sone) measured during daytime and the respective evaluation of dwellers was determined. In order to understand the psychological quality of ambient noise, users` perceptions on loudness, discomfort, annoyance and stress were identified. Findings show that the evaluations and therefore the perceptions differ across seasons. Only the summer measurements show a significant accordance between perceptions and noise levels or psychoacoustic loudness.

We cannot fully explain this seasonal effect on the basis of the present results. Possibly, the overall comfort during summer might have an impact on the validity of perceptions. It should also be taken into account that there are more environmental factors, which might influence perceptions in an urban environment. Here, the thermal comfort, the wind speed or the perceived humidity could have an effect. Future studies will have to analyze the joint or combined effects of different stressors on human perceptions. Another interesting field of research is directed to user diversity. So far, we conducted a quite undefined sample of dwellers and city visitors of a wide age range. However, it is more than plausible that the individual sensitivity to loudness and the personal coping strategy are crucial factors that may determine the relative amount of discomfort or stress perceptions. Thus, further research should concentrate on the diversity of users, taking gender, age, health states, and individual sensitivities to environmental stressors into account. In addition, we will also concentrate on the relative impact of context diversity. The perceptions of noise stress could also depend on the social reasons why persons visit a city (leisure time vs. duty stroke) [3], [9–11]. Further, we should examine more extreme urban stressors, in order to validate the evaluations.

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