Pleasantness evaluation of combined environmental sounds

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ABSTRACT

Predicting human evaluation of complex acoustical environments still poses a challenge. In order to explain annoyance reactions to combined sounds, various models have been developed, often based on a weighted combination of loudness or sound pressure levels. However, these models are limited regarding the evaluation of sound quality and pleasantness. Natural sounds, for example, can also have a beneficial effect in noisy environments, although they represent additional sound sources, which increase the overall sound pressure level. Moreover, a superposition of different sounds can produce musical structures like rhythm patterns or harmonic constructs, which influence the evaluation as well. Behind this background, we investigated how pleasantness ratings of singular sounds affect the overall evaluation of their respective combinations. Since pleasantness judgements are often confounded with loudness, a listening experiment was conducted, to separate these two variables. A positively and a negatively perceived sound, each one with three different loudness levels, were combined in pairs in all possible configurations and evaluated by test participants. The results of this experiment were used to validate a linear regression model, which explains well the overall pleasantness evaluation of two combined environmental sounds, using the weighted sum of the singular pleasantness ratings and their interaction.

Keywords: Sound Quality, combined sources, environmental sounds I-INCE Classification of Subjects Number(s): 01.7, 63.7, 69

1. INTRODUCTION

According to a survey of the German Federal Environmental Agency 44% of the German population feel annoyed by more than one noise source in their home environment (1). In fact, humans usually are not exposed to singular sound events in everyday life, but they are surrounded by complex acoustical settings, where various environmental sounds interfere with each other and contribute in different ways to an overall impression of the perceived environment. However, predicting the effect of combined environmental sounds with various characteristics poses a particular challenge, due to the great variety of interaction effects, like spectral masking, temporal patterns (2) or even musical structures influencing human evaluation of the sonic environment.

Research on the effect of combined sounds often focuses on annoyance reactions to combined traffic sounds (road, railway and aircraft noise) or industrial noise. In this domain, various computational models predict the total annoyance based on sound pressure levels or loudness of singular sources (3), often supplemented by perception related correction factors derived from dose-response-studies (4). Recent developments like the linear mixed model combine the advantages of different model approaches (5). However, these kinds of annoyance models are limited regarding the evaluation of overall sound quality in complex acoustical environments, particularly when different types of sounds are present. In this context, Marquis-Favre gives a review on qualitative aspects of sounds and their implications for the evaluation of annoyance (6). Furthermore, the evaluation criterion annoyance represents only one qualitative dimension, since a not annoying sound

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is not necessarily pleasant. Besides, it is only one factor amongst others influencing perceived sound quality. Moreover, no standard definition of noise annoyance exists yet. According to Guski (7), "…noise annoyance is a multi-faceted psychological concept, including behavioral, and evaluative aspects." Annoyance reactions are subject to emotional factors as well as to cognitive factors like attitude towards and knowledge about specific sounds. In addition, context variables like disturbance of action or communication play an important role in the evaluation process. Hence, the factor noise annoyance is treated differently in many field and laboratory studies.

Research shows that the application of natural sounds like water or bird song into noisy environments can have a positive influence on the sound quality (8). In urban parks, water fountains are a common instrument to decrease the perceived annoyance caused by traffic noise. In an experiment on the effect of an acoustically optimized water fountain in a courtyard also higher pleasantness ratings were achieved for the combination of water and traffic noise (9). This positive effect, which can be attributed to psychological factors like attention distraction, cannot be explained with models based on sound pressure levels, since the natural sound represents an additional source, which increases the overall sound pressure level or loudness.

As a result of perceptual and cognitive processing of a sound, a pleasantness rating already integrates non-acoustical influence variables like personality factors and contextual variables. Behind this background, it is worth considering a modeling approach based on judgements and to investigate to what extent an overall rating of an acoustical environment can be predicted on the basis of pleasantness ratings of singular sound events. In the course of a research project at the Hochschule Düsseldorf, University of Applied Sciences, funded by the Federal Ministry of Education and Research, the fundamental relationship between pleasantness assessments of singular environmental sounds and their combinations is investigated. The aim of the project is to provide an empirically based description of human evaluation strategies in complex acoustical environments with multiple sound sources. Based on the results of two listening tests a linear regression model was proposed, which explains well the overall pleasantness evaluation of two and three combined environmental sounds, using the weighted sum of the singular pleasantness ratings and their interaction (10). In this model, unpleasant sounds receive a greater weight compared to pleasant ones, which might be attributed to masking effects and a negativity bias (11) affecting human evaluation processes. However, this model also provides for a 'halo effect', which can be evoked by positively connoted sounds. In comparison with the previously mentioned annoyance models, the pleasantness model explains the results from the listening test in a more accurate way.

Since pleasantness ratings are often confounded with loudness, a validating experiment was concluded in the next step, where both variables were separated. The effect of pleasant and unpleasant environmental sounds with systematically varied loudness was investigated in a listening study.

2. LISTENING EXPERIMENT

2.1 Sample

23 persons (4 female, 19 male) with a mean age of 29.22 years (SD: 8.71 years) participated in the listening experiment. The participants were students and employees of Hochschule Düsseldorf, University of Applied Sciences and employees of HEAD acoustics company in Herzogenrath, Germany.

2.2 Stimuli

In a short pretest, outdoor recordings of four different environmental sounds were selected, two of them being evaluated as pleasant (stream, ocean) and two as unpleasant (lawn mower, wind turbine). Each sound was graded in three different loudness levels ($N5$ = 5, 10 and 15 sone). Then two stimulus sets of pairwise combinations of one pleasant and one unpleasant sound were prepared as depicted in Table 1. The singular sounds were summed without any loudness modification to create the combinations. The first stimulus set contained all nine possible loudness combinations of the stream and the lawn mower sound. The ocean and the wind turbine sound were combined equivalently in the second stimulus set. Moreover, 57 different environmental sounds, within a similar loudness range, were selected as distracting sounds. The only selection criterion for the distracting sounds was that the sound should be recognizable. Each stimulus had a length of 12 seconds.

Table 1 – Distribution of pleasant and unpleasant environmental sounds in Stimulus Set 1 and 2

Loudness	Stimulus Set 1		Stimulus Set 2	
(N5)	Pleasant	Unpleasant	Pleasant	Unpleasant
5 sone	Stream low	Lawn mower low	Ocean low	Wind turbine low
10 sone	Stream medium	Lawn mower medium	Ocean medium	Wind turbine medium
15 sone	Stream high	Lawn mower high	Ocean high	Wind turbine high

2.3 Test procedure

The experiment was conducted in the sound studio of HEAD acoustics company in Herzogenrath, Germany. Each participant performed the test independently using a computer-based questionnaire. The sounds were presented via headphones (Sennheiser HD650) in randomized order and only once. Participants were asked to evaluate the *Pleasantness*, *Loudness* and *Sharpness* of the perceived sound on an 11-step bipolar rating scale in the context of spending some leisure time outside. The evaluation items *Loudness* and *Sharpness* were used only as distractors to avoid, that participants anticipate the experimental question and adapt their evaluation behavior. Due to the great number of stimuli, the experiment was divided into two parts with a short break in between. In the first part the participants had to evaluate 56 sounds in total (Stimulus set 1 consisting of 6 single sounds, 9 sound combinations, 41 distracting sounds) and in the second part 31 sounds (Stimulus set 2 consisting of 6 single sounds, 9 sound combinations, 16 distracting sounds).

3. RESULTS

3.1 Experiment part 1

The arithmetic means of the *Pleasantness* ratings (unpleasant = 1) from the first part of the listening test are depicted in Figure 1. The dashed lines represent the single sounds “stream” and “lawn mower” and the solid lines show the combination results. The three different loudness steps (N5 = 5, 10 and 15 sone) of the singular sounds are labelled as “low”, “medium” and “high”.

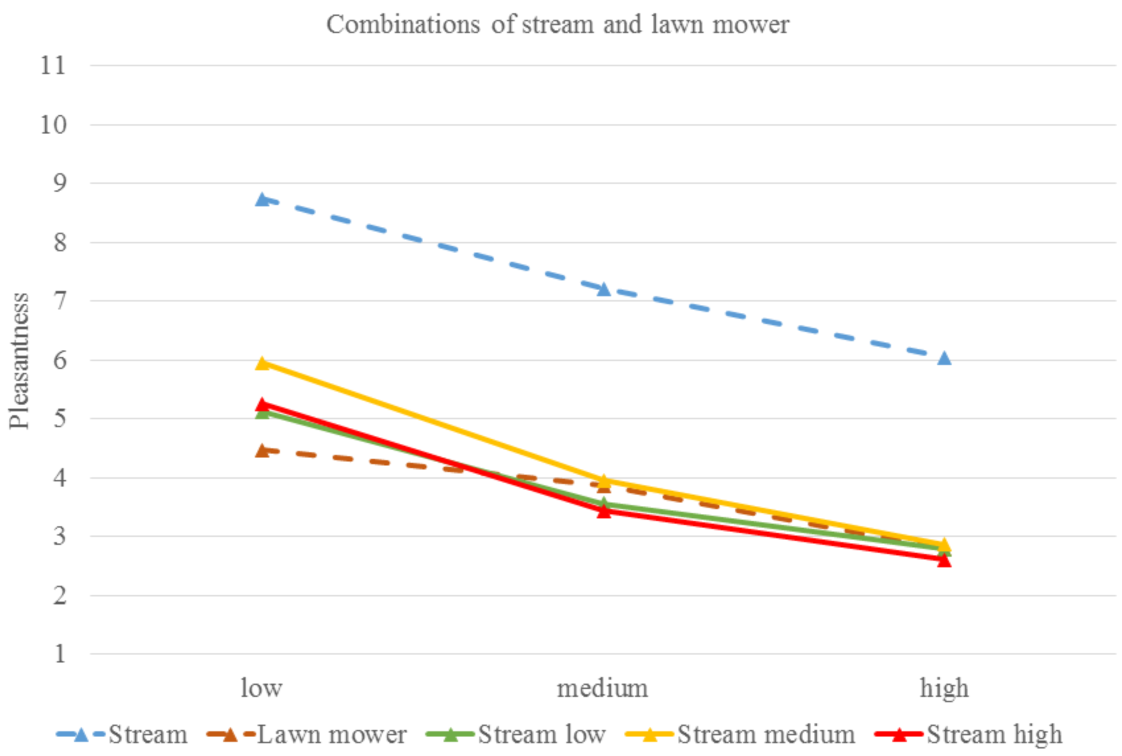

Figure 1 – Pleasantness ratings (arithm. means) of single sounds (dashed) and their combinations (solid)

With increasing loudness, the *Pleasantness* rating of the stream sound decreases from a mean value of 8.7 (SD: 1.9) to 6.0 (SD: 2.6). The mean values of the lawn mower range from 4.5 (SD: 1.5) to 2.8 (SD: 1.2). The combination ratings show, that the lawn mower sound has a dominating effect on the overall *Pleasantness*, independent from its loudness. In all cases, the combination ratings are significantly lower than the singular stream sound. The apparent increase of mean *Pleasantness* of the low lawn mower sound when being combined with the three versions of the stream sound is not statistically significant (p > .08, α = .05).

Source	SS	df	MS	F	p	etaSq	partEtaSq	genEtaSq
Subj	103.44	23.00	4.50					
A	9.90	2.00	4.95	2.00	0.1465	0.0138	0.0801	0.0227
B	278.12	2.00	139.06	60.29	0.0000	0.3875	0.7239	0.3945
A x B	2.85	4.00	0.71	0.63	0.6401	0.0040	0.0268	0.0066
A x Subj	113.66	46.00	2.47					
B x Subj	106.10	46.00	2.31					
A x B x Subj	103.59	92.00	1.13					
Total	717.66	215.00						

Figure 2 – two-way ANOVA (repeated measurements)

The dominant influence of the lawn mower sound on the overall rating is supported by the results from a two-way ANOVA for repeated measurements shown in Figure 2, where factor A (F = 2.00, p = .15, α = .05) represents the stream sound and factor B (F = 60.29, p = .00, α = .05) the lawn mower sound. In this case, there is no significant interaction effect between both predictors (F = .63, p = .64, α = .05).

3.2 Experiment Part 2

The *Pleasantness* ratings from the second part of the experiment, where the combination of the ocean sound with wind turbine noise was investigated, are depicted in Figure 3.

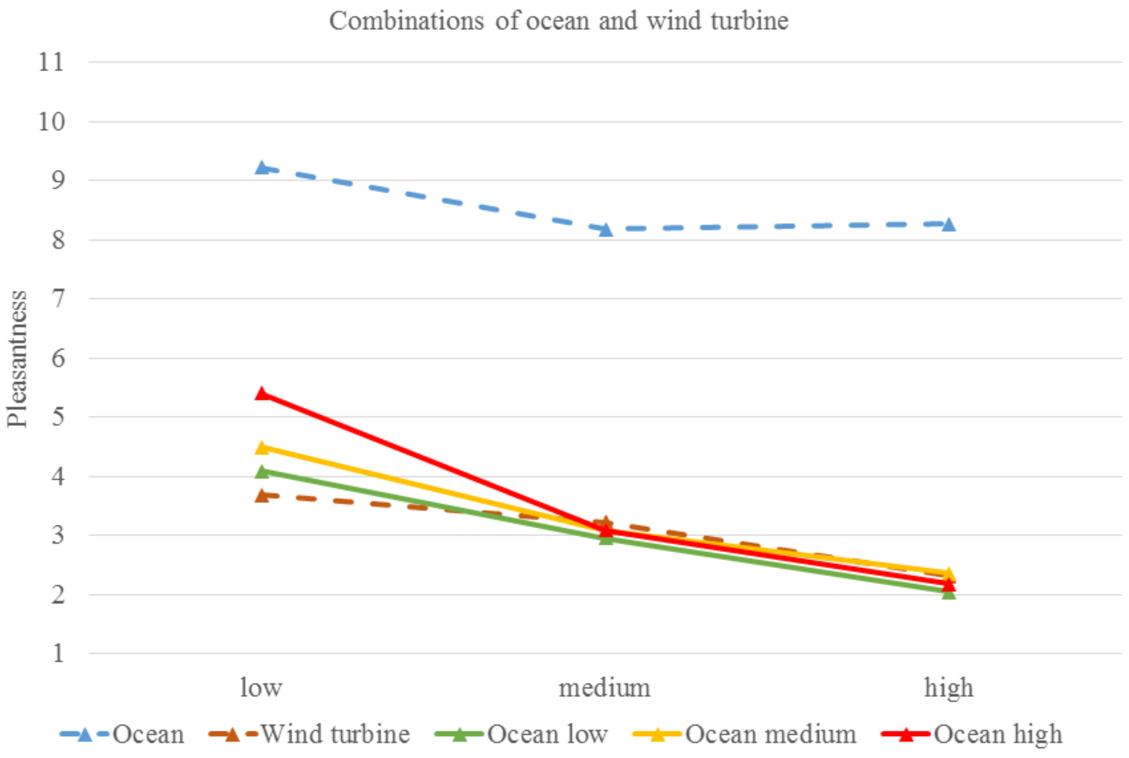

Figure 3 – Pleasantness ratings (arithm. means) of single sounds (dashed) and their combinations (solid)

The low ocean sound achieved a mean *Pleasantness* rating of 9.2 (SD: 1.6). The medium and high version of this sound were rated slightly worse and have nearly similar mean values of 8.2 (SD: 2.1) and 8.3 (SD: 2.1). The *Pleasantness* of the wind turbine noise decreases from a mean value of 3.7 (SD: 1.0) to 2.3 (SD: 1.1) with increasing loudness. Regarding the combination of wind turbine noise with the ocean sound, two different observations can be made: The *Pleasantness* ratings of the high wind turbine noise combined with the three versions of the ocean sound are similar to the rating of the singular high wind turbine noise. The ocean sound does not enhance the *Pleasantness* of the wind turbine noise. The same applies for the combination of the medium wind turbine noise with the three versions of the ocean sound. However, the combination of the high ocean sound with the low wind turbine noise has a mean *Pleasantness* value of 5.4 (SD: 2.0) and was rated significantly better than the singular wind turbine noise ($p < .01$, $\alpha = .05$). In this case, the ocean sound has a beneficial effect on the overall Pleasantness rating. The two-way ANOVA shows three significant predictors. The ocean sound is represented by factor A ($F = 9.2$, $p < .01$, $\alpha = .05$) and the wind turbine noise by factor B ($F = 46.31$, $p < .01$, $\alpha = .05$). As already seen before, the unpleasant sound has a stronger effect on the combination rating than the pleasant sound also in this part of the experiment. However, the highly significant variable A x B ($F = 5.54$, $p < .01$, $\alpha = .05$) depicts an additional interaction effect of both sounds, which was not observed in the first part.

Source	SS	df	MS	F	p	etaSq	partEtaSq	genEtaSq
Subj	164.86	22.00	7.49					
A	10.55	2.00	5.28	9.20	0.0005	0.0180	0.2949	0.0296
B	214.99	2.00	107.49	46.31	0.0000	0.3673	0.6780	0.3831
A x B	13.59	4.00	3.40	5.54	0.0005	0.0232	0.2012	0.0378
A x Subj	25.23	44.00	0.57					
B x Subj	102.13	44.00	2.32					
A x B x Subj	53.96	88.00	0.61					
Total	585.30	206.00						

Figure 4 – two-way ANOVA (repeated measurements)

4. DISCUSSION

In both parts of the experiment the unpleasant singular sound had a stronger effect on the *Pleasantness* ratings of the combinations than the pleasant sound. The combination ratings predominantly match the *Pleasantness* values of the 'negatively connoted' singular sound, independent of its loudness. This might be explained by the negativity bias mentioned before. Obviously, the characteristic sound of the lawn mower, with a high amount of roughness, created a dominant negative impression in the evaluation context of this study, which could not be improved by any version of the stream sound. Consequently, no significant interaction effect between both singular sounds was observed in the first part of the experiment.

In the second part of the test, the results are slightly different. Although the singular wind turbine noise with the lowest loudness was rated as very unpleasant, the combination with the ocean sound resulted in higher *Pleasantness* ratings in all three cases. Even the loud ocean sound contributed to an improved overall evaluation. One reason might be the fluctuating time structure of the ocean sound, which presumably influenced the perception of the wind turbine noise, due to the occurring temporal masking effects. Moreover, contextual factors like associations with a relaxing beach ambiance have to be mentioned as potential influencing variables. This presumably creates an additional value, which results in a higher *Pleasantness* rating of the sound combinations. The results from the ANOVA show, that both singular sounds and their interaction have a significant effect on the overall evaluation. However, when the loudness of the wind turbine noise was increased, no beneficial effect of the ocean sound on the combination ratings was observed any more.

In summary, the findings from this experiment support the assumption, that a Pleasantness model based on singular ratings is a promising tool to provide a more precise prediction of overall sound quality evaluations than measures based on loudness or sound pressure levels. However, more research is required to validate the model with regard to more complex sonic environments. Since moving sources raise attention easier than stationary sounds, their contribution to an overall rating has to be examined in detail. When distinct temporal and harmonic structures occur, additional evaluation mechanisms like musical taste also become relevant. Finally, the effect of non-acoustical stimuli should be systematically included in further experiments.

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