The perception of susurration: Envelopment in indoor and outdoor spaces

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Abstract

This paper investigates a connection between perceptions of indoor and outdoor soundscapes. The word susurration is used in non-scientific writing to describe sounds such as wind in trees and rushing water. It is hypothesised that these sounds give rise to a sensation of envelopment in a similar manner to the indoor susurration of reverberated speech, even when reproduced monophonically. Fifty-three listeners were asked to rate perceived envelopment for susurration and non-susurration sounds. One group of subjects rated the envelopment of susurration sounds highly. Mean envelopment for these listeners is correlated with low-frequency auto-covariance.

1. Introduction

Listener envelopment is recognised as a key determinant of quality in concert hall acoustics [1]. Several components of perceived spaciousness have been identified and most can be related to inter-aural cross-correlation. Objective measures based on IACC are found to correlate highly with subjective quality indices [2]. In another field, recent interest in soundscape design has prompted study of the perceptual attributes of sounds in outdoor environments [3]. Listening to monophonic recordings of wind in trees and applause suggested the following hypotheses:

H_1: Perceived envelopment for monophonic susurration sounds is greater than that for non-susurration sounds.

H_2: Perceived envelopment for monophonic susurration sounds is related to their autocorrelation.

2. Method

Fifty-three untrained subjects, all first-year students of acoustics, took part in the experiment. Five monophonic 30 s stimuli were presented to the subjects, each three times. The stimuli were: rushing water, 1 kHz sine wave, reverberated speech babble, dry speech babble and birdsong. All the subjects listened to the stimuli together in a non-reverberant classroom. The stimuli were reproduced with a single loudspeaker at the front of the room and were all normalised to the same L_{Aeq}. This varied from 71.0 dB at the front of the room to 65.1 dB at the back. The subjects were asked to rate perceived envelopment and preference for each stimulus on an unmarked continuous linear scale. 10 s was allowed for the two judgements after each presentation.

3. Results and Discussion

3.1. Subject responses

Responses were normalized within each subject so that all data reported here is from 0 to 1. An analysis of variance revealed that subject position in the room was not found to be significant. However, there was a significant interaction between subject and stimulus. The subjects split into two groups (n_1 = 14 and n_2 = 39), depending on how they rated the envelopment of the sine tone. Mean envelopment ratings for the two groups appear in Figs. 1 and 2. The stimuli are enumerated in the order given in the Method.

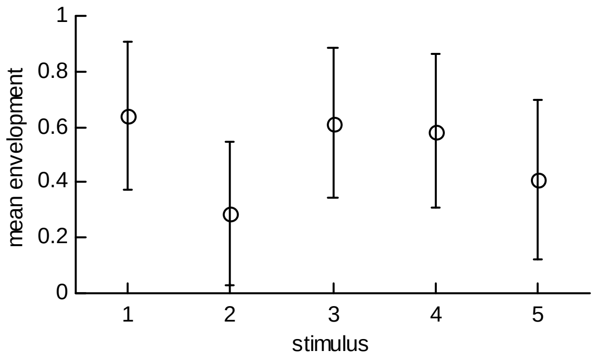

Figure 1: Mean envelopment for subject group 1.

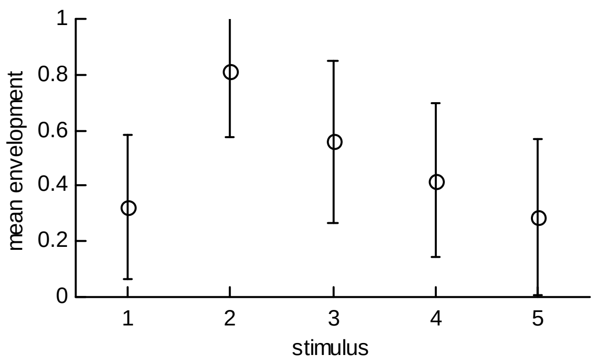

Figure 2: Mean envelopment for subject group 2.

We see that, for both groups of subjects, envelopment varies with stimulus, even though the sounds were presented monophonically. For both subject groups, the envelopment of rushing water (1) and the sine wave (2) are significantly different. Subject group 1 seems to have interpreted the stimuli as envisaged in H_1. Subject group 2 rates the sine wave as the most enveloping stimulus. This surprising result may arise from using the subtle concept of envelopment with untrained subjects. It may be that group 2 have interpreted 'envelopment' as meaning 'hard to localise'. We might expect the single-frequency continuous tone to be harder to localise than the broadband noise of rushing water.

The subjects were more homogeneous in rating their preference for the stimuli, so the mean for all subjects is shown in Fig. 3. Envelopment and preference are significantly different. For example, birdsong (5) represents a natural sound that is pleasant, but does not give rise to high envelopment.

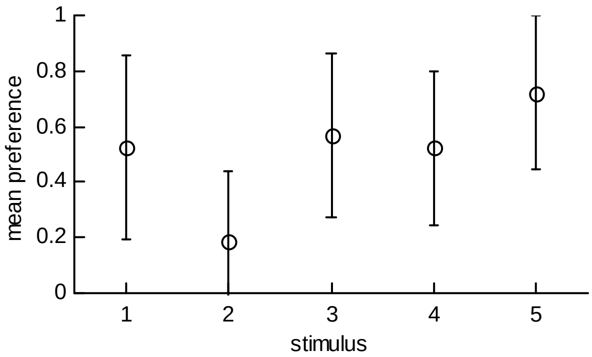

Figure 3: Mean preference ratings for all subjects.

3.2. Correlation with objective data

To investigate H_2, the auto-covariance of each stimulus was found. From informal listening, it was surmised that susurration might be perceived as enveloping because it sounds self-similar. Susurration might be characterized as many similar (but not identical) events overlapping each other. The auto-covariance was therefore passed through a low-pass filter to reveal low-frequency self-similarity. Figure 4 shows a typical plot, the auto-covariance of stimulus 1 (water), filtered at 20 Hz. The main peak around $\tau = 0$ is surrounded by a series of smaller peaks representing significant self-similarity. This feature is shared by stimulus 3 and 4 (babble) but not by stimulus 2 (sine) and 5 (birdsong).

A single-figure measure of self-similarity can be obtained by evaluating the rms of Fig. 4, excluding the central peak. This has been done for all five stimuli and the results plotted against the mean envelopment from subject group 1. Figure 5 shows that there does appear to be a relationship between this measure of self-similarity and perceived envelopment, at least for one group of subjects. The correlation coefficient of Fig. 5 is 0.89.

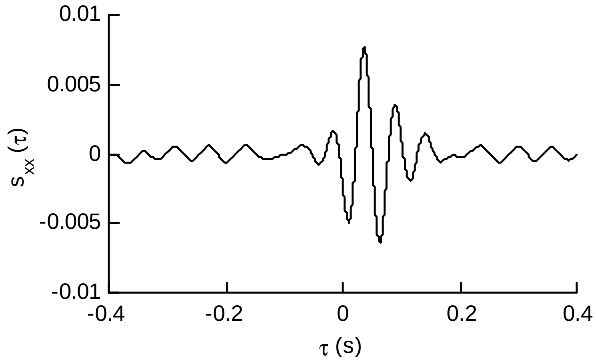

Figure 4: Low-pass filtered auto-covariance of rushing water.

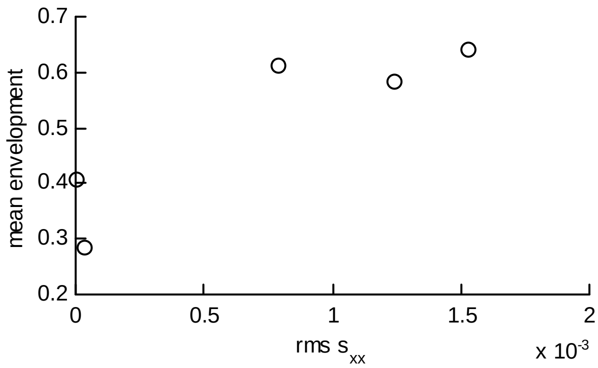

Figure 5: Mean envelopment vs. rms auto-covariance.

4. Conclusions

Tentative evidence has been presented to show that susurration sounds may be perceived as inherently enveloping and that this is related to their properties of self-similarity. Considerable refinement of the pilot experiment is now needed to exert more control over the stimuli and explore listener response in more detail using trained subjects.

5. References

[1] Bradley, J. S. and Soulodre, G. A., "Listener envelopment: An essential part of good concert hall acoustics", *J. Acoust. Soc. Am., Vol. 99, 1996, p 22-22.*

[2] Beranek, L. L., "Subjective rank-orderings and acoustical measurements for fifty-eight concert halls", *Acta Acust., Vol. 89, 2003, p 494-508.*

[3] De Coensel, B., Botteldooren, D. and De Muer, T., "1/f noise in rural and urban soundscapes", *Acta Acust., Vol. 89, 2003, p 287-295.*