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MEASUREMENT OF ANNOYANCE COMPONENTS

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1. INTRODUCTION

Indices that best approximate human reaction to adverse sound environment have to incorporate human evaluations of noise annoyance which in turn have to be based on selected physical attributes responsible for the annoyance perception. Currently, the most popular approach defines noise annoyance in terms of a single physical variable, that is, sound pressure level, which is easily identified and measured in laboratory conditions. This traditional model implies that changes in sound pressure level result in changes in loudness as well as changes in annoyance perception. Annoyance is thus but a special case of loudness and research in this area is restricted to studies of how to best adjust noise indices to situations that have been assessed as annoying. It should be emphasized that this approach does not allow for measuring annoyance with satisfactory validity. Only in artificial, laboratory conditions where subjects are exposed to non-complex, isolated, specially prepared signals can their evaluations of annoyance be identified with loudness measures. However, such results cannot be generalized to natural sound environments. Noise index based on loudness used as a measure of annoyance in a natural sound environment is an idealization that goes too far. Physical description of natural sound cannot be identified with a description of a highly idealized simple acoustic signal. This approach deprives the natural sound of precisely those features which are decisive in evoking annoyance perception. Therefore, a physical description of a sound event which occurs in the natural environment should take into account other attributes which, apart from loudness, contribute to noise annoyance.

In this paper, I propose an environmentally oriented multicomponent approach to noise annoyance which comprises three components: annoying loudness, intrusiveness, and distortion of informational content. Scale values of the three components can be objectively measured and calculated with the help of annoyance formula. Moreover, the proposed annoyance formula explicitly takes into account the role of background sound in calculating the values of the three components of annoyance. It should be stressed that the proposed approach is not based on well developed research about physical causes of annoyance but it preserves the belief in the plausibility of constructing such an annoyance index. This approach also enhances the idea that certain components of annoyance such as intrusiveness and confusion brought about by the impairment of information, which are considered to be subjective, can be defined with objective attributes.

2. ENVIRONMENTAL SOUND

The distinction between sound and noise in the environmental approach is made in reference to the natural and distorted sound environment. If we make a distinction between perception of sound and reception of noise we can say that in the natural environment sound is perceived whereas in the distorted environment noise is received [11]. It is the distorted environment that produces sensation of annoyance; it occurs when a specific sound, "noise", distorts the natural sound environment.

The difference between natural and distorted sound environments refers to subject's ability to selective processing of information. In the natural sound environment perception is unconstrained, that is, an individual can selectively focus on a particular sound or a group of sounds, shifting his/her attention at will. Each sound can be perceived as either a signal or a background sound. In a distorted sound environment, where noise is imposed on a hearer such shifting of attention is impossible.

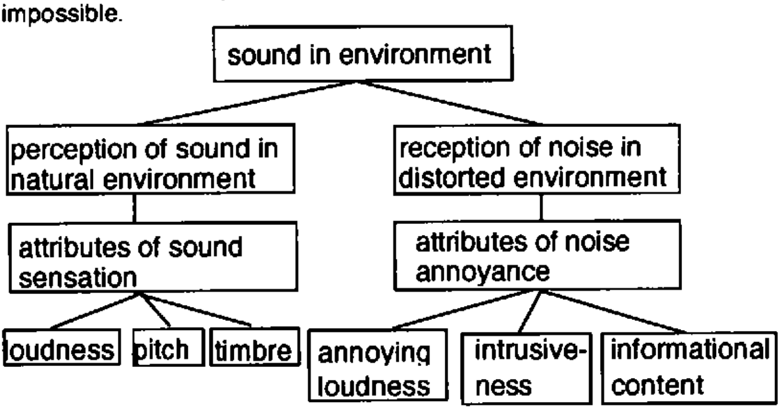

Figure 1. Distinction between sound and noise according to the environmental approach.

It follows that the concept of annoyance makes sense only in the context of distorted sound environment: sounds belong to the natural environment and noises - to the distorted environment (Fig. 1).

3. MULTICOMPONENT APPROACH TO ANNOYANCE

The limitations of the common loudness approach to annoyance have been recognized by several researchers: [2], [7], [8], [9]. Based on my own research, I would like to suggest an alternative approach to annoyance. I propose to consider annoyance as a complex attribute of noise. By noise annoyance I mean an auditory event that appears in distorted sound environment. Exposure to such distortions evokes an annoyance perception. It follows then, that the annoyance perception depends on the relationship between a foreground noise and a background (ambient) sound.

Noise occurs simultaneously with a certain background sound and, as its background changes, the annoyance perception changes too. Although this phenomenon is well recognized [6], it has not substantially affected research and therefore existing noise indices underestimate the influence of background sound on noise annoyance. Furthermore, it is claimed that physical parameters of both noise and background sound, are important and should be taken into account in constructing a more subtle noise index.

The proposed annoyance formula comprises three-components: annoying loudness (AL), intrusiveness (IN), and distortion of informational content (DR). This formula takes into account how changes in these components influence the annoyance perception. The first sketch of the three-component concept of annoyance was presented in [4]. The expanded version of it which defined these components in relation to background sound and also accounted for the environmental character of annoyance was reported in [11].

Two of the components, AL and IN, are defined in a similar way. Annoying loudness is the time-averaged value of the difference between the loudness of the noise and of the background sound, related to the time-averaged background loudness. Intrusiveness is also the time-averaged value of the difference between the sharpness of the noise and of the background sound, related to the time-averaged background sharpness. The third component, distortion of informational content is the ratio of the duration of all distortions in the measured sound to the total time measurement.

The formula for noise annoyance (An) can be expressed as follows,

$$An = \alpha \cdot AL + \beta \cdot IN + \gamma \cdot DR + \delta, \qquad (1)$$

where α, β, γ, and δ are free parameters and AL, IN and DR are the variables. For steady-state sounds, this formula has the following form

$$An = \alpha \cdot AL + \beta \cdot IN + \delta, \qquad (2)$$

with three free parameters α, β, δ and two variables AL and IN.

Loudness Based Annoyance

The approach proposed here assumes that the assessments of annoyance are not based on absolute judgements of loudness. It is claimed that noise annoyance due to loudness is determined mainly by the relative judgements of noise loudness. Therefore, annoying loudness is defined as follows,

$$AL = \frac{\frac{\Delta t}{T}\sum_{i=1}^{n}\left\{L_{ZS}(t_i) - L_{Zb}(t_i)\right\}}{L_{Zb}}, \tag{3}$$

where T is the time period of measurement, Δt is the time interval between the (i)th and (i+1)th moments of time, $L_{ZS}(t_i)$ is Zwicker's loudness value (sometimes the symbol N is used to denote this loudness) for the noise in the i-th moment of time, $L_{Zb}(t_i)$ is Zwicker's loudness value for the background sound at the same time (i–th moment), and L_{Zb} is the time-averaged of loudness value of the background sound.

Equation 3 defines the physical parameters involved in the human perception of annoyance: it determines how certain changes in environmental loudness (loudness of a foreground noise related to the loudness of definite background sound) produce changes in the annoyance perception. The way in which the AL component is defined here takes into account different annoyance judgments for the same foreground noise occurring in different background sounds.

Intrusiveness Based Annoyance

The concept of intrusiveness was introduced to specify a class of sounds which are judged as highly annoying, but existing noise indices qualify them as non-annoying. In the literature the term intrusiveness is frequently used as a "surrogate for annoyance produced by low-level noise exposure" (e.g., Fidell et al., [6], p. 1427). This definition limits the use of the term to low-level sounds. However, in the natural environment there are many sounds which are perceived as annoying irrespective of whether they are loud or soft. An example is the sound of a finger nail scraping against glass. According to Preis [10] intrusiveness of a sound depends primarily on the quality of the sound and is independent of the value of its sound pressure level.

Existing noise indices can be used in annoyance estimation only if applied to a limited class of sounds. This class does not comprise a large number of low-level sounds commonly considered annoying because of their acoustic features ([5], [6]). A quantitative measure of intrusiveness is based on sharpness calculated according to Aures model [1]. His formula for sharpness is as follows

$$S = c\frac{\int_{z=0}^{24Bark} N'(z)g'(z)dz}{\ln\left\{\frac{N/sone+20}{20}\right\}sone}acum, \qquad (4)$$

where N′ is specific loudness for a certain critical band, z, and g′ is a weighting function (described in detail in [1]), and c is a constant which gives the quantity 1 acum for the reference sound.
Using Aures model of sharpness and assuming that similarly as it was with loudness, sharpness of noise should be relativized to the sharpness of background sound we can define intrusiveness in the following way,

$$IN = \frac{\frac{\Delta t}{T}\sum_{i=1}^{n}\left\{S_s(t_i) - S_b(t_i)\right\}}{S_b}, \qquad (5)$$

where T is the time period of measurement, Δt is the time interval between (i)th and (i+1)th moments of time, $S_s(t_i)$ is the sharpness of the signal measured in the i-th moment of time, $S_b(t_i)$ is the sharpness of the background sound at the same time, and S_b is a time-averaged of the sharpness of the background sound. Intrusiveness is particularly important in calculating annoyance of soft sounds [5]. Its role has also been discussed, especially with regard to annoyance of equally loud sounds [3].

Distortion of Informational Content

In the study on distorted speech [12], the changes in acoustic structure of auditory events consisted of a certain "distribution" of interfering gaps or noise in the speech signal. The proposed measure, that indicates how these interfering elements contribute to overall perceived annoyance is called the distortion of informational content (DR). DR is defined as the ratio of the sum of the duration of the distorting parts to the total signal duration,

$$DR = \frac{\sum_i \Delta t_i}{T}, \qquad (6)$$

where T is measurement time, Δt_i is the i-th time interval in which distortion occurs. The DR is that component of the noise annoyance measure which accounts for interferences in meaningful acoustic signals that hamper the decoding of the information contained in it.

The rationale behind such definition of annoyance formula is based on a belief that listener's feelings about the noise itself require far more complex physical representation than is usually allowed. The listener detects and reacts to the complex sound situation that in essence is equivalent to the distortion occurring in the natural sound environment. Such a distortion is able to evoke an annoyance for several reasons. First, noise can be so loud that it masks all simultaneously co-occurring sounds. In the extreme case, the value of the AL component suppresses the values of the two other components. In the case of softer sounds, however, annoyance perception depends mainly on intrusive aspects of the sound. And finally, when the sound is neither very loud, nor intrusive, annoyance may be evoked by the extensive distortion of the informational content carried by the sound. In such a case the DR component contributes most to the annoyance value.

4. CONCLUSIONS

1. The traditional approach to annoyance is based on a one-component concept of its physical counterpart. An environmental approach to noise proposed here replaces the single-component model with a multicomponent model of annoyance. The multicomponent approach to annoyance can be seen as a radical extension of the common traditional acoustical approach. Annoyance is not a function of loudness only (or sound pressure level), but of three independent components: annoying loudness, intrusiveness, and distortion of information content.
2. In the traditional approach annoyance scales are directly related to properties of sound perceived in normal (undistorted) conditions. In such conditions, sounds are perceived according to their loudness, pitch or timbre. The definition of annoyance proposed here assumes that annoyance perception applies to the distorted sound environment where normal hearing conditions are distorted by the occurrence of an unwanted signal imposed on subject. I do not think that the concepts of pitch, loudness or timbre of sounds can be easily transferred from the domain of sound perception and applied to the domain of noise reception. It seems, that in a distorted sound environment annoyance reception depends on other parameters than loudness, pitch and timbre. Experimental results reported in [11] indicate that main components of annoyance are fairly well represented by annoying loudness, intrusiveness, and distortion of informational content.

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