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How Acoustical Noise can cause Physiological and Psychological Reactions.

Behavioural-Ecological Considerations on the Origin of the Capability to Experience Annoyance

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ABSTRACT

"Traditional noise research" starts from psycho-physics of auditory perception, is based upon the correlation between annoyance ratings and physical measurements of sound energy, and defines annoyance usually by the level of sound pressure. In this approach, ecological or psychological meaning of acoustical events are not taken into account. In contrast, "ecological noise research" emphasizes the psychological function of sounds, e.g. for communication, environmental monitoring, or sensory feedback of motor activity. In this approach, annoyance is attributed to experienced interference between sounds carrying information about the current task, and sounds not compatible with the task. Therefore, physical noise measurements are considered as improper descriptions of noise annoyance.

The aim of the present paper is to outline a unifying theory of noise annoyance, which considers, apart from traditional and ecological aspects as mentioned above, also the biological function of being annoyed. In the resulting "psycho-biological" approach, a pre-consciously operating PLOF-detector (possible loss of fitness detector) is introduced, the output of which signals a person that fitness may diminish when continuing to stay in that situation, and therefore motivates a person to switch to a behaviour appropriate to overcome that situation.

Mathematically, in a first approximation the PLOF-detector's output can be considered as correlating with the energy equivalent sound pressure level. However, the psycho-biological approach implies that the PLOF-detector (a) marks man-made sounds originating from unfamiliar con-specifics as particularly threatening, and (b) is also capable of learning, such that, besides of the sound pressure level, originally neutral sounds can cause considerable reactions dependent on previous experiences. Therefore, the approach can explain differential effects of, and individual reactions to, sources and loudness of noisy events.

Three experiments are reported favouring the PLOF-model.

INTRODUCTION: MODELS OF NOISE ANNOYANCE

"Traditional noise research" predicts annoyance or other psychological or physiological reactions to noise from physical noise measurements. At present, the favourite measurement procedure is the energy equivalent sound pressure level (Leq). In order to answer the question, how precise the prediction is, the concepts of 'reliability' and 'validity' defined in the 'theory of psychological testing' can be applied (Kalveram 1995, 1997c). Thereby, the noise measurement procedure is regarded as 'test' and the related annoyance ratings as 'criterion'. The coefficient of correlation between these two variables then is the validity of the measurement procedure indicating its prediction power, and the coefficient of correlation between two successive series of measurements of the same sound sources represents its reliability. The reliability of the Leq (and derived measurement procedures) is, as often in case of physical measurements, close to its maximum value 1, its validity, however, turns out to be only moderate (about 0.5). This means that the Leq misses a good deal of the factors influencing personal annoyance ratings, but suffices to predict the average reactions to noise of groups of persons exposed to the same physical noise level.

Whereas traditional noise research focusses strongly on the psycho-physics of auditory perception with the Leq being the pillar, the present paper is dealing with the question, what else - apart from the Leq - causes people's noise annoyance? Or, expressed more precisely, what is the mechanism making people experience annoyance? Recent theories based originally on Gibson's "affordances" (Gibson 1979) emphasize that acoustical signals have a psychological function, e.g. they convey information about the environmental state, or provide for feedback of the individual's actions, or are used for communication or environmental monitoring (e.g. Guski 1991, Cutting 1982, Kaminski 1989). In this "ecological noise research" annoyance is considered to originate from acoustical signals not compatible with, or even severely disturbing, these psychological functions. In these theories, therefore, interference with current activities is the primary effect of noise exposure, followed by annoyance as the psychological reaction.

In the present paper this functional approach is extended implying also the biological function. In this "psycho-biological approach", annoyance following noise exposure is considered to convey a "possible loss of fitness signal" (PLOF-signal) indicating, that the individual's Darwinian fitness will decrease if she or he continues to stay in that situation (Kalveram 1997a, 1997b). Darwinian fitness can shortly be defined as the general ability to master life and to have reproductive success. Especially, non-familiar conspecifics appearing in the habitat diminish fitness of the inhabitants because they are going to exploit the same but restricted resources. Therefore, sounds carrying the information that they are man made are likely to evoke more annoyance than other sounds of equal level and spectral density. Annoyance then is the primary effect of noise exposure, distracting attention from the current activity in order to enable either retreat, aggress, stand by or coping behavior with respect to the source of the sound. A further conclusion drawn from this "psycho-biological" approach is, that the PLOF-detector should also be capable of learning to associate sounds with noxious sources.

An extended outline of the PLOF-concept is given in Kalveram (1997a). It can shortly be summarized as follows: First a harmful variable is assumed to be present in the environment, which affects the individual's (Darwinian) fitness. Then a chance is given that a neural detector will evolve, the input of which is the sensory – here acoustical - stimulation correlated with this harmful variable, while the output is motivating to actions which diminish that sensory input, thereby interrupting current behavior. An essential part of this detector can be called *event related integration of sensory data*. This prinziple relates the annoyance A caused by a sample of N harmful events to the expression I * N * dt/T, where T represents the time intervall under regard, N the number of events in that intervall, dt the mean duration of these events, and I the mean maximum acoustical intensity joined with these events. In logarithmic terms one yields log I + log N + log dt/T, which obviously approximates the energy-equivalent sound level (Leq) defined over the time T of observation. That means, annoyance A, measured by the Leq, can indeed be considered as representing primarily a possible-loss-of-fitness signal (PLOF-signal). This approach, however, is rough and does not evaluate variables modulating this relationship (Schick 1990).

Figure 1 depicts the three models of noise annoyance in terms of flow diagrammes. Especially the differences between the ecological and the psycho-biological approach are marked. In the ecological approach, noise interferes with the task related auditory signal. The feature detector extracts the task relevant signal and feeds it into the behavioural control which uses it to select the appropriate behavour and to adjust the task relevant activity. If interference is recognized, the interference detector produces an output signal interpreted as annoyance which makes the individual experiencing stress, but which has no further function in this model. The behavioural control unit tends to continue the current behaviour, however, it may happen, that the interference causes severe disturbations which force the individual to interrupt the task related activity (not shown in fig. 1).

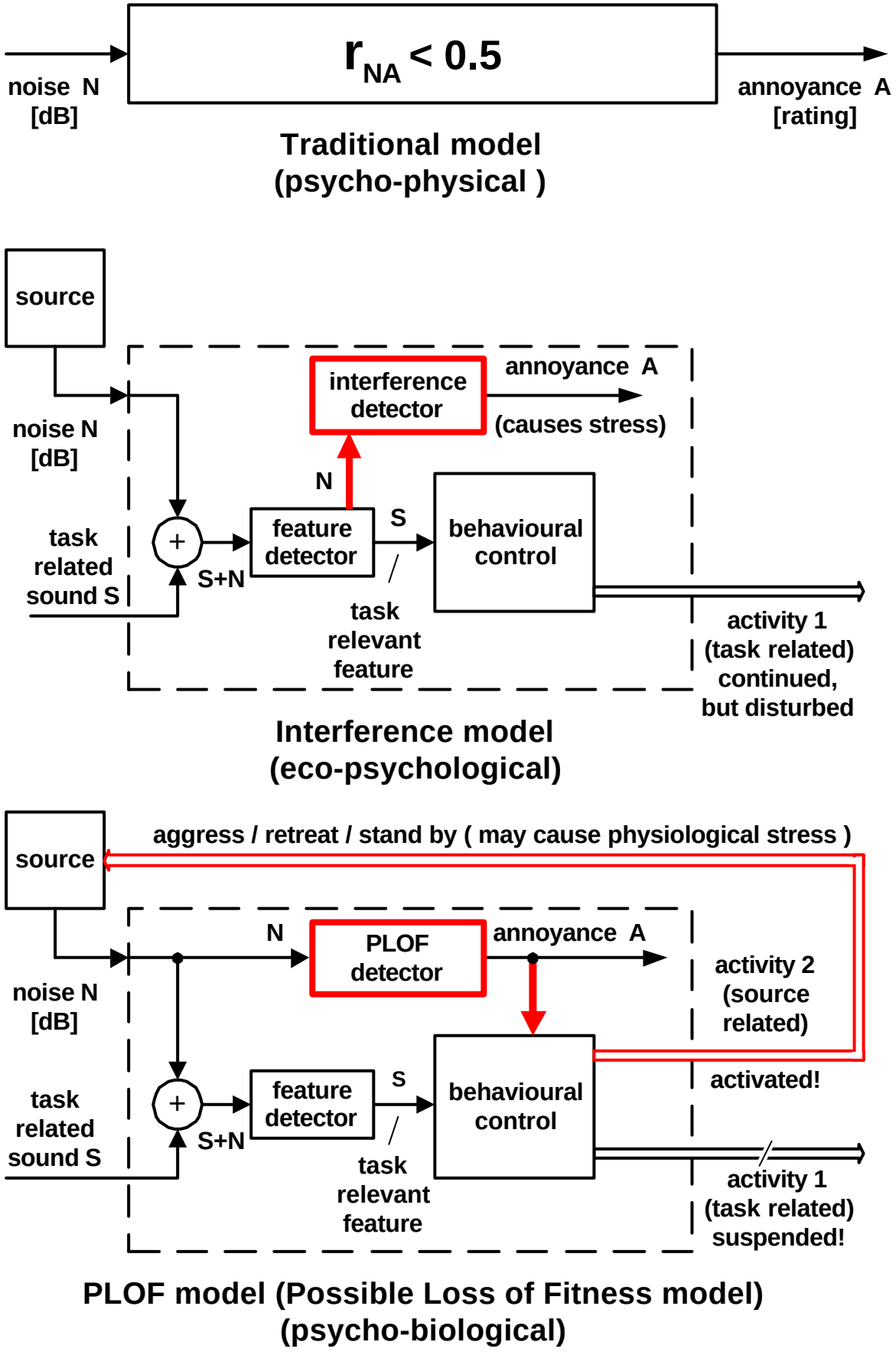

Figure 1: Three approaches to noise annoyance: The psycho-physical (top), the ecological (middle) and the psycho-biologicial model (bottom). For more inform ion see text.

In the psycho-biological approach, the interference detector is replaced by the PLOF-detector. Its input is the noise itself, and its output is the annoyance signal which acts upon the behavioural control, inducing it to suspend the current activity and to switch over to a behaviour appropriate to diminish the threatening indicated by the annoying sound. This can be performed by "aggress", that means actively removing the source, or by "retreat", that is leaving the situation. If no decision favouring one of these alternatives is made, "stand by" behaviour occurs which usually is conjointed with anger. Another type of behaviour can be called "coping", that means an inner adaptation process which enables the individual to relinquish outer source related activity, for instance by increasing the PLOF detector's threshold for putting out annoyance (not shown in fig.1; for types of behavioural control: see Kalveram 1998).

EXPERIMENTS

The three experiments reported below provide evidence for the psycho-biological model. They show that spectrally equalized or even identical sounds can have quite different effects on annoyance, dependent on wether they were attributed by the subjects as man-made or natural, or were associated with previous negative or neutral social experience. Descriptions and main results of three experiments are shortly summarized as follows (see also table 1):

Table 1: Short descriptions and main results of three experiments.
EG: experimental group. CG: Control group.
Statistical significance: >: p<5% . =: p>5% . (>): 5%<p<10%)

	Experiment 1	**Experiment 2**	**Experiment 3**
Sounds	party murmur / ocean surf	splashing water	intercom clicks
Condition	same context	different contexts: wastewater / brook	different history by instructions: anger inducing / neutral
Leq	54 dB(A)	52 dB(A)	55 dB(A)
Subjects	2 x 15	2 x 24	2 x 8
Results:			
Annoyance	$A_{EG} > A_{CG}$	$A_{EG} > A_{CG}$	$A_{EG} > A_{CG}$
Mental performance (error counts)	P_{EG} (>) P_{CG}	- -	$P_{EG} = P_{CG}$
Stress indicator	$A_{EG} = A_{CG}$	- -	$A_{EG} > A_{CG}$

In experiment 1 (Kalveram et al. 1999a) subjects heard recorded sounds of ocean surf and party murmur. Both sounds were carefully equalized regarding third-octave spectral energy and overall level (Leq =54 dBA). In the man made sound condition subjects felt significantly more annoyed. In this condition, subjects also tended to be more impaired in a free recall memory test. However, physiological stress indices (potassium/sodium measured in saliva) didn't discriminate significantly between the conditions.

In experiment 2 (Becher et al. 1997) an artificial sound mimicing splashing water (52 dB(A)) was presented to the experimental and control group with two different pictures: One picture showed a big pipe with wastewater comming out, the other a brook in a forest. Annoyance experienced in the wastewater condition was significantly higher than in the brook condition. Mental performance and stress variables where not recorded in this experiment.

In experiment 3 (Kalveram et al. 1999b) subjects (Ss) were exposed in a classical conditioning paradigm first to a click sound comming from an intercom, and then either to a neutral (control group, CG) or to a provocating anger inducing instruction (experimental group, EG). The Leq measured over the conditioning period was about 55 dB(A) in both groups. The click did not contribute essentially to the sound level because it was too short. Thereafter, the Ss were exposed to the click sound without an instruction, but now they had to perform mental arithmetics. Now, the Ss of the EG experienced

psychologically the click sound more annoying and reacted physiologically with higher arousal than the Ss of the CG, however, mental effectivity was not impaired. Furthermore, the Ss of the EG exhibited a tendency to adapt to the sound events slower than the Ss of the CG, and hence seem to develop a non-adapting physiological defensive reaction (Sokolov 1963; Jansen 1959, Kalveram et al. 1999b).

DISCUSSION

The results support the hypothesis, that, considered biologically, the main function of noise annoyance is to warn a person that fitness may diminish, but not necessarily to induce actual stress. There are hints that annoyance is caused primarily by the sound itself, not by experienced interference or disturbation as claimed by the ecological approach. Sure, in experiment 1 the enhanced error counts under the murmur condition can also be assigned to the interfering 'irrelevant speech effect'. However, especially experiment 3 exhibits, that an annoyance reaction can be acquired only by associating a click sound to a noxious social experience, without any introduction of interference with current activity. This additionally explains the frequently reported finding that moderate noise, though annoying, causes only little or even no mental impairments and/or physiological stress reactions. The warning signal put out by the PLOF-detector and experienced as annoyance can, therefore, be considered the primary effect of noise exposure, distracting attention from the current activity in order to enable either retreat, aggress, stand by or coping behavior with respect to the source of the sound.

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