TRAFFIC NOISE ANNOYANCE ON ROADS (TNA_R)

Michael Cik [a], Kurt Fallast [a], Robert R. Höldrich [b]

[a] Institute of Highway Engineering and Transport Planning, Graz University of Technology, Rechbauerstraße 12/2, 8010 Graz, Austria, E-mail: michael.cik@tugraz.at
[b] Institute of Electronic Music and Acoustics, University of Music and Dramatic Arts Graz, Inffeldgasse 10/3, 8010 Graz, Austria, E-mail: hoeldrich@iem.at

Abstract: *Noise is known as one of the most frequently reported negative environmental effects of traffic. At present, according to the current standards and calculation specifications, the impact of road traffic noise is represented by the A-weighted energy-equivalent sound level ($L_{A,eq}$). This quantity does not account for the subjective annoyance of sound events as it is perceived by the affected persons. The main focus of our research was to improve the sound analysis methods in order to include the subjective effects, especially annoyance, caused by traffic noise. This has been accomplished by the consideration of psychoacoustic findings. The result is joint target measure called traffic noise annoyance on roads (TNA_R). This TNA_R should be considered for future use in road- and traffic planning and therefore may serve construction engineers in addition to traffic planners as a supplemental tool.*

Key words: road traffic noise, psychoacoustics, annoyance;

1. INTRODUCTION

In a time of intensified efforts for environmental protection noise (especially traffic noise) has become of greater importance. We are concerned not only with the avoidance of hearing damage, which occurs only as a result of relatively high noise levels or long & persistent acoustic exposure, but also the reduction in well-being of the person.

The interfering effect of noise is referred to as "annoyance" in this research field. The annoyance of noise can be predicted only with difficulty, because a noise can be desired at a certain moment in time or disturbing in another context.

Noise causes certain reactions in specific people. These reactions depend on the one hand on the signal characteristics (amplitude, frequency spectrum, time characteristic), on the other hand upon the physical and psychological condition as well as the respective activity of the person concerned.

If the individual measured variables are consciously separated, then we can assume that the resulting value would provide an 'true' and reproduceable "noise annoyance" in a laboratory situation. Building upon a pilot study of "uninfluenced annoyance" [1] we characterize as "psychoacoustic annoyance" that portion of the disturbance or irritation which is exclusively influenced by auditory factors [2,3]. This occurs in a laboratory situation, if the test persons do not possess a relationship to the acoustic source; i.e. the sound contains no information. The annoyance is caused exclusively by the sound signal under defined test conditions during the experiment.

Sound is analyzed or processed by our auditory senses on the basis of psychoacoustic physical laws. An effective description of noise and the resulting annoyance can only be meaningfully achieved by taking into account the characteristics of the human hearing. It is therefore appropriate to draw on auditory perception in order to improve the description of "annoyance". These parameters (which are largely independent of each other) used by our hearing to classify sound, are for example, loudness, sharpness and roughness.

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The main focus of our research was to improve sound analysis methods in order to take account of the subjective effects, especially annoyance, caused by traffic noise. This has been achieved by the consideration of experimental psychoacoustic findings. The result is joint target measure called ‘traffic noise annoyance for roads’ (TNA_R).
Our study was a project cooperation between the Institute of Highway Engineering and Transport Planning of the Graz University of Technology, the Institute of Electronic Music and Acoustics of the University of Music and Dramatic Arts Graz and the Institute of Hygiene of the Medical University Graz.

2. METHODS

1.1. Recording technique and study design

In the first step, different road surfaces characteristics, most commonly found on Austrian highways, were determined and selected for sound recordings. Out of these various road surfaces, three different types were chosen: concrete, asphalt concrete and split-mastix-asphalt (SMA). In order to include a further typical parameter road sections with different noise protection barriers were selected for the sound recordings.
The pass-by noise of different passenger cars and motor trucks with variable speed profiles on each of these road surfaces was binaurally recorded with a dummy head measurement system from HEAD acoustics. Recordings were carried out on 600 m long homogeneous road sections (RVS 4.02.11, Austrian guidelines for roads and traffic) with free sound propagation within a distance of 100 m. Speed measurement of each passing vehicle was recorded by a velocity monitoring system. In order to keep the meteorological influence as small as possible, all measurements were performed between 2.00 and 4.00 am under conditions of identical temperature, approximately stable humidity and zero wind.
In the second step, from the database of the single passing vehicle recorded samples twenty-five vehicle ensembles considering different road surfaces, varying speed profiles, defined number of vehicles and noise barriers were synthetically composed by an audio editing software. The defined vehicle ensembles were created with duration of 30 seconds simulating an average traffic occurence on Austria’s highways during a representative time (Fig.1.). The designed vehicle ensembles contained A-weighted sound levels from a minimum of 52 dB to a maximum sound level of 72 dB.

Time	Composed passing vehicle ensemble
180 sec	**Vehicle ensemble A** ▪ 5 cars with 130 km/h ▪ 1 motor-truck with 90 km/h ▪ SMA (Highway A2 – km 141)

Fig.1. Synthetically composed passing vehicle ensemble

1.2. Distance transformation

In order to obtain conclusions about different recording distances other than 100 m, we developed a distance transformation methodology which processes recorded passing vehicle noise samples to make it sound like recordings in the predefined distance.
On this account we made two mono-recordings of a defined passing vehicle noise with constant speed in a distance of 50 and 100 m (Fig.2.). Afterwards we transformed the recorded 50 m noise sample into a transfered 100 m sample which sounds immediately like the original 100 m sample.

For this distance transformation four effects are relevant:

- Influence of the pitch by the Doppler effect (pitch-shifting)
- Modification of the sound level
- Frequency dependent air absorption [4]
- Frequency filtering of the angle dependent sound emitted characteristic [5]

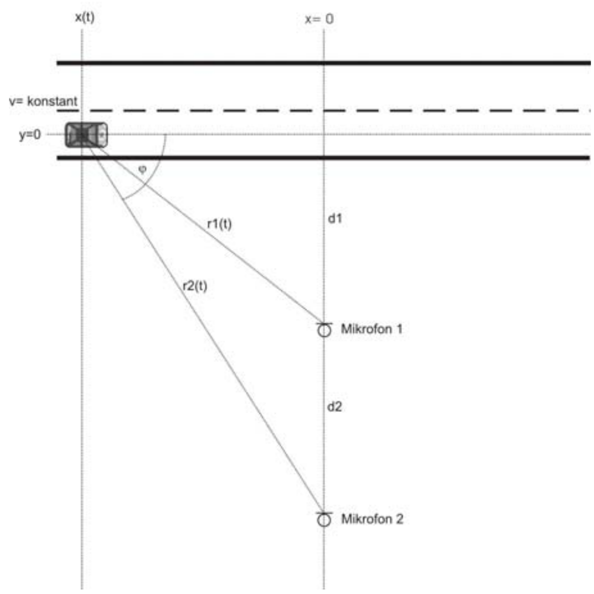

Fig.2. Drawing of the distance transformation

These effects were generated and implemented as a filter in Matlab. For multi-channel playback the mono samples were transformed into multi-channel signals by PD (Pure Data) and used for the hearing test in the IEM-Cube.

1.3. Hearing tests

For the hearing tests two hundred persons in different sessions were selected and tested under laboratory conditions in the specially adapted hearing laboratory at the Institute of Highway Engineering and Transport Planning and the IEM-Cube of the Institute of Electronic Music and Acoustics.
In a preliminary phase an experiment design was developed. In order to rate the annoyance a combination

of direct measure estimation with a pair comparison was selected. The annoyance of the vehicle ensembles was rated on an 11-graded interval scale from "less annoying" to "very annoying" by the study subjects. Therefore, a software-related experimental assembly of the defined vehicle ensembles was developed and displayed on a monitor in front of the test subject. The test person could activate the noise samples by clicking the assigned start-symbol on the monitor. In this way, the test person had the facility of comparing the vehicle ensembles to each other, if necessary, several times and finally judging subjective annoyance by clicking a marker on the interval scale. These judgements could be changed at any time during the evaluation period. Furthermore, the test person was advised not to judge only the varying loudness of the noise contained in the individual samples, but also its sound characteristics.

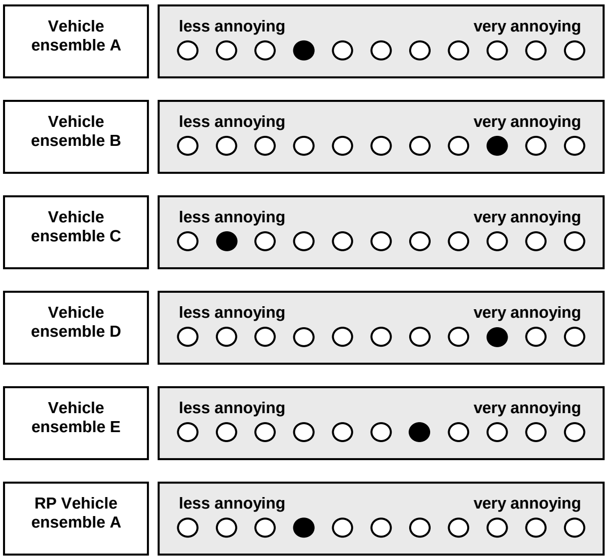

Fig.3. Software-related experimental assembly of one assessment group with defined vehicle ensembles (including reproduceable ensemble RP) as it was displayed on a monitor in front of the test subject.

With a small sample of study-subjects and a marginal group of the synthetically composed vehicle ensembles some relevant parameters (noise diversity, variability, reciprocal effect on validity, load of the test subject, controllability) of the hearing test were verified. To exclude the effects of any prior existing hearing deficiencies test subjects underwent audiometry before each session. In addition a standardized questionnaire reflecting the study participant's subjective estimation of being disturbed by road traffic noise by day and night time was also included at completion of the experiment. The questionnaire also checked for impairments of activities like communicating, working, and reading, concentrating, relaxing and sleeping in their residential area.

In the main hearing test (PH 1…psychoacoustic hearing test 1) in 6 assessment groups 12 defined vehicle ensembles were rated by 120 study subjects. Every assessment group consists of 5 or 6 ensembles with a reproduceable one in every group (Fig.3). Each ensemble occurs also in another group. Finally an experimental design with 27 vehicle ensembles was judged by the study-subjects.

In an additional hearing test (PH 2…psychoacoustic hearing test 2) ensembles which were recorded on wet road surface were integrated. This wet-level was investigated because this parameter has not been duly considered in research to date. For this test with a group of 25 study-subjects the ensembles of the main design and the new wet road surface recorded ensembles were combined and tested under laboratory conditions.

In our final hearing test physiological parameters including heart rate and respiratory rate were recorded during an extra designed hearing test with 51 study participants. This research was a project cooperation with the Medical University Graz and was carried out with regard to the fact that road traffic noise, which is steadily increasing, is considered a significant environmental health problem [6].

1.4. Statistical analysis

In the final step, the defined vehicle ensembles were processed with the Psychoacoustics Module of the ArtemiS Analyses System (HEAD acoustics). The psychoacoustic parameters: loudness, roughness, sharpness, tonality and fluctuation strength were chosen for calculation. As a comparative parameter the A-weighted energy-equivalent sound level was calculated. For a better description the new parameter "loudness excess" was designed. It shows the individual loudness maxima from the separate passing vehicles and compares the cars with the motor-trucks of this composed vehicle ensemble. From each psychoacoustic parameter different percentile data was generated for the next process.

Results obtained from the subjective personal rankings of the annoyance were combined with the objective psychoacoustic parameters by multiple regression analysis (analysis of variance) and displayed in percentiles. For the final results the 50% percentile was chosen as the one of relevance. At first each parameter was individually analysed and then the significant parameters together. Finally, the relevant parameters were statistically combined in an index called traffic noise annoyance TNA_R.

3. RESULTS

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The test persons who participated in all hearing studies on noise pollution and their hearing may be regarded as representative of the Austrian population with respect to sex and the age when compared to the microcensus collection of the statistics Austria 2003 [7].

The concept of the annoyance was accepted and understood by the study-subjects.

The experimental set-up worked excellently and no clustering regarding the different noise sensitivity of the subjects was determined.

3.1. Subjective results

The following fundamental conclusions with regards to the subjective results of the hearing attempts are as follows:

- The different road surfaces, the varying speed profiles and the defined number of vehicles have significant influence on subjective annoyance perception.
- A higher volume of traffic, independent of speed profile and road surface, means a higher subjective annoyance.
- In the case of a doubling of the volume of traffic the annoyance increases by 1.5 points of index on the 11-rated interval scale.
- A higher speed of the vehicles, independent of volume of traffic and road surface, results in a higher subjective annoyance. Vehicle ensembles with speed profiles of 130 km/h for cars and 90 km/h for motor-trucks (130 km/h - 90 km/h) are evaluated as more annoying than 100 km/h - 90 km/h and this again more annoying than 80km/h - 60 km/h.
- With the increase of the speed profile of the cars from 100 km/h to 130 km/h the annoyance increases on concrete and asphalt concrete more than one point on the index-scale.
- Equally annoying is the SMA at a speed profile of 80 km/h - 60 km/h to 100 km/h - 90 km/h.
- Also the road surface affects the annoyance significantly independent of the other parameters:
  - concrete = asphalt concrete + 1,5 points on index
  - asphalt concrete = SMA + 2 points on index
- The noise protection barrier is the parameter which has the largest influence on the reduction of the subjective annoyance. It reduces the annoyance by 2.7 points on index with SMA.
- A wet road surface is evaluated as more annoying than a dry road surface on all researched road surfaces. In further investigations this parameter is to be considered in detail.

3.2. Modelling of the subjective and objective parameters

The important results of the modelling between the objective psychoacoustic parameters with the subjective annoyance are characterised below:
The loudness is the best descriptive single parameter for the annoyance (Fig.4.). It describes the annoyance significantly better than the A-weighted energy-equivalent sound level ($L_{A,eq}$) (Fig.5.):

- loudness: $r^2 = 0.744$ with a significance of $p < 0{,}001$
- $L_{A,eq}$: $r^2 = 0.698$ with a significance of $p < 0{,}01$

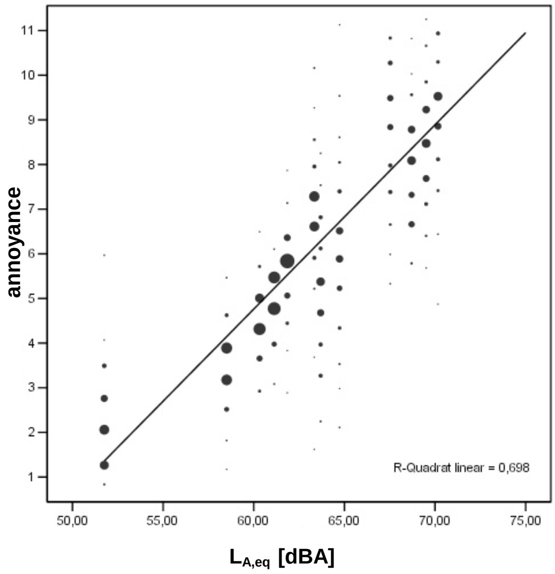

Fig.4. PH1: annoyance against $L_{A,eq}$ [n = 120]

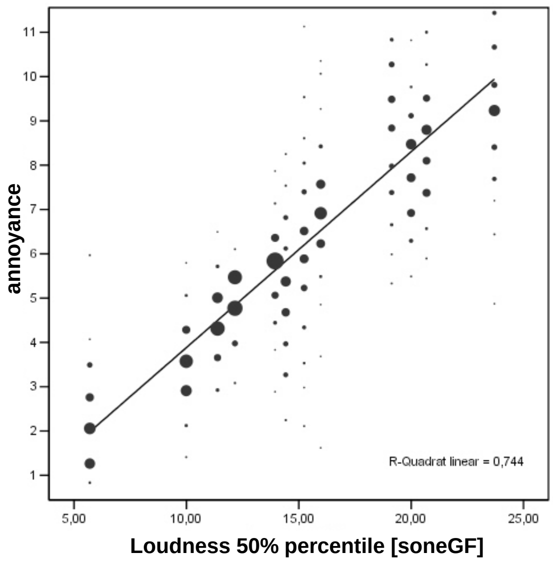

Fig.5. PH1: annoyance against loudness [n = 120]

The roughness as a psychoacoustic single parameter obtains the same results as the loudness, because their connection is highly correlated
The fundamental psychoacoustic parameters like fluctuation strength, tonality and sharpness do not explain a relevant portion of the annoyance.
The new designed parameter loudness excess is the second significant influence parameter besides loudness (Fig.6.).

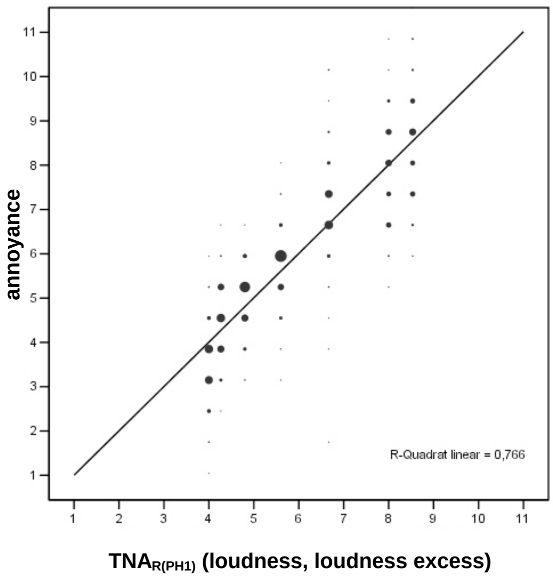

Fig.6. PH1: annoyance against loudness and loudness excess [n = 120]

Analyzing the additional hearing test (PH 2) we saw that sharpness as a third significant parameter is additionally relevant in combination with the parameters loudness and loudness excess. These three parameters together (r^2 = 0,812) (1) describe the correlation with subjective estimation of noise-induced annoyance significant better than the A-weighted energy-equivalent sound level (r^2 = 0,711) (Fig.7.).

$$TNA_{R(PH2)} = f(loudness, sharpness, loudness\ excess) \quad (1)$$

As a conclusion of the physiological hearing test we can say that the vehicle ensembles that caused significantly higher increases in heart rate were rated significantly more annoying than the other vehicle ensembles [8].

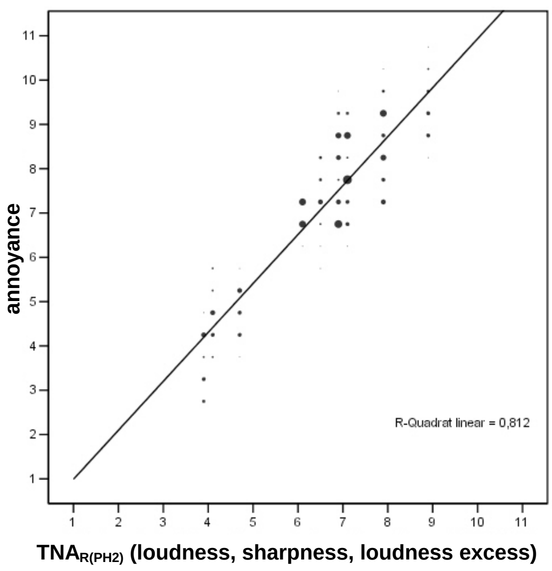

Fig.7. PH2: annoyance against loudness, sharpness and loudness exess [n = 25]

4. CONCLUSION

With the current configuration of traffic noise annoyance on roads (TNA_R) we have a verification of the concept which still requires further investigations in order that road operating agencies may make a safe prognosis.

In an extension of the research project the past realizations are to be used to extend the characteristic area concerning the subjective annoyance by additional relevant dimensions and developments (for example: influence of the wet-level for each road surface, special speed profiles, new defined volumes of traffic and more diverse noise barrier situations).

The TNA_R should be considered for future perspectives in road- and traffic planning and therefore may serve construction engineers as well as traffic planners as a supplemental tool. In future-oriented noise control we are not only concerned with a reduction of the sound level in order to fall below any particular set limit value of a technical measured variable.

It is more important to shift human perception to the centre of our attentions by using new relevant parameters like the TNA_R. We are thus forced to pursue other noise reduction measures such as changing road surfaces, tyre profiles, reducing speed profiles and adapting noise barriers in order to target that component of noise which is perceived to be annoying.

In addition a substantial reduction of costs for structural noise protection could also result.

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