Traffic Noise Annoyance on Roads and Rail (TNA_R) in an experimental laboratory setup

M. Cik[1], K. Fallast[1], R.B. Raggam[2], E. Marth[2], E. Gallasch[3], A. Lackner[4], M. Fellendorf[1]

[1] *Institute of Highway Engineering and Transport Planning, Graz University of Technology, Austria, Email: michael.cik@tugraz.at*

[2] *Institute of Hygiene, Microbiology and Environmental Medicine, Medical University of Graz, Austria, Email: reinhard.raggam@medunigraz.at*

[3] *Institute of Physiology, Medical University of Graz, Austria, Email: eugen.gallasch@medunigraz.at*

[4] Department of Neurotology, ENT University Hospital, Medical University of Graz, Austria, Email: andreas.lackner@medunigraz.at*

1. Introduction

In a time of intensified efforts for environmental protection, noise and especially traffic noise has become of greater interest. There are concerns not only regarding the avoidance of hearing damage, which occurs only as a result of relatively high noise levels or long and persistent acoustic exposure, but also regarding the reduction in the well-being of the person. The main interfering effect of noise is referred to as “annoyance”. 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. Therefore, noise causes certain reactions in human beings. 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 (Guski 1999; Babisch 2000). If the individual measured variables are consciously separated, then it may be assumable that the resulting value would provide a ‘true’ and reproducible “noise annoyance” in a laboratory situation. Based upon the findings out of a pilot study investigating “uninfluenced annoyance” (Zwicker 1991), this is characterized as “psychoacoustic annoyance” (Zwicker & Fastl 1990; Widmann 1992) that portion of the disturbance or irritation which is exclusively influenced by auditory factors. 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 almost exclusively 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.

At present, according to the current standards and calculation specifications, the impact of road and rail 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 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 a joint target measure named “traffic noise annoyance for roads and rail” (TNA_R).

2. Methods

2.1. Sound recording technique

In a 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. In order to include a further typical parameter, road sections with different noise protection barriers were selected for the sound recordings. In a second step different Austrian rail sections were determined and selected for 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 (HEAD acoustics, Herzogenrath, Germany). The same measurement was done on the rail sections for different passenger and freight trains with variable distance and speed. Recordings were carried out on 600 m long homogeneous road and rail sections with free sound propagation within a distance of 100 m. Speed measurement of each passing vehicle or train 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 a third step, out of the recorded single passing vehicles and trains, a total 31 vehicle and rail ensembles were chosen and synthetically composed by audio editing software. These ensembles containing the following qualities: different road surfaces, varying speed profiles, different train distances, defined number of vehicles and trains, various noise barriers. Ensembles were set to duration of 60 seconds simulating an average traffic occurrence on Austria’s highways and rail sections during a representative time. The designed vehicle and rail ensembles contained A-weighted sound levels from a minimum of 51 dBA to a maximum sound level of 75 dBA.

2.2. Study design, hearing tests and rating methods for annoyance

For the hearing tests 200 persons were selected and tested under laboratory conditions in the specially adapted hearing laboratory at the Institute of Highway Engineering and Transport Planning. The study was approved by the local ethic committee, Medical University of Graz, study participants gave written and informed consent.

In order to rate the grade of perceived annoyance caused by road and rail traffic noise, two different scaling methods were used. Firstly, the annoyance of the vehicle and rail ensembles was rated on an 11-graded interval scale from "less annoying" to "very annoying" using the personal noise ranking scale (PNRS) as a combination of direct measure estimation with a pair comparison by the study subjects as previously described (Raggam et al. 2007). Therefore, a software-related experimental interface of the defined vehicle and rail ensembles was developed and displayed on a monitor in front of the test subject (Fig. 1). The test person could activate the noise samples by clicking the assigned start-symbol on the monitor. In this way, the test person was able of comparing the vehicle and rail ensembles to each other, if necessary, several times and finally rating subjective annoyance by clicking a marker on the interval scale. Furthermore, the test person was advised not to rate only the varying loudness of the noise contained in the individual road and rail traffic noise ensembles, but also its sound characteristics.

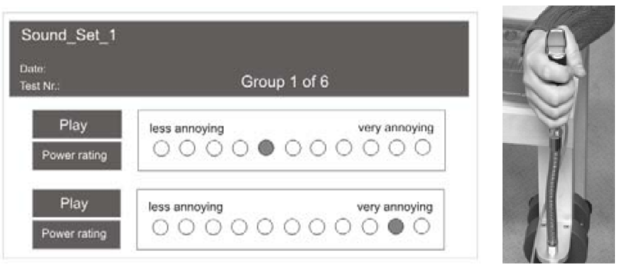

Figure 1: Software-related experimental interface and hand power-dynamometer

Secondly, the annoyance of the vehicle and rail ensembles was rated by a hand power-dynamometer which measures the intensity of the applied strength of the test person (Fig. 1). The hand power-dynamometer was calibrated for each test person on their maximal and minimal intensity of the applied strength before starting the tests. The grade of annoyance is reflected by the intensity of pressing the hand power-dynamometer.

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 traffic noise by day and night time was also included at completion of the experiment. The questionnaire checked for impairments of activities like communicating, working, reading, concentrating, relaxing and sleeping in their residential area and also the actual mental state of the test persons.

In the hearing test 31 ensembles (26 different vehicle-, rail- and 1/f-noise-ensembles; 5 repetitive ensembles checking for reproducibility) were rated by the test persons.

2.3. Statistical analysis

In the final step, the defined 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 "low frequency fluctuation strength" was designed.

Results reflecting grade of annoyance either obtained with the PNRS or the hand power-dynamometer were combined with the objective psychoacoustic parameters by linear regression analysis. 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 by multiple linear regressions yielding an index defined as TNA_R.

3. Results

The test persons who participated in this study are representative for the Austrian population when compared to the microcensus collection of the Statistics Austria 2005. The concept of the annoyance was accepted and understood by the study-subjects. The experimental setup gave reproducible results and no clustering effects regarding the different noise sensitivity of the subjects were observed.

3.1. Rating of annoyance

Both, the subjective rating of annoyance (PNRS) and by the hand power-dynamometer show a significant difference between the three sound characteristics namely vehicle traffic noise, rail traffic noise and 1/f-noise (Fig. 2).

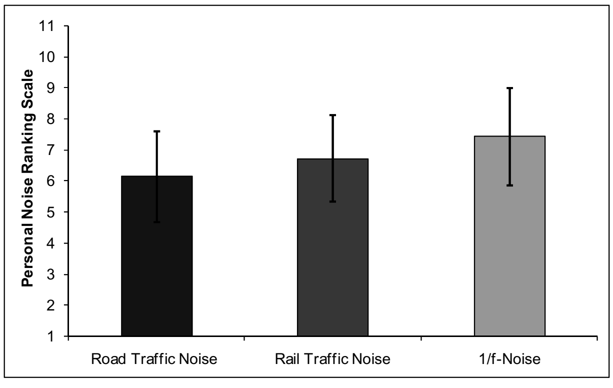

Figure 2: Results of the PNRS averaged over three sound characteristics (road noise, rail noise, 1/f-noise) of the hearing test [n=171] (p = 0.00)

Therefore the mean of the annoyance of all ensemble groups was combined and analysed. The $L_{A,eq}$ of the three ensemble groups is equal. Furthermore, a vehicle and a rail traffic noise ensemble with the same $L_{A,eq}$ was compared. Both ensembles were rated with the PNRS and the hand power-dynamometer showing a significant difference of annoyance rating results (Fig. 3; Fig. 4).

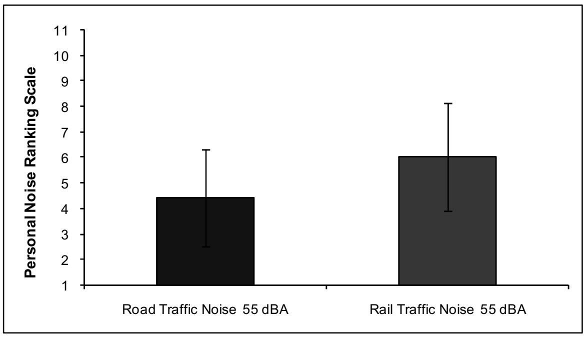

Figure 3: Difference between road and rail traffic noise with the personal noise ranking scale at a $L_{A,eq}$ of 55 dB [n = 171] (p = 0.00)

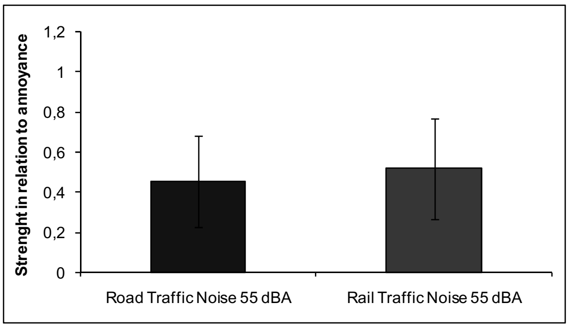

Figure 4: Difference between road and rail traffic noise with the power-dynamometer at a $L_{A,eq}$ von 55 dB [n = 171] (p = 0.00)

3.2. Modelling of the subjective and objective parameters

Results of the modelling between the objective psychoacoustic parameters with the subjective annoyance by linear regression are summarized in Table 1. Briefly, the loudness is the best descriptive single parameter of the annoyance. It describes the annoyance significantly better than the A-weighted energy-equivalent sound level $L_{A,eq}$. The sharpness is the second significant influence parameter besides loudness. The new designed parameter “low frequency fluctuation strength” is the third significant influence parameter.

Results of the linear and multiple linear regression		
PNRS against $L_{A,eq}$	$r^2 = 0.672$	($p < 0.001$)
PNRS against loudness	$r^2 = 0.722$	($p < 0.001$)
PNRS against loudness, sharpness and low frequency fluctuation strength	$r^2 = 0.807$	($p < 0.001$)

Table 1: Results of the linear and multiple linear regression [n =171]

4. Discussion and conclusion

The TNA_R, presented herein this study, can be considered for future perspectives in road- and rail 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.

Therefore, 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 and rail surfaces, tyre profiles, speed reducing concept and adapting noise barriers in order to target the components of noise which are perceived to be annoying. In addition a substantial reduction of costs for structural noise protection could also result.

With this existing configuration of TNA_R there is a verification of the postulated noise annoyance concept. However, further investigations whether it will serve as a safe prognostic tool for road- and rail operating agencies, needs to be done. Moreover, this tool may be useful to determine the role of different road and rail traffic noise sources and their effects on human physiological stress parameters.

Acknowledgements

This study was part of a project cooperation between the Institute of Highway Engineering and Transport Planning of the Graz University of Technology and Medical University of Graz and was financially supported by the Hygiene-Fonds of the Medical University of Graz.

References

[1] Guski, R.: Personal and social variables as co-determinants of noise annoyance. Noise Health, 1, 45-56, 1999

[2] Babisch, W.: Gesundheitliche Wirkungen von Umweltlärm. Ein Beitrag zur Standortbestimmung. Zeitschrift für Lärmbekämpfung 47, 95-102, 2000

[3] Zwicker, E.: Ein Vorschlag zur Definition und zur Berechnung der unbeeinflußten Lästigkeit. Zeitschrift für Lärmbekämpfung 38, 91-97, 1991

[4] Zwicker, E., Fastl, H.: Psychoacoustics - Facts and Models. 2nd Updated Ed., Springer Verlag Berlin, 1999

[5] Widmann, U.: Ein Modell der psychoakustischen Lästigkeit von Schallen und seine Anwendung in der Praxis der Lärmbeurteilung, Dissertation, TU München, 1992

[6] Raggam, RB., Cik, M. et al: Personal noise ranking of road traffic: Subjective estimation versus physiological parameters under laboratory conditions, Int. J. Hyg. and Environmental Health, 210, 97-105, 2007