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Noise indicator evaluation of road and rail traffic noise for indoor-outdoor differences in acoustic parameters

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ABSTRACT

The two main objectives of the extensive project ”INTRANOISE” were to study the effect of road and rail traffic sound on human sleep patterns and explore the relationship between the subjective perception of 100 test persons and objectively measured acoustic and physiological parameters. The free field measurement arrangement includes binaural dummy head measurements at the façade of the test subjects' home and within the bedroom, thus providing a solid basis for evaluation. Indoor-outdoor differences were assessed for various sound indicators and their relation with people's subjective and objective responses. People are able to distinguish between the investigated noise sources. This ability contributes to their subjective traffic noise annoyance and can be linked to acoustic parameters. Indoor noise is the dominant factor for physiological reactions during sleep, leading to observable cardiovascular reactions. The link between reactions and acoustic measurements varies depending on the health indicator. Further studies are needed to determine, which noise indicator is more appropriate. This paper aims to describe people's subjective and objective response to road and rail traffic noise using the difference of indoor-outdoor sound pressure levels.

Keywords: Naturalistic traffic noise, annoyance, physiological parameters, noise indicators

1. INTRODUCTION

The public increasingly recognizes noise as a larger scale problem. More and more people become aware of the effects noise has on the human organism. These effects are well documented in scientific literature and can be summarized as direct physiological effects and psychological effects. Physiological effects can involve impairment of sleep, reflected by various sleep disorders, physical stress reactions reflected by activation of the autonomic nervous system, arterial hypertension and associated cardiovascular diseases reflected by ischemic myocardial dysfunctions. Psychological effects often includes impairment of well-being and psychological stress through a reflection of the grade of annoyance (1,2).

Especially urban soundscapes are increasingly affected by environmental noise from transport sources (3,4). The direct effect of sound energy on the human hearing is scientifically well researched and widely accepted (5,6). Generally, aural effects can be neglected in assessments, as the sound pressure level of the auditory traffic noise is typically below levels, which are known to cause hearing damage. This means, that non-auditory effects of noise on the human health is generally not the direct result of sound energy, but noise as a more general stress inducing factor.

Non-auditory noise effects include both physiological and psychological effects. The result of those both types of effects is in most cases annoyance, mental health issues, sleep disturbance and physiological functions as well as effects on cognitive processes such as communication and cognitive performance (7). These non-auditory effects of noise are less well researched and accepted, compared to auditory effects.

It is estimated that about 28% of the total population living in the European Union, are constantly affected in their quality of life, well-being or sleep patterns, which results in an increased health risk for the individual and increased health costs for the public (8).

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One part of the problem is the still open question of a describing, clinically relevant threshold level of noise caused by various traffic modes. To date, no clear consensus has been reached.

Additionally, it is unclear which parameters can and should be used, in order to scale for serious health impairment. In most scientific noise studies, data was obtained either from epidemiological field studies or from studies performed in sleeping laboratories. Such laboratory studies do offer the clear advantage of standardized conditions and usage of complex measuring equipment (e.g. polysomnography - PSG) (9-11). This standardization level of test conditions cannot be achieved in field studies, which mostly are influenced by a broad range of external factors.

However, these controlled laboratory studies clearly allow a better simulation of actual in-situ conditions and further epidemiological studies with representative sample sizes (12-15). It must be noted, that the mentioned epidemiological studies, made use of questionnaires for reflecting the subjective estimation of noise-induced discomfort in terms of data generation, and therefore lack objective variables.

The prediction of subjective noise-induced discomfort is a difficult task (16). As the informational quality of a certain sound like semantic or pragmatic aspects and the intentional attitude of a person are highly situation-specific, they cannot be modelled in a reliable way. Therefore, fuzzy mathematical soft-computing methods describing the relationship between noise-induced discomfort and objective noise parameters are important to consider (17) and should be further investigate.

1.1 Annoyance resulting from noise exposure

When used in combination with environmental influences the term annoyance presents itself with some ambiguities. In general the term annoyance is used to describe negative feelings, as for example disturbance, displeasure, dissatisfaction, nuisance and irritation. Guski suggests to even include somatic damage, loss of control and orientation, negative assessment of the noise source and high sound levels (18).

Since noise is described as unwanted sounds, the combined term noise annoyance may be understood as an emotional process, as the reaction is closely tied to the affective experience of the individual towards the noise source. Evidence of this assertion stems from investigations on aircraft noise, where the existence of some correlation between the judgment of annoyance caused by aircraft noise and the fear of aircraft accidents has been found (19,20). In relation to this, an attitudinal dimension may extend noise annoyance, as the subjective rating of severity of annoyance often depends on the acquired information about and the feelings towards the source of noise (21). This relation of noise to the test subject may be expanded by considering the dependence of the subject to the source of noise. When considering subjects, who for instance economically depend on the source of noise, might tend to feel less annoyed by it, as compared to others who are not.

Traffic noise continues to be a subject of continuous and increasing concern to people causing annoyance and associated sleep disturbances, representing the direct and most relevant factors affecting health.

1.2 Cardiovascular reactions

Considering physiological effects of noise, the basic reaction of the human body to noise events is the prompt increase of the heart rate and change in systolic blood pressure. Carter et al. (22) were able to show the immediate rise in heart rate following a noise event under laboratory conditions. They were able to show, that intermittent or periodic noises during sleep induce a biphasic heart reaction with a transient constriction of the peripheral blood vessels as well as clear changes in the electrocardiography (ECG). The biphasic response of the heart first shows a rise of the heart rate followed by a decompensation reaction with a marked drop in heart rate.

Griefahn et al. found a connection of the autonomic arousals during sleep and traffic noise in their study, in which the response of the heart rate to traffic noise during sleep was analyzed. The extensive study took place in a laboratory under standardized conditions (9,10).

However, these studied cardiac effects have been solely based on laboratory data. Large epidemiologic studies, which examine the cardiac risk are solely based on questionnaires, yet those are essential for scaling the burden and identifying the meaningful limits for preventive actions against noise emissions. To a certain extent, it might be obvious, that the normal surroundings and habits of a test subject might describe a risk better, than the unfamiliar surroundings of a sleeping laboratory. Presently, the Night Noise Guidelines for Europe of the World Health Organization (WHO) (8) demanding for a NOAEL (no observed adverse effect level) of NOAELAmax $\geq$ 42 dB. The heart rate reacts very sensitive to external stimuli as it is regulated by the autonomic nervous system. The WHO recommends in the Night Noise Guidelines for Europe that field studies must be carried out, in order to better describe the influence of traffic noise regarding its potential in causing chronic disorders, e.g. sleep disturbances or cardiovascular diseases, more accurate.

2. METHODOLOGY

The two main goals of the study's concept were to investigate the influence of road and rail traffic noise on sleep of individuals and additionally to explore the relationship of subjective perception of test subjects with objective measured psychoacoustic and physiological parameters. The crucial point of the project was, that all measurements were done in the free field. Since the project itself was already previously presented, only the most relevant aspects will be presented in the following subchapters 2.1 and 2.2 (23,24).

2.1 Study design, measurement area and choice of test subjects

In the first step test subjects were selected from a database consisting of test subjects having participated in our previous studies (510 persons were tested in their general health, well-being and connectivity to traffic noise). For this study 100 representative test subjects were intended to be investigated. Two different areas for measurements were provided:

- Areas dominated by road traffic noise
- Areas dominated by rail traffic noise

All measurements were done at the home of the test subjects and were performed for 5 consecutive days (4 nights) per each test subject. For the study 3 relevant time periods were identified:

- Evening: pre-sleep phase
- Night: sleep phase
- Morning: post-sleep phase

2.2 Free field study

For the field study different relevant parameters were investigated and analyzed. The most relevant parameters for this paper will be described in the following sub-chapters.

2.2.1 Subjective and socio-demographic data and health status

Collection of socio-demographic data and health status was done by means of a basic questionnaire at the beginning of the investigation including the most important factors for test subjects in connection with environmental influences, especially traffic noise: Sex, Age, Education, Housing conditions regarding traffic noise exposure and further residential surroundings.

In addition, the individual health status of each test person was assessed at the beginning of the measurement week in a conversation, during which the most important health-relevant parameters such as regular consumption of certain drug groups, use of a heart pacemaker or hearing aid, general hearing problems, therapy of cardiac arrhythmias or obstructive sleepapnoe were asked by a physician.

2.2.2 Annoyance questionnaire

In the "evening" and "morning" measurement periods a continuous questioning of the current traffic noise annoyance on basis of the ICBEN 11-graded interval scale (14) using the so called „experience sampling method" (time near seizing of experiences, feelings and behavior) (25,26) was done. In individual investigation areas the test subjects evaluated their half hourly annoyance by rail and/or road traffic noise and also responded to the questions of the experience sampling method in the measurement periods on the days of investigation.

2.2.3 Objective acoustic measurements

Goal of the acoustic measurements was to achieve a time-synchronicity between the result of the annoyance questionnaire (traffic noise annoyance-rating, experiences, feelings and behavior) and acoustic parameters including sound pressure level and psychoacoustics reflecting the total quantity of the test subject's acoustic load. Measurements (recordings) of current existing sound emissions with 2 binaural dummy heads HSU III.2 were done in combination with a SQuadriga II mobile recording system (HEAD acoustics GmbH) to get a realistic illustration of the traffic noise exposure of each test subject in the investigated area. For each test subject one measuring point was inside the house in the sleeping room and the second one was outside in front of the house or apartment. Measurements were done during all three time periods and afterwards statistically correlated with the collected subjective and physiological data. The recordings were analyzed using the software package

"ArtemiS SUITE V7.3" by HEAD acoustics GmbH by means of the latest acoustic und psychoacoustic standards.

Data collection of traffic volume in the investigated time period was also done for comparison.

2.2.4 Measuring physiological parameters

Sleep disturbances, defined both as awakenings or changes in depth of sleep, are frequently associated with traffic noise and are an important criterion in defining limits for noise pollution. The physiological measurements were done during the 4 night periods for each test subject in the investigated area.

For this project it was necessary to assess sleep parameters in a reliable way, which needed to be easy to use for non-professionals. A suitable tool to monitor changes in the depth of sleep is an actimeter. This is a simple method that can be used on several subjects simultaneously. The results obtained are in good comparison of those obtained using the PSG allowing the assessment of changes in depth of sleep at home (27).

In this project, heart rate and also body movements were measured by using a wrist-actigraph, specifically type "wActiSleep-BT Advanced Activity Monitoring Solution with Heart Rate" from ActiGraph, LLC. The measurement and interpretation of heart rate variability (HRV) allows conclusions concerning the adaptability of the heart to internal and external stimuli. The actigraph is equipped with an acceleration sensor that translates arm movements into a numeric representation, which is stored in memory. Afterwards, the acquired raw data was analyzed using the proprietary software package "ActiLife V6" by ActiGraph, LLC. For the in-depth analysis, two algorithms for different age groups were used:

- Sadeh algorithm: Is considered for younger test subjects, because it was developed using subjects of an age span ranging from 10 to 25 years (28).
- Cole-Kripke algorithm: Is considered for adult test subjects, because it was developed using subjects of an age span ranging from 35 to 65 years (3229

Therefore, two different age groups were distinguished when analyzing the obtained sleep data. Sadeh's algorithm is applied to sleep data from test subjects who were 18 to 25 years old and Cole-Kripke's algorithm is used for sleep data from test subjects who were 26 years and up at the time of data acquisition.

2.3 Aim of this paper

Since it is still an unsolved question, which noise indicator is to be used as means to properly assess noise caused by various traffic modes for consideration in regards of both physiological and psychological research questions, further studies are needed.

This paper aims to describe people's subjective and objective response to road and rail traffic noise using the difference of indoor and outdoor sound pressure levels. The difference of the indoor to the outdoor sound pressure levels is used as assessment of the sound dynamics of traffic noise in the surrounding of test subjects homes and tested for applicability regarding the description of physiological and psychological effects.

3. RESULTS

During the four years of conducting the study 97 test subjects were analyzed over 97 measuring weeks on different investigation sites. In general, the methodology was understood well by the test subjects. The technical part consisting of physiological and acoustic measurements worked well on site. The rating of subjective annoyance and completing of questionnaires was done without major problems. During the course of the project small inconsistencies occurred while gathering data of 3 test subjects. Therefore, only the data of 94 test subjects will be included in the analysis of the acoustic parameters.

Generally, people were able to distinguish between the investigated noise sources. This ability contributes to their subjective traffic noise annoyance and can be linked to acoustic parameters. Indoor noise is the dominant factor for physiological reactions during sleep, leading to observable cardiovascular reactions. The link between reactions and acoustic measurements varies depending on the health indicator.

The factor of indoor-outdoor difference will be described as delta of outdoor subtracted by indoor sound pressure levels regarding a specific time domain.

3.1 Results of the indoor-outdoor difference regarding annoyance ratings

The participating test subjects were asked for a rating (based on the 11-graded ICBEN interval scale)) of their subjective traffic noise annoyance for time periods of 30 minutes. In a first step, these ratings were tested using a linear regression model against different acoustic parameters, including the indoor-outdoor difference, describing the 30 minute rated timeframe. It quickly became apparent, that although most parameters produced statistically significant results ($p < 0.05$), the explained variance of the best model was rather low with about 5%, which is a result of the amount of “not feeling disturbed” ratings of about 43.7%. This could not be improved by excluding those ratings, as the explained variance decreased to about 4.9, while still producing significant results. Previous evaluations of the raw data showed a broad variability of the concerned sound pressure level parameter for each rating from 0 to 10 (23,24). Therefore, it was necessary to include socio demographic parameters of the test subjects in a multivariate linear regression model to put the ratings in perspective. The best results were produced by including the factors gender, age, general annoyance, noise sensitivity, health condition and perception of sleep disturbance due to traffic noise. These results are presented in Table 1, which shows the 5 best “conventional” sound pressure level parameters, as well as all of the delta-values.

Table 1 – Multivariate linear regression of acoustic parameters, gender, age, general annoyance, noise sensitivity, health condition and perception of sleep disturbance due to traffic noise against annoyance ratings

Parameter	p-Value	Significance ($p < 0.05$)	Variable adjusted R^2
SPL [dB(C)] outside 75th percentile	8.29578E-19	Yes	0.2113873
SPL [dB(C)] outside arithmetic mean	1.06468E-16	Yes	0.209128
SPL [dB(C)] outside maximum value	1.18102E-16	Yes	0.2090797
LCeq outside	1.57983E-16	Yes	0.2089442
SPL [dB(C)] outside median	2.91478E-16	Yes	0.2086589
delta maximum SPL [dB(A)]	3.85321E-05	Yes	0.1967772
delta LAeq	6.43069E-05	Yes	0.1965444
delta 95th percentile SPL [dB(A)]	0.000120647	Yes	0.1962591
delta 75th percentile SPL [dB(A)]	0.000144185	Yes	0.1961785
delta arithmetic mean SPL [dB(A)]	0.000215739	Yes	0.1959966
delta 25th percentile SPL [dB(A)]	0.00153317	Yes	0.1951199
delta median SPL [dB(A)]	0.00222493	Yes	0.1949555
delta 5th percentile SPL [dB(A)]	0.002964853	Yes	0.1948293
delta maximum SPL [dB(C)]	0.008318639	Yes	0.1943807
delta LCeq	0.03098191	Yes	0.193825
delta 95th percentile SPL [dB(C)]	0.08214834	No	0.1934321
delta 75th percentile SPL [dB(C)]	0.1088335	No	0.1933236
delta minimum SPL [dB(A)]	0.1356018	No	0.1932407
delta arithmetic mean SPL [dB(C)]	0.1883469	No	0.1931211
delta median SPL [dB(C)]	0.2630704	No	0.1930059
delta 25th percentile SPL [dB(C)]	0.3157415	No	0.1929467
delta minimum SPL [dB(C)]	0.6530683	No	0.1927528
delta 5th percentile SPL [dB(C)]	0.6718815	No	0.1927473

3.2 Results of the indoor-outdoor difference regarding physiological measurements

In addition to the subjective half hourly annoyance ratings, the test subjects' sleep was assessed during the week, in order to test for physiological effects of traffic noise. Similar to the annoyance ratings, the sleep parameters were first tested using a linear regression model against different acoustic parameters, including the indoor-outdoor difference, describing the normal night timeframe of 10 pm to 6 am. Although most parameters produced statistically significant results ($p < 0.05$), again the explained variance of the best model was rather low with about 6%. This is plausible, as physiological data needs to be evaluated and corrected for various parameters regarding the test subjects. Several sleep describing parameters have been evaluated for explanatory socio demographic variables of the test subjects. Based on the acquired data, those vary for each sleep parameter. In this paper, we will focus on the parameters sleep efficiency and total sleep time. As for the sleep efficiency models, a combination of the acoustic parameters and health condition and age proved to be the best match (cf. Table 2, showing the 5 best "conventional" sound pressure level parameters, as well as all of the delta-values). The best results concerning the total sleep time were achieved by including gender, age and perception of sleep disturbance due to traffic noise (cf. Table 3, showing the 5 best "conventional" sound pressure level parameters, as well as all of the delta-values).

However, apart from the LCeq indoor-outdoor difference, no significant result ($p < 0.05$) could be achieved for the other parameters. This proved to be different for the total sleep time, which produced significant results for all of the indoor-outdoor difference models, though the explained variance was low for both sleep efficiency and the total sleep time.

Table 2 – Multivariate linear regression of acoustic parameters, health condition and age against sleep efficiency

Parameter	p-Value	Significance ($p < 0.05$)	Variable adjusted R^2
LCeq inside	2.11E-05	Yes	0.06522817
SPL [dB(C)] inside maximum value	0.000528259	Yes	0.04956241
SPL [dB(A)] inside maximum value	0.001722714	Yes	0.04385209
SPL [dB(C)] inside 95th percentile	0.002925597	Yes	0.04131
LAeq inside	0.006099754	Yes	0.03780801
delta LCeq	0.03314535	Yes	0.02992482
delta maximum SPL [dB(C)]	0.116618	No	0.02439899
delta 95th percentile SPL [dB(C)]	0.1179285	No	0.02435216
delta maximum SPL [dB(A)]	0.1579803	No	0.0231471
delta median SPL [dB(A)]	0.2066695	No	0.02208054
delta minimum SPL [dB(A)]	0.2950832	No	0.02074634
delta minimum SPL [dB(C)]	0.3406099	No	0.02024212
delta 75th percentile SPL [dB(C)]	0.3756299	No	0.01991187
delta LAeq	0.4098199	No	0.01962858
delta 25th percentile SPL [dB(A)]	0.4547769	No	0.01930503
delta 5th percentile SPL [dB(A)]	0.7332986	No	0.01811671
delta 25th percentile SPL [dB(C)]	0.8080164	No	0.0179634
delta median SPL [dB(C)]	0.8457079	No	0.01790651
delta 75th percentile SPL [dB(A)]	0.8564483	No	0.01789269
delta 95th percentile SPL [dB(A)]	0.877693	No	0.01786839
delta 5th percentile SPL [dB(C)]	0.9488414	No	0.01781582

Table 3 – Multivariate linear regression of acoustic parameters, gender, age and perception of sleep disturbance due to traffic noise against the total sleep time

Parameter	p-Value	Significance ($p < 0.05$)	Variable adjusted R^2
SPL [dB(A)] inside maximum value	3.77E-07	Yes	0.1113088
delta 75th percentile SPL [dB(A)]	1.04E-05	Yes	0.09565355
delta 95th percentile SPL [dB(A)]	1.54E-05	Yes	0.0937927
delta median SPL [dB(C)]	0.000111062	Yes	0.08441378
delta maximum SPL [dB(A)]	0.000161302	Yes	0.08264567
delta 75th percentile SPL [dB(C)]	0.000205198	Yes	0.08150593
delta 25th percentile SPL [dB(C)]	0.000592569	Yes	0.07649366
delta median SPL [dB(A)]	0.000594685	Yes	0.07647685
delta 95th percentile SPL [dB(C)]	0.000677861	Yes	0.07585957
delta minimum SPL [dB(C)]	0.000920045	Yes	0.07442076
delta 25th percentile SPL [dB(A)]	0.002174228	Yes	0.07038563
delta 5th percentile SPL [dB(C)]	0.002541042	Yes	0.06965721
delta LAeq	0.002691289	Yes	0.06938908
delta maximum SPL [dB(C)]	0.004669397	Yes	0.06682598
delta 5th percentile SPL [dB(A)]	0.005624777	Yes	0.06596414
delta LCeq	0.006706187	Yes	0.06515218
delta minimum SPL [dB(A)]	0.01341816	Yes	0.06197449

4. DISCUSSION AND CONCLUSION

The aim of this paper has been to describe people's subjective and objective response to road and rail traffic noise, using the difference of indoor and outdoor sound pressure levels. The difference of the indoor to the outdoor sound pressure levels was intended to be used as assessment of the sound dynamics of traffic noise in the surrounding of test subjects homes. It was tested for applicability regarding the description of physiological and psychological effects of traffic noise. Although the factor didn't prove to be useful regarding the explanation of every aspect of physiological and psychological effects of traffic noise, it seems to be one way to explain a subset of them.

The experience, gathered while conducting the study, shows, that people are able to distinguish between the investigated noise sources and focus on them. This ability contributes to their subjective traffic noise annoyance and can be linked to acoustic parameters for the outside of their homes, which is indicated as well in the evaluation, as inside models are not conclusive. In regards of sleep, indoor noise is the dominant factor for physiological reactions, leading to observable cardiovascular reactions. It is important to mention, that annoyance ratings and sleep efficiency were best explained by models using the C-weighting.

As a conclusion, it can be stated, that the data acquisition methodology works well and the methods can be applied within other projects. The amount of acquired data is extensive and provides a good basis for further detailed research projects, combining different fields of expertise. However, the acquired data seems to feature a few unknown relations, which need to be determined in order to be able to make the correct interpretations. Therefore, it needs to be further evaluated, especially concerning the connection of the acquired objective with the subjective questionnaire data.

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REFERENCES

1. Den Boer LC, Schroten A. Traffic noise reduction in Europe. CE Delft, March 2007
2. Ising H, Kruppa B. Health effects caused by noise : Evidence in the literature from the past 25 years. Noise Health 2004;6:5-13
3. Babisch W. Transportation noise and cardiovascular risk: Updated review and synthesis of epidemiological studies indicate that the evidence has increased. Noise Health 2006;8:1-29
4. Bluhm G, Nordling E, Berglind N. Road traffic noise and annoyance-an increasing environmental health problem. Noise Health 2004;6:43-9
5. Babisch W. Noise and health. Environmental Health Perspectives 2005, 113(1), A14-A15
6. Kryter KD. The Effects of Noise on Man. 2nd Edition. Orlando, FL: Academic Press. 1985
7. World Health Organization -WHO. Guidelines for Community Noise. 2000
8. World Health Organization -WHO. Night Noise Guidelines for Europe. 2009
9. Basner M, Müller U, Griefahn B, Hume KI. Evaluation of traffic noise effects on sleep. Proceedings of the EURONOISE 2009 and Acta Acustica united with Acoustica, Volume 95, Supplement 1, Edinburgh, Scotland. 2009
10. Griefahn B, Marks A, Robens S. Noise emitted from road, rail and air traffic and their effects on sleep. Journal of Sound and Vibration. 2006;295(1-2):129–40.
11. Ögren M, Öhrström E, Jerson T. Noise and vibration generation for laboratory studies on sleep disturbances. Proceedings of the 9th International Congress on Noise as a Public Health Problem (ICBEN) 2008, Foxwoods CT, USA. 2008
12. Öhrström E. Sleep disturbances caused by road traffic noise - studies in laboratory and field. Noise Health 2000;2:71-8. 2000
13. Skånberg A, Öhrström E. Sleep disturbances from road traffic noise: a comparison between laboratory and field settings. J Sound Vib 290 (1) (2006), pp. 3–16
14. Miedema HME, Oudshoorn CGM. Annoyance from Transportation Noise: Relationships with Exposure Metrics DNL and DENL and Their Confidence Intervals. Environmental Health Perspectives. 2001;109(4):409.
15. Miedema HME, Vos H. Associations Between Self-Reported Sleep Disturbance and Environmental Noise Based on Reanalyses of Pooled Data From 24 Studies. Behavioral Sleep Medicine. 2007;5(1):1–20.
16. Morgan DE, Dirks DD. Loudness discomfort level under earphone and in the free field: the effects of calibration methods. The Journal of the Acoustical Society of America. 1974;56(1):172–8.
17. Botteldooren D, Lercher P. Soft-computing base analyses of the relationship between annoyance and coping with noise and odor. The Journal of the Acoustical Society of America. 2004;115(6):2974–85.
18. Guski R, Felscher-Suhr U, Schuemer R. The Concept Of Noise Annoyance: How International Experts See It. Journal of Sound and Vibration. 1999;223(4):513–27.
19. Leonard S, Borsky PN. A Causal Model for Relating Noise Exposure, Psychosocial Variables and Aircraft Annoyance. Proceedings of the International Congress on Noise as a Public Health problem, Dubrovnik, p. 691-705. 1973
20. Miedema HME, Vos H. Demographic and attitudinal factors that modify annoyance from transportation noise. The Journal of the Acoustical Society of America. 1999;105(6):3336–44.
21. Jonsson E, Sörensen S. Relation between Annoyance Reactions and Attitude to Source of Annoyance: Two Experiments in Sweden Tested Reactions to Aircraft and Motor Traffic Noise. Public Health Reports (1896-1970). 1970;85(12):1070–4.
22. Carter NL, Hunyor SN, Crawford G, Kelly D, Smith AJM. Environmental noise and sleep - a study of arousals, cardiac arrhythmia and urinary catecholamines. Sleep 17: 298-307. 1994
23. Lienhart M, Cik M, Fellendorf M, Fallast K, Marth E, Freidl W et al. Noise indicators of road and rail traffic noise based on subjective perception, psychological and physiological parameters. In Euronoise 2018 - Conference Proceedings. 2018
24. Lienhart M, Cik M, Fellendorf M, Fallast K, Marth E, Freidl W. Psychoacoustic indicators of road and rail traffic noise, subjective perception and psychological and physiological parameters. In Proceedings of the INTER-NOISE 2017: 46th International Congress and Exposition on Noise Control Engineering. 2017. p. 6351-6360. 635
25. Wagner J, Cik M, Marth E, Santner BI, Gallasch E, Lackner A, Raggam RB. Feasibility of testing three salivary stress biomarkers in relation to naturalistic traffic noise exposure. International Journal of Hygiene and Environmental Health 2010, 213(2): 153-155
26. Hektner JM, Schmidt JA, Csikszentmihalyi M (Eds.). Experience Sampling Method: Measuring the Quality of Everyday Life. Sage Publications, Inc. 2006
27. Larson R, Csikszentmihalyi M () The experience sampling method. New Directions for Methodology of Social and Behavioral Science, 15, 1983, 41-56
28. Martoni M, Bayon V, Elbaz M, Léger D. Using actigraphy versus polysomnography in the clinical assessment of chronic insomnia (retrospective analysis of 27 patients). La Presse Médicale. 2012;41(3).
29. Sadeh A, Sharkey K, and Carskadon MA. Activity-based sleep-wake identification: an empirical test of methodological issues. Sleep 17(3):201-207, 1994.
30. Cole RJ, Kripke DF, Gruen W, Mullaney DJ, Gillin JC. Automatic sleep/wake identification from wrist activity. Sleep. 1992;15(5):461–469.