



Transport Research Arena (TRA) Conference

Psychoacoustic parameters in noise assessment – A research within the BMDV Network of Experts

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Abstract

The research project “Testing psychoacoustic parameters for innovative noise reduction strategies” is dedicated to the applicability of psychoacoustic parameters for the assessment of traffic noise. In order to characterize road traffic noises in detail and to demonstrate the perceptual impact, knowledge of the underlying dimensions that influence the evaluation of traffic sounds in everyday situations is required. Various studies on the effects of acoustic environments have shown that sound perception is multidimensional in nature, with classical affect models often being derived. In a first study, stimulus-dyad comparisons were used to systematically explore relevant descriptive variables and attributes, which describe the latent perceptual dimensions underlying the evaluation of road traffic sounds. In an open survey, subjects commented on the perceptual differences between stimulus pairs, i.e. road traffic situations presented in an audio-visual context based on 360° camera and Higher Order Ambisonics recordings. The road traffic scenes were presented via a head-mounted display and a 21.2-channel Ambisonics system. The stimulus dyads comprehensively covered the feature space of road traffic sounds and systematically took into account factors such as traffic volume, traffic flow, traffic composition, road surface, and permissible maximum speed. The paper explains the experimental methodology, shows the derived attributes, and outlines the development of a questionnaire as a measurement tool to determine perceptual impressions in the context of road traffic sounds.

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1. Introduction

Nomenclature

Research on noise effects has been dealing with the impact of traffic noise on humans and the resulting extra-aural noise effects including noise annoyance for many years (see e.g. Berglund et al., 1999). Noise annoyance is usually related to the averaged sound pressure level (e.g. L_{Aeq} , L_{DEN}) of unwanted noise sources and dose-response relations are derived (Miedema & Vos, 1998). Accordingly, noise effects are almost exclusively described by the degree of annoyance in relation to dose expressed by level indicators, and a differentiated consideration of the different aspects of noise perception and assessment has not been performed so far. However, some noise protection measures do not follow completely the expected reduction of annoyance on the basis of a reduced sound pressure level of the respective noise source (e.g. Nilsson & Berglund, 2006). Nilsson et al. showed later that this discrepancy can be mostly explained by using the psychoacoustic parameter loudness L_N (Nilsson et al., 2008). Pedersen et al. observed that low noise pavements cause a lesser slope of exposure-response functions than expected (Pedersen et al., 2013). In context of crossing over road markings, the strong increase of noise annoyance could be explained by the use of psychoacoustic parameters capturing the amount of noise patterns responsible for the increased noise annoyance (Müller et al., 2015). Even the potential benefit of masking road traffic noise by pleasant sound sources, such as fountain noise, as a kind of active sound design measure is discussed in the context of noise protection (Kang and Hao, 2013).

Thus, further (psychoacoustic) factors seem to have an influence on the perception and evaluation of traffic noise. At the same time, the influence of non-acoustic factors on noise evaluation is beyond dispute (Guski, 1999), and the influence of psycho-acoustic parameters on perception of environmental noises has been widely investigated and documented (Engel et al., 2021). Therefore, a detailed investigation of the relevant aspects of road traffic noise moderating the human responses needs to be carried out to understand the process of noise annoyance and to use this knowledge to choose most efficient noise abatement measures from a perceptual point of view beyond level considerations only.

The aim of the study was to collect descriptive attributes that are verbalized specifically during the experience of road traffic sounds in a realistic situation using a virtual reality application. Although some works (e.g., Axelsson et al., 2010) already explored different dimensions that seem to underlie the perception of environmental noises, the dimensions were identified neither specifically for road traffic sounds, nor in the context of virtual reality with a high level of immersion. To fill this research gap, different road traffic scenarios with realistic characteristics were generated in the Mixed Reality Design Lab at TU Berlin and UdK Berlin, and descriptive and differentiating attributes were elicited from participants (Fiebig et al., 2022).

2. Method

2.1. Sample

A total of 22 participants (9 female, 13 male) with an age between 22 and 64 years took part in the audio-visual listening test. The mean age was 38.6 years with a standard deviation of 13.4. The mean value of the noise sensitivity, which was determined by the noise sensitivity questionnaire LEF-K by Zimmer and Ellermeier (1998), was 13.6 with a standard deviation of 4.5. Half of all participants reported previous experience with VR glasses and/or VR environments. The majority of the participants stated that they did not have any explicit expertise in the field of acoustics.

2.2. Stimuli

A total of 39 road traffic scenes recorded by an Insta360 Pro II 360° camera, a Zylia ZM1 Ambisonics microphone, and an NTI XL2 sound level meter (see measurement setup in Fig. 1) served as the basis for generating the test stimuli. The Ambisonics microphone allowed the generation of third-order Ambisonics recordings.

The recordings differed according to various criteria, such as traffic volume, traffic composition, point of immission, road surface, road layout and the maximum permitted speed. Moreover, recordings were used in which other noise sources were audible in addition to the road traffic noise. The recordings with a measurement duration of eight minutes, covered a wide range of sound pressure levels (L_{Aeq} from 55.0 dB(A) to 78.0 dB(A)) as well as considerable differences in traffic volume (DTVw from 4,500 to 54,000) with a varying proportion of heavy goods vehicles of up to 6,400 DTVw.

Scenes with a duration of 20 seconds representing specific traffic situations were extracted from the recordings. The scenes were arranged in pairs (dyads) for the test in such a way that they differed in several of the above-mentioned criteria and thus contrasted strongly. The majority of scenes were in the medium sound pressure level category ranging from 60 dB(A) to 64 dB(A). A total of 73 different scenes were generated and presented in 40 dyads. Figure 2 illustrates exemplarily the range of road traffic situations presented.



Fig. 1. Setup for measuring audio-visual road traffic scenes with Ambisonics microphone (Zylia ZM1), sound level meter (NTI XL2) and 360° camera (Insta360 Pro II)



Fig. 2. Examples of presented road traffic situations (visual scene)

2.3. Apparatus

The audio-visual scenes were reproduced in the Mixed Reality Design Lab of TU Berlin and UdK Berlin using 3D audio (21.2-channel Ambisonics) and a head-mounted display (Varjo VR-3 OLED, 1920 x 1920 px per eye, 115° FoV) in a controlled manner with the original sound pressure level (see Fig. 3).

2.4. Procedure

The 40 dyads were presented in three-dimensional audio-visual form to the participants in a randomized order. First, a traffic scene of a dyad was displayed and after a short freeze frame of three seconds (white aperture), the second scene followed immediately.

The participants were asked to name expressions that best described their individual auditory impression related to the presented dyad. They were invited to comment spontaneously and freely on the experienced scenes.

A training sequence consisting of three test dyads was used to get acquainted with the experimental environment, to adapt and get used to the VR world and to demonstrate the methodology. The first test dyad was presented as two separate traffic scenes one after the other and participants first practiced verbalizing the auditory impression by means of adjectives. Subsequently, the two following test dyads were played as a pair, i.e., with only the separating aperture.

The participants were then invited to discuss any open issues with the experimenter and proceed to the actual trial. They were encouraged to rest according to their individual needs and to take a break at least after half of the test time, i.e., after 20 dyads.

The elicited attributes were reported verbally by the participant to the experimenter, who recorded the terms unedited and in full. Participants were instructed to name up to five attributes per dyad for each of the two traffic scenes and, if possible, also up to five attributes describing the differences of the stimuli in the dyad. Each participant partook individually in the experiment and was placed in the sweet spot of the loudspeaker system (Fig. 3, left). An experiment lasted 60 to 90 minutes in total, including information and documentation on the compliance with hygiene measures as well as the completion of questionnaires on demographic data and individual noise sensitivity after the audio-visual experiment.

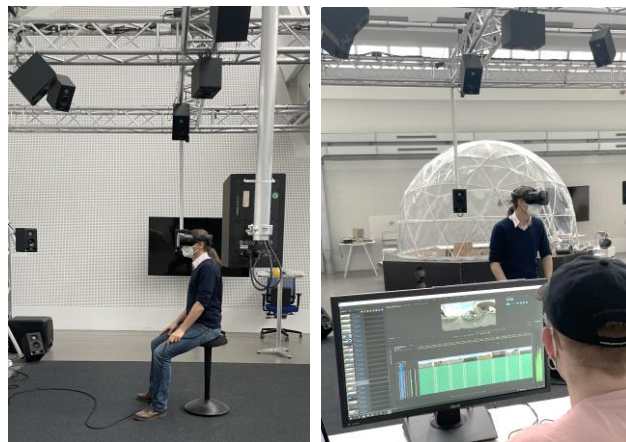


Fig. 3. Participant with Head Mounted Display (HMD) in the sweet spot of the Mixed Reality Design Lab (left) and technology lead (right).

3. Results

3.1. Key figures for the generated attributes

Semantic qualitative data analysis of the more than 4,000-word mentions was carried out. First, the raw data were cleaned of descriptions that primarily referred to visual impressions or included groups of words without naming any

attributes. After this step, the data set for further analysis included a total of 742 different adjectives. During the experiment, between 88 and 310 attributes ($M = 183.4$, $SD = 50.9$) were stated by each of the participants. Approximately 33% of the mentioned words were single attributes in the sense of individually chosen words, while the other part were terms that were also given by other participants (inter-individual agreement).

Figure 4 shows the ranking order of the inter-individually (in relative terms) most frequently mentioned attributes for the characterization of the audio-visual road traffic scenes that were experienced by the participants.

In order to categorize or cluster the high number of similar attributes, they were assigned to relevant descriptive dimensions based on semantic considerations and theoretical plausibility. For this purpose, three persons (2 psychologists, 1 psycho-acoustician) independently categorized all terms. An assignment to a category was made when at least two of the three raters assigned an attribute to the identical category.

Known dimensions in the field of perception of environments in general and environmental sounds in particular are *valence* (ISO/TS 12913-3:2019), *activation/arousal* (Andringa & van den Bosch, 2013) and *eventfulness* (Axelsson, 2010), *dominance* (Choi et al., 2015), *loudness* (Yu et al., 2016), and *familiarity* (Zhang & Kang, 2020). These were used as hypothetical categories in clustering the collected terms. Furthermore, the analysis revealed other plausible categories that were more related to the noise character, to audio-visual aspects, to the perception of space, or to the separation of foreground and background.

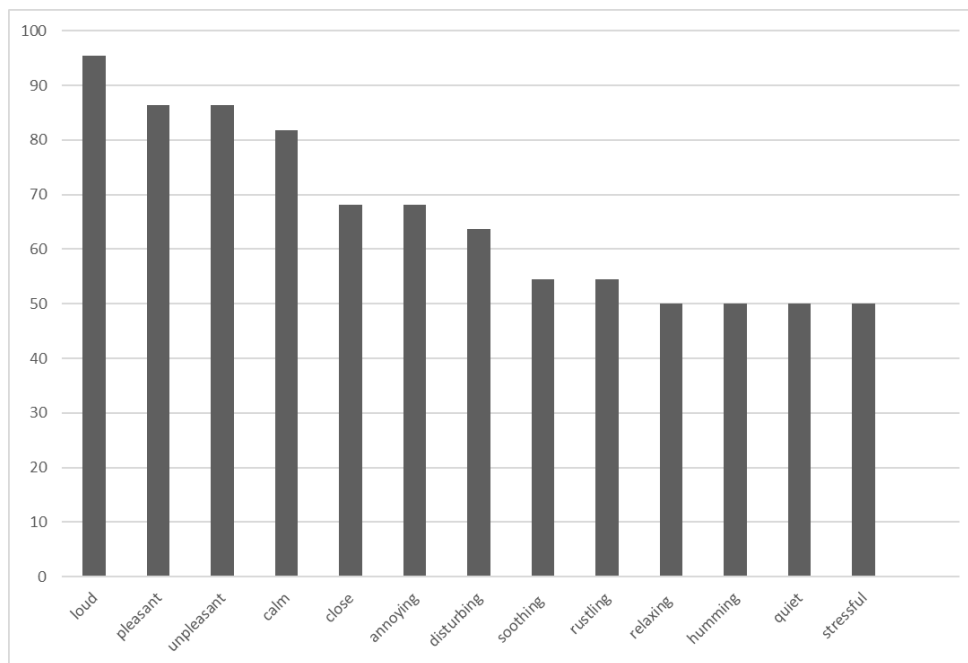


Fig. 4. Ranking order of the most frequently mentioned terms to describe the experienced differences between two road traffic scenes in relation to the sample size in %

Table 1 provides the frequencies of attributes mentioned across the categories used for clustering. Terms that refer to preference, rejection, acceptance, or preference can be assigned to the *Valence* category. Exemplary attributes for this category are "pleasant" (angenehm), "acceptable" (akzeptabel), "annoying" (nervig) or "tolerable" (zumutbar). Descriptors within the *Activation* category include, for example, "activating" (aktivierend), "monotonous" (monoton), "hectic" (hektisch), whereas the *Dominance* category refers to the control experienced in a situation. Descriptive adjectives for this are "threatening" (bedrohlich), "dominant" (dominant) or "aggressive" (aggressiv).

In the category *Time Structure*, terms such as "periodically" (regelmäßig), "cyclically" (zyklisch) and "sporadically" (sporadisch) were assigned, whereas "full" (voll), "jumbled" (durcheinander) or "much" (viel) were

assigned to the category *Eventfulness*. In the category *Familiarity*, terms such as "normal" (normal), "realistic" (realistisch), "expectable" (erwartbar) or "familiar" (vertraut) were included.

Attributes of the *Clarity* category describe the impression of "tangibility" of the environment. Exemplary attributes are "blurred" (verschwommen), "transparent" (transparent) or "clear" (klar). The category *Space*, on the other hand, includes terms that contain a spatial, enclosing, or directional component, such as "open" (offen), "closed" (geschlossen) or "enveloping" (umhüllend).

The category *Audio-visual aspects* includes attributes that have a clear visual reference. Examples are "industrial" (industriell), "summersy" (sommerlich) or "urban" (städtisch). According to the figure-ground theory, the aspects of *Foreground and Background* describe everything that refers to the separation of foreground and background. Examples are "in front" (vordergründig), "behind" (hintergründig) or "present" (präsent).

Table 1. Proportion of attribute mentions in the categories (total number, percentage)

Category	Total number of mentions	Percentage of mentions
Valence	945	23.4
Sound character	696	17.2
Noise level	562	13.9
Activation / arousal	444	11.0
Temporal structure	298	7.4
Foreground / background	290	7.2
Dominance	205	5.1
Space	181	4.5
Familiarity	134	3.3
Eventfulness	134	3.3
Audio-visual aspects	117	2.9
Clarity	41	1.0

3.2. Specification of sound character category

The category *sound character* functioned as a container for auditory phenomena that are directly related to the auditory impression triggered by specific acoustic properties and have a direct link to signal properties (see Fig. 5).



Fig. 5. Word cloud for the most common attributes in the category *Sound Character*

At this point, a further subdivision into subcategories seemed appropriate in order to further break down the variety of attributes into semantic units. Overall, it becomes apparent that about half of all terms assigned to the category *Sound Character* are related to the spectral center or the timbre. Terms such as "sharp" (scharf), "whooshing" (zischend), "light" (hell), "muffled" (dumpf), "deep" (tief), "high" (hoch), "shrill" (schrill) or "high-frequency" (hochfrequent) are used here quite often. In psychoacoustics, the parameter "sharpness" (DIN 45692:2009-04) is proposed for the auditory sensation, which refers directly to the spectral center of gravity of a sound without considering the spectral fine structure. It is assumed that a higher spectral center of gravity, a sharper sound, goes along with a higher noise annoyance (cf. DIN 45692:2009-04).

Furthermore, terms referring to the perceived bandwidth (e.g., "narrowband" (schmalbandig), "broadband" (breitbandig)) or to typical sounds of disturbance "droning" (dröhnend), "booming" (brummend), "squeaking" (quietschend), "clattering" (klappernd), "rumbling" (polternd), "rattling" (ratternd), "humming" (wummernd) are often used (cf. FVV, 2001). In total, about 20% of all terms from the category *Sound Character* are related to those disturbing noise phenomena. In addition, sporadic terms are mentioned that can be assigned to other auditory basic sensory quantities, such as "tonality" (tonal), "roughness" (rau), and "fluctuation strength" (schwankend). Moreover, in the context of the sound character category, a few terms can also be directly assigned to the area of sound quality and refer to quality aspects with attributes like "soft" (sanft), "melodious" (melodiös), "sonor" (sonor), "fat" (fett), "harmonic" (harmonisch) or "thin" (dünn).

3.3. Selection of questionnaire items

The questionnaire items were selected in a two-step procedure. Subsequent to their categorization, all attributes were submitted to a rating process performed by six members of the research team (2 acoustics experts, 4 psychologists). Each attribute was independently assessed regarding its comprehensibility, its representativity for the respective category, and its suitability for the questionnaire as perceived by each researcher. In this step based on the analysis of the independent ratings of the research team, a total of 186 attributes were selected. In a second step, a consensus meeting was held amongst the research team to further reduce and consolidate the list of possible items covering the assumed underlying dimensions of sound perception in the context of road traffic noise. As a result, 59 attributes were submitted to the final item list. In the most frequent cases, these correspond to the five attributes of their respective category with the highest overall agreement regarding questionnaire suitability from the previous rating step (e.g., *calm, monotonous, pleasant, annoying, aggressive, threatening, hectic, chaotic, eventful, dynamic, rhythmic, familiar, loud, enveloping, sharp, booming*). Each attribute will form an unipolar item with a continuous rating scale from 0 to 100, thus facilitating data variance and the application of various statistical procedures as planned (cf. Chyung et al., 2018).

4. Summary and Outlook

Various audio-visual stimuli were presented in the Mixed Reality Design Lab Berlin and perceptual attributes were derived by means of an explorative study design for the development of descriptive dimensions to evaluate road traffic sounds.

The participants generated a large number of descriptions, some of which showed high inter-individual agreement. As expected, established dimensions from the soundscape theory (affect model) were found in the data, i.e. the well-known dimensions valence, activation and eventfulness. Furthermore, terms were identified which address acoustic aspects (e.g., loudness, temporal structure) and the auditory perceptions they evoke (e.g., timbre). In addition, the degree of familiarity seems to be relevant for the participants to characterize and distinguish the experienced scenes.

The pool of attributes formed a comprehensive starting point for the development of a questionnaire to evaluate road traffic sounds. To create an item list suitable for listening experiments, 59 attributes were selected in a two-step consensus process by evaluating the items independently and discussing subsequently the resulting list of items.

Currently, a study is being prepared in which this item list will be used to evaluate the auditory impression of different road traffic scenes. The study will again take place in the Mixed Reality Design Lab described above. Based on the stimulus evaluation and a subsequent factor analytic evaluation, meaningful dimensions to assess road traffic

sounds will be derived. At the same time, the general suitability of selected items will be tested. Further analysis will focus on correlations between the psychoacoustic parameters inherent in the stimuli and the perceptual ratings collected in the study. This will allow to assess the effect on noise mitigation measures on annoyance more accurately.

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