ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

ENVIRONMENTAL IMPACT OF INDUSTRIAL NOISE: A PERCEPTUAL TYPOLOGY OF PERMANENT SOURCES

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Abstract

Controlling the environmental noise impact of industrial facilities goes through a better understanding of the perception of the different noise sources. A first step in this way consists in creating a perceptual typology of the sources, that will be helpful to assess their relative annoyance. This paper presents a typology of permanent industrial noise sources, resulting from a categorization test with realistic sound stimuli, which was carried out in laboratory conditions. Using a physical classification of major industrial sources, about 50 permanent sources have been recorded separately and close to the source so as to avoid unwanted noises. Sound stimuli are then created by filtering the recordings in order to simulate the sound attenuation between the recording point and a receiver point which would represent a dwelling located further away from the source. In a previous study, the software calculation parameters have been chosen to get a realistic rendering of the filtering, both from a physical and perceptual point of view. A categorization test is set up with these stimuli, resulting in a typology of the sources as they would be perceived at the receiver point. Listening test protocol and results are detailed.

1- INTRODUCTION

A number of studies were carried out about noise annoyance due to transportation sources (cars, trains, airplanes), but the environmental noise impact of industrial sources has not been extensively studied yet. As industrial sources are numerous and most of them work 24 hours a day, the characterization of the induced noise annoyance should be examined further in detail.

To assess the noise impact of industrial sources, some countries (France [1], Australia [6]) base their legislation standards on a comparison between ambient noise

Eds.: J. Eberhardsteiner, H.A. Mang, H. Waubke

level (when source is on) and residual background noise level (when source is off). Limits vary with the period of day. In the United Kingdom, the standard is based on a comparison between noise level of the source and background noise level [3].

In some cases, a basic noise level comparison seems to be inappropriate: concerning the French noise standard for industrial sources (emergence level), a previous study [16] found that for a given emergence level, annoyance judgments differ according to the kind of source. Such standards need to be refined depending on features of the source.

If penalties accounting for acoustic features of noise do exist (such as tonal or impulsive character), laboratory experiments show that the criteria which are suitable for noises presenting one specific feature are not adapted to real industrial noises, which can present multiple acoustic features [4],[5]. For instance, listening tests led by Berry and Porter [5] have shown that an addition of penalties corresponding to specific acoustic features cannot account for annoyance of an industrial noise (in the case of an industrial noise with two-tone complexes or an industrial noise with impulsive and tonal character). In this case, it would be thus interesting to develop improved descriptors related to features that are perceptually relevant for real industrial noises, i.e. descriptors that are related to perceptual categories of industrial sources.

In order to build a perceptual typology of these sources as they would be perceived in the environment, they should be compared in the same listening conditions: same distance, same propagation conditions. Therefore, a method has been developed to create sound stimuli corresponding to different industrial sources and heard at a virtual point located at a given distance from the sources [13]. They were created by filtering audio recordings of the sources, made at a closer distance (in order to avoid unwanted noises). The filter simulates the effect of sound propagation above a plane grassy ground, with downward refraction conditions, and without any obstacles between source and receiver. Section 2 details the stimuli creation process.

An auditory experiment is set up in laboratory conditions in order to compare these stimuli. A categorization test and a direct scaling of annoyance are performed by 60 listeners, in order to assess annoyance and to examine the relationship between this annoyance and the different perceptive categories of sounds. Sections 3 to 7 detail the listening test protocol and results.

2- SOUND STIMULI

Recording and selection of sound sources

A bibliographical study was conducted in order to identify industrial noise sources. The list of sources was mainly extracted from the Imagine Project [10]. The resulting typology is given in Table 1. Note that indoor sources located in a same enclosure are gathered in one category “machinery halls”, considering the sources enclosure as a whole.

Based on this typology, and focusing on **permanent sources** only, around 60 sources were recorded (stereophonic recordings, ORTF technique), following the protocol detailed in [11].

A reduced set of 30 sources was selected considering the following principles:

- each category of Table 1 should be represented (except the category 'material extraction/handling' which contains no permanent sources) ;
- the source and its environment should be modeled with good precision in the sound propagation software used for the filter calculation (see next subsection) ;
- for subcategories presenting a large amount of sources, the number of sources has been reduced using arguments of similarity between sources and quality of the recording or modeling process.

In Table 1, the resulting number of selected sources is indicated in the last column.

Table 1: Functional typology of industrial noise sources

Categories	Details / Subcategories	Nb. of recordings (permanent sources)	Nb. of stimuli selected
combustion devices	furnaces, flares, internal combustion engines	2	2
electrical machinery	transformers, alternators, motors, high voltage wires	11	6
liquid flow devices	cooling towers, mixing tanks	7	4
	pumps	5	3
gas flow mechanical devices	valves, blowers, gas jets, exhaust stacks	10	5
	fans	6	5
	piping	3	1
machinery halls	indoor sources located in a same enclosure	12	4
material extraction / handling	conveyors, trucks and other devices	no permanent sources in this category	

Filtering and equalization

Sound stimuli are created by filtering the recordings in order to simulate the sound attenuation between the on-site recording point and another point which would represent a dwelling location, at a distance of 250 m and in direct view from the source. The filters are calculated with third octave definition by a sound propagation software, which takes into account the influence of distance, atmosphere (downward refraction conditions) and ground effects (flat terrain). Further details about the filter calculation are given in [13].

In order to suppress the influence of noise level, which is known to be an important factor of annoyance, the stimuli were first equalized at a sound level of 45 dB(A), which is the mean level of the sources at 250 m. Then, the loudness of all sounds were rounded off to the same value (N= 4.85 sones).

3- APPARATUS

The experiment was computer controlled, via a graphical user interface. The sounds were reproduced in a listening room (w×l×h = 3.3×5×3.5 m) by means of a stereophonic system (two loudspeakers Tannoy System 1200 and a high quality amplifier), connected to the computer via the sound card optical output. The central unit is placed in an adjacent room, so as to avoid computer fan noise. In the listening room, the background noise level is below 24 dB(A).

Figure 1. Listening room.

4- EXPERIMENTAL PROCEDURE

The main objective of this study is to get perceptual categories of sources, to assess relative annoyance, and to examine the relationship between this annoyance and the different categories of similar sounds. Consequently, the protocol has been defined to include two main tasks : a free categorization task, and a direct scaling of annoyance.

The test is divided in three distinct parts. As an introduction, subjects were explained that the experiment was a general study on the perception of noises from various industrial sources, not specific to EDF installations. Between Part I and Part II, a 10 minutes break was imposed.

Part I - Categorization task

The first part of the test consists in a free categorization task [15]. Subject is asked to move sound icons on the screen and make categories of similar sounds. For this part of the test, the duration of each sound is 5s. The disposition order of the sound icons on the screen is randomised.

After this task, subject is asked to describe the categories he has formed. This verbalization task is done as an interactive dialog with the experimenter.

Part II – Scaling of annoyance

Following the categorization task, the second part of the experiment consists in a direct rating of the noise annoyance of each sound (same sounds as in Part I). Following the recommendations made by Guski [8],[9], the English term "annoyance" was translated into the French word "*nuisance*" rather than "*gêne*" as the latter refers to a broader concept.

The listener is asked to imagine himself being at home, hearing industrial noises, and must answer the question '*How would you qualify the noise annoyance induced by this sound ?*' using the scale represented in Figure 2. This is a continuous scale, graduated by five verbal labels, ranging from '*very low*' to '*very high*'.

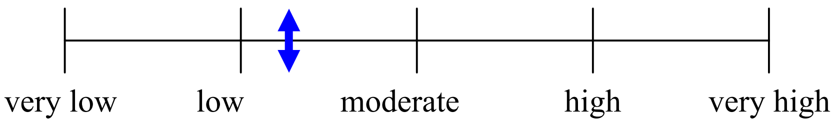

Figure 2. Direct rating scale used in part II. The cursor (represented here as an arrow) can be moved in a continuous way between the five graduations.

The sounds are presented one after another, in a random order. Duration of the sounds is 15 s. For each sound, the number of playbacks is unlimited. The first playback is not interruptible.

As an introduction, a training phase of 4 sounds (the same for all subjects) is performed in presence of the experimenter, in order to check the good comprehension of the task.

Part III - Questionnaire about industrial noise

The last part consists in a questionnaire, gathering usual questions about the subject and about important non-acoustic factors cited by previous studies [7],[12],[14]. The following factors were supposed to be potentially influent and applicable to our laboratory study:

- self-reported noise sensitivity (direct question) ;
- fear of certain persons that the industrial activities whose noise they hear could be somewhat dangerous ;
- attitude towards industrial noise sources (belief that noise could be prevented ; link with the noise source) ;
- exposure to noise at work or at home.

5- SUBJECTS

A total of 60 listeners, 27 males and 33 females, all with self-reported normal hearing, participated in the experiment. Their age varied between 21 and 65 (average 43). They were recruited by an independent company. 70 % of them lived “in the city” (towns with over 6000 inhabitants) and the rest “in the country” (in villages with less than 6000 inhabitants). They were paid for their participation.

6- ANALYSIS AND RESULTS

Detailed analyses and results will be presented at the conference.

7- SUMMARY

This study allowed us to define a typology of permanent industrial noise sources, resulting from a categorization test with realistic sound stimuli, which was carried out in laboratory conditions. Relative annoyance has also been assessed and analyzed with regard to the different perceptive categories of sources. This study is part of a research project entitled “Noise index investigation for the assessment of industrial noise annoyance”. The project is a collaboration between EDF R&D and LASH, and is cofinanced by AFSSET (the French Agency for Environmental and Occupational Health Safety [2]).

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