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Subjective rating and assessing environmental sound of an industrial nature with tonal and impulsive characteristics

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ABSTRACT

The aim of this work is to develop methods to assess the perception and community response to environmental sound from industrial sources. Acoustic features such as tonality, impulsivity and intermittency can increase the significance of impact over that expected from a comparison between the specific sound level and the background sound level. When such features are present, the British Standard BS 4142:2014, Methods for rating and assessing industrial and commercial sound offers an approach where a character correction is added to the specific sound level to obtain a rating level. Where tonal and impulsive characteristics are present, corrections are normally added linearly. However, this approach has little perceptual basis. In this paper, research using perceptual testing is described to establish the momentary and overall assessments of industrial sounds containing various levels of tonal and impulsive characteristics. The results show a strong correlation between the kind of stimuli, the kind of participant, and the order in which the stimuli are placed into the sample. The implication of this work is that the methodology described could be used to develop a more robust system for rating and assessing environmental sound with tonal and impulsive characteristics of an industrial nature.

Keywords: Noise, Environment, Annoyance, Psychoacoustic, BS4142
I-INCE Classification of Subject Number: 81

1. INTRODUCTION

Although there are numerous publications about noise annoyance [1, 2] only few papers can be found on industrial noise and commercial noise. Most of these studies are focused on transportation noise instead on industrial noise, presumably because this noise is less widespread [3]. In this sense, this may be due to the fact that industrial noise sources could be considered heterogeneous as noise can be generated by a great variety of different industrial activities. Therefore, this implies the complexity of the noise sources and consequently in the variety of the noise generated being composed by various types of components such as impulsive, intermittence and tonal depending on the origin of the industrial sources. Other limiting factor investigating an industrial and commercial noise exposure is related on non-acoustical factors. In this sense, knowing the impact of industrial and commercial noise on residents requires a better understanding of how these noise sources are perceived. Thus, this should be considered in the determination of noise annoyance indicators.

Both industrial and commercial noise are generated in different localities around the UK. In particular, industrial noise has been recognised as a of main sources of common law nuisance by the UK Courts since 1800s. The first methodologies recognisance with guidance applicable to the establishment of industrial noise date from the 1960s, Kosten and Van Os [4] being most notably Community Reaction Criteria for External Noises and the Committee on the Problem of Noise [5] simplified methodology to establish the reaction to industrial noise in mixed residential areas.

Both researches determined annoyance due to industrial noise could be subjective and this could be affected by many factors additional to the absolute decibel level. The study of Kosten and Van Os [4] established decibel penalties when different characteristics from noise were considered, as for example: the receiving room (context), pure tone perceptibility (character and sensitivity to specific character), impulsivity and/or intermittency (character, frequency and duration), occurrence during work hours only, percentage of time present (duration), any economic tie (benefit of noise to receiver and control over noise) and the character of the receiving locality. However, in the study proposed by the Committee on the Problem of Noise, specific characteristics, time of occurrence, duration (min) of noise during one hour or half day and type of district were considered for assessing reaction to industrial noise in mixed residential and industrial areas. Due to the magnitude of the problem, British Standard 4142 [6] had been published that provide guidance on acoustic measurement procedures and assessment criteria. In this sense, the work of Committee on the Problem of Noise can be considered as the predecessor to BS4142 1967. The BS 4142 was first published in 1967, this being revised in 1990 to accomplish with the requirements of future ISO 1996 [7]. In the version of 1967, this standard already established a 5 dB (A) correction to the measured noise level if noise sources presents one or more of these features: discrete, continuous note (whine, hiss, screech, hum, etc); impulses (bangs, clicks, clatters or thumps) or the noise is irregular enough to attract attention. The measured noise level with corrections was defined as the corrected noise level (CNL) which was compared with either the measured background noise level or its surrogate corrected criterion if the noise could produce complaints. The same methodology was proposed into the Planning and Noise Circular 1073.

After 25 years without changes happening, in 1997 a new edition was published with the aim to clarify aspects in the light of comments from acoustic community. This version introduced the concept of LAeq for the quantification of the specific and rating noise levels. The 1994 revision of Planning and Noise also incorporated it.

Latest 2014 version of the British Standard 4142 suggests, instead of capping a correction at 5 dB(A) depending on the characteristics of noise source, the application of a penalty for each characteristic if the noise source contain more than one. After, a linear summation of all penalties should be applied taking into consideration the possible effect on relationship response – perception. Thus, this could entail until 15 dB (A) penalty if the noise source contains highly perceptible tonal and impulsive characteristics plus 3 dB (A) in the case that the source could be intermittent with identifiable on and off conditions.

when both features proposes different measurement and calculation methods for the assessment of annoyance due to industrial or commercial noise on nearby sensitive receivers.

However, the revised version of ISO-R-1996 1971 established that “steady noise with an impulsive character (like hammering of riveting) or with discrete noise impulses is rated by the sound level LA in dB(A) plus a correction of 5 dB(A)” . Next revision happened in 1987 which included the concept of impulse adjustment K2, stating that “If impulse is an essential characteristic of the sound within a specified time interval, an adjustment may be applied, for this time interval, to the measured equivalent continuous A-weighted sound pressure level. The value of this adjustment shall be stated. For large amplitude noise, such as noise generated by sonic booms, mining or quarry blasts, measurements with C-weighting are used in some countries”. The revised version in 2007 included a objective method based on the analysis of one-third octave band’s Sound Pressure Level (SPL) for assessing the audibility of tones in noise so the results can be graduated adjustment of 0 dB (A) to 6 dB (A). However, using the one-third octave band measurement technique is not always possible to detect a tonal component as is the case of the tonal falls on the edge of two bands. The Joint Nordic Method (JNM) is standardized in ISO 1996:2007, the penalty k being established from tonal audibility and added to A-weighted sound pressure level. Perceived noise level (PNL) was implemented to quantify subjective annoyance of aircraft noise where this is calculated from one-third octave band values; tone-corrected perceived noise level (PNLT) is a revised version of PNL adding of a tone correction factor. In 2017 other revision version was published introducing a method to predict the equivalent continuous A-weighted sound pressure level under meteorological conditions.

Council Directive 79/113/ECC was published in 1979 relating to the determination of the noise emission of construction plant and equipment. In this Directive gave a new definition of impulsive noise this being considered when the difference between LAI - LAS >4 dB. However, for detection of noise with discrete tones, this had not established anything as the Committee were working on adaptation to technical progress. This Directive was in force until the arriving of Directive 2002/49/EC to the assessment and management of environmental noise.

Despite the effort by the acoustic community and the variety of regularizations established in this regard, the determination of penalties in a subjective way is not clear or difficult to establish. In this sense, it could be due to the variety of steady-state and permanent industrial and commercial noise sources which can contain characteristic features like tonality, impulsivity and intermittence join together, for example, to the background noise or combined them. This is one of the most intriguing factor associated with the determination of the annoyance of the sound in a subjective way. For this reason, there are only very few conclusive studies in this sense.

This study aims to investigate the perceptual validity of the method given by BS 4142:2014 for obtaining a rating level, specifically where the application of linearly adding characteristic penalties is concerned, which appears to have no perceptual basis.

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2. MATERIALS AND METHODS

2.1 Participants

The 16 listeners (8 woman, 8 men; mean age=36.4 yrs, SD=10,6 yrs) were staff, students and professor at University of Salford (United Kingdom) which were recruited during two days. They didn't receive any rewards for doing the experiment. Before to do the experiments, the participants had to sign the consent and to read the instructions where was explained the use of the interface, the number of the sounds, the kind of sounds, among other information. The half of participants were considered as naïve as they didn't never do a listening test previously. The other half of the participants were researches and professor from the Acoustics Research Centre considered as experts as they have worked in designing and doing listening tests. In this sense, most of the listening test carried out in the literature about listening test done including tonal and impulsive stimuli used naïve participants (85.7%). Regarding to the number of the participants, almost a 57.1% of the papers established that the ideal number of participants should be between 11-20. Also, Rice (1996) determined that the minority sex should be at least 25% of the sample (ref). In this sense, the 57.1% of the studies carried out meet the requirements established by Rice. About the average age, almost a 65% of the studied used participants ranged between 18-54 years old. In this sense, this work follows the requirements of previous researches carried out.

2.2 Stimuli

The tonal stimulus presented in this experiment were recorded at University of Salford, a outdoor fan from a cafeteria in the Campus was recorded and filtered. The background noise was recorded in Castelfield, (Manchester, UK). The recordings were done by sing the H6 Handy Recorder Zoom with stereo microphones and were saved as wave files (stereo, 16 bit, 44.8 kHz). Additionally, the impulsive stimulus was achieved from a online sound library (free sounds).

A detailed descriptions of the features of the sounds is shown in Table 1. The sounds were composed to have two distinct peak moment with a duration of 10 seconds each one, respectively. The total duration of the each sample was 100 seconds to ensure the influence of long-term memory and attention effects. The position of the tonal or impulsive stimuli was changed randomly. The different random test orders were carried out before to do the experiment nullifying potential order effects. A total of 17 samples were played and one sound (No. 5) was always presented twice in the course of the experiment to estimate the test-retest reliability of the judgments [ref]. However, the fifth sample could be different for the participants as the sound was played randomly. In this work, photographs associated with the acoustical environment were not shown on the computer screen as the participants should be moving the slider to judge the sound all time.

Whole stimulus set was calibrated to 0 dB(A) reference. An the other penalties were added for each tonal or impulsive stimuli.

2.3 Apparatus

The experiment took place in an acoustically treated sound studio at Acoustics Research Centre at University of Salford where the recording were presented via stereo pair. The different recordings were adjusted in perceived loudness by the researches to match the impression of the real acoustic environments, and then the volume setting was kept constant throughout the experiment. A Power Griffin button was used connected to the computer to move the slider in the screen in a easy way.

2.4 Procedure and design

The participants were seated on a confortable chair and the position of the loudspeakers was 30º regarding the participant forming an equal-sided triangle. To kept the same position of the participant, a mark was placed in the floor to know the correct position of the chair. This position can be regarded as the optimum seating location for listening to stereo recordings. First, participants should do a trial to get familiarized with the interface and the use of the external button. Their task was to rate the annoyance of each sound with the aid of a continuous rating scale, ranging from not at all annoying (=0) to extremely annoying (=10). The scale was displayed in the form of a slider on a computer screen, and with the value marker set to the middle position before each trial. When the sound played was finished participants have to give an overall judgment in a eleven Likert scale cero being not at all annoyance and ten being extremely annoyance. The interface was developed using Matlab R2018a. The design of the interface was aiming to be as simple as possible. The first screen was a trial test, see Fig. 1.

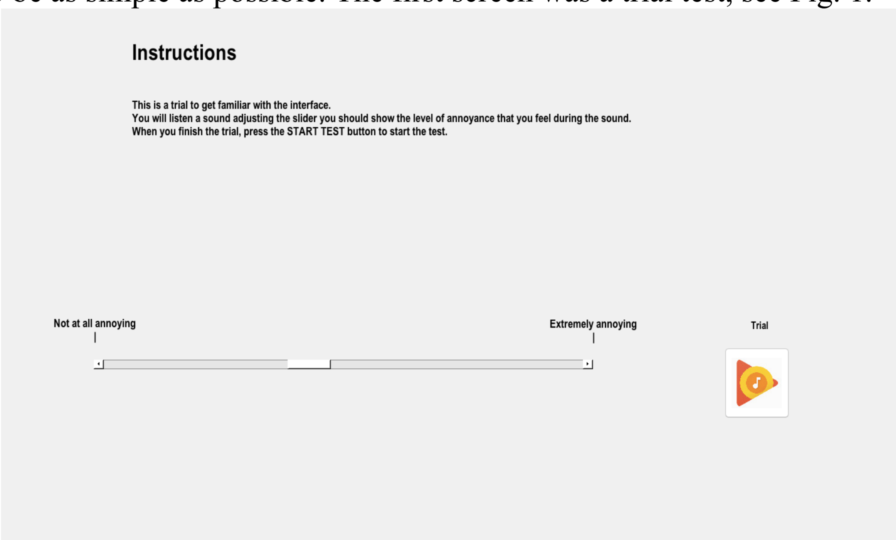

Figure 1. First screen of the listening test.

After finish this trial test, participants are advised about they are going to start the main test, see Fig. 2. Figure 3 shows how is the screen to judge the overall annoyance.

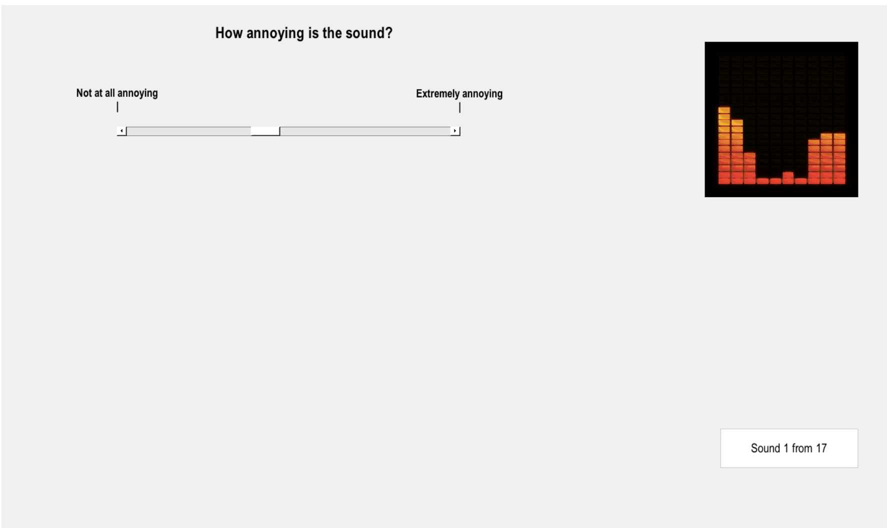

Figure 2. Momentary judgment in the listening test.

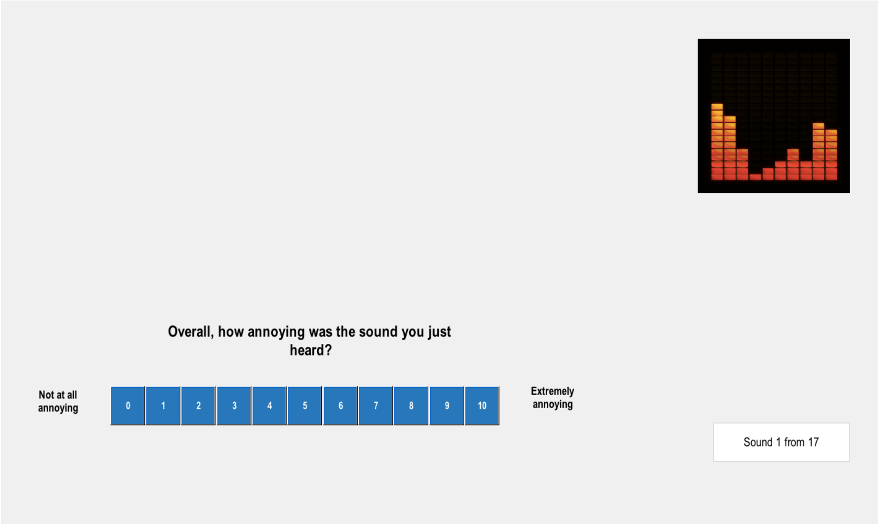

Figure 3. Overall judgment in the listening test.

2.5 Data analyses

The main objective of this study was to investigate the influence of the different penalties when combined stimulus are used both in the momentary and overall judgments. Therefore, correlation and regression analyses were conduced using Matlab R2018a.

Moreover, two-tailed t-test were conduced to test for significant differences between overall judgments and different strategies hypothesized to govern them.

3. RESULTS

Figure 4 and 5 show the average annoyance profiles of the momentary judgments for each sound including their linear trends, the standard deviation and the loudness. First, one can check the average momentary annoyance follows the trend of the loudness.

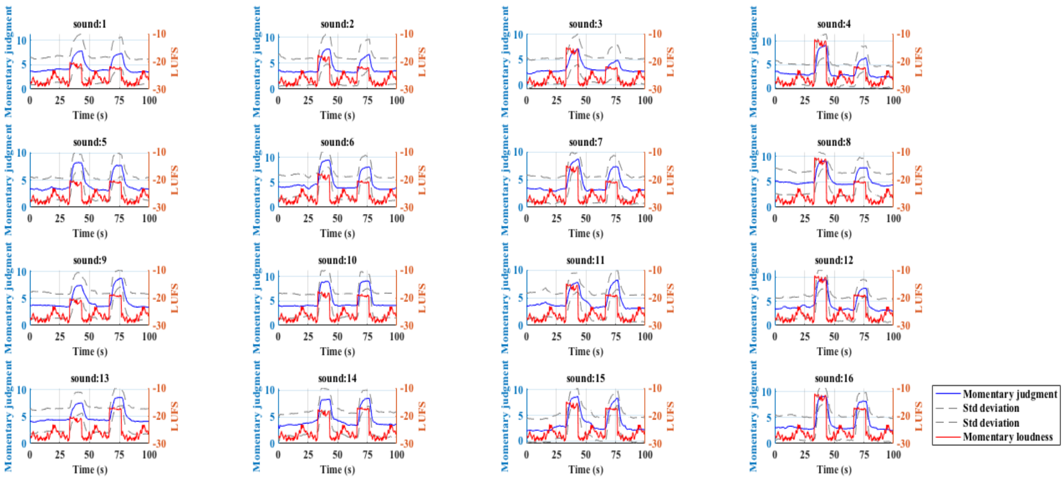

Figure 4. Momentary loudness of samples when Impulsive stimulus is the first sound that participants listened (red line); Momentary judgment of the participants (blue line) and their standard deviations (grey lines).

Table 1 shows the stimuli used (Columns 2 and 3) and different average and peak values, features of the temporal experiences which are hypothesized to have an effect on them. “Mean” (Columns from 3, 4, 7-11) denotes the arithmetic mean of the momentary judgments xn(t) of a sound averaged over time t and across participants n. Therefore, all momentary judgments of one participant made over time were averaged by summing the ratings (Σ) and divided by the number of measuring times t. Accordingly, the n temporally averaged judgments made by each participant were again averaged, this time across participants by summing these judgments and dividing them through the number of participants n. “ “Peak” (Columns 6,7, 13-16) is based on the maximum annoyance occurring in the temporal course of the mnomentary judgment xn(t) of a sound made by one participant. These n minima were afterwards averaged across participants by summing the single minima and dividing the sum through the number of participants n. Moreover, a distinction has to be mentioned when appears “only stimuli” this means that the data were shorted to only use the results of the stimuli (from 30-70 seconds of the sample).

Table 1. Averaged overall and momentary judgments as well as the features of the samples.

Sample	Tonal stimuli (dB)	Impulsive stimuli (dB)	Overall mean	Momentary mean	Overall peak	Momentary peak	Momentary only stimuli mean	Overall mean (First Tonal)	Overall mean (First Impulsive)	Momentary mean (First Tonal)	Momentary mean (First Impulsive)	Overall peak (First Tonal)	Overall peak (First Impulsive)	Momentary peak (First Tonal)	Momentary peak (First Impulsive)
1	0	0	5,60	5,26	9,00	8,621	5,12	5,67	5,54	3,75	4,24	7,00	7,00	7,89	7,74
2	0	3	6,06	5,98	8,00	10,00	5,18	6,25	5,88	4,73	3,74	8,00	7,00	8,71	7,63
3	0	6	5,84	4,16	9,00	8,09	5,02	6,27	5,40	4,38	3,02	7,00	8,00	9,23	6,95
4	0	9	6,57	4,26	6,00	10,00	5,02	6,80	6,33	4,42	3,35	8,00	8,00	8,60	9,12
5	2	0	5,91	3,54	8,00	10,00	4,96	5,82	6,00	3,79	4,05	7,00	7,00	7,26	8,21
6	2	3	6,11	6,25	8,00	10,00	5,21	5,82	6,40	3,94	4,70	9,00	9,00	7,72	9,47
7	2	6	6,00	4,37	6,00	7,07	5,04	6,00	6,00	3,98	3,85	7,00	9,00	8,35	8,62
8	2	9	6, 40	8,88	7,00	9,67	5,45	6,22	6,57	3,84	5,23	8,00	9,00	8,65	9,06
9	4	0	5,87	7,42	8,00	8,44	5,31	5,83	5,90	4,37	4,25	7,00	7,00	8,33	8,63
10	4	3	5,99	4,55	5,00	10,00	5,05	6,18	5,80	3,66	4,81	8,00	8,00	7,65	9,05
11	4	6	5,99	5,53	5,00	7,22	5,14	6,22	5,71	3,96	4,06	7,00	8,00	8,50	8,12
12	4	9	6,69	6,48	8,00	10,00	5,23	6,13	7,25	4,23	4,19	8,00	8,00	7,72	9,47
13	6	0	6,50	5,55	6,00	10,00	5,55	6,00	7,00	4,01	4,84	9,00	8,00	8,65	8,51
14	6	3	6,25	4,63	7,00	10,00	4,63	6,38	6,13	2,45	4,36	8,00	9,00	6,64	8,42
15	6	6	6,97	5,61	8,00	7,10	5,15	6,60	7,33	4,26	3,32	9,00	9,00	8,42	8,68
16	6	9	7,02	8,57	9,00	9,15	5,42	7,33	6,71	4,67	3,78	8,00	9,00	8,88	9,02

Moreover, it can be observed that the overall peak (Columns 13-14), if impulsive stimuli is presented before than tonal, is higher. However, for the overall mean (Columns 9-10), the score achieved is similar independently if the first stimuli is tonal or impulsive.

If the results of overall mean is compared (Columns 4, 5, 7), it can be seen these are very similar although there are some different when the 9 dB (A) penalty to impulsive stimuli is applied. A correlation analysis of these variables is shown Table 2, which reveals a high coherence between the factors such as overall mean and peak, overall and momentary peak, momentary and momentary only considering the stimuli peak, overall mean and momentary mean considering the stimuli peak. Momentary peak (first tonal) is correlated with overall peak (first impulsive) however, the relationship with the overall peak (first tonal) is inversely.

Observing the boxplot (Fig. 5), this is possible observed that for sample 8 and 13 the overall annoyance is higher. These are corresponded with 9 dB (A) of impulsive stimuli and 2 dB(A) of tonal stimuli (sample 8) and 0 dB (A) of impulsive stimuli and 6 dB(A) of tonal stimuli.

Table 3 shows the results of ANOVA test using the overall score as variable response. In this can be seen the correlation between the score for tonal and impulsive as well as the participants is correlated as the p-value is smaller than 0.05.

In the Fig. 6 the mean overall score from expert and naïve participant can be appreciated. Although the trend is similar for both kind of participants, it is possible to see that the score given for expert participants is higher in most sample. As exceptions, it is possible to observed that for sample 5 and 8 the mean score is almost similar and for sample 6 is the same.

In Table 5 the results of Bonferroni test's for the comparation of the results in sample 5 and 17. This test was used as each participant had a different sound in sample 5 and thus, to do the statistical analysis as ANOVA, we need the same number of data. The results of Bonferroni test's show there is a significative differences between Columns 1-2, 1-4, 1-5, 2-3, 3-4 and 3-5. However, there is a significative differences between the momentary mean for sample 5 and sample 7, although the overall score seems to be good correlation for both sample.

4. CONCLUSIONS

Please follow these manuscripts preparation instructions carefully. This study investigated the influence of the different penalties applied to two stimuli: tonal and impulsive such as BS4142 establish. The results has shown a strong correlation between the kind of stimuli, the kind of participant, participants and the order where the stimuli was placed into the sample. The difference between the overall mean score sample 4 (without tonal stimuli) and sample 16 (with 6 dB(A) tonal stimuli) is only 0.5 point. However, comparing the results of overall peak for samples 4 and 16, there are meaningful differences as the difference is of 3 points. This could point out that the addition of the penalties should be established as said the BS4142. However, Steffens et al [ref] established that average annoyance is predominant over the momentary judgment. A sound event occurring as peak not only affects the judgment of this limited time period but aldo the average of the whole momentary judgment both momentary and This results are correlated with the findings of Steffens et al [8] as they established.

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