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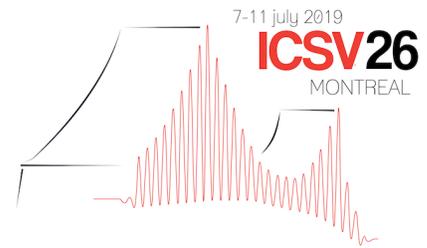
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MENTAL REPRESENTATIONS EVOKED BY AIRCRAFT NOISE COMPONENTS

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This study aims at better understanding aircraft noise annoyance through an analysis of mental representations associated to aircraft noise. From a theoretical point of view, we investigate top-down strategies of sound perception. In particular, we want to identify mental representations that are evoked by the sounds and that drive listeners' sound perception. Thanks to interviewing techniques, we helped participants to explicit what they had in mind when listening to the different sounds, and without asking them about annoyance. We focused on three main aircraft noise signal components: multiple pure tones (MPT), blade passing frequency (BPF) and broadband noise (BN). Two sets of sounds corresponding to two types of large aircraft were heard by 84 participants in an isolated sound booth. Each sound was played once, and for each sound participants were asked to answer a series of questions aimed at collecting verbal descriptions on the played sound. Seven different questions were created to help the participants produce a detailed description of his/her perception of the sounds. A content analysis was performed on the verbal data to explicit the relations between the different terms that are present in the verbal data in order to create semantic categories. This method has proven to be efficient since a large and reach verbal corpus has been collected. The linguistic analysis of this corpus revealed specific mental representations of each aircraft noise component. In particular, both MPT and BPF had negative connotations, with different levels and with specific semantic profiles in contrast with BN. Finally, this study leads to new perspectives in the analysis of aircraft noise annoyance since that annoyance is also function of mental representations that are evoked by aircraft noise, and not only by acoustic parameters.

Keywords: sound perception, mental representations, aircraft noise

1. Introduction

Because of the continuously increasing air-traffic that has reached wider parts of the world, annoyance due to aircraft noise is still a research field of high societal interest [1]. On an acoustical viewpoint, the noise emitted by many aircraft at take-off may be described by three acoustical parameters that are combined together : a broadband noise (BN) (e.g., airframe noise as well as noise sources from the engine) and two types of tonal components : (1) a multiple pure tones component

(MPT) and (2), a blade passing frequency (BPF) made of a single high frequency pure tone. Differences can also be heard between two different types of engine (engine a and b) : a BPF with a fundamental frequency at 1400 Hz versus 3600 Hz respectively, and two different overall spectral envelopes of MPT for each type of engine. In addition, aircraft sounds can present spectro-temporal fluctuations generated by the Doppler effect, atmospheric turbulences and ground reflections. Figure 1 presents a spectro-temporal analysis of the MPT component with the two spectral envelopes used for each type of engine.

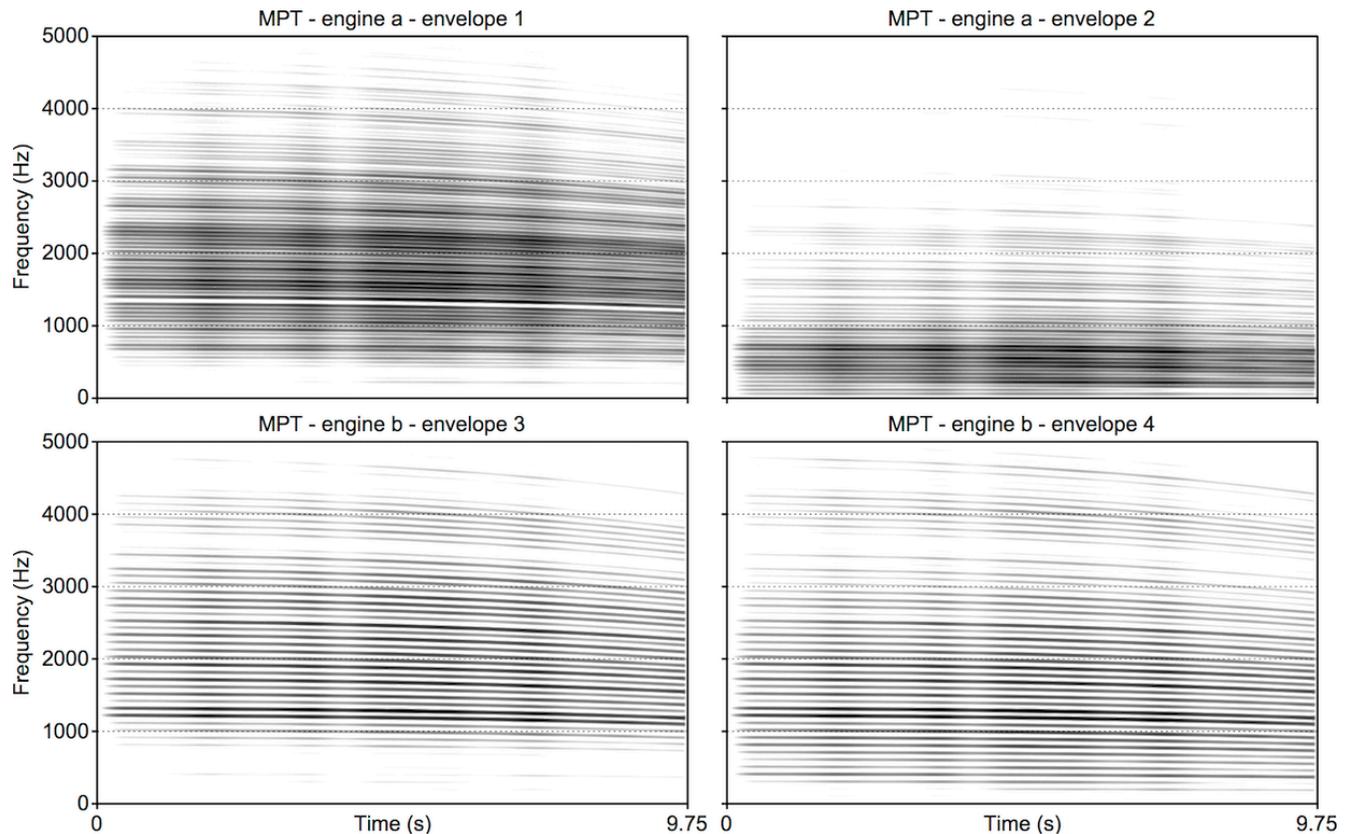


Figure 1: spectro-temporal analysis of the four types of MPT used in this study (time resolution = 6 ms, frequency resolution = 5 Hz)

Presently, the Effective Perceived Noise Level (EPNL) and the A-weighted decibel (dBA) are the two conventional metrics used respectively for aircraft noise certification and community noise assessment [2]. Both metrics are centred on the signal only, although some amount of human-centred researches showed that the annoyance experienced by residents varies not only with the acoustical characteristics of the noise, but also with a range of non acoustical factors of social, psychological or economic nature [3].

In this study, interviews of a panel of French listeners were analyzed in order to understand how listeners perceive individually the three aircraft noise main components, beyond the physical similarity of sounds. We hypothesized that (1) each component could refer to different meaningful representations for listeners and (2) it is possible to identify these representations based on what is verbally reported. To not induce negative judgment on listeners' perception, we chose to propose a questionnaire that addresses the global perception of sound rather than noise annoyance. The present paper thus aims to open a discussion about the concepts and emotions that are conveyed by different components contained in aircraft noise, depending not only on the physical characteristics of the signal (such as the intensity), but also on its meaning and perceptual relevance for the listeners.

2. Method

2.1 Stimuli

Two sets of 4 synthesized aircraft sound components presented separately were used in this experiment. The sound synthesis method is the same as the one used in [4]. Table 1 presents the two sets : they correspond to the simulation of two types of engines (engines a and b), each type of engine producing its specific BPF frequency as well as two types of spectral envelopes for MPT. Only BN is the same sound between the Set 1 and the Set 2. All sounds were 9.75 seconds in duration in order to keep the rising and falling contour of both MPT and BPF. No fade in was used, and a fade out of 250 ms was applied to the two MPT sounds and the BN. The perceptual loudness of the seven stimuli were equalized in a preliminary experiment, with the reference sound (broadband noise alone) measured at 65 dBA (L_{Amax}) at listening position.

Table 1: Two sets of the 4 synthesized aircraft sound components

	Set 1 : engine a	Set 2 : engine b
Sound 1	MPT : envelope 1 (a-1)	MPT : envelope3 (b-3)
Sound 2	MPT : envelope 2 (a-2)	MPT : envelope 4 (b-4)
Sound 3	BPF (a)	BPF (b)
Sound 4	BN	BN

2.2 Equipment

This experiment took place in the platform [PETRA](#) that comprises a series of cutting edge audio equipments dedicated to research on sound perception, and a double walled isolated sound booth in which experiments are ran. Participants were seated in front of two Focal Solo 6BE loudspeakers at a distance of 1.50 m, driven by a RME ADI-8 digital to analogue converter and a TASCAM DM3200 mixer. Participants' answers were collected by the experimenter through a graphic interface developed in Max 7.

2.3 Participants

A total of 83 participants (51 females and 32 males, mean age 25.3, standard error 3.8) were recruited for this experiment : 43 participants ran the experiment with stimuli Set 1 and 40 participants with stimuli Set 2 (see Table 1). They all reported to have normal or corrected-to-normal vision as well as normal hearing.

2.4 Procedure

This experiment was conducted in an interview-like interaction in which the experimenter had to make each participant describe his/her perception of the sounds. In general, it is not an easy task to verbally describe what we perceive when we listen to sounds, and it is even less easy when sounds do not refer directly to a specific object that is well known [5]. Therefore, a questionnaire was designed to help the participants produce a detailed description of his/her perception of the sounds. Thanks to interviewing techniques, the experimenter could help the participants explicit what they had in mind and what they wanted to answer to the questions without influencing them. Each sound was played once, and for each sound participants were asked to answer a series of questions aimed at collecting verbal descriptions on the played sound. The experimenter had a previous experience in psycho-social interviews and ran three preliminary participants in order to get trained to this experiment.

Table 2: Questionnaire

1. <i>What does this sound make you think of? What elements of the sounds make you think of this ?</i>
2. <i>If you had to describe this sound to someone, what adjectives, nouns and verbs would you use ?</i>
3. <i>If you had to describe this sound to someone, what comparison would you make ?</i>
4. <i>If it was a natural phenomenon, it would be:</i>
5. <i>If it was a transport, it would be:</i>
6. <i>If it was an animal scream, this would be:</i>
7. <i>If it was an everyday object, this would be:</i>

Seven different questions were created (see Table 2). The first three questions focus directly on sound. The following questions have been imagined on the basis of the “*chinese portrait*” method, i.e, they were based on the conditional structure “*if it was a(n) X, it would be ...*”. Using a metaphor, the listeners use known and familiar domains (*source domain*) to talk about unknown and unfamiliar objects (*target domain*) [6]. On this way, four source domains related to the sound field were selected : natural phenomenon, transport, animal scream and everyday object. The listeners were asked to justify their answer in a few sentences. The comparison between two objects from different domains aims at identifying which similar meaning features are shared as well as better understanding the emotions that are linked with perception.

3. Results

3.1 Content analysis

All the answers given by all the participants to the seven questions were collected. A qualitative and quantitative content analysis was performed on this verbal data. First, we selected and sorted meaning units that are “constellation of words or statements that relate to the same central meaning” [7]. Then, we calculated their recurrence and redundancy to identify semantic categories. A set of meaning units becomes a semantic category when a minimum of 20 occurrences are found (which represents half of the participants’ verbalizations per aircraft noise component). A total of 2673 meaning units were considered in the analysis.

3.2 Categories and categorization

Based on Rosch’s categorization principles [8], we consider that semantic knowledge (defined as a general knowledge about our world; see [9]) is structured in different levels of abstraction. Categories are related to one another by means of class inclusion. It implies a hierarchy of categories. In our study, the similarities emerging in the identification and qualification of sounds were analyzed in order to identify a set of organized categories of terms. For example, the listeners used very often the terms “*high*” and “*ultrasound*” for the two types of BPF, and Figure 2 illustrates a hierarchical organization was created from these two meaning units. According to their similarities, it was possible to group them into one semantic category of a higher level of abstraction “*High frequency*”. Then, this semantic category could also be included within one another category “*Sound qualities*” in order to go back to the highest level of abstraction.

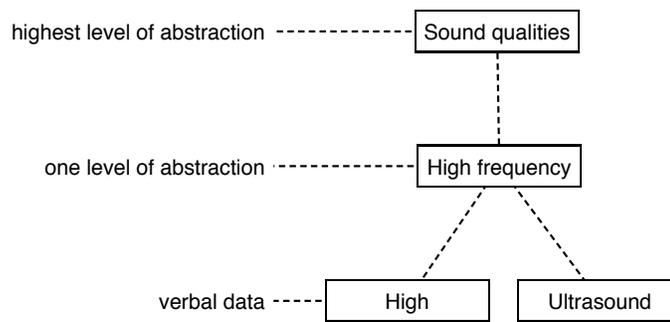


Figure 2 : Example of the hierarchical organization of the Category 1 “*Sound qualities*” from the verbal data produced by the listeners for the two types of BPF (engines a and b).

3.3 Endogenous and exogenous categories

At the highest level of classification, five semantic categories were found by the content analysis. Category 1 refers to the sound qualities, Category 2 refers to the type of source evoked by the sounds, and Category 3 refers to the perceived qualities of the source. These three categories are exogenous because they are directly related to the sound. Conversely, Categories 4 and 5 are endogenous because they refer directly to the effects of sounds on listeners: negative perception and negative feeling, respectively.

In the following sections, Tables 3, 4 and 5 present the subcategories underlying these highest level categories. The subcategories were created from an analysis of semantic similarities between the terms used by the participants as illustrated in section 3.2. The tables also present the relative proportions of this terms (number of meaning units).

3.3.1 Related to the sound

As shown in Table 3, the first category is made of one subcategory, i.e., high frequency, that has been used only to describe BPF.

Table 3: Subcategories for the Category 1: “Sound qualities”

	MPT				BPF		BN
	a-1	a-2	b-3	b-4	a	b	
Sound qualities							
High Frequency					

Number of similar meaning units		
• 21 to 30	•• 31 to 40	••• more than 41

3.3.2 Related to the source

Two categories were related to the sources evoked by the sound : types and qualities of sources. The category “*Types of sources*” was related to objects, actions or phenomena involved during the production of the sound. The meaning units were sorted into seven semantic subcategories. Some were

linked with the elements of comparison proposed in the questionnaire (everyday objects, animals, natural phenomenon, transports). For example, MPT sounds were compared to everyday objects such as cutting machines. Descriptions of BPF and BN evoked acoustic phenomena related to air circulation such as “*air pressure*”, “*wind*”, “*whistling*” or “*breath*”. In the semantic fields related to animals, a contrast has been found between MPT and BPF : MPT (engine b) was compared to “*Harmful flying insects*” whereas BPF was compared to “*Animals with acute screams*”. The subcategories “*Vibration*” and “*Foley sounds : falls*” were found to be used only in the verbal descriptions of the BPF. These descriptions appeared with Questions 1, 2 and 3 that encouraged listeners to produce free comparisons with known sounds. The category qualities of sources refers to the properties of the evoked sound sources. Specific semantic profiles were found for each sound : an idea of variation for MPT (b-4) and BPF (a), and movement or displacement for MPT (engine b), BPF (b) and BN. Finally, some descriptions for MPT (a-2) were related to the bad condition of the sources as “*State of malfunction*”.

Table 4: Subcategories for the Categories 2 and 3, “Types of sources” and “Qualities of sources”

	MPT				BPF		BN
	a-1	a-2	b-3	b-4	a	b	
Types of sources							
Harmful flying insects			•	••			
Animals with acute screams					•	•	
Cutting machines		•	•	•			
Air transport	•	•	••	•••		•	•••
Air circulation					•	•	••
Vibration			•	•			
Foley sounds : falls						•	
Qualities of sources							
Variation				•	•		
Displacement			•	•		•	•
State of malfunction		•					

3.3.3 Effects of sound on the listeners

The semantic categories 4 and 5 were related to the effects of sounds on the listeners, i.e., their emotions and feelings when listening to the sounds. These emotions were all negative and the verbalizations were sorted in two categories : “*Negative perception*” and “*Negative feeling*”. The category 4 “*Negative perception*” corresponds to an homogeneous lexical field of annoyance that was evoked for MPT (a-1 and b-3) and BPF. Then, the category 5 “*Negative feeling*” corresponds to a feeling of insecurity. This category was found to be used only in the verbal descriptions of the two BPF sounds. For this component, participants talked about accidental events such as “*crashes*”, “*falls*”, “*danger*” and “*bombs*”.

Table 5: Subcategories for the Categories 4 and 5 : “Negative perception” and “Negative feeling”

	MPT				BPF		BN
	a-1	a-2	b-3	b-4	a	b	
Negative perception							
Annoyance	•		•		•	•	
Negative feeling							
Insecurity					•	•	

4. Discussion and conclusion

From the verbal descriptions of each aircraft sound component, the content analysis of the content analysis revealed a hierarchical organization of meaning units with different levels. At the highest level of abstraction, this hierarchy is made of three categories : (1) acoustical properties of sounds, (2) sound sources (i.e., imagined sources producing the sounds and in what state the source is) and (3) emotions and feelings evoked by the sounds. These categories are coherent with the previous researches on environmental sound categories [10, 11, 12].

At a basic level in the hierarchy, the different categories of meaning units highlighted a specific semantic profile for each aircraft sound component (Table 6), that is, the most common descriptions across participants. Two subcategories “*Air transport*” and “*Displacement*” were common to all sound components even though it was never mentioned to listeners that they were sounds related to aircraft. Similarly, listeners talked about noise annoyance for both MPT and BPF despite the fact that the interviewer never asked questions specifically about annoyance.

In addition, it is important to observe annoyance is not an equivalent perception between BPF and MPT components. This difference can be explained thanks to the rest of the semantic profile. Regarding BPF, from the acoustical point of view, annoyance could be linked to the subcategories “*High frequency*” and “*Animals with acute screams*”. From the psychological point of view, it could also be related to the analogy with the Foley sounds of falling objects and to the feeling of “*Insecurity*” expressed by listeners. Regarding MPT, annoyance can also be interpreted in connection with acoustical properties of the source such as “*Vibration*”, “*Variation*” and by analogy to the sounds of “*Cutting machines*” and “*Harmful flying insects*”. In particular for MPT a-2, listeners talked about malfunctioning appliances. In terms of mental representation, the analogies to insects could also convey a notion of danger : the insects cited (“*mosquitos*”, “*wasps*”, “*bumblebees*”) may be harmful either by the noise that causes their flight or by the stings. Regarding the broadband noise component, despite most of the descriptions of referred to the semantic field of aircraft, this component was not judged negatively.

These results shed light on how listeners interpret sounds, depending not only on the physical parameters of the signal, but on its meaning and relevance [13].

Table 6: Synthetic view of the categories of representative verbalizations identified by the content analysis.

MPT	BPF	BN
Harmful flying insects Cutting machines State of malfunction	High frequency Animals with acute screams Foley cartoons: falls	
<p style="text-align: center;">Air transport</p>	<p style="text-align: center;">Air transport</p>	<p style="text-align: center;">Air Transport</p>
<p style="text-align: center;">Displacement</p>	<p style="text-align: center;">Air circulation Displacement</p>	<p style="text-align: center;">Air circulation Displacement</p>
Vibration Variation Annoyance	<p style="text-align: center;">Annoyance Insecurity</p>	

5. Conclusions

In conclusion, the method designed to produce verbal descriptions to talk about sounds was efficient. The content analysis allowed to produce semantic portraits for each aircraft noise components. The notion of annoyance appeared for two of the aircraft noise components : MPT and BPF. We have seen that a sound can be perceived negatively because of its intrinsic acoustic properties but also because of the similarities that it shares with other sounds and their meanings [15]. Such a human-centered approach was intended to contribute to the analysis of mental representations of aircraft noise components. When all these components are combined together, the interactions between them as well as the impact of their mental representations on global sound perception still need to be further investigated.

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