A New Experimental Approach for Urban Soundscape Characterization Based on Sound Manipulation : A Pilot Study

Grégoire Lafay, Mathieu Lagrange, Mathias Rossignol, Jean-François Petiot, Nicolas Misdariis

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G. Lafay[a], M. Rossignol[b], N. Misdariis[b], M. Lagrange[a] and J.F. Petiot[a]
[a]Ecole Centrale de Nantes, IRCCyN, 1 rue de la noe, 44321 Nantes, France
[b]IRCAM, 1 Place Igor-Stravinsky, 75004 Paris, France
gregoire.lafay@irccyn.ec-nantes.fr

In this paper, we aim at better understanding how human mental representations are structured in the specific case of the perception of urban soundscapes. This task is traditionally studied using questionnaires, surveys or categorization tasks followed by a lexical analysis. In contrast, we propose a new experimental approach to tackle this aim. In this approach, the subject is asked to manipulate sound events and textures within a dedicated computer environment in order to recreate two complex urban soundscapes, one ideal and the other not ideal. Subjects have access to a sound data set which has been designed and structured based upon perceptual considerations, and may alter the physical parameters of the selected sound samples. In order to achieve this, we use an audio-digital environment and a web audio interface for sound mining developed for the purpose of this study. The latter allows subjects to explore a sound database without resorting to text. By focusing on the auditory modality during the experimental process, this new paradigm potentially allows the subject to be better put in context and provides a more detailed description of the actual mental representations. In the light of the results presented in this paper, it seems that it also reduces the potential bias of only using verbalization during the experiment.

1 Introduction

Even if the city has always been a noisy environment, whatever the times, our perception of this noise has evolved. It is in the 80s that the association between noise and pollution has been the strongest. Noise was considered as an overall degradation of the quality of life [1]. In response, " anti-noise " legislation took place and planed to fight the noise by reducing its intensity level. But the problem remains, and for good reason, noise is a subjective phenomenon, that depends on the " listener appreciation ". The noise is a matter of context. It may entertain as well as disturb or annoy. Improving the sound environment by only focusing on acoustical parameters, which are by definition objective, is not enough. Besides, this acoustical approach does not tackle directly the issue of improving the soundscape, as it is focused on isolated " negative sounds ", and not on interconnected " positive sounds ". To summarize, a pleasant city is not a silent city.

Understanding the noise requires a methodology that differs from the more traditional approach of psycho-physics, as noise is more " a cognitive object than a physical object " [2]. For those reasons a new concept of soundscape had been introduced by R.M. Schafer [3]. A commonly agreed definition of the " soundscape " has been given by Truax who worked into the *World Soundscape Project*: " an environment of sound (sonic environment) with emphasis on the way it is perceived and understood by the individual, or by a society " (Truax quoted in [4]). Soundscape is a subject centered approach that considers a sound environment from the listener point a view. It assumes that the qualitative evaluation of a soundscape mainly depends on the context, and the knowledge of the community or the subject that experiment the environment. The question is no longer when the noise is annoying, but why the sound is annoying.

Since its introduction, this approach has been widely used to study urban sonic environment [5]. It allowed the development of a database of useful qualitative descriptors and sounds to better understand the way humans perceive their sound environments. One major today's challenge is to connect these perceptual data derived from questionnaires, categorization tasks and psycho-linguistic studies to acoustic measurements in order to establish an effective policy of noise reduction adapted to each situation [6]. To this end, we propose a new experimental approach to study soundscape perception. In order to investigate what could be the nature of an ideal urban environment, we ask subjects to simulate two soundscapes, one qualified as " ideal " (in which you would like to live) the others " not ideal " (in which you would not live), from a dedicated urban sound data set. By analyzing the reconstruction process, we are able to objectify the mental representations of an ideal (not ideal resp.) sound environment.

We will first introduce the experimental paradigm as well as the technological devices on which it relies, then we will detail the creation of our sound data set, and finally we will present the results of a pilot study.

2 Experimental Protocol

2.1 Paradigm of the proposed approach

Traditional psycho-cognitive studies addressing mental representations of sound environments use linguistic resources to objectify mental categories. Two types of approach has been widely used: The sorting tasks, where subjects are asked to sort sounds and label the classes (categorization tasks), and the describing tasks, where subjects are asked to describe a sound via a adapted questionnaire (usually free or semi structured questionnaire). Both approaches consider verbal data as input, and thus rely on psycho-linguistic analysis to objectify generic and meaningful mental categories from names or labels.

In this paper, the proposed approach is also a psycho-cognitive one, as we also consider subjective literal data. But these data are related to quantitative data that are assumed to be directly linked to the " reality of the word ". To do so, we adopt a simulation paradigm. The subject is asked to recreate a complex sound environment, by choosing sound classes in a sound data set, and modifying their physical properties (sound levels, time positioning). The selection process is made without any text-written help (see Section 2.3 for more details). The subject must name each selected sound. At the end of the creation process, the subject has to give a global name (title) to the simulated scene, and freely comment its creation. Doing so, we obtain 2 types of data: the objective data and the subjective data. The subjective data depend on the subject. They are composed of the names given by the subjects to the sound classes they selected, the titles of the simulated scenes, and the free comments. The objective data depend on the sound data set. They are non ambiguous and may be controlled by the experimenters. The objective data are composed of 1) the numerical data that are the values of the audio control parameters set by the subject to simulate the scene, and 2) non ambiguous verbal data called tag. A tag is the " real name " of a sound class of the data set. It is given by the experimenter who recorded it. The tags of the sound classes act as a ground-truth compared to the names given by the subjects.

Mixing both objective and subjective data allows us to obtain subject-centered results that are both meaningful and easily analyzable. These two outputs may always be weighted relative to each other in order to give meaningful results.

2.2 Creation of the sound data set

Special care has been taken to build the sound data set as it represents the " sonic world " upon which subjects will rely to simulate a desired soundscape. The goal was to propose a sound data set that 1) is representative of the diversity of all the sounds that populate the urban environment, 2) is able to offer several variants of a same sound class, and 3) could be quickly explored in order to supplies to the time constraints of the experiment. Moreover, as our *tags* entirely depend on the sound data set nomenclature, a consistent and, as much as possible, generic typology of the different classes of urban sounds has been designed. To this sense, the sound data set structure was motivated by practical and perceptual considerations.

We decided to divide the sound data set in two subsets, each corresponding to a specific type of sounds: the sound events and the sound textures. Several studies have pointed out that this two types of sounds provoke two distinct cognitive processes. Maffiolo [7] showed that *event sequences* lead to a descriptive (semantic) analysis, which mainly rely on the identification of the sound events, whereas *amorphous sequences*, which are sequences without salient events that can be regarded as textures (" traffic hubbub ", " street hubbub "), lead to a holistic analysis which depends on the acoustical properties of the sequence. McDermott and Simoncelli [8] recently showed that sound textures perception mainly depends on the analysis of simple statistical properties of the acoustical signal. For those reasons we consider a soundscape as " a skeleton of events on a bed of textures " [9].

Several studies address the difficulty of obtaining a generic classification of all the elements that populated the sound environment [4, 10], as it is difficult to regroup them under consistent and non ambiguous classes. Indeed, sound classes as " traffic sound ", " human voice " or more specific classes as " cars " or " sounds of a man " may regroup a large variety of sounds, depending on the context of the study. Considering these remarks, we design a hierarchical sound data set of urban environmental sounds adapted for our approach. In this hierarchy, top level classes represent large categories of concept such as " sounds of nature " or " motorized transportation sounds ". Deeper the class is in the hierarchy, and lesser is the diversity between the sounds that belong to it. Each class of the leaf level (" car passing ", " man yelling "), regroup several recording of sound samples that are perceptively close. In order to choose relevant class name (tag) for the typology, we did a bibliographical review of several papers addressing mental categories of urban environmental sounds [2, 4, 7, 10, 11, 12, 13, 14].

It has to be noted that subjects only interact with the leaf classes to simulate the soundscape, and not with the recorded samples.

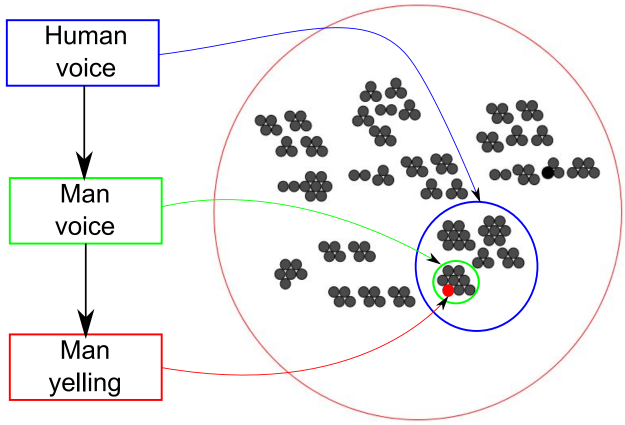

Figure 1: Sound selection Interface of *Simscene* with illustration of the urban sound data set hierarchy

2.3 Simulating a soundscape

To simulate a soundscape we use a web software called *Simscene*. *Simscene* allows the user to manipulate sound classes of events and textures (" man yelling ", " car passing ", " rain ", " parc hubbub ") in order to simulate a soundscape. To free the subjects from the influence of the pre-established nomenclature of the sound data set, the selection interface of *Simscene* has been designed not to use a keyword based search. The selection interface allows the subject to explore the data set by listening to the sounds. To do so, the leaf classes of the typology are distributed in a 2D space, each leaf class being represented by a circle (see figure 1). The space configuration of the circles depends on the hierarchical structure of the typology. Circles representing leaf classes belonging to the same class are packed together, and so on until the top-classes are reached. Relative positions of the top-classes are meaningless.

Subjects may explore the data set by clicking on the circles. When a circle is clicked, the subject hears the sound prototype of the leaf class represented by the circle. By listening to the different prototypes, the subject may select a sound class.

When a sound class is selected, a time sequence populated with the samples (event or texture) belonging to the selected leaf class is displayed. The subject may then adjust the control parameters of the sequence being the average/variance of time intervals between samples, or average/variance of sound levels. As subjects interact with sound classes, control parameters have been designed to manipulate sequences of sounds and not unique samples. *Simscene* can be accessed via the link `http://soundthings.org/simScene/`.

3 The Pilot study

3.1 Task and collected data

Subjects are asked to successively create two urban soundscapes. The first must be ideal (*i.e.* the favorite urban soundscape of the subject), the second not ideal (ie. the worst urban soundscape of the subject). Subject are not restricted o, their design choices. The only constraint is to simulate a physically plausible urban environment. In other words, unrealistic situations as "a dog barking every 10 milliseconds" are forbidden.

Two types of data are collected: The verbal data and the numerical data. For the verbal data, we consider the title of the soundscape, the names given by the subject to each selected sound class, the free comment describing the simulation process, and the missing sounds, that is, the sounds that were not found by the subject in the sound data set. The numerical data are the audio control parameters from which we analyze the sound levels of each samples, and the time intervals between sound events.

3.2 Participant

Participants are 10 french subjects individually selected from volunteers. They are 7 males and 3 females and are about the same age (M : 24.1, STD 1.7). All of them are urban dwellers.

3.3 Apparatus

Subjects have access to a sound data set of 483 urban environmental sounds including 381 sound events and 102 textures. Among them, 260 events and 72 textures were recorded. 121 sound events and 30 textures which proved to be particularly difficult to record came from existing sound banks. All recordings were performed using a shotgun microphone *audio technica* AT8035 connected to a *ZOOM* H4n recorder. We chose to use a shotgun microphone (highly directive) in order to isolate sound recordings from undesired events. All the sounds were normalized to the same peak level.

The experiment is run with one subject at a time, in the audiometric test booth of the IRCAM french institute[1]. Audio is presented in monophonic to each participant via *Yamaha MSP 5* speakers (active speaker), on *Macintosh Mac Book Pro* type computer, connected to a *RME FireFace 800* sound card. The software (SimScene) is located on a distant server and loaded via Google-Chrome navigator in a Linux operating system. At the end of each task, data is automatically collected server side. One experimenter is always present to give instructions and answer queries if needed. Experiment lasts about one hour and a half for each subject.

4 Results of the Pilot study

4.1 Objective and Subjective verbal data analysis

Selected sound classes analysis

For the ideal scenes, subjects used 51 event classes and 27 texture classes. For not-ideal scenes, they used 96 event classes and 32 texture classes. This result indicates that not-ideal scene are composed of a larger number of sound sources than ideal scenes. Table 1 shows the number of texture and event classes used, averaged over the subjects.

The *tags* (see section 3.1) of the sounds chosen by the subjects are now analyzed. *Tags* were regrouped based

[1]Ircam: (*Institut de Recherche et Coordination Acoustique/Musique*) www.ircam.fr/

Table 1: Average and standard deviation of the numbers of event and texture classes used by each subject

	Events	Textures
Ideal scenes	5.1;2.4	2.7;1.1
not-ideal scenes	9.6;3.1	3.2;1.8

on their position in the typology. For ease of reading, We chose the semantic hierarchical levels that are the most meaningful. Figure 2 and 3 display the results for the ideal and not ideal scenes. The dominant event classes for the not-ideal scenes are: "alarm" and "horn" (35% of occurrences), "construction work" (22% of occurrences) and "traffic" (13.5% of occurrences). The majority of the texture classes belong to the classes "construction work" (*construction work hubbub* : 28% of occurrences , *work vehicles* : 19% of occurrences) and "human voice" (25% of occurrences). For the ideal scenes, event classes are mainly sounds of humans (*footsteps* : 21.6% of the occurrences, and *human voices* 19.6% of occurrences), sounds of "birds" (11.8% of occurrences), "sounds of bicycle" (11.8% of the occurrences) and "bells" (11.8% of occurrences). For the textures, sounds of humans are well represented (*voice*: 33.3% of occurrences).

Some results may be considered as counter-intuitive. For the ideals scenes, we observe the presence of the classes "alarm", "construction work" and "traffic". Traffic textures ("traffic hubbub") are also well represented (25.9% of occurrences). The same applies to the not-ideal scenes where textures of "human voices" and "fountains" are observed.

To check if those results are due to a misidentification of the sounds by the subjects, we look at the *names* (see section 3.1) given by the subjects to each selected sounds. To achieve the linguistic analysis, we rely on the following rules: We connect a *name* to a *tag* of our typology when the former makes explicit reference to an event class ("foot step", "man calling someone"), or a texture class ("courtyard", "street atmosphere"). For the *names* that cannot be explicitly connected to a *tag*, we check if some of them belong to the same lexical field.

1. If we detect a common lexical field along the *names*, we regroup them under the same designation
2. If we do not detect a common lexical field, we eliminate the isolated *name* of the analysis. These sounds are then referred to as "untreated"

We show the results of the linguistic analysis in the Figures 4 and 5 for respectively the ideal scenes and the not-ideal scenes. In general, the events were well identified with 90% of non ambiguous associations between *names* and *tags* for the ideal scenes, and 92% for the not-ideal scenes. The identification is less obvious for the textures with only 48% of non ambiguous associations between *names* and *tags* for the ideal scenes, and 47% for the not-ideal scenes. We observe that more than 25% of the textures names do not refer to a sound source, but rather to a global description of the all texture. These observations are in line with those obtained by Maffiolo [7] which states that *sequences of events* trigger a semantic analysis (*i.e.* identification of sound sources), while *amorphous sequences* are subject

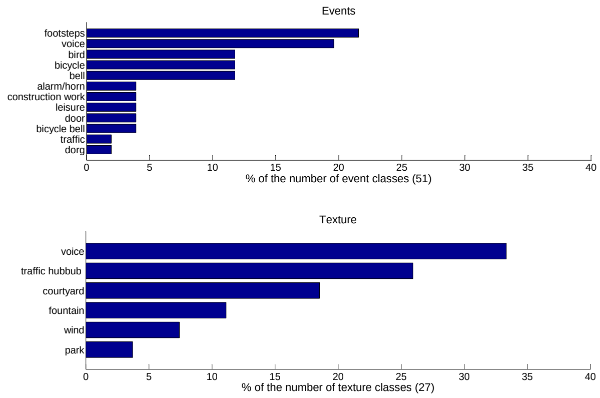

Figure 2: *Tags* chosen by the subjects for the ideal scenes (percentage of the total amount *tags* used)

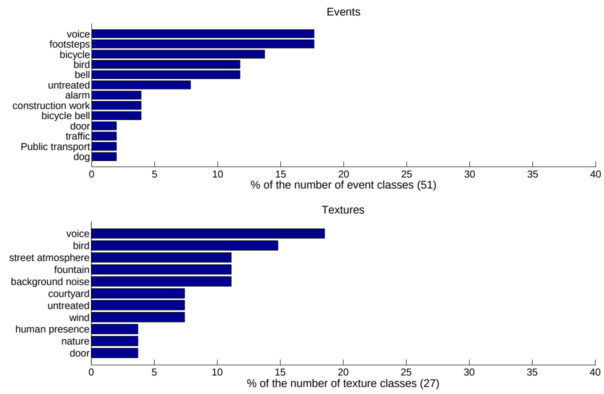

Figure 4: *Names* given by the subjects for the ideal scenes (percentage of the total amount of *names* used)

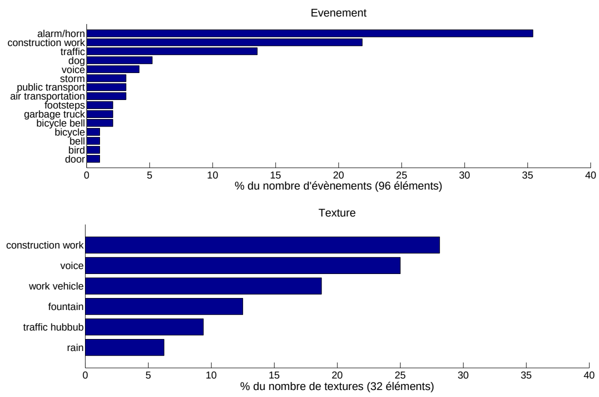

Figure 3: *Tags* chosen by the subjects for the not-ideal scenes (percentage of the total amount of *tags* used)

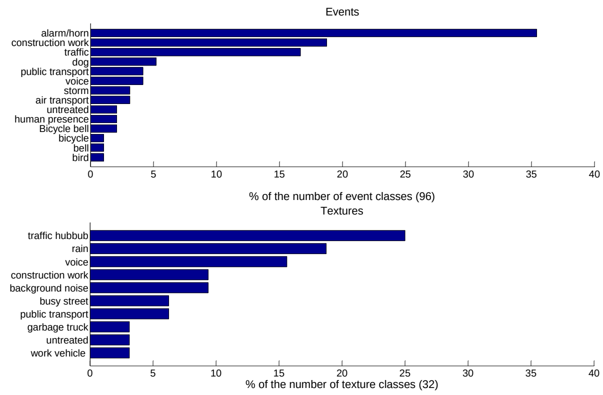

Figure 5: Names given by the subjects for the not-ideal scenes (percentage of the total amount of *names* used)

to a holistic treatment, which depends on the acoustical properties of the signal, and thus does not promote the identification of sound sources.

Several names given to the textures for the ideal as well as the not-ideal scenes directly refer to what could be considered as sound events (birds, public transport). This is most probably due to the fact that it is very difficult to record a scene without any sound events. Some of them, specially birds sounds, occur in the texture sequences. It is interesting to note that it is those unwanted events that drive the identification process of the textures, even if they are poorly represented in the textures. This underlines the fact that semantic value of a soundscape mainly depends on the recalled sound events.

Considering the textures of the ideal scenes, we see a significant decrease of the number of sounds related to “traffic hubbub” between the *tags* and the *names*. Traffic sounds are designated by the subject with generic names: “street atmosphere” (french: “ambiance de rue”), or “background” (french: “bruit de fond”), indicating that sounds related to urban traffic are accepted only if they are part of the background of the scene. There is a notable difference between the *tags* and the *names* for the not-ideal textures. Many sound tagged “construction work” has been identified as urban traffic sounds.

Tags analysis reveals the presence of sound events belonging to the “alarm/horn” category (sounds used by one subject) and *construction work* (sounds used by 2 subjects) in the ideal scenes. By analyzing the free comments given by the subjects, we note that the alarm sounds have been chosen conscientiously, and are described as “discreet and nice to hear”. According to the subjects, “construction work” sounds have been chosen for realistic considerations.

We propose to compare our results to those obtained with a similar study conducted by Guastavino [12], in which she asked subjects to describe their *ideal urban sound environment*. Thanks to a psycho-linguistic analysis, she derived categories of *positive* and *negative* sounds. For the ideal scenes, our results are consistent with those of Guastavino. In both cases the main represented categories are: human sounds (footsteps and voice) and sounds of nature (animals, weather). The difference lays in the appreciation of some categories. In both studies, sound categories of “traffic”, “construction work“, “alarm/horn” are used to characterize ideal cities. In the case of Guastavino, terms relative to those categories are found in negative construction (“with no cars” or “with less traffic”), as they give rise to negative judgments. In our case, the analysis of the free comments made by the subjects of their scenes showed that these sounds were used to make the simulated environment plausible. Several subjects clearly indicated that they found distant sounds of “traffic” and “construction work” pleasant.

Missing sounds analysis

We identify 23 references to missing sounds, 14 for the ideal scenes and 9 for the not-ideal scenes. Among these sounds, 3 refer to musical sounds and 10 refer to sounds that are present in the data set, and were not found by the subjects. As musical sounds are deliberately not integrate in the typology, this leave us with 10 well missing sounds. This small number tends to show that the proposed corpus is representative of the diversity of an urban sound environment. 50% of the subjects spontaneously specified in the free comments that the diversity of the corpus was sufficient for the ideal scenes (20% subjects), the not-ideal scenes (20% subjects), or both (10% subject).

Title analysis

We perform the analysis of the titles given by the subjects to the simulated scenes. The goal is to identify categories of geographic location. As a title may contains several distinct semantic entities, one title may be put in several geographical categories. From the lexical analysis of the titles of the 10 ideal scenes, 4 categories were derived: "park" (4 subjects) "pedestrian space" (3 subjects), "courtyard" (2 subjects) and "quiet street" (2 subjects). Titles categories refer to urban area where traffic noise is absent or limited, but where human sounds are well represented. From the analysis of the not-ideal titles, 4 geographical categories were identified: "street" (4 subjects) , "boulevard" (2 subjects), "avenue" (2 subjects) and "crossroads" (2 subjects). 3 subjects titles clearly suggests the presence of construction work sounds, and 3 others the presence of traffic sounds.

4.2 Numerical data analysis

Relative sound levels and time intervals

In this section the sound levels and the time intervals set by the subjects via the control parameters are investigated. Table 2 displays the means and standard deviations of the events and textures sound levels for the ideal and the not-ideal scenes. It should be noted that all sounds have an initial relative level fixed to 0 dB SPL. Subjects may only reduce the sound level. Results show that the mean sound levels for the ideal scenes is lower than for the not-ideal scenes. Similarly textures levels are lower than events levels (*t-test*: between ideal events and textures: $p = 0.02$; between not ideal events and textures: $p = 5.10^{-4}$).

Table 3 shows the averages and standard deviations of the time intervals between events. This parameters apply only to the event classes. Given the length of a simulated scene (60 seconds), we note that the average time intervals between events are not significantly different for the ideal and the not ideal scenes (*t-test*: $p = 0.59$).

Results tend to indicate that if the overall sound level of an ideal city is lower than that of a not-ideal city, the ideal city remains an active environment in term of sound events activity.

5 Discussion and perspective

In this paper, a new experimental protocol used to objectify mental representations of urban soundscapes has been introduced. To perform the experiment, we created

Table 2: Average and standard deviation of the events and textures sound levels for the ideal and the not-ideal scenes

	Events(dB)	Textures(dB)
Ideal scenes	-6.1;7	-10.3;8.1
Not-ideal scenes	-1.2;3.2	- 4.1;5.5

Table 3: Average and standard deviation of the time intervals between events for the ideal and the not-ideal scenes

	Events
Ideal scenes	17;16
Not-ideal scenes	18.5;16.5

a corpus of environmental sounds based on a typology established from a dedicated literature review. To free the subjects from the influence of an a priori nomenclature, as well as the lack of lexical words to describe adequately the acoustic phenomena [15, 12], we have developed an interface which allows subjects to explore a sound data set by listening to the sounds themselves.

The comparison between our results and those of Guastavino [12] shows that the proposed approach provides consistent outputs. However, while the approach of Guastavino allows to consider the mental representations of an urban sound environment as a whole, the proposed paradigm allows to refine the analysis of the categories, thanks to the pre-established typology.

The pilot study shows that the proposed protocol provides us with ecologically viable data. Indeed, motivated by a realism concern, some subjects have voluntarily placed in their ideal scenes sounds that could be a priori considered as unpleasant events. The same tendency is observed for the textures of the ideal scenes from which 25.9% are sounds relative to "traffic hubbub". Several subjects stated in their free comments that they deliberately deleted sound elements of their soundscape in order not to overload the final sound environment, particularly for the ideal scenes. This fact reinforces the ecological validity of the experimental protocol. This deletion is in fact the result of an awareness, by the subject of the sonic context of an urban environment. This awareness is encouraged by the experimental paradigm. We believe that the simulation process acts as a mirror, allowing the subject to adjust its responses during the experiment, and thus provides meaningful data. Subjects do not manipulate isolated sounds, but interconnected sounds as they are perceived in the "real word".

The analysis of the numerical data shows a significant difference between the average sound levels of an ideal urban environment and that of a not-ideal environment. Nevertheless, both environments present the same activity in terms of occurrences of sound sources.

To conclude, the pilot study described in this paper validates the potential of this new experimental paradigm, as well as many of the design choices that were made. In order to reach conclusive results about the points discussed in this section, future work will focus on the development of this experiment at a larger scale.

Acknowledgments

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