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MULTIDIMENSIONAL ASSESSMENT OF THE ACOUSTIC QUALITY OF URBAN ENVIRONMENTS

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ABSTRACT
With the aim of assessing the acoustic quality of urban environments, two perceptive tests were carried out. They were based on the same semantic differential questionnaire and required an exclusive auditory judgement measured in audio-visual conditions (with co-occurring visual settings). The first test was organised in situ (actual urban situations) and the second one in laboratory situations (recreated urban situations). A multidimensional statistical analysis revealed three factors describing at best variations in auditory judgement on various urban situations (the same for both the tests). These factors proved to be independent of our experimental conditions. A fourth factor is only relevant for the in situ test. Impact of visual setting was examined for specific urban situations and revealed some auditory rating scales particularly sensitive to co-occurring visual settings.

1 - INTRODUCTION
The present research (Viollon [1]) aims at assessing the acoustic quality of urban sound environments. Its originality rests in its concern for a realistic and optimal approach, taking account of eventual interactions between visual information and auditory scenes.
Very few studies have been conducted about audio-visual interactions in an urban environmental context (Kastka [2], Tamura [3], Carles [4]). They all emphasise that this research field is complex and is worth studying further, as visual and auditory information may interact and influence one another.
The experiment described in this paper aimed at a multidimensional assessment of the acoustic quality of urban environments. It led to a set of relevant factors describing at best variations in auditory judgement on various urban sites. It was divided into two perceptive tests carried out in audio-visual conditions: auditory judgements were measured *with co-occurring visual settings*. Both the tests involved the same questionnaire representative of urban sound quality, they applied to similar visual and auditory environments and they were based on the same factorial analysis. The only difference came from the experimental conditions: one of the test was carried out in situ (actual urban situations) and the other one in laboratory (recreated urban situations in a dark and semi-anechoïc room: visual field = slides and auditory field = sound-tracks). The common experimental task involved an *auditory* judgement on various urban situations: participants were required to respond to a semantic differential questionnaire descriptive of sound environments.

2 - EXPERIMENTAL METHOD

2.1 - Questionnaire descriptive of the acoustic quality of urban environments
27 semantic differential scales (= pairs of opposite terms) were selected to be representative of urban sound quality. A questionnaire was composed of these 0-10 auditory rating scales. It was thus descriptive of urban auditory scenes and divided into two parts: a) rather a *subjective* description ("emotional" reaction from the subject towards sound environments, e.g. "Pleasant-Unpleasant") and b) rather an *objective* description (related to physical characteristics of sound environments, e.g. "Silent-Noisy").

2.2 - Urban sites

12 urban sites were tested in the experiment. They were selected for yielding a large set of sound environments representative of common urban situations: a market, four roads, a school, two pedestrian streets, a station, a park, a panorama (sound scene = wind and birds) and more original, a glass-roof (sound scene = birds and musical instruments from a near music school). During the in situ test, photographs and sound-tracks of the 12 urban sites were made and were afterwards used for the laboratory test, which guaranteed the similarity of visual and auditory urban environments between both the experimental conditions (actual and recreated ones).

2.3 - Common experimental procedure

Commonly to both the perceptive tests of the experiment, participants were required to rate the sound environment of the 12 various urban sites along the 27 auditory rating scales of the questionnaire. Their judgements were exclusively related to auditory modality but were measured with co-occurring visual settings (audio-visual approach of urban acoustics).
8 participants were tested for the in situ test and 25 for the laboratory test.

2.4 - Experimental conditions

The experiment involved two perceptive tests varying in their experimental conditions:

- The in situ test was carried out in actual urban environments. Participants were brought all together on the 12 various urban sites and responded to the auditory questionnaire for each of these sites.
- The laboratory test involved urban environments recreated in a dark and semi-anéchoïc room thanks to a specific audio-visual simulation technique (visual field = colour slides projected on a large screen − 1m70 × 1m10; auditory field = stereo sound-tracks diffused on two loudspeakers). Participants individually responded to the auditory questionnaire for each of the 12 audio-visually simulated urban sites.

2.5 - Data processing

Data were processed through two main statistical analyses: a) a descriptive statistical analysis performed on participants' ratings and b) a Principle Components Factors Analysis performed on the rounded means calculated over all the participants ("variables" = the 27 auditory rating scales of the questionnaire and "individuals" = the 12 urban sites).

3 - RESULTS: DESCRIPTIVE STATISTICAL ANALYSIS

Dispersion affecting auditory ratings was examined through the repartition of the 324 standard deviations (σ) (324 = 12 urban sites × 27 variables) in the three possible values groups: $\sigma \leq 1$, $1 < \sigma \leq 3$, $\sigma > 3$ (N.B.: scale dynamic = 10).
Most of the standard deviations belong to the middle values group $1 < \sigma \leq 3$ (75% for the in situ test and 97% for the laboratory test). A negligible percentage of standard deviations belongs to the third values group $\sigma > 3$ connected to the greatest dispersion (3% for the in situ test and null for the laboratory test). In conclusion, results of both the tests seem quite reliable, whatever the experimental contexts.

4 - RESULTS: PRINCIPLE COMPONENTS FACTOR ANALYSIS

The Principle Components Factor Analysis gave rise to a reduced set of principle components or synthetic factors summarising at best the initial variables. Indeed, these components account for the internal structure of the questionnaire, amalgamating the auditory variables subjected to similar variations between the urban sites.
Two objectives were aimed: a) determining a reduced set of factors describing at best variations in auditory judgements on urban environments and b) examining the influence of measuring auditory judgements in actual or laboratory experimental conditions and yielding results independent of our experimental conditions.
For the in situ test, four relevant and independent factors were extracted. They account for 85,8% of the whole inertia. For the laboratory experiment, only three factors are relevant and account for 84,7% of the whole inertia. A main difference appears between both the tests; it does not rest in the explained percentage of the whole inertia (both similar and high) but in the number of relevant factors required to explain this inertia (four to three). This disappearance of the fourth factor implies that auditory judgements are less many-sided and involve fewer subtleties in laboratory conditions. This result is

logical: recreated urban sound environments are not as "perfect" (imperfect sound reproduction quality) and as "realistic" (limited interaction with the subject) as actual sound environments.
According to our results, the number of relevant factors is different between both the tests (three to four). Then, an important question comes to mind: are the first three factors also different between both the tests? If it was the case, our multidimensional assessment would not be reliable, dependent of the experimental conditions (actual or simulated). Positively, it is not the case in our experiment. Whatever the experimental conditions, the first three factors are significantly and virtually correlated to the *same* variables: they can be interpreted in a similar way. In conclusion, three factors account for main variations in auditory judgement on our urban situations and they are independent of our experimental conditions.
Each of these factors are now described; the auditory variables of the questionnaire which are significantly correlated to them are indicated with the associated correlation ($\underline{r}$) and statistical significance level (p) [T_{situ} = in situ test and T_{labo} = laboratory test].

4.1 - First factor
The first factor accounts for 46,6% (T_{situ}) and 42,1% (T_{labo}) of the whole inertia. More than 40% of variations in auditory judgement between the various urban environments can be described by this factor, which emphasises its relative importance (whatever the experimental conditions).
Thirteen auditory variables are significantly correlated to this factor, *commonly* to both the tests:

Pleasant	T_{situ}: $\underline{r}$ = 98%, $p < .001$; T_{labo}: $\underline{r}$ = 95%, $p < .001$
Reassuring	T_{situ}: $\underline{r}$ = 93%, $p < .001$; T_{labo}: $\underline{r}$ = 88%, $p < .001$
Comfortable	T_{situ}: $\underline{r}$ = 96%, $p < .001$; T_{labo}: $\underline{r}$ = 95%, $p < .001$
Relaxing	T_{situ}: $\underline{r}$ = 93%, $p < .001$; T_{labo}: $\underline{r}$ = 89%, $p < .001$
Stimulating	T_{situ}: $\underline{r}$ = 90%, $p < .001$; T_{labo}: $\underline{r}$ = 95%, $p < .001$
Rural	T_{situ}: $\underline{r}$ = 83%, $p < .001$; T_{labo}: $\underline{r}$ = 90%, $p < .001$
Enhancing communication	T_{situ}: $\underline{r}$ = 94%, $p < .001$; T_{labo}: $\underline{r}$ = 95%, $p < .001$
Impression of freedom	T_{situ}: $\underline{r}$ = 94%, $p < .001$; T_{labo}: $\underline{r}$ = 91%, $p < .001$
Merry	T_{situ}: $\underline{r}$ = 85%, $p < .001$; T_{labo}: $\underline{r}$ = 61%, $p < .04$
Friendly	T_{situ}: $\underline{r}$ = 95%, $p < .001$; T_{labo}: $\underline{r}$ = 79%, $p < .002$
Interesting	T_{situ}: $\underline{r}$ = 87%, $p < .001$; T_{labo}: $\underline{r}$ = 65%, $p < .03$
Fluid during time	T_{situ}: $\underline{r}$ = 81%, $p < .001$; T_{labo}: $\underline{r}$ = 71%, $p < .01$
Silent	T_{situ}: $\underline{r}$ = 63%, $p < .03$; T_{labo}: $\underline{r}$ = 70%, $p < .02$

Table 1.

The first factor, the most important, could account for variations in auditory judgement connected to preferences, enjoyment and positive providing of listening to urban sounds. It could be named as "Affective impressions, preferences". It is independent of our experimental conditions.

4.2 - Second factor
The second factor accounts for 18,0% (T_{situ}) and 30,2% (T_{labo}) of the whole inertia. These percentages are different because more auditory variables are significantly correlated to the second factor for laboratory conditions (13) than for actual conditions (7) (with 5 common variables). The interpretation of the second factor is similar between both the tests, even though it should be pursued further for the simulation test connected to a more many-sided meaning (further investigation was not conducted).
Five auditory variables are significantly correlated to this factor, *commonly* to both the tests:

Bustling	T_{situ}: $\underline{r}$ = 84%, $p < .001$; T_{labo}: $\underline{r}$ = 97%, $p < .001$
Marked by living creatures	T_{situ}: $\underline{r}$ = 81%, $p < .001$; T_{labo}: $\underline{r}$ = 84%, $p < .001$
Variable during time	T_{situ}: $\underline{r}$ = 64%, $p < .03$; T_{labo}: $\underline{r}$ = 67%, $p < .02$
Dense in space	T_{situ}: $\underline{r}$ = 64%, $p < .03$; T_{labo}: $\underline{r}$ = 72%, $p < .008$
Noisy	T_{situ}: $\underline{r}$ = 61%, $p < .04$; T_{labo}: $\underline{r}$ = 59%, $p < .05$

Table 2.

For both the tests, urban sound scenes which were the most involved in the creation of this factor were the followings: pedestrian streets, market, school (positive side of the factorial axis) contrasting with birds, fountain in a park, roads (negative side of the factorial axis). The second factor may differentiate urban sound scenes which are marked or not by human presence. According to the auditory variables significantly correlated to it, it could account for the activity, agitation created by human beings. It could be named as " Activity due to sound presence of human beings". It is independent of our experimental conditions.

4.3 - Third factor

The third factor accounts for 11,6% (T_{situ}) and 12,4% (T $_{labo}$) of the whole inertia (similar percentages for both the tests).
Two auditory variables are significantly correlated to this factor, *commonly* to both the tests:

Unexpected	T_{situ}: $\underline{r} = 91\%$, p <.001; T_{labo}: $\underline{r} = 82\%$, p <.001
Impression of falsehood	T_{situ}: $\underline{r} = 87\%$, p <.001; T_{labo}: $\underline{r} = 86\%$, p <.001

Table 3.

This factor is linked to terms which can only be grasped with a reference. Participants proved to be sensitive to urban sound scenes which were original or did not correspond to what they expected to listen to. This third factor, independent of our experimental conditions, could be named as "Auditory expectations".

4.4 - Fourth factor (only significant for the in situ test)

The fourth factor accounts for 9,6% (T_{situ}) of the whole inertia (N.B.: 30,2% for T_{labo}). It is less reliable than the first three factors because it is not enhanced by the community of its interpretation whatever the experimental conditions.
Two auditory variables are significantly correlated to this factor:

Informative	T_{situ}: $\underline{r} = 68\%$, p <.02
Clear	T_{situ}: $\underline{r} = 61\%$, p <.04

Table 4.

These auditory variables refer to the sound environment as a source of useful perceptive information. The disappearance of this fourth factor is thus quite logical in the case of the laboratory test (the possibility and the usefulness of using auditory information was quite limited). This fourth factor could be named as "Quality of auditory information".

5 - INFLUENCE OF VISUAL SETTING ON SOUND RATINGS

Influence of visual setting on sound ratings was examined thanks to the "principle of audio-visual decorrelation" which consists in associating decorrelated (independent) visual and auditory environments in the *same* site. It was successfully applied for two pairs of urban sites, these ones involving two construction levels (case of a footbridge and of a flagstone).
Differences in auditory ratings between the urban sites of each pair (similar sound environments *but* different visual settings) may certainly be due to changes in visual settings. They were calculated for each of the 27 auditory variables of the questionnaire and each of the 3 principle components (for each test).
The various factorial plans show (whatever the test) a quasi-parallelism of variations between both pairs of sites: changes in visual settings involved in the aggregate the same set of auditory variables. The examining of differences in auditory ratings point that these differences were the greatest in the case of the first factor. Two auditory variables proved to be particularly influenced by visual information. They are the most representative of variations in *auditory* judgements given rise to by changes in *visual* settings: Unpleasant / Pleasant and Stressful / Relaxing.

6 - CONCLUSION

Variations in auditory judgements between twelve urban situations are described through three main factors independent of our experimental conditions (in situ or laboratory ones). These factors yield a multidimensional assessment of the acoustic quality of urban environments, whether these ones are actual or simulated. They are reliable, enhanced by the community of their interpretation for both the tests. They are named as follows: 1) Affective impressions, preferences, 2) Activity due to sound presence of human beings, 3) Auditory expectations. A classical result for studies based on the semantic differential method is the leading to an EPA factorial structure (Osgood [5]): E = Evaluation, P = Potency and A = Activity. Besides, our factorial structure reveals both the dimensions Evaluation (first

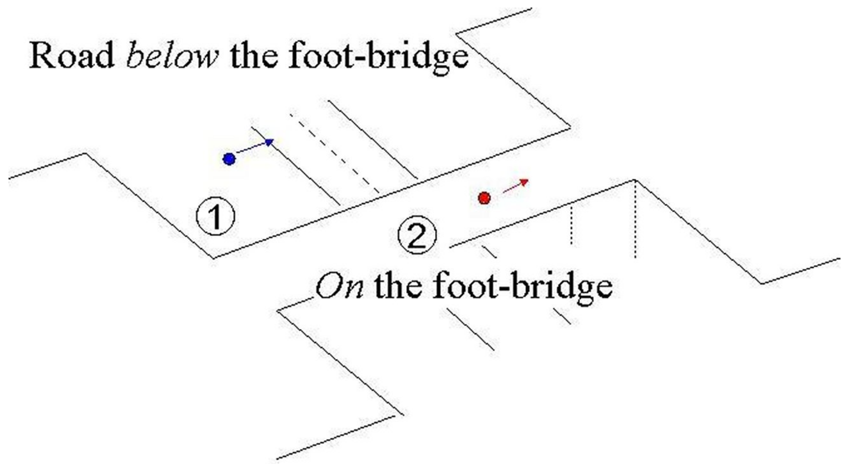

Figure 1: "Principle of audio-visual decorrelation", example of a footbridge; at the lower level (1), the subject could hear *and* see the road; yet, at the upper level (2), he could still hear the road *but* with a different visual setting; both the urban sites (1) and (2) involve similar sound environments (road traffic noise) but different visual settings.

factor) and Activity (second factor). Our audio-visual simulation technique proved to be reliable but imperfect: a fourth factor accounting for the quality of auditory information is only relevant for the in situ test. Impact of visual setting was examined for specific urban situations and revealed two auditory rating scales particularly sensitive to co-occurring visual settings: Unpleasant / Pleasant and Stressful / Relaxing.

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