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Sound pleasantness evaluation of pedestrian walks in urban sound environments

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Abstract

The health benefits of a daily physical activity, and of walking in particular, are widely acknowledged. However, walking in urban environment inevitably leads to an increased exposure to noise, which forms a drawback of choosing this transportation mode. Being able to estimate the sound pleasantness associated with an urban walk trip has many potential applications, such as informing pedestrians about the sound along their intended walk, which may help them to optimize their route choice. In the past decade, various studies have focused on characterizing and estimating the sound pleasantness perceived at specific locations, on the basis of perceptive and physical measurements. However, to estimate the sound pleasantness along an urban walking trip, an additional step is required, which consists of assessing how a pedestrian evaluates the overall pleasantness of a sound environment that varies along the walking trip. In this work, the results of two laboratory experiments and one field experiment are discussed, which were designed to assess the overall evaluation of the sound environment along an urban walk. Physical and perceptive measurements at specified positions or continuously along a series of tested routes are available, in addition to a global evaluation of the route. A comparison between the results of the three experiments provides a rich source of information to understand how the sound pleasantness of a pedestrian walk is evaluated. The main conclusion is that for short walks (of about 1 minute), a recency effect is observed, which tends to disappear when the duration of the walk increases.

Keywords: Sound quality, soundscape, urban walk, recency effect

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1 Introduction

The health benefits of practicing daily a physical activity, and walking in particular, is widely acknowledged [1]. Soft transportation modes are also known to ease traffic flows. Thus, municipalities promote more and more the use of walking or cycling to their city dwellers for commuting, and invest in facilities that encourage these practices [2], [3]. The environmental quality at the local neighborhood scale strongly influences the choice for walking as transportation mode [4], [5]. Therefore, being able to estimate the exposure associated to an urban walk trip has many potential interests, such as informing a pedestrian about the health cost associated with his/her intended walk, or optimizing the choice of route through specific algorithms [6], [7].

Recent works started to establish the relations between perceptive evaluations (e.g. sound pleasantness or overall loudness) and physical measurements. These perceptive evaluations not only account for the energetic dimension, but also for the temporal and spectral dimensions of noise exposure [8], [9]. In addition, introducing explicitly sound sources (e.g. vehicles, voices, birds, etc.) in the modeling improves sound pleasantness estimations [10]–[12].

However, to estimate the sound pleasantness along an urban walking trip, an additional step is required, which consists of assessing how a pedestrian evaluates the overall pleasantness of a sound environment that varies along the walking trip. Specific works investigated how time-varying sound environments are evaluated. For example, Västfjäll et al. showed that a recency effect interferes with retrospective sound quality evaluations [13]. Steffens and al. compared momentary and retrospective evaluations, and showed with a corpus of various 1 min-length samples that both peaks and recency influence sound evaluations [14].

This paper deals with the influence of the temporal structure of urban sound sequences on their sound pleasantness evaluation. It summarizes the results of three experiments performed within the GRAFIC project (French acronym for “Sound quality cartography of locations and pathways in an urban context”), which aimed to investigate how the sound pleasantness of an urban walk can be estimated. Section 2 to 4 present the protocol and results of three perceptive tests: section 2 is dedicated to an in situ experiment, section 3 to a laboratory experiment with artificial sound sequences, and section 4 to a laboratory experiment with real audiovisual sequences. The section 5 proposes a short discussion combining the results of the three analyzed experiments.

2 Experiment 1: In Situ Experiment

2.1 Method

The experiment consisted of a perceptive test performed 4 times (referred further as “runs” in the text) over a 2,1 km-long path, located in Paris (13rd district); see Figure 1.

Perceptive data were collected during 3-to-5 minutes stops, over 19 points located on the path, resulting in a test duration of approximately 45 minutes. The points were chosen to contain a large variety of urban sound environments on both sides of soundscape transitions, resulting in a distance of on average 115 meters in between points.

Participants were divided into four runs, with about 10 participants per run on average, which is small enough to not modify the surrounding sound environment while keeping a sufficient number to perform statistical analysis. 37 subjects participated to the test. The four perceptive tests were performed on the Mondays 23/03/2015 and 30/03/2015, the path being travelled each day alternated from West to East (WE) and from East to West (EW). The participants received a small monetary compensation, and participated in only one of the four runs.

Figure 1 Noise Map of the studied path, interpolated from mobile measurements (Leq - dB)

The perceptive test consisted of a questionnaire with 16 questions on perceptive dimensions, rated over 11-point bipolar semantic scales from 0 to 10, administered at each of the 19 points. The questions covered four categories of perceptive parameters, most of which were already investigated in previous studies [21]. The following four parameters were used in this study: (i) the Segment Pleasantness (SP), which describes the pleasantness of the sound environment during the path between the previous point and the evaluated point, from “unpleasant” to “pleasant”; (ii) the Change of the Sound environment (CS), which describes the perceived change of the sound environment between the previous point and the evaluated point, from “identical” to “very different”; (iii) the Speed of the Change (SC), which describes the speed of the change described before, from “sudden” to “progressive”, when a change was perceived;

(iv) the Pleasantness (P), which describes the pleasantness of the sound environment at the evaluated point, from “unpleasant” to “pleasant”.

The participants had also to respond to the same questionnaire, relatively to the first half of the path (at point 9), to the second half of the path, and to the route as a whole. The models proposed in this section are constructed at the run-scale, which averages the participant evaluations at each point for each run, in order to account for the run variability and to guarantee that each collected perceptive data corresponds to a different sound environment.

2.2 Results

2.2.1 Short segment sound pleasantness

The Sound Pleasantness is first assessed over the 18 short segments that compose the path. Kolmogorov-Smirnov tests are performed to assess the influence of the walking direction, on the SP estimates. The individual collected evaluations are divided into two groups WE and EW to perform the Kolmogorov-Smirnov test.

Table 1 Mean deviation of the perceived pleasantness for the segments ΔSP(WE-EW) and perceived change of sound environment (SC). Stars guarantee that the deviation is significant at a 95% level following the Kolmogorov-Smirnov test.

	$S_{[1-2]}$	$S_{[2-3]}$	$S_{[3-4]}$	$S_{[4-5]}$	$S_{[5-6]}$	$S_{[6-7]}$	$S_{[7-8]}$	$S_{[8-9]}$	$S_{[9-10]}$
ΔSP	-0,83	**-3,26***	-0,61	-0,24	2,05	0,43	1,12	0,72	-0,62
SC	3,5	8,7	5,3	5,4	6,3	3,2	6,7	4,6	8,1
	$S_{[10-11]}$	$S_{[11-12]}$	$S_{[12-13]}$	$S_{[13-14]}$	$S_{[14-15]}$	$S_{[15-16]}$	$S_{[16-17]}$	$S_{[17-18]}$	$S_{[18-19]}$
ΔSP	-1,54	1,35	0,62	1,33	1,63	-0,52	**-2,84***	0,10	-1,62
SC	6,5	5,9	5,6	4,9	8,2	2,5	8,8	6,2	8,0

Table 1 gathers the discrepancies, for each perceptive parameter, between the two groups. The pleasantness assessments are significantly dependent on the walking direction for segments $S_{[2-3]}$ and $S_{[16-17]}$ only. Both segments are also the ones with the highest perceived change in the sound environment (SC=8.7 and 8.8). Interestingly, the perceived change of the sound environment (SC) and the mean deviation of the perceived pleasantness for the segments (ΔSP), correlate significantly ($r=0.65$, $p<0.005$). This suggests that the segment evaluation depends on its ending sound environment, which might be explained by a recency effect. Indeed, such effects were shown in recent works on transitions between different sound environments [15], or on the temporal dynamics of sound environments and its evaluation [14].

Thus, the Segment Pleasantness (SP) of a given segment can be estimated with the sound environments assessed at the two stopping-points situated at each extremity of the given segment P_{end}, and their averaged value P_{mean} or $(P_{begin} + P_{end})/2$. A multiple linear regression is proposed, which explains a large part of the variance (83%); see Equation 1. Again, this highlights the influence of the walking direction on segment pleasantness.

$$SP = 0.85 + 0.45 * P_{mean} + 0.44 * P_{end} \tag{1}$$

R²adj=0.83, RMSE=0.74, F=165***(p<0.001)

2.2.2 Large Path sound pleasantness

Sound Pleasantness is now estimated at the path scale. The Figure 2 shows the relation between the pleasantness assessments of a path evaluated globally, and the pleasantness averaged over the stopping-points that compose this path, for the global route and both halves of the route.

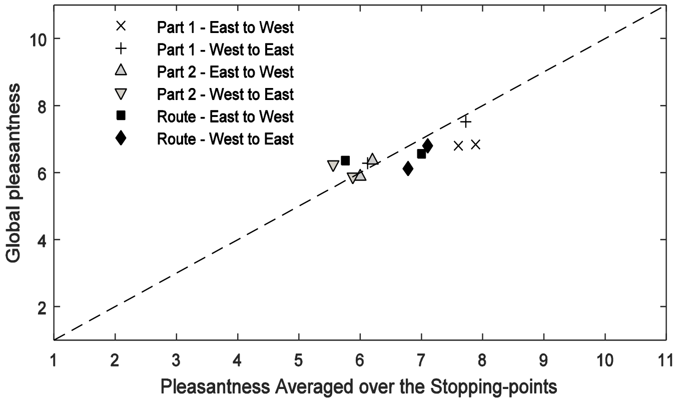

Figure 2 Global pleasantness, relatively to both halves of the path (Part 1, Part 2) and the route as a whole (Route), and the pleasantness averaged following the 4 runs (n=12), r=0.8, p<0.005.

The pleasantness values averaged by stopping points correlate well with the global ones (r=0.8, p<0.005). However, only twelve assessments are compared, and the route pleasantness depends on the pleasantness of the various segments along the path, so these results should be handled with care. Nevertheless, this suggests that averaging the sound pleasantness estimated per stopping point sampled regularly on the global path can be a potential good estimator of the global path sound pleasantness. It is worth noting that no recency effect is observed in this analysis at the path scale, whereas the global path extremities (P1, P9 and P19) have very different sound environments (see Figure 1).

3 Experiment 2: Laboratory test with artificial sound sequences

3.1 Method

The listening test of the first experiment took place in a semi-anechoic room. The evaluation was conducted individually: the participant was seated in a chair in front of a computer showing the test instructions. A very blurry image of an urban environment was projected on a screen located behind the computer, in order to have a realistic luminosity; however the stimuli were audio only. The sound sequences were reproduced through the transaural technique [16], using a 2.0 system. A calibration tone (1 kHz @94dB) was recorded during the measurements by the binaural microphones. Using this reference signal, the sound levels in the laboratory test were set equal to the sound levels as measured along the recordings in the field. A group of 30 subjects participated in the experiment. The subjects were naive with regard to the hypotheses under test, and received a small monetary compensation for participation.

Sixteen sound sequences have been reconstructed, based on a different combination of 2 initial sound sequences α and β of 90s each, in order to focus on the effect of the sound sequences temporal structure on the sound pleasantness evaluation. The resulting sound sequences have a duration of 3 minutes, which represents the median duration of a pedestrian trip in the city of Paris [17]. The sequence α was recorded in a small park (Pt 19), and the sequence β nearby a large boulevard (Pt 2). The 16 sound sequences were formed with a slow or quick alternation between α and β, evolving from calmness to noisiness or the inverse. The Table 2 presents the different configurations and the average sound pleasantness note of the 16 sequences.

As a first step and to get familiar with the test, the participants was first asked to rate on an 11-points bipolar semantic scale the sound pleasantness of the two sequences α and β after listening them. Then, the 16 sequences were played to each participant in a random ordination. The participant was asked to rate on the same scale the sound pleasantness P continuously. The evaluation was made while listening, through pointing on the screen to the evaluated instantaneous sound pleasantness. At the end of the sound sequence, the participant had to evaluate the global sound pleasantness (GP) of the sequence.

3.2 Results

Figure 3 depicts, for each of the 16 sequences, the 1s-sound pleasantness evolution P, mean values and standard deviation for the 25 participants.

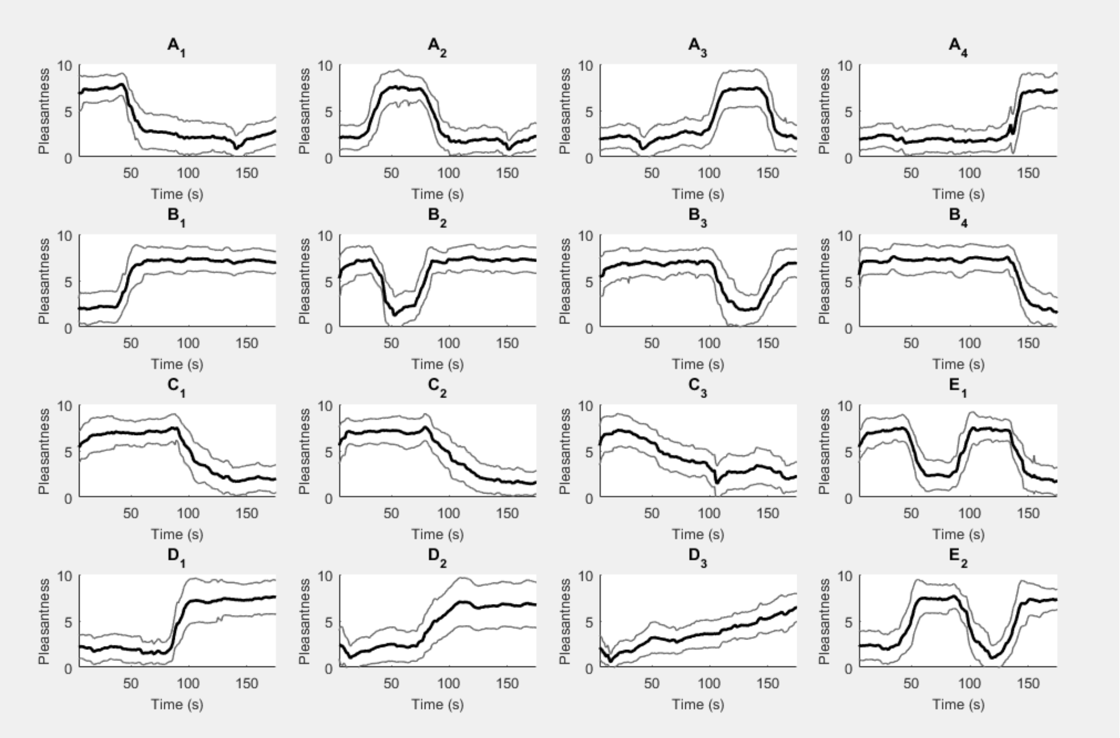

Figure 3 Time series of the sound pleasantness mean and standard deviation for each of the 16 sequences

The table 2 shows P_{mean}, GP, along with their differences, for each of the 16 sequences. A relation between the sound sequence temporal structure and the global sound pleasantness seems to emerge. For sequences that mainly consist of a park interrupted by the boulevard sequence β (compare sequences B1, B2, B3 and B4), the more β appears near the end of the sequence, the more the GP decreases. Inversely, although less pronounced, for sequences that mainly consist of a boulevard interrupted by a park sequence α (compare sequences A1, A2, A3 and A4), the more α appears near the end of the sequence, the more the GP increases.

Table 2 Averaged continuous pleasantness, global pleasantness and their differences for each of the 16 sequences.

Sequence	P_{mean}	GP	$\Delta_{(GP-Pmean)}$	Sequence	P_{mean}	GP	$\Delta_{(GP-Pmean)}$
A1 (αβββ)	3.7	2.9	-0.7	C1 $(\alpha\beta)_{fast}$	4.8	4.2	-0.6
A2 (βαββ)	3.4	2.6	-0.9	C2 (αβ)	4.7	4.3	-0.4
A3 (ββαβ)	3.5	3.4	-0.1	C3 $(\alpha\beta)_{slow}$	4.2	3.5	-0.7
A4 (βββα)	3.1	3.4	0.4	D1 $(\beta\alpha)_{fast}$	4.6	4.9	0.3
B1 (βααα)	5.8	6.4	0.6	D2 (βα)	4.5	5.6	1.0
B2 (αβαα)	6.0	6.3	0.3	D3 $(\beta\alpha)_{slow}$	3.6	4.1	0.5
B3 (ααβα)	5.6	5.7	0.1	E1 (βαβα)	4.9	4.8	-0.1
B4 (αααβ)	6.1	5.6	-0.5	E2 (αβαβ)	4.8	5.1	0.3

In order to investigate the possible psychological effect when evaluating the global sound pleasantness of a sound sequence, a multiple linear regression is constructed. Equation 2 presents an optimized linear regression, estimated through a stepwise procedure, maximizing the adjusted explained variance, including the variables P_{mean} and the sound pleasantness P_{end}, which corresponds to the arithmetic average of the sound pleasantness collected during the 30 last seconds of the sequence (the sequences are constructed such that their 30 last seconds always have a stable sound environment). Introducing other variables such as the sound pleasantness collected during the first 30 seconds, the maximum and minimum sound pleasantness values (peak values), did not improve the GP estimates.

$$GP = -1.04 + 0.96 * P_{mean} + 0.22 * P_{end} \qquad (2)$$

R^2adj.=0.95 / RMSE=0.27 / F=136 ($p < 0.001$)

The explained variance (95%) is higher than the one obtained by the linear model linking P_{mean} to GP, which is 75% (r=0.87). This highlights the influence of the end of the sequence on the evaluation of the global sound pleasantness.

The influence on global sound pleasantness of the speed at which sound environment switches occur, is less pronounced. For example, if one compares sequences C1 and C3, which evolve from the park to the boulevard fastly or very slowly, the sound pleasantness GP is lower than P_{mean} for both sequences, in accordance with the demonstrated recency effect, but in a similar extent. This would suggest that the speed at which sound environments evolve from one to the other has no influence on the global sound pleasantness evaluation.

4 Experiment 3: Laboratory test with real sound sequences

4.1 Method

A third experiment was based on 10 real urban sound environment sequences of 3 minutes, recorded in the 13rd district of Paris during April 2015. The audio recording and restitution followed the same protocol as in the Experiment 2. In addition, a video sequence was joined to the sound, in order to enhance the immersive power. In order to have time-varying sound environments, the 6 first sequences consisted of a transition between two different sound environments, and the 4 last sequences of a transition between three different sound environments. The 10 sequences corresponded to five pathways ran in both directions, in order to test the recency effect hypothesis. Before starting the sequences evaluation, a part of the paths was evaluated. The 10 sequences were presented to each participant in random order; the participant was asked to rate P and GP following the same protocol as in the Experiment 2. A group of 30 subjects participated in the experiment.

4.2 Results

Figure 4 and Table 3 depict the results of the sound pleasantness evaluations for the 10 sequences. The correlation coefficient between GP and P_{mean} is 0.87 ($p<0.01$/RMSE=0.78).

Interestingly, this correlation is identic to the correlation observed between GP and P_{mean} in the other laboratory experiment (r=0.87).

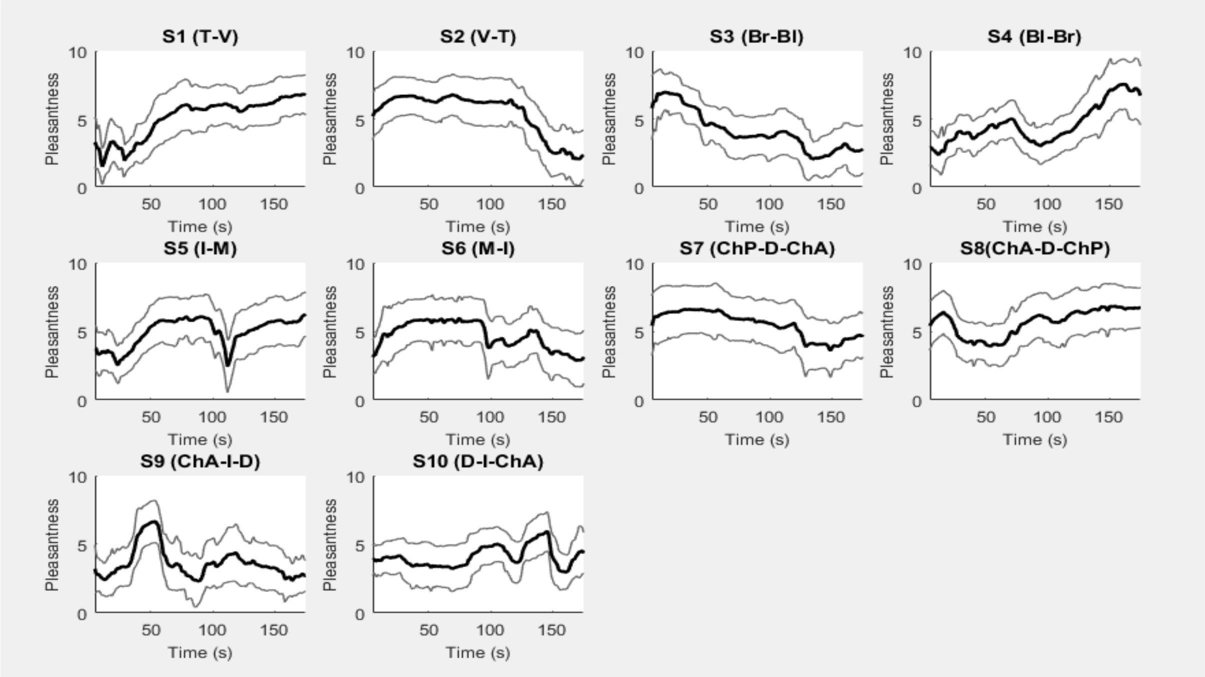

Figure 4: Time series of the sound pleasantness mean and standard deviation for each of the 10 sequences

In contrast to Experiment 2, the GP values are globally higher than the P_{mean} values, what might again be caused by the influence of visual factors on sound appreciation, which has been already shown in [18]–[20].

Table 3 Averaged continuous pleasantness, global pleasantness and their differences for each of the 16 sequences.

Sequence	P_{mean}	GP	$\Delta_{(GP-Pmean)}$	Sequence	P_{mean}	GP	$\Delta_{(GP-Pmean)}$
S1	5.3	6.2	0.9	S6	5.2	4.8	-0.4
S2	6.1	6.7	0.6	S7	6.1	7.5	1.4
S3	4.8	4.9	0.1	S8	5.9	7.2	1.3
S4	4.6	5.6	0.9	S9	4.0	4.8	0.8
S5	5.2	5.8	0.7	S10	4.4	4.0	-0.4

No conclusion on the effect of the temporal structure of the sound sequence on the global pleasantness assessment can be drawn from this experiment. Two hypotheses are formulated to explain this absence of recency effect in Experiment 3: (i) the sound sequences are less contrasted than the artificial sound sequences used in Experiment 2, what would temper the formulated conclusions about a recency effect for the sound pleasantness assessment of real sound sequences in Experiment 2, (ii) the video content might have helped subjects to analyze the sequences in their integrality, thus attenuating the recency effect.

5 Discussion

This paper summarizes the results of three experiments, which aimed to estimate both the instantaneous and the global sound pleasantness of urban sound sequences of 1 min, 3 min and ~30 min. Experiment 1 was in situ: the subjects had to evaluate the sound pleasantness of a walking path, at 19 stopping points placed along the pathway, as well as its two halves and the overall path. Experiments 2 and 3 were laboratory tests, respectively using artificial and natural sound sequences; the subjects had to evaluate the sound pleasantness continuously along the sound sequences, and globally at its end.

The conclusions are:

- The sound pleasantness of a 1min-segment is well estimated based on the perceived pleasantness at its extremities.
- The modeling of the recency effect improves the estimation of the global sound pleasantness over short sound sequences (about 1min). This effect tends however to disappear when the sound sequences are nearer to real sound environments or longer periods.
- The global sound pleasantness of pathways that takes more than 3 minutes to be walked in real conditions can be efficiently estimated with the arithmetic average of the instantaneous sound pleasantness values.

These three experiments are a step towards the understanding of how the temporal structure of urban sound sequences influence their sound pleasantness evaluation. Combined with undergoing research on the sound pleasantness modeling based on physical variables, this research will lead to the estimation of the sound pleasantness of urban walking routes. Further investigations are however needed to improve the pleasantness estimation of realistic walking routes. Also, extending the experiment to various other environments, including more parks, very noisy or animated locations, will give birth to more universal models.

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