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Pleasantness of typical acoustic environments inside a living room in a European residential context

Romain DEDIEU[1,2], Catherine LAVANDIER[2], Cédric CAMIER[1], Sylvain BERGER[1]

[1]Saint-Gobain Research Paris, 39 quai Lucien Lefranc 93303 Aubervilliers Cedex, FRANCE,
romain.dedieu@saint-gobain.com, cedric.camier@saint-gobain.com, sylvain.berger@saint-gobain.com
[2]ETIS, UMR 8051, Université de Cergy Pontoise, Site de Saint Martin, 2 rue Adolphe Chauvin, 95 302 Cergy-Pontoise Cedex, FRANCE, catherine.lavandier@saint-gobain.com

Abstract
Acoustic comfort defined in first approach as the absence of unwanted sounds and the quality of desired sounds while doing an activity arouses a growing interest in sociology, psychology and building industry. Comfort is influenced by the acoustic performances of building, by the various types of sound sources, and by individual aspects (sociological background, musical preferences etc.). A study based on three perceptive tests aims to address these aspects. The first perceptive test consists in the evaluation of pleasantness for various sound sources according to their semantic content and their origin (from the neighbor, the outside, or the room). Thus, 67 focused listeners rated the pleasantness of every stimulus. Statistical analysis showed a consensus on intrusive sounds coming from outside, people preferring bird songs and rejecting site work sounds. For intrusive sounds coming from neighbors, there is also a consensus, people preferring classical music and rejecting human sounds. Participants can be clustered in two groups, one preferring nature sounds and the other preferring music sounds. Moreover, the ratings of the human sound pleasantness (diner, laughs, etc.) are influenced by the sound sensitivity of the participant, the more sensitive the less pleasant the sound.
Keywords: Perception, Comfort, Building

1 INTRODUCTION

In residential building, various sound sources may be heard without consent or control. These sounds may have different origins (from the neighbor, the outside, the room itself, the staircase) and types (mechanical, living, nature, etc.). Pleasantness of these sound sources may vary according to human preferences and socio cultural factors. Comfort in dwellings is however generally only based on respect of regulations but the type of sources that compose the intruding sounds is also important as revealed by a lot of field surveys [1–6]. In order to study the influence of intruding sources on the comfort inside living room, several perceptual tests are organised in a laboratory context: (1) study of the source preferences, (2) study of masking sources and (3) study of comfort due to the combination of the intruding sources (neighbor and outside sounds) in a living room. In this paper, only the first test is presented. The aim of this test is to characterize the corpus participants who will be involved into the 3 perceptual tests, focussing on their taste about intruding sounds. The method is based on a listening approach. Participants are asked to listen carefully every sound stimulus and rate sound pleasantness on a semantic scale going from unpleasant to pleasant.

2 METHOD AND MATERIAL

2.1 Participants

67 listeners participated in the listening test. An hearing test was conducted for every participant right after the perceptive test. The audiogram release showed that 1 listener had hearing losses too significant in order to remain in the corpus based on the audiometric classification of hearing impairment [7]. Among the 66 remaining participants (42 % male / 58% female), 54% are workers aged 30 to 50 and 46% are students aged 18 to 30.

All participants grew up in urban or outlying suburbs and they lived in a residential building at the time of the listening test. Median of the noise sensitivity distribution is about 6.5 over 10 based on a self evaluation scale.

2.2 Sound sources

Semantic categories of urban sounds environments have been studied and defined in the literature [8–11]. Categorization of environmental sound sources including domestic stimuli have also been studied [12, 13] distinguishing categories according to their types. Acoustic comfort in residential buildings has been explored following an on-site approach [1, 2], and [3, 4]. Perceptive questionnaires were filled by residents living in buildings respectively in Sweden, France, and Finland. Based on this literature review, 35 sound sources have been selected and presented in table 1. Sound stimuli have been chosen to be the prototypes of their semantic categories. This corpus of stimuli aims to represent the wide variety of sound sources potentially encountered in a dwelling. Every sound stimulus is listened at the same equivalent sound pressure level L_{eq} equal to 35 dB(A) so that mostly the semantic content might affect the perception. Background noise in the room is about 23 dB(A). Stimuli were composed in selecting samples from sound libraries (BBC sound library, Free Sound, Urban Sound, Universal sound bank, and Free sound) or thanks to direct measurements carried out using either Zoom H7 recorder (with XY mics) or ORTF CCM Schoeps microphones. Each stimulus has a 30 s duration and is played in loop. In both cases, a mix of Left+Right channels is performed to get mono signals. These mono signals are then auralized following a method described in section 2.4.

2.3 Building performances

When a sound stimulus encounters a building component, the propagation through the materials filters the incoming signal. In order to account for the building acoustic performances, simulation is carried out based on Statistical Energy Analysis (SEA). SEA calculation is described in standard NF EN 12354-1 [14]. Simulations are based on a building described in in table 2.

2.4 The laboratory

The laboratory and its sound reproduction system have been presented at CFA'18 [15]. Figure 1 presents a picture of the furnished laboratory/living room. The sound reproduction system consists in 16 Yamaha HS7-I speakers and 1 Genelec 7070A subwoofer driven by 1 audio processor Yamaha DME64N. Sound strategies are designed and controlled through the software Max/MSP 7. As described in table 1, neighbors sound sources may have two different origins, either from above or next door and outdoor sounds all come from the front facade. Auralization strategy consists in placing 9 regularly spaced virtual point sources for radiating surfaces of the room (the facade, the ceiling, and the adjacent neighbor's partition). Every point source is then spatially rendered using Vector Based Amplitude Panning (VBAP) [16]. The ventilation coming from the room itself is auralized as a point source virtually placed at 138 deg. in azimuth and 43 deg. in elevation.

Figure 1. Picture of the spatialized sound reproduction laboratory (La MIR, Neuville sur Oise, France)

2.5 Subjective assessments and questionnaires

Participants were asked to listen carefully to the sounds for 30 seconds before answering on a tablet controlled with the software Max/MSP 7. The General User Interface (GUI) consists in 6 tactile sliders going from -50 to +50 (-50: Unpleasant; 50: Pleasant) corresponding to 6 sounds evaluated at the time. Every stimulus is listened separately. On the other hand, a questionnaire has been designed to evaluate mostly non-acoustic factors. The questionnaire is organized in five main parts (general information, feedbacks on the listening test about sound realism and ability to identify the origin of sound, participant's dwelling description, sound sensitivity evaluation

Table 1 – Sound stimuli description

Designation	Description	Type	Origin
Traf.	Urban trafic on Paris street	Mechanical	
Steady Traf.	Highway Trafic	Mechanical	
Hum. & Traf.	Trafic on small street with human voices (child and woman) and footsteps	Mix*	
Hum. & Traf. 2	Trafic on small street with human voices and footsteps		Mix*
Traf. & Nat.	Trafic, storm and rain	Mix*	
Traf. & Nat. 2	Trafic, and birds chirping	Mix*	
Nat. & Hum.	Children playing and birds chirping	Mix*	
Nat. & Hum. 2	Bird chirping, people chatting and walking	Mix*	
Hum.	People talking	Living	Facade
Nat.	Birds chirping, water streaming	Nature	
Nat. 2	Water streaming	Nature	
Hum. & Traf. & Nat.	Birds chirping, cars passing, child talking, and footsteps	Mix*	
Road work	Work site with jack-hammer blows	Mechanical	
Flyover	Aircraft flyover		Mechanical
Vacc. next door	Vacuum cleaner	Mechanical	
Washer	Washer in spinning mode	Mechanical	
Flush	Pipe noise of toilet flushing	Mechanical	
Diner	neighbors talking, laughing	Living	
Party	Music and neighbors talking, laughing	Mix*	
Argument	Woman arguing		Living
Children next door	Children playing with furniture ratting	Living	
Children next door 2	Voices of children playing	Living	
TV Doc.	Television broadcasting an BBC wildlife documentary		Living
TV Film	Television broadcasting the film The Dark Knight	Living	Neighbor next door
Music LF next door	2.1 HI-FI system playing Hip-Hop music Kendrick Lamar - Humble	Music	
Music Pop.	2.1 HI-FI system playing Pop. music Ed Sherann - Shape of you	Music	
Music Guitar	neighbor playing the guitar Erik Satie Gnossienne No. 01	Music	
Music Piano	neighbor playing the piano Chopin Nocturne No. 20 in C-Sharp Minor	Music	
Tears	Woman crying	Living	
Work	neighbor's drill working	Mechanical	
Vacc. above	Vaccum cleaner	Mechanical	
Children above	Children playing with furniture ratting	Living	Neighbor from above
Music LF above	2.1 HI-FI system playing Hip-Hop music Kendrick Lamar - Humble	Music	
Ventilation	Ventilation system	Mechanical	From the room
Staircase	Footsteps and slamming door in staircase	Living	Neighbor next door

based on Griefahn [17] questionnaire, and quality of life assessment [18].

2.6 Procedure

Listeners were first informed of the nature of the experiment (Pleasantness evaluation of several sound stimuli). The experiment started with a training session consisting in four stimuli allowing the listeners to become familiar with the computer tool and to the various types of sound sources they may listen. The listening test was then carried out. Six sound stimuli are rated on the same screen. Once the 6 first stimuli are listened and

Table 2 – Acoustic performances of the building components simulated for the perceptive test. Global indicator R_w computed according to ISO 717/1 standard.

	Facade		**Floor**	**Neighbor's lateral wall**
	12cm concrete	4mm glazing	15cm concrete	Alveolar partition 72
Rw(C;C_{tr}) (dB)	57(-2;-6)	22(0;-1)	57(-2;-6)	29(-1;-1)

assessed, participants may continue to the next sheet to listen and evaluate the next sounds and so on until the 35^{th} stimulus. At any time, participants are allowed to go back to the previous sheets in case they wish to change their ratings or listen again previous sounds stimuli. The origin of the different sounds was not specified. As soon as they finished the listening test, they filled the final questionnaire. Finally, an audiogram test was performed and participants could leave the session with their audiogram.

3 RESULTS

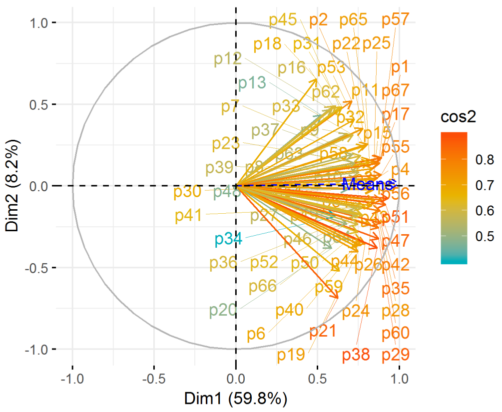
3.1 Sound localisation: Neighbor above & next door

As described in table 1, three sound sources have been listened from two specific directions, one time coming from the ceiling, the other coming in direction of the neigbor next door from the right. This duplication on two distinct directions is meant to evaluate whether the origin of sound influences the pleasantness assessment. Results show that mean and median values for each pair are very close (maximum 2 pt. differences in mean on the 100 point scale). Paired Student tests have also been carried out and results show that mean differences are not significant since p-value > 0.05 in all cases. Hypothesis $H_0 : \mu_0 = \mu_1$ is accepted, there is no significant difference of pleasantness according to the origin of sound when the origin is clearly identified (from ceiling Vs. next door). For the rest of the study, all assessments of sounds heard from the ceiling were removed from the dataset so as not to artificially increase their influence in the analysis.

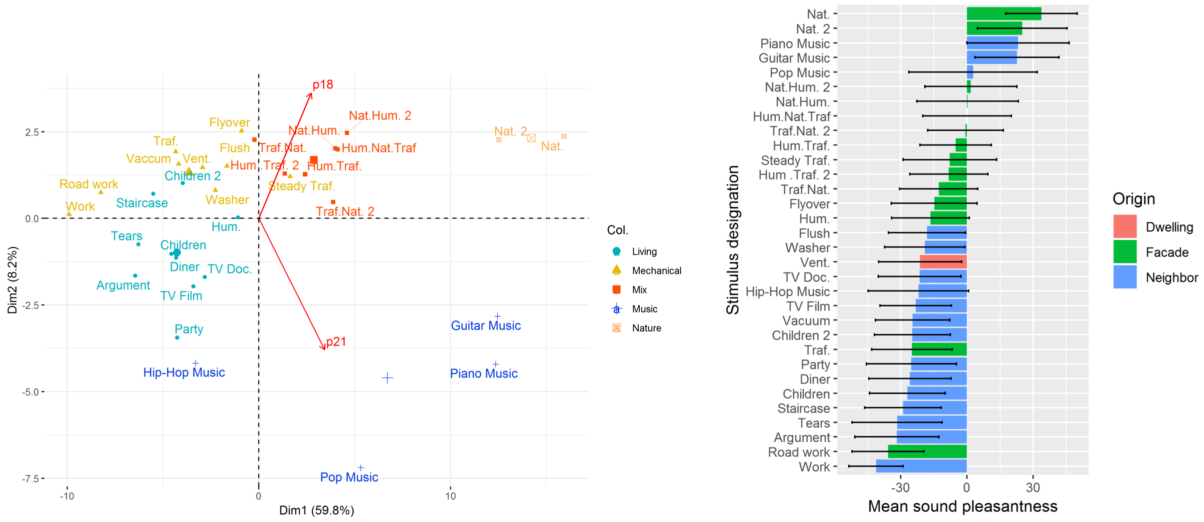
3.2 Principal Component Analysis (PCA)

PCA allows to get summarized results to better understand how participants evaluated the stimuli. The principal components are the principal axes of variability in the dataset. When the dataset consists in a large number of variables, PCA analysis tends to summarize all variables in a few dimensions for which inertia is maximized. At first, PCA is carried out in taking every participant as a variable. This first PCA should help regrouping highly correlated individuals and has been carried out using the programming language R, in applying the PCA() function available in FactoMineR package developed by Lê; Josse; Husson [19]. Results are presented on fig. 2. Figure 2 shows the two main dimensions of variability (70% of the total variability) and the correlations of every participant to both axes. First, the diagram demonstrates that the first axe of variability is consensual. Indeed, almost all participants are highly and positively correlated to the first axe. Figure 3a shows the sound stimuli on this plan of maximal variability (Dimensions 1 & 2). The consensus is found both for intrusive sounds coming from the neighbor as well as from the outside. For intrusive sounds coming from outside, people prefer bird songs and reject site work sounds. For intrusive sounds coming from neighbors, there is also a consensus, people preferring classical music and rejecting human sounds. Moreover, the

Figure 2. Correlation diagram projected on the two main dimensions of variability



mean variable, ie the average over all participants for every stimulus is computed. Then, the correlation coefficient between the first principal component and this vector "Mean" is calculated and found equal to 1.0 as showed in blue on fig. 2. The first component of maximal variability is the mean of pleasantness for this corpus of sound stimuli. Sound stimuli with a low and negative coordinate on the principal component are unpleasant in average and those with high and positive coordinates are pleasant in average. Figure 2 shows that one group of participants is very correlated to the mean and the first principal component. Indeed for 27 participants, correlation between their individual responses profile and the mean variable is equal or higher than 0.80. In contrast, participants 18 and 21 who are opposed on dimension 2 are among the least correlated variables.
Second, in order to interpret what dimension 2 refers to, fig. 3a shows the sound stimuli on the same plan of maximal variability. Correlations of participants 18 and 21 on both dimensions are presented again as a reminder. Dimension 2 is mostly influenced by the participants' preferences regarding music stimuli compared



(a) Correlation diagram (b) Pleasantness ranking

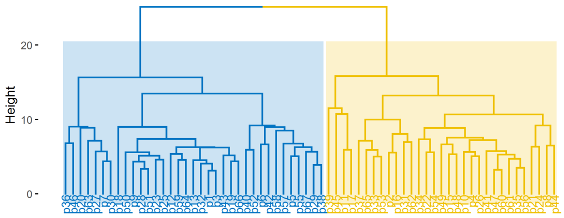
Figure 3. Sound pleasantness profile for the 35 stimuli. (a) Representation on the correlation diagram ; (b) Rank of typical sound sources in residential building - Mean sound pleasantness and standard deviation

to nature stimuli. For instance, participants 18 and 21 are opposed on dimension 2. Participant 21 perceives pleasant all kind of music stimuli coming from the neighbor. His preference goes toward the music stimuli rather than stimuli of nature. Participant 18's perception is the opposite, preferring sounds of nature coming from the outside compared to any kind of music stimuli coming from the neighbor.
So this analysis discriminated two groups of participants, one which appreciates music whereas the other appreciates the natural sounds such as bird songs. Non-acoustic describing these two groups have not been found. Finally, PCA showed that even if there is significant inter-individual variability, the main source of variability in the dataset is the mean pleasantness variable summarizing 60% of total variability. Ranking sound sources pleasantness according to their mean is presented on fig. 3b. In average, only 6 sound stimuli have been perceived positively (sounds of nature and sounds of music). In contrast, the most unpleasant sound in average are the site work and trafic from the outside, and all human related activities such as a party, a woman crying, or some footsteps from the neighbor or the staircase.

3.3 Clustering into 2 groups

Hierarchical Clustering on Principal Components (HCPC) is carried out to show relations between participants based on the similarities in their pleasantness profile [19]. Similarities are measured based on the euclidean distance following Ward method (minimization on the inter-cluster variability). HCPC results are presented in a dendrogram on fig. 4. In order to decide how many clusters must be taken into account, 3 statistical methods have been tested. The result depends on the method (elbow, silhouette, or gap statistic) and varies from 1 to 4 recommended clusters. The choice of two clusters is finally confirmed due to the ease of the interpretation. Group 1 and 2 consist in respectively 32 and 34 individuals. These two groups are made of other participants than those formed thanks to the PCA and defined due to music preferences.

Figure 4. Participants dendrogram from HCPC following Ward method



Two types of tests have been carried out in order to characterize these two groups. Based on the questionnaire answers, some pieces of information are either on the qualitative form or on the quantitative form (noise sensitivity, age, etc.). In order to evaluate whether a quantitative variable characterizes one cluster, 1 statistical test is carried out for each cluster and for every quantitative variable. The v.test as defined in section 3.3 of FactoMineR package description [19], tends to compare the values taken by the variable for a given cluster compared to those taken by a random variable. If the hypothesis H_0 assuming that the values taken by the variable for the given cluster are random, then the quantitative variable does not describe the cluster. In contrast, if the values taken by the variable for the given cluster are unlikely to follow a random distribution, then the quantitative variable well characterize the cluster. Results of the v-test[1] are presented on table 3. Table 3 presents 12 of the variables for which the v.test is higher than 1.96. The p-value describing the risk to be wrong in assuming H_0 invalid is also presented with the addition of the mean and standard deviation of the quantitative variables in each cluster compared to overall. Two descriptive variables (not used for the

Table 3 – Description of clusters through quantitative variables

Designation	**v.test**	**p.value**	**Mean in category (± SD)**		**Overall mean**
			Cluster 1	**Cluster 2**	
Sensitivity	2.91	3.60e-03	7.03±1.41	5.94±1.38	6.47±1.50
Acoustic comfort	-2.11	3.50e-02	2.81±1.18	3.47±1.24	3.15±1.26
Children next door	-6.01	1.88e-09	-40.12±9.65	-14.76±12.73	-27.06±17.01
Staircase	-5.29	1.21e-07	-40.62±11.08	-17.97±14.59	-28.95±17.25
Diner	-4.81	1.48e-06	-37.28±12.82	-15.15±16.56	-25.88±18.52
TV Film	-4.72	2.35e-06	-32.84±13.20	-14.03±12.85	23.15±16.06
Hum.	-4.25	2.15e-05	-26.00±16.14	-7.53±13.60	-16.48±17.52
TV Docu.	-4.14	3.39e-05	-31.34±15.95	-12.21±15.95	-21.48±18.60
Party	-4.41	3.39e-05	-31.34±15.95	-15.15±19.39	21.48±18.60
Argument	-3.95	7.72e-05	-41.31±12.40	-22.82±19.47	-31.79±18.85
Work	-3.79	1.52e-04	-47.15±12.24	-35.64±14.24	-41.23±12.24
Children next door 2	-3.75	1.75e-04	-32.94±14.24	-17.02±15.90	-24.74±17.08

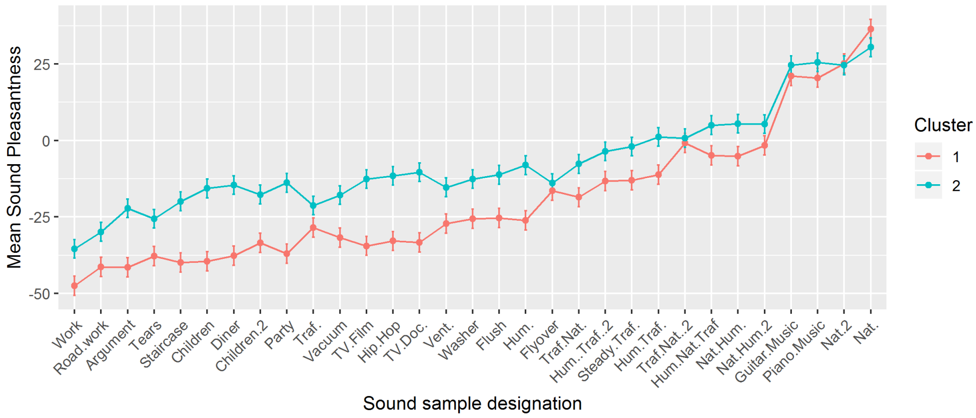
HCPC calculation) have a significant contribution to describe the two clusters: the evaluation of noise sensitivity and the evaluation of how the participants perceive the acoustic acoustic comfort in their dwelling. Statistical analysis shows that noise sensitivity for participants in cluster 1 (respectively in cluster 2) is significantly higher (resp. lower) than the overall mean sensitivity. Moreover, participants in cluster 1 feel less satisfied with their home's acoustic comfort than participants part of cluster 2 (2.81 resp. 3.47) compared to the overall mean evaluation of comfort (3.15/5).

Participants in cluster 1 are more sensitive, are less satisfied of the acoustic comfort in their dwelling , and perceive more unpleasant intrusive sounds related to human activity (Children playing, Footsteps in the staircase, Diner, Film etc.). In contrast, participant in cluster 2 are less sensitive to noise, are more satisfied of the

[1] "v.test" values are only mentioned for the cluster 1. For the cluster 2, they are the same in absolute but with the opposite sign

acoustic comfort in their dwelling, and perceive more pleasant intrusive sounds related to human activity. The other two quantitative and descriptive variables (self-evaluation of life quality, and age) do not describe these 2 clusters. $\chi_2 - tests$ have not allowed to better describe the clusters with the remaining descriptive and qualitative variables. For instance, there is not significantly more workers aged 30-50 and less students aged 18-30 in 1 cluster. Moreover, mean sound pleasantness per cluster and per sound stimulus are calculated and presented on fig. 5. In general, participants in cluster 1 evaluated less pleasant almost all sound stimuli. Mean differences are significant.

Figure 5. Clusters comparison - Mean sound pleasantness according to the sound stimuli



4 CONCLUSION

Subjectivity in human perception generates variability when evaluating the pleasantness for the various types of sounds in residential building. The present study aims to quantify this variability and evaluates whether it can be explained by individuals preferences or socio-cultural factors. In order to address this problematic, a listening test was conducted in a sound spatialization laboratory. Pleasantness of 35 sound stimuli has been rated on a semantic scale from unpleasant to pleasant. Principal component analysis revealed a consensual dimension highly correlated to the mean pleasantness variable. Some sounds are perceived either unpleasant for all (site work, trafic, or neighbor's work) or pleasant for all(sounds of nature, classical music). Human activities coming from neighbor are also perceived unpleasant. However, PCA and HCPC found out two main viewpoints. One group dislikes human related activities coming from the neighor with a rating much lower than the other group. This group is composed of individuals more sensitive to noise in average and are unsatisfied with the acoustic comfort at home. In contrast, the second group is made of people rather less sensitive to noise and more satisfied with their dwelling acoustic comfort. They seem to better tolerate intrusive sounds since they rated more pleasant almost all sound sources. Preferences are also found out regarding sounds of nature versus sounds of classical music indicating that even if all of them are perceived pleasant, one group of individuals prefers intrusive classical music coming form the neighbor whereas the other group prefers listening to sounds of nature coming from the outside of the building.

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