Virtual reality simulated aircraft flyovers: Influence of the landscape on the overall pleasantness of the environment

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ABSTRACT

To give residents better understanding of the impact of future airport scenarios, a virtual reality application with sound simulation will be tested in the frame of the European ANIMA project. The set-up has been evaluated in laboratory before being used in real situation. This paper presents the laboratory experiment whose aim is to assess the application's relevance for simulating flyovers. Although the perceptual experiment is designed to test the influence of aircraft vision crossed with aircraft sound, this paper focusses only on the impact of the landscape where the flyovers are observed. Two landscapes (park and buildings) are presented to 60 participants, in balanced order, with 12 audio-visual stimuli in both landscapes. Participants had to rate four differential semantic

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scales. Globally there is no influence of the landscape on the overall pleasantness, but when looking at the individual answers, it appears that three groups of participants can be discriminated. The majority of people do not change their pleasantness ratings in both landscapes, but some participants prefer experiencing the flyovers in the park landscape because it is visually more pleasant, and others prefer the opposite because it is more annoying to be submitted to aircraft noise in a green park landscape.

1. INTRODUCTION

Auralization and visualization tools have the potential to provide credible communication and engagement with people around airports and to allow for the integration of audible and visual aircraft noise-related information in interactive land-use planning. This might lead to a more effective communication and engagement which can help reducing levels of annoyance.

These virtual reality tools (auralization and visualization) can be used by residents to give them better understanding of the impact of future airport scenarios in land-use planning, as the virtual reality creates a higher immersion for the user. But this immersion has to be ecologically valid if authorities want to be trusted by residents during communication campaigns.

The Royal Netherlands Aerospace Centre (NLR) has developed a Virtual Community Noise Simulator (VCNS) based upon earlier work done at NASA Langley [1] to support airport community and other stakeholders who want to experience aircraft noise in their own environment. Such tools have proven to be convincing in previous research and demonstrations [2]–[5].

The laboratory perceptual experiment presented in this paper has been carried out in order to assess the relevance of such a tool for simulating flyovers in regard to audio and visual realism, and to study influence of the landscape (visual) associated to the background (audio) and to the vision of the aircraft (here the size and the architecture of the source) on the sound evaluation of the flyover.

The design of the experiment should allow to answer the following research questions:

- Does the quality of the landscape have an influence on the perceived quality of the environment when aircraft flies?
- Do visual characteristics of the aircraft (size, novelty, hidden source by clouds) have an influence on the perceived environment?
- Do acoustic characteristics have influence on the perceived environment?

In the corpus of this paper, only the landscape influence is studied.

2. METHOD AND MATERIAL

2.1. Selection of audio-visual stimuli

In order to evaluate the VCNS, 24 audio-visual stimuli have been designed (See Figure 1). The goal of the listening test being the influence of the visual impact on noise perception, the three sounds have been mixed with the visual data.

The audio-visual scenes are defined according to three perceptual dimensions:

- The landscape;
- The aircraft sound auralization;
- The aircraft visual model.

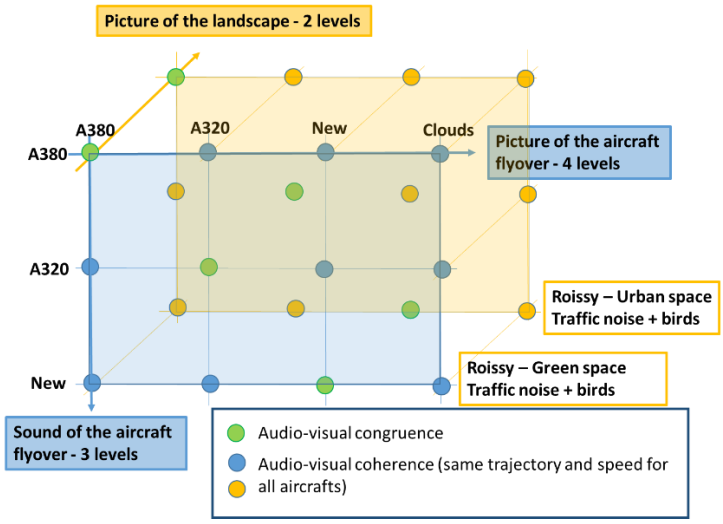

Figure 1: Laboratory study - Design of experiment

2.2. The landscapes

The virtual environments consist in 2 urban landscapes. Half the scenes take place in an urban district, and the other half take place in a park (See Figure 2). They have been recorded in a Paris suburb using a 360 degrees video camera.

Figure 2 : Landscape screenshots used for the laboratory study. Urban district in Sarcelles (on left) and green park in Saint-Brice sous Forêt, France (on right).

2.3. The aircraft visual models

The visuals of three distinct aircraft are used for the experiment. These three aircraft are the Airbus single aisle family (noted A320neo), a wide body aircraft, noted A380, and a revolutionary design called the "BOLT" (Blended wing body with Optimized Low-noise Technologies, see Figure 3), anticipated for 2050 operations. BOLT has been conceived and designed in European Union's Horizon 2020 research project ARTEM (Aircraft noise Reduction Technologies and related Environmental iMpact). These 3D models are superimposed on the virtual environment in the simulator, creating an augmented view of a virtual flyover of these aircraft. A separate background mask is used in the simulation software to ensure the aircraft are not visible behind obstructing trees or buildings in the virtual environment.

a) BOLT (© University RomaTre)

b) Airbus A320 Family

c) Airbus A380

d) Hidden aircraft due to cloudy sky

Figure 3: Four visuals consisting in three aircraft visual models (a) the BOLT aircraft, (b) the Airbus A320 Family, (c) the Airbus A380, and (d) one visual for which the aircraft cannot be seen due to the presence of clouds.

The aircraft models have different MTOW (Maximum Take-Off Weight) capabilities. Design MTOW for BOLT is 230 metric tons, whereas A320 is around 70 mt, and A380 is around 500 mt.

2.4. The aircraft sound auralizations

The notion of auralization is defined here as a series of software composed on noise prediction tools and sound synthesis tools. For the experiment, all aircraft approaches have been synthetized in accordance with a one-segment certification trajectory defined in Section 2.5. These sound syntheses are the mono audio signals corresponding to the three aircraft flyovers. BOLT sound synthesis was designed by ONERA prediction tool [6] whereas A320, and A380 flyover were synthetized by Airbus prediction tool. The resulting SPLs over time are presented in Figure 4. The wave files have been synchronized to ensure that the max dB SPL is reached at the time 30 s for each sound synthesis in Figure 4.

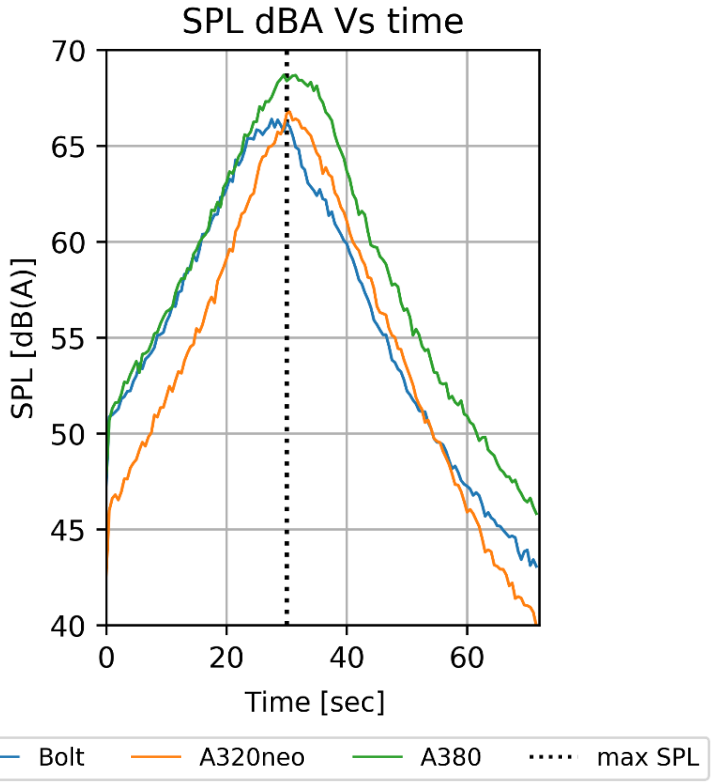

Figure 4: BOLT, A320neo, and A380 flyover SPLs over time (in dB(A)).

The resulting global acoustic indicators show that A380 is louder and gets the highest max SPL (See Table 1).

Table 1 : Global acoustic indicators (Leq, Loudness, max SPL) for the three sound auralizations (BOLT, A320neo, and A380 flyover).

	BOLT	A320neo	A380
Leq [dB]	65.5	65.4	70.9
Loudness [sone]	13.6	12.5	15.4
Max SPL (@30sec) [dB]	71.3	72.1	76.1

In the simulator, these (mono) aircraft sounds were associated with the matching flight trajectory in order to present a directional sound to the participants, using the head tracking of the Virtual Reality headset and binaural reproduction in the headset.

2.5. The non-varying parameters: trajectory, listener position, and background noise

In order to study the interaction of the audio and the aircraft visual only, some parameters must remain constant.

2.5.1. The background noise

The sound sample consists in sounds of nature with the presence of birds chirping, wind, and sounds of moving leaves in trees. One vehicle pass by at distance is also noticed. The sample is a 1st order ambisonic recording. It has been calibrated at an equivalent sound level equal to 45 dB(A). This background noise is always part of the sound environment during the experiment.

2.5.2. The aircraft trajectory, airspeed, and slope

The aircraft trajectory (See Figure 5) is defined with respect to a one-segment trajectory, with a constant slope and a constant calibrated airspeed. In order to have the same trajectory for both aircraft, CAS has to be the same and, for this reason, corresponds to the average of A320neo and A380. BOLT trajectory follows the same path (See Figure 5).

2.5.3. The listener position

The listener is located at x=10.5 km, y=380 m, z=1.2 m from the runway threshold. However, the listener is free to move his head and rotate on a chair so that the entire 360° scenery is accessible by sight.

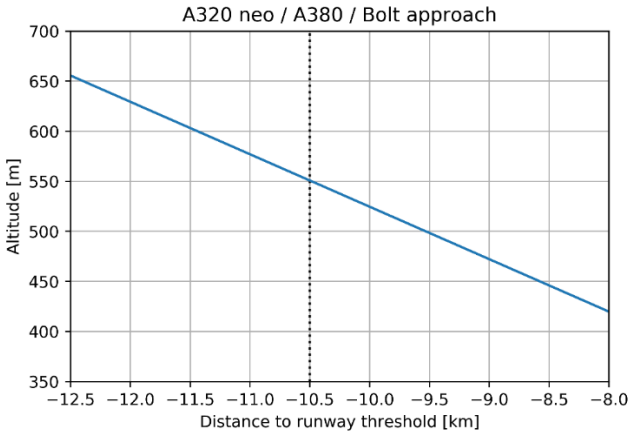

Figure 5: A320neo, A380 and BOLT trajectories (blue line) (Altitude vs. distance to runway) and x listener position (dotted black line).

2.5.4. Participants

60 listeners participated to the listening test. A hearing test was conducted for every participant and the audiogram release showed that 2 listeners had too significant hearing losses in order to remain in the corpus. The decision was taken based on the audiometric classification of hearing impairment [7]. Among the 58 remaining participants (57% female / 43% male), 29 participants are aged between 18-29 years old, and the other half is aged between 30-50 years old.

Other personal pieces of information were collected for the experiment:

- Zip code;
- Questionnaire assessing the noise sensitivity developed by Griefahn [8];
- Questionnaire assessing the Quality of Life (QoL) developed by Da Rocha [9].

2.6. Subjective assessments

2.6.1. Audio-visual stimuli evaluation

During the experiment, participants are asked to fill a questionnaire assessing each of the 24 audio-visual stimuli.

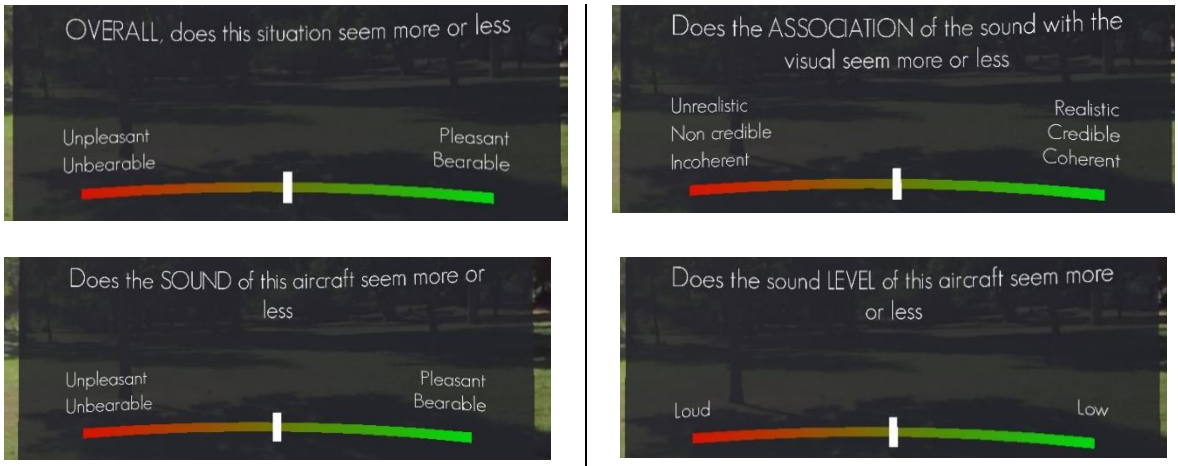

Figure 6: Audio-visual stimuli's subjective assessment in the virtual world (translated from French)

In order to facilitate the listening test operability, the questionnaire shows up in the virtual world (See Figure 6). It consists in four questions, two relatives to the overall audio-visual environment, and two focused on the aircraft sound. For each stimulus, the questionnaire shows up 10 s after the aircraft sound is maximal in terms of dB SPL. Participants used the joystick on the touch controller in order to move the white cursor on the 101 points scale with semantic differential [-50, +50]. No figure appeared on the scale seen by participants.

2.6.2. Final questionnaire

The final questionnaire is arranged in a few parts. The first part aims to assess the simulator overall efficiency in restituting the reality. The second part aims to assess the listener noise sensitivity. It's a French translation of the R-NoiSeQ [8] and it consists of 12 questions. The third part evaluates the participant's self-evaluation regarding his/her quality of life [9]. The fourth part collects personal information.

2.7. Procedure

The procedure had been declared to the Data Protection Officer (DPO) in charge of the General Data Protection Regulation (GDPR) and validated by the ethical comity. The protocol had been reinforced due to the sanitary crisis. Participants were given a gratification of 30 euros for their duties.

Listeners were first informed of the nature of the experiment. The audio impairment evaluation was then introduced, and after that, the audiogram test was conducted. Whatever the result of the audiogram release, they all kept on with the VR experiment. After having installed the VR equipment, the experiment started. First, a training session consisting of two audio-visual stimuli were carried out. The first part that is kept for the analysis consisted in evaluating all 12 first audio-visual stimuli in the same 360° landscape. Half participants started with the green park landscape and the other half with the urban district (See Figure 2). After completing the first session, the participants withdrew the headset and had a 5-min break. The second part took then place in the other landscape with the second series of audio-visual stimuli assessment. As soon as they finished the audio-visual test, they filled the final questionnaire described in Section 2.6.2.

The order of stimuli was designed to ensure that:

- The randomization of the stimuli order was controlled to ensure a regular distribution;
- Half the participants started in Landscape 1 (in park) and continued in Landscape 2 (urban district) and the other half had the reversed order (Landscape 2 → Landscape 1);
- The aircraft visual cannot be the same two times in a row;
- The aircraft sound cannot be the same two times in a row.

2.8. Material

The Virtual Reality equipment consists in the Oculus Rift Consumer Version 1 device running on a laptop DELL Precision 7730 with a graphic card NVIDIA Quadro P5250. Along with the VR headset, the left Oculus touch controller has been used. Finally, the binaural sound restitution was performed using the headset Sennheiser HD650 plugged on a soundcard RME Fireface UC. The headset sensitivity response has been determined prior the experiment in order to calibrate the audio stimuli.

3. RESULTS

Overall, participants found the virtual world very realistic. Feedbacks were mostly positive, with for example Subject S28 who wrote: “The landscapes were very realistic, it was impressive”. Another example with subject S24 who explained: “Whether it’s in the park or the urban district, the situations were very realistic”.

3.1. Analysis of variance

A factor analysis of variance (ANOVA) in respect with a repeated measure design is performed for the landscape variable. Results show the absence of landscape influence (See Table 2).

Table 2: ANOVA summary for the evaluation of the landscape influence on the overall pleasantness ratings (df: degrees of freedom, MSE: Mean Square of the Error, ges: generalized eta square). Greenhouse-Geisser corrections are applied due to lack of sphericity.

	Effect	df	MSE	F	ges	p.value
1	Landscape	1, 57	50.36	0.80	.001	.376

The overall pleasantness is not significantly influenced by the landscape environment. Being in immersion in a green park does not significantly change the feeling of overall pleasantness compared to being immersed in the urban square (See Figure 7). Mean evaluations are not significantly different.

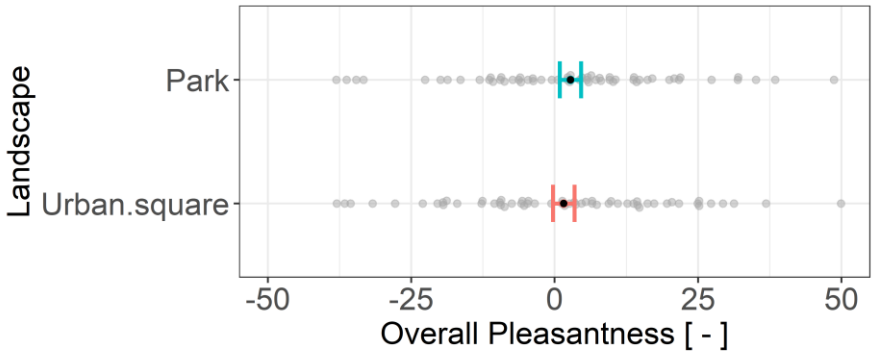

Figure 7: Post hoc pairwise comparison for the overall pleasantness estimated means according to the surrounding landscape (-50: Unpleasant ; +50: Pleasant). Individual observations are plotted in circles shades of grey and estimated mean values are depicted in black points. Error bars show the “within-subjects standard errors/confidence intervals” following Cousineau’s approach [10]

3.2. Beyond the overall mean evaluation, the opposed viewpoints regarding the landscape influence

Even if in average, the quality of landscape does not significantly influence the subjective evaluation of overall pleasantness, a Principal Component Analysis (PCA) carried out on participants (as objects) should provide an additional interpretation in revealing differences in viewpoints. The variables for the PCA are each of the 24 audio-visual stimuli, and every observation is a participant’s

rating (matrix of 58 rows x 24 columns). The inertia explained for each dimension is presented in Figure 8.

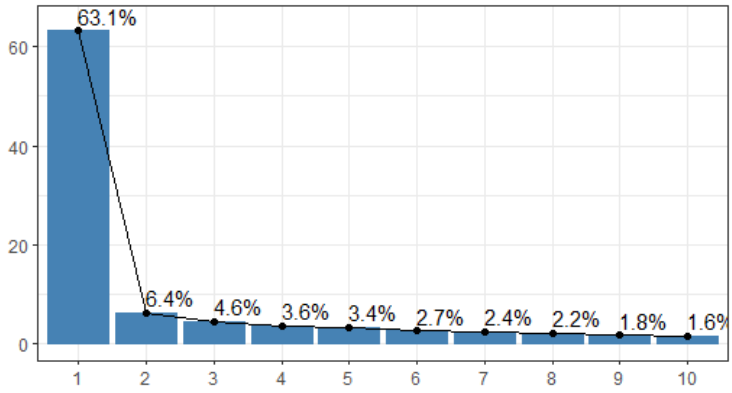

Figure 8: Global pleasantness: Inertia explained for each dimension of the PCA.

The first dimension summarizes more than 60% of the total variability in the dataset. There is a significant gap between the first and all the other dimensions since the second principal dimension represents only 6.4% of the total variability. Based on these explained variances, only the first main dimension should be selected and analyzed in details, but the second dimension has been nevertheless kept because it explains differences between people point of views.

The first outcome of the PCA is presented in a diagram in where the variables are the audio-visual stimuli according to their correlations with the two main dimensions (Figure 9). The variable labelling is described in Table 3.

Table 3: Nomenclature designated the audio-visual stimuli in the PCA correlation diagram

Denomination	Landscape	Aircraft sound model	Aircraft visual model
ParkSBoltVBolt	Park	BOLT	BOLT
ParkSA320VBolt		A320neo	BOLT
ParkSA380VBolt		A380	BOLT
ParkSBoltVA320		BOLT	A320neo
ParkSA320VA320		A320neo	A320neo
ParkSA380VA320		A380	A320neo
ParkSBoltVA380		BOLT	A380
ParkSA320VA380		A320neo	A380
ParkSA380VA380		A380	A380
ParkSBoltVClouds		BOLT	Clouds (no A/C)
ParkSA320VClouds		A320neo	Clouds (no A/C)
ParkSA380VClouds		A380	Clouds (no A/C)
UrbanSBoltVBolt	Urban square	BOLT	BOLT
UrbanSA320VBolt		A320neo	BOLT
UrbanSA380VBolt		A380	BOLT
UrbanSBoltVA320		BOLT	A320neo
UrbanSA320VA320		A320neo	A320neo
UrbanSA380VA320		A380	A320neo
UrbanSBoltVA380		BOLT	A380
UrbanSA320VA380		A320neo	A380
UrbanSA380VA380		A380	A380
UrbanSBoltVClouds		BOLT	Clouds (no A/C)
UrbanSA320VClouds		A320neo	Clouds (no A/C)
UrbanSA380VClouds		A380	Clouds (no A/C)

Figure 9 shows that all variables are positively correlated to the first dimension of the PCA meaning that it's a consensual dimension.

Regarding the second dimension along the y axis, there is a divide because of the landscape influence on the evaluations. 10/12 variables corresponding to the audio-visual stimuli evaluated in the park are positively correlated to the second dimension, and reciprocally 10/12 variables corresponding to situations evaluated in urban square are negatively correlated to this second dimension. We can interpret this dimension as the difference in perception toward the landscape. These differences in perception can be interpreted in displaying the participants coordinates on the correlation diagram (See Figure 10).

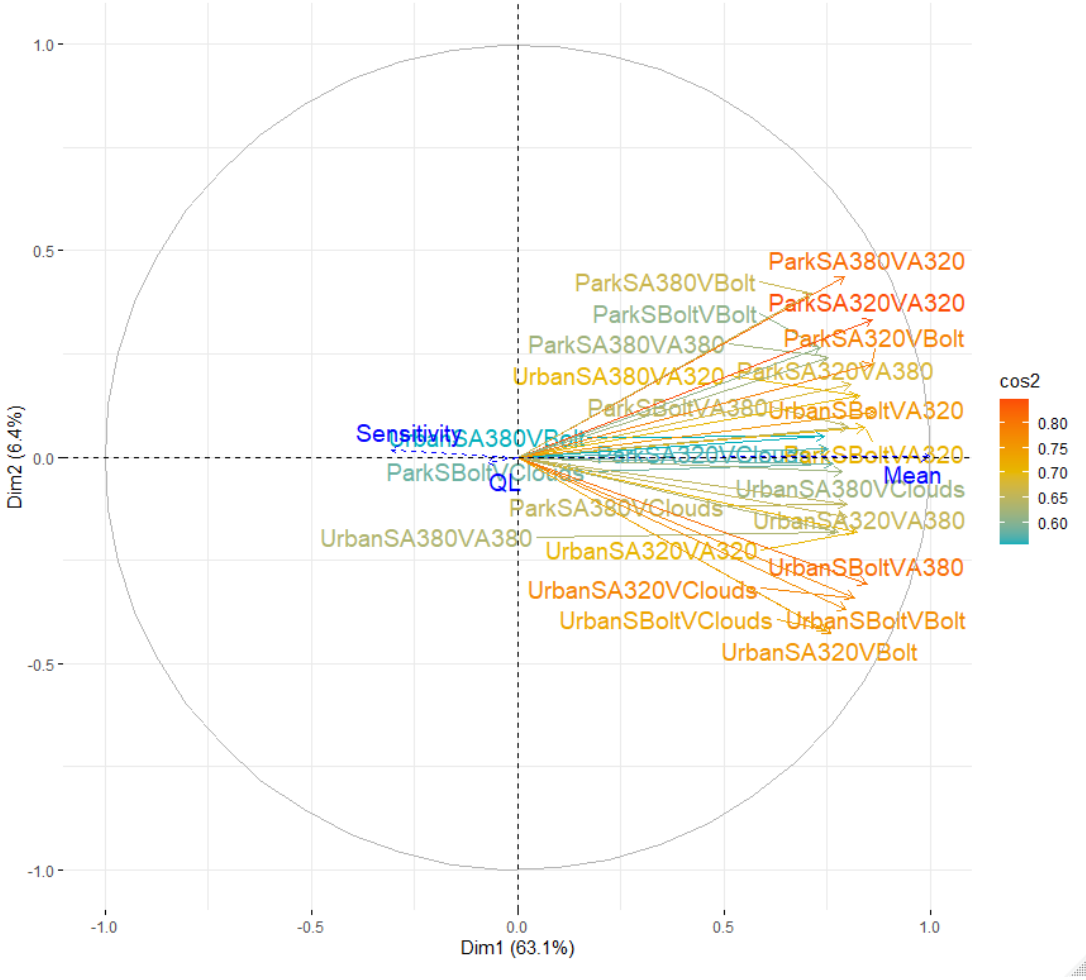

Figure 9: Correlation diagram from PCA showing a representation of the audio-visual stimuli according to their correlations with the two main dimensions of variability. Informative supplementary variables are added in blue. Variables are represented as arrows and the color is defined based on the indicator cos2.

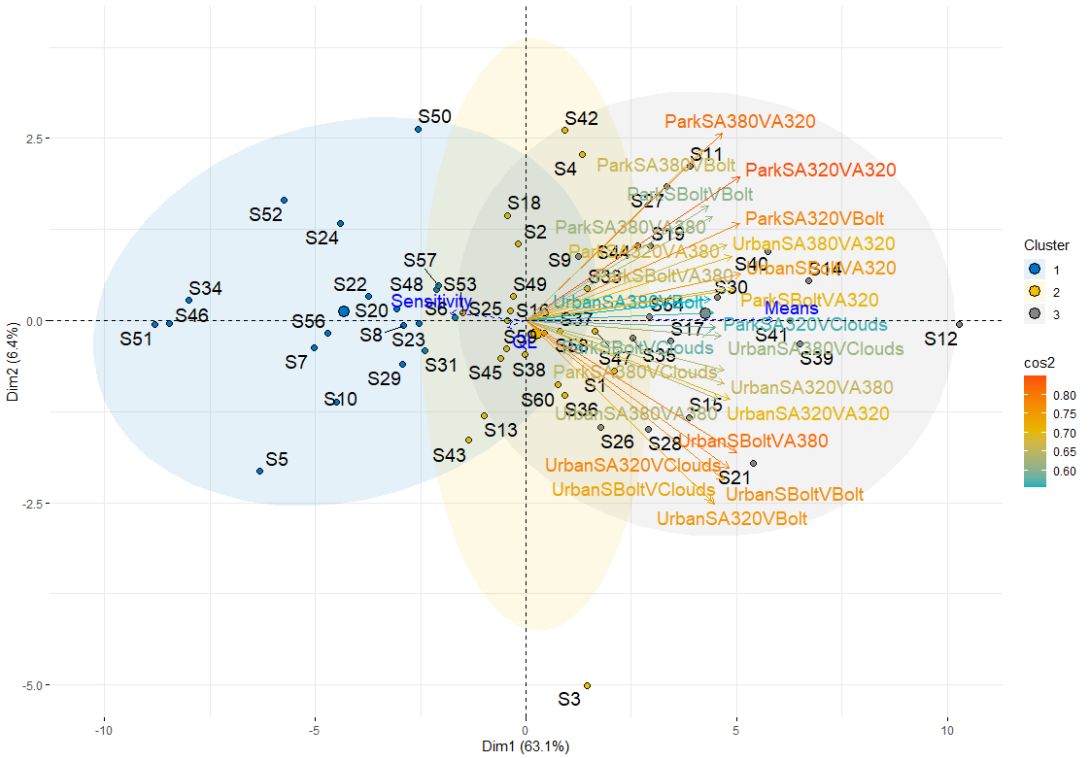

Figure 10: PCA results for the overall pleasantness ratings – Bi-plot showing both the variables (the stimuli) and the participants coordinates (in colored circles + ID labels) on the two main dimensions of the PCA. Variables are represented as arrows and the color is defined based on the indicator "cos2".

First regarding the first factor, participants are widely spread over the entire axis. The participant S12 for example is opposed with the participant S51 on this dimension. Subject S12 found pleasant all stimuli (ratings > 35) whereas Subject S51 evaluated all stimuli (except one) unpleasant. This first dimension spread participant's responses according to their overall mean pleasantness.

In order to ease the interpretation of the second factor, ratings of 2 participants are presented in Figure 11. Participants with a quite high and positive coordinate on dimension 2 (example with S42) tend to assess more pleasant the audio-visual stimuli in the park whereas the participants with negative and quite high (in absolute) coordinate on this same second dimension tend to prefer the audio-visual stimuli in the urban square (Example with S21 on Figure 11).

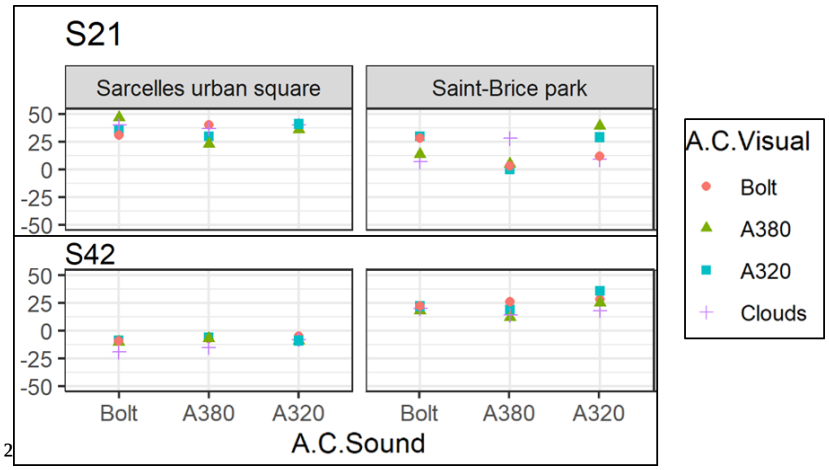

Figure 11: Overall pleasantness ratings according to the audio-visual stimuli for two opposed contributors on dimension 2 of the PCA: Subjects S21, and S42

So even if the analysis of variance does not show any influence of the landscape, it's partly because two viewpoints are opposed with one group preferring the park (S3, S5, S13, S21, S26, S28, S43) and another preferring the urban district (S4, S11, S18, S27, S42, S50, S52). Some free comments provide interesting explanations of these differences in viewpoints.

For example, Subject S26 who is part of the group preferring the park explained:
« Being in the urban square makes the aircraft flyovers more bearable because it's more coherent ».
Being part of the same group, subject S43 said:
« *In a park, whether the aircraft sounds low or loud, it is unpleasant to hear the airplane whereas in town it is less problematic. When you go to a park it is to put aside all kinds of noises.* »

In contrast, some participants explain their discomfort regarding the urban landscape:
« I feel sorry for the people who live there (ie in this urban environment). At the beginning it's bearable but with the repetition it becomes very annoying » (Subject S18).
« I could not live in such place » (Subject S50).

To sum up, one group preferred the flyover in the park, because the situation is greener. Viollon et al. [11] showed that the less urbanized or the greener the landscape, the more pleasant the sound environment. In studying open spaces, Pheasant et al. showed that the percentage of natural features present in the location is a key factor influencing tranquility [12]. In contrast, the other group disliked the flyover in the park because it disturbs the quietness of this environmental situation. This second result is consistent with some previous work. Brambilla et al. showed that the subject's expectation to hear a sound in a specific environment, that is its congruent with the environment where it is heard, influences the corresponding annoyance. The more congruent the sound, the less is the evoked annoyance [13]. And Mace et al. showed the importance of natural sounds, and the negative impact of aircraft noise exposure in a national park [14].

Analyzing the two groups, none of the additional descriptive variables (such as the age, the noise sensitivity, etc.) highlighted commonalities for each group.

4. CONCLUSIONS

A perceptual audio-visual experiment has been conducted using a VR headset. The experiment consisted in evaluating flyovers approaching (360° visuals and sounds). 60 participants finished the experiment. Half the situations took place in an urban square, and the other half in a green park. This paper reports the results regarding the influence of the landscape on the overall perceived pleasantness. A majority of participants was not influenced by the landscape, but two opposed viewpoints have emerged. One group tends to appreciate being in the park more than being in the urban square because it's greener and because they would not have imagined living well in this kind of urban neighborhood. In contrast, another group of participants was more annoyed in the park because they expect such place to be very calm. For them, aircraft flyovers are more distractive in a green park than in an urban district.

Future work will be carried out on the impact of the aircraft (vision and audition) on the four perceptual questions (overall pleasantness, sound pleasantness, audio-visual realism). We have also to assess the quality of the simulations in more depth in statistically analyzing the final questionnaire (regarding the realism, the immersion in the virtual world, etc.). But we can right now say that, globally, the virtual reality experiment has been appreciated for collecting perceptual feedbacks.

5. AKNOWLEDGMENT

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