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COURTYARD TREES AND AIRCRAFT NOISE: INVESTIGATING THE EFFECT OF URBAN GREENERY ON AIRCRAFT NOISE PERCEPTION USING VIRTUAL REALITY (VR)

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ABSTRACT

Aircraft noise exposure causes annoyance, sleep disturbance and contributes to the development of severe long-term health outcomes for populations living under frequently used air routes. Traditional land-use based noise abatement strategies have shown limited success in mitigating these effects, prompting interest in alternative design measures such as the use urban greenery to improve soundscapes and reduce noise annoyance. This study assesses the effect of the visual presence of trees on aircraft noise perception during flyover events in a controlled setting. An audio-visual Virtual Reality (VR) experiment was conducted, showcasing two scenarios of a residential inner courtyard during a flyover event with and without trees. Following each scenario, participants (N=33) rated their soundscape perception using standardized soundscape questionnaires (ISO-12913). Preliminary results suggest that the scenarios with the trees present were on average perceived as acoustically more pleasant compared to those without greenery. This suggests that greenery, particularly trees, positively influence the perception of aircraft noise in urban environments through non-acoustical factors, warranting further investigation. These results contribute to a more mechanistic understanding of the effect of urban greenery on aircraft noise perception and aim to provide a base for future in-situ studies.

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1. INTRODUCTION

Exposure to aircraft noise causes annoyance, disrupts communication and daily activities, and disturbs sleep [1-2]. Epidemiological studies found that these effects, in the long run, may contribute to the development of severe physical and mental health outcomes, with populations exposed to higher aircraft noise levels (Lden) reporting a higher likelihood of suffering from cardiovascular disease (CVD), anxiety and depression compared to less exposed ones [3-4]. Aircraft noise primarily affects populations in airport regions living near frequently used flight paths, who are exposed to aircraft flying at low altitude during takeoff and landing phases. According to noise annoyance surveys, aircraft noise is often perceived as the most annoying among traffic noise sources, followed by road and railway traffic noise [5]. To mitigate the effects of aircraft noise, local governments and planning professionals have traditionally employed strategic zoning (ICAO Balanced approach) [6]. These land-use policy measures aim to reduce the exposure of noise-sensitive buildings (residential, hospitals, daycare/schools, etc.) by limiting or banning the construction of new buildings in areas where the modelled aircraft noise levels exceed set threshold values. In the context of a small, densely populated country such as the Netherlands, however, such zoning regulation reduces the space available for the construction of new residential areas (as well as urban retrofitting projects), a scarce resource needed to meet the growing housing demand during the recent housing shortage. Additionally,

zones falling outside of these regulations are still exposed to high levels of aircraft noise and greenery could be used to improve soundscapes also in these locations. Research has therefore expanded towards finding alternative planning and design measures that can complement zoning in reducing aircraft noise annoyance, in existing and planned residential developments in airport regions.
Urban greenery and Nature-Based Solutions are commonly employed by city governments as climate adaptation and nature conservation measures. In recent years, increasing attention has been paid to their effects on the perception of the sound environment, i.e., the soundscape, and noise annoyance [7-9].
Several studies have found that urban greenery may be associated with lower road and rail traffic noise annoyance [10-12]. On the other hand, limited research has been conducted on the effects of urban greenery on the perception of aircraft noise, with conflicting results [13-14].
This study aims to contribute to more mechanistic understanding of the visual effect of urban greenery on aircraft sound perception ratings by conducting an audio-visual soundscape experiment in Virtual Reality. Doing so, the study seeks to answer the following research question: *"how does the visual presence of urban greenery, in the form of courtyard trees, influence the soundscape of a residential environment during an aircraft flyover event?"*.

2. METHODOLOGY

2.1 Study design

The study consisted of the collection of soundscape questionnaires (based on ISO-12931) following the randomized exposure of the participants to two Virtual Reality scenes. To isolate the effect of the visual presence of trees on the participant soundscape ratings, the acoustic environment was kept constant in both scenes, while the visual environment was modified. In one scene, hereafter named the "No Trees" condition, the courtyard was empty. In the other, the "Trees" condition, eight mature European Hornbeams (*Carpinus betulus*) were added in two rows of 4 trees each (see Table 1 and Fig. 1).

Table 1. Virtual Reality scenes composition

Scene	Audio input	Visual input
Trees	Background sound + aircraft sound	Courtyard with trees
No Trees	Background sound + aircraft sound	Courtyard without trees

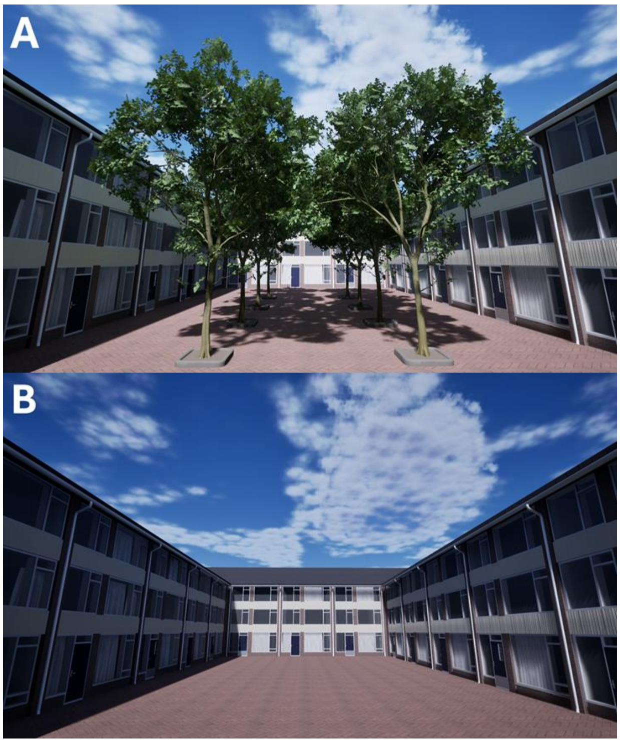

Figure 1. View of the VR inner courtyard in the Trees (A) and No Trees (B) conditions.

2.2 Participants

The participants (N=33, 9 females and 24 males) were recruited from the staff and student body of the Amsterdam Institute for Advanced Metropolitan Solutions (AMS Institute), in Amsterdam. The study took place between February 6 and March 1, 2024, at the AMS Institute in a dedicated, normally insulated room. Participation was on a voluntary basis and the experiment duration was on average 1 hour long.
All participants signed an informed consent and study procedure briefing indicating that they could stop their participation at any moment during the experiment if needed. Furthermore, they gave permission to use the data gathered during the experiment with respect with privacy and confidentiality. The experiment was approved by the Human Research Ethics Committee (HREC) of the Delft University of Technology on March 5, 2024, under application number 3766.

2.3 Virtual Reality Environment

2.3.1 VR Set up

The Virtual Reality environment was designed using Rhinoceros 7 and rendered on the game engine Unreal Engine 5.3.1. The Head-Mounted Display (HMD) used for the experiment was the HTC VIVE Pro 2, wired to a desktop computer. The combined resolution was 4896 x 2448 pixels at 120Hz refresh rate. The audio input was reproduced via wireless headphones, model Bose QuietComfort 35 connected via Bluetooth with the Active Noise Cancelling turned off.

2.3.2 Visual input

The inner courtyard environment was designed based on the form of real-life courtyards of the Urban Comfort Lab project field laboratory located in Hoofddorp, The Netherlands. [15] The building facade was inspired by a typical residential neighborhood in Rijsenhout, a noise-affected village located near Schiphol Airport, the Netherlands.
All materials, assets and textures included in the environment were downloaded from the freely available Quixel Megascans and the Epic Games Launcher libraries. The trees included in the environment were downloaded from the Megascans Trees European Hornbeam collection, and their dynamic shader simulating wind was enabled, making the trees move slightly according to the wind direction and speed. The aircraft was downloaded from the Commercial-Long Range Aircraft asset and was animated via the Unreal Engine spline function following the Kaagbaan air route trajectory in terms of altitude, direction and angle in its relation to the Urban Comfort Lab project field laboratory location.

2.3.3 Audio input

The auditory environment consisted of two recordings, overlayed in Unreal Engine. The first one featured a city background sound recorded near the AMS Institute in Amsterdam, the other an aircraft flyover sound recorded at the Urban Comfort Lab project field laboratory, in Hoofddorp. In both scenes, the background sound lasted for the entire duration of the simulation, for a total of 2 minutes and 30 seconds. The aircraft flyover recording, on the other hand, was gradually introduced as the simulated aircraft approached the courtyard, starting at minute 1:00 and lasting for 1 minute.

2.4 Soundscape questionnaires

Every participant answered the soundscape questionnaires twice, immediately each after exposure to the Virtual Reality scenes. The soundscape questionnaires used were based on the ISO/TS 12913-2:2018 questionnaires, modified only to fit the Virtual Reality study design. All questionnaires were provided and answered by participants in English.
The question used to assess the soundscape of the participants was therefore “based on what you experienced just now in VR, for each of the 8 scales to what extent do you agree or disagree that the surrounding sound environment was… (1 = Strongly agree, 7 = Strongly disagree)”. The scales provided were the standard soundscape descriptors, i.e., pleasant, chaotic, vibrant, uneventful, calm, annoying, eventful, monotonous, loud.

3. RESULTS

3.1 Descriptive statistics

3.1.1 Soundscape Pleasantness distributions in Trees and No Trees conditions

Figure 2 shows the distributions of the participants' Soundscape Pleasantness ratings in the Trees and No Trees conditions.
As can be seen in the histogram, in the No Trees condition, the distribution is skewed towards higher values, with mean and median values of 4.97 and 5, respectively. On the other hand, in the Trees condition the frequency is highest at 3, and the mean and median are lower than for the No Trees condition, at 4.24 and 4, respectively. This suggests that on average participants reported a higher Soundscape Pleasantness in the Trees condition compared to the No Trees condition.

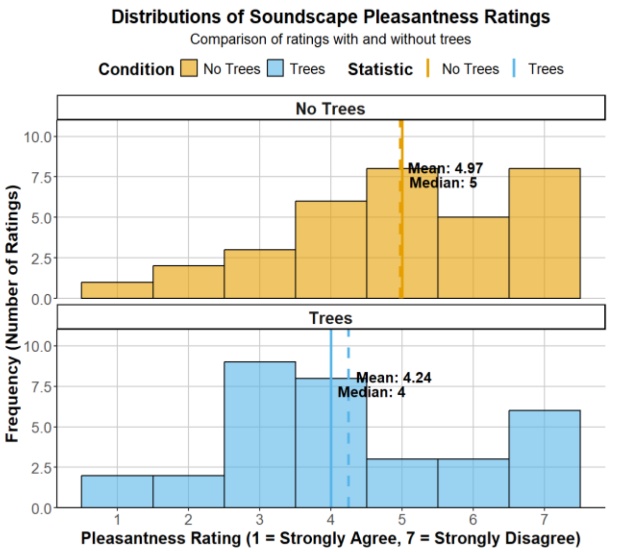

Figure 2. Distributions of Soundscape Pleasantness Ratings in the Trees and No Trees conditions.

3.1.2 Changes in Soundscape Pleasantness categories between conditions

To understand the changes in Soundscape Pleasantness between conditions, ratings were classified into 3 categories, i.e., Pleasant, Neutral and Unpleasant.

As shown in Table 2, the Pleasant category comprised all ratings reporting that the participants at least "Somewhat Agreed" that the sound environment was pleasant (ratings 3 and lower). The Neutral category included all ratings reporting that the participants did "Neither Agree nor Disagree" that the sound environment was pleasant (ratings at 4). Lastly, the Unpleasant category comprised all ratings where participants at least "Somewhat Disagreed" that the sound environment was pleasant (ratings 5 and above).

Table 2. Pleasantness Categories and their thresholds

Category	**Thresholds** (Likert eq.)
Pleasant	1 to 3 (Strongly Agree to Somewhat Agree)
Neutral	4 (Neither Agree nor Disagree)
Unpleasant	5 to 7 (Somewhat Disagree to Strongly Disagree)

Figure 3 shows a Sankey Diagram comparing the percentage of ratings falling in each category in the Trees vs the No Trees conditions.

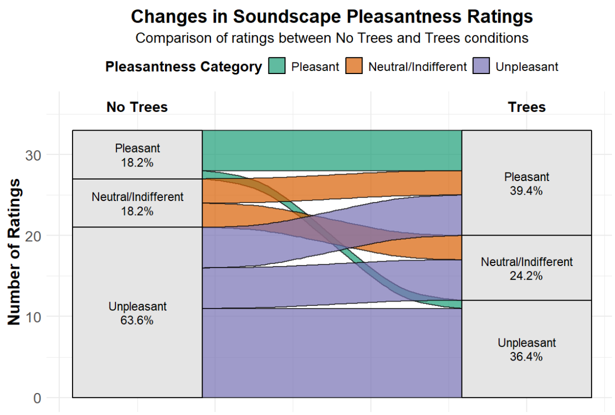

Figure 3. Sankey Flow diagram of changes in Soundscape Pleasantness Ratings between conditions.

As can be seen in the diagram, when comparing the No Trees condition (left) to the Trees condition (right), the 'Unpleasant' category, i.e., the percentage of participants who at least Somewhat Disagree that the sound environment is *pleasant*, drops from 63% to 36%. The resulting difference in ratings either fall in the 'Neutral' category, or in the 'Pleasant' category, these two flows seem equally split. Figure 3 shows that the percentage of ratings falling in the Neutral/Indifferent category also changed between the Trees and No Trees conditions. Part of the ratings shifted towards the Pleasant category, and part remained in the Neutral category. These findings suggest that the visual presence of trees may influence the reported Soundscape Pleasantness of the courtyard during an aircraft flyover positively, shifting the perception of some participants from the Unpleasant category towards the Neutral and Pleasant categories, as well as from the Neutral category towards the Pleasant category. Due both fluxes, when moving from the No Trees condition to the Trees condition, the percentage of people who at least Somewhat Agree that the sound environment is *pleasant* more than doubles, increasing from 18.2% to 39.4%.

3.2 Inferential statistics

A Wilcoxon Signed Rank Test was used to determine the difference in Soundscape Pleasantness ratings between the Tree and No Tree conditions. Table 3 shows the results of the Shapiro-Wilk test, used to determine normality and the Wilcoxon Signed Rank Test used to evaluate the influence of trees on Soundscape Pleasantness Ratings. As shown in Table 3, the distribution of ratings in both conditions was not normal. Furthermore, the results of the Wilcox-Signed Rank Test show that there is a statistically significant difference between the Soundscape Pleasantness Ratings reported in the Tree and No Tree conditions (p = 0.006). The test's effect size (ES) of -0.481, indicates a medium-to-large effect according to Cohen's guidelines and the fact that it is negative is representative of the inverted scale (1 = Strongly agree, 7 = Strongly disagree). These findings overall indicate that participants reported a significantly higher Soundscape Pleasantness in the Tree condition compared to the No Trees condition. Figure 4, a raincloud plot shows the Wilcoxon test results, the boxplots of the Soundscape Pleasantness Ratings, and their distributions in both conditions.

Table 3. Results of the Shapiro-Wilk Normality Test and Wilcoxon Signed-Rank Test for Soundscape Pleasantness Ratings.

Test	Statistic	p-value	ES
Shapiro-Wilk (Trees)	0.915	0.013	NA
Shapiro-Wilk (No Trees)	0.918	0.017	NA
Wilcoxon Signed-Rank Test	27.000	0.006	-0.481

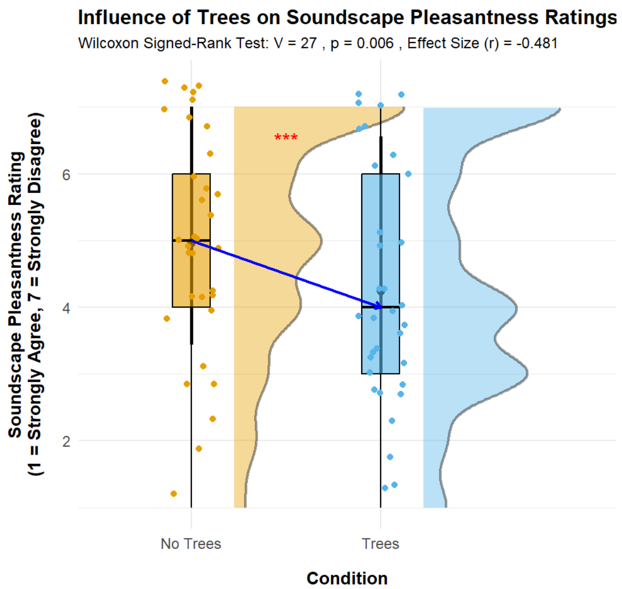

Figure 4. Raincloud plot of the influence of Trees on sounds Soundscape Pleasantness Ratings in the Tree and No Tree conditions.

4. DISCUSSION & CONCLUSION

This study aimed to investigate the influence of urban greenery on aircraft sound perception by conducting an audio-visual soundscape experiment in Virtual Reality.
Two scenes were compared, one featuring trees (Tree) and one without (No Trees). The results of the descriptive and inferential statistics suggest a positive effect of the visual presence of trees when comparing the Soundscape Pleasantness ratings of the two VR conditions. Specifically, the Wilcoxon Signed Rank test shows a significant difference between the conditions, with a medium to large effect size. This non-parametric test was chosen because the Soundscape Pleasantness ratings data in both conditions was not normally distributed. Furthermore, the Wilcoxon Signed Rank Test accounts for the Within-Subject study design, i.e., the fact that we compare ratings given by each participant in both conditions, thereby controlling for inter-individual variability.
The choice to employ Virtual Reality for this experiment was because of its capacity to isolate and manipulate the visual environment features while keeping auditory environment constant. This set up minimized other confounding factors, making it possible to attribute the observed differences in Soundscape Pleasantness primarily to the visual presence of urban greenery. At the same time, this approach presents limitations. While Virtual Reality technology has improved substantially during the last years, the level of realism is not yet comparable to real life, even strictly considering the visual input. Furthermore, while this study accounts for the visual presence of urban greenery, from an acoustic perspective, trees also add sounds to our living environments, both in the form geophonic (e.g. leaves and branches rustling) as well as biophonic sounds (birds and insects living on them. Lastly, future research should consider expanding upon these findings by exploring additional variables. For example, accounting for the density, type, and arrangement of urban greenery, influence of seasonality, tree growth and canopy cover. All of these could shed further light on the underlying mechanisms of how urban greenery influences soundscape perception.
In conclusion, this study aimed to investigate the effect of the visual presence of trees on sound perception ratings in a controlled, Virtual Reality soundscape experiment. The results of the study suggest that the visual presence of trees might yield a significant increase in Soundscape Pleasantness ratings. These results contribute to a more mechanistic understanding of the effect of urban greenery on aircraft noise perception and aim to provide a base for future in-situ studies.

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