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LOUNGE: a living room as a laboratory environment for the research of perceived noise

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Abstract

Research on perceived noise annoyance seeks to identify conditions into circumstances where certain sound events elicit adverse psychological or physiological effects to those exposed. Within this research field two primary methodologies are often applied: laboratory-based studies, utilising sound laboratories or noise simulators to control and manipulate sound exposure, and field studies, which involve assessing the impact of sound events on individuals in real-world environments where they are already exposed to such noises. The advantage of laboratory experiments is that sound events are fully controlled, while a field study measures people in their natural environment. To reconcile these approaches, the LOUNGE laboratory environment has been developed. It offers a controlled environment, combining benefits of laboratory experiments and field studies, by replicating a natural living room setting, thereby enabling the exposure of participants to various sound events in a comfortable and realistic manner. The LOUNGE is equipped with an audio reproduction system to generate positional, directional sound events, such as aircraft flyovers, and cover a frequency range of 19Hz-20kHz. Initial studies that have been undertaken already include the comparison of a VR-based noise simulator with the LOUNGE environment and the evaluation of aircraft noise events while conducting two different cognitive tasks.

Keywords: *Noise annoyance, aircraft noise, sound reproduction, laboratory study.*

1. Introduction

Noise annoyance is not only a burden for people affected by (human induced) sounds, but can also lead to health complaints or even health issues due to direct or indirect effects that noise causes [1]. For this reason, noise regulations are in place to protect people from negative effects of noise. But to understand the impact of noise on people, research is needed to estimate the impact of noise. Research on perceived noise annoyance seeks to identify conditions into circumstances where certain sound events elicit adverse psychological or physiological effects to those exposed. Such research helps to determine applicable noise metrics and noise limits, that can be used in mandatory or recommending regulations. A well-known method is the use of exposure-response data to determine based on a certain metric (e.g. loudness) the maximum limit (e.g. a certain dBA) that is acceptable for most of the tested population. For aircraft noise, the established Schultz curves [2] are one of the first models to quantify the relation between aircraft noise and people's annoyance. Subsequent research by Miedema et al. refined these curves [3], [4] based on datasets from additional studies. These studies base perceived (general) annoyance on long term exposure, as known as field studies or empirical studies. But they do not explain which activities are more or less affected when aircraft noise is experienced. What's also not included is the effect of being in an indoor environment, as it is known this has an effect on noise perception [5], [6]. To examine specific activities and the influence or aircraft noise, either the specific activities must be reported while experiencing aircraft noise in an in-situ field study [7], or a controlled laboratory study must be conducted to understand the impact of noise on predefined tasks [8]. For a laboratory study, a representative environment helps to make the study realistic for the situation where participants are tested for. This would mean that for a study that involves the execution of tasks done an indoor domestic setting, as such laboratory environment should closely match this domestic setting as well.

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2. The LOUNGE facility

A multifunctional testing environment, designated as the ‘LOUNGE,' was developed by NLR to facilitate human perception studies on aircraft noise annoyance in simulated domestic settings. NLR researchers set out requirements for this room that were both functional and practical. Functional to ensure the room would be suited for the envisioned human perception studies. But also practical due to limitations related to the location and the space that was available: a to be renovated building at NLR Amsterdam was available, so location and space had to be selected based on the researcher’s requirements and the other requirements of the plans of the renovation. Because the room would be used to play and listen to audio, interior walls could be isolated to prevent sounds from the room to adjacent chambers, or vice versa. However, as the room was in the corner of the ground floor of the building, insulation possibilities from outdoor sounds were limited and are still partially needed after initial completion. Also, having a living room setting as a listening room also has other limitations as reverberation time of the room will be longer than that of an anechoic chamber. The room is equipped with an audio reproduction system that allows spatial audio playback of stimuli using five surrounding speakers, four ceiling level speakers and a subwoofer. The room is decorated as a home living

Figure 1. A panoramic picture of the LOUNGE facility. On the left, the corner bench is placed, on the right next to the bookcase, a table with chairs can be seen. A bit right of the middle, the one-way observation window can be seen.

room, including a couch and comfortable chair, a living room table with chairs, a cupboard and a bookcase. Adjacent to the room is another room that has a one-way window to observe participants in the LOUNGE. This room also contains the hardware to control the audio system and is storage for physiological measuring equipment that can also be used for human studies. Although the authors will use this room for acoustics research, it will also be available for other human studies, such as general behaviour, fatigue studies, or studies to evaluate workload of professionals (e.g. pilots). If the room is not used for these purposes, it is available as well for doing workshops, meetings, or relax or reading to ensure optimal occupation of the facility. A panoramic picture of the LOUNGE is found in Figure 1.

2.1 Audio reproduction system

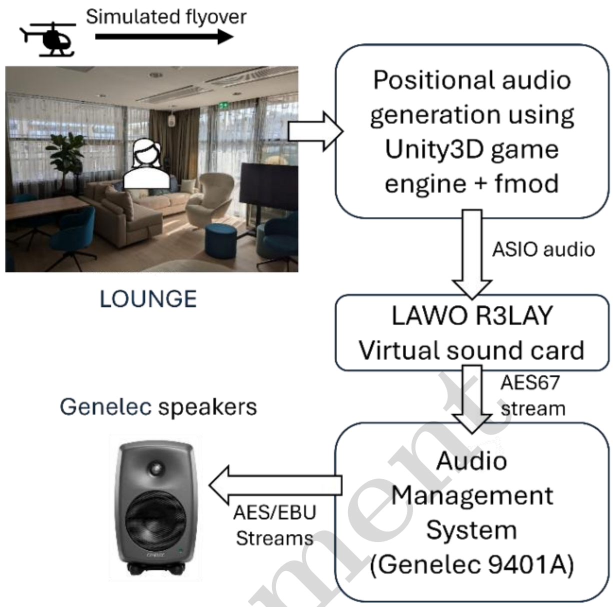

Figure 2. A schema explaining the audio reproduction system to play positional audio in the LOUNGE facility.

For the generation of positional audio playback, both the sound events and the location, or in case of a moving audio source, a path should be defined. Sound events can be either prerecorded sounds, possibly cleared by filtering out unwanted sound artefacts, or sounds that are synthetically created using a technique called “auralization” [9]. Additional processing may be needed to adjust the generated sound for the outdoor-to-indoor propagation or the acoustics of the room. We use the Unity3D Game engine software to control and trigger the sound events, and to generate the combined audio and positional data needed in the required (interpolated) update resolution to make it playable for the rest of the audio chain. Other solutions may suit a similar purpose, but this system is familiar with the authors and is already used by our Virtual-Reality-based Virtual Community Noise Simulator (VCNS) [10]. The Unity3D solution makes use of a fmod audio plug-in system [11] to create a digital ASIO audio stream for a Virtual Sound Card (VSC). A LAWO R3LAY VSC is used that converts the ASIO audio stream towards a AES67 audio stream, mapping all speakers in the LOUNGE to specific channels in the AES67 stream. The audio system is based on a Genelec audio stack, consisting of a Genelec 9401A audio management system and Genelec studio-grade speakers. This system uses an Audio-over-IP (AoIP) connection using the AES67 audio stream to connect the audio generation system with the individual speakers via a digital AES/EBU (Audio Engineering Society/European Broadcasting Union) connection. Using digital connections prevents signal loss, although it requires the need to generate a digital AES67 audio stream that contains the audio signal that needs to be played. A total of 11 Genelec 8330A SAM speakers with a frequency response of 58Hz-20KHz (± 1.5 dB) are used for 7 surround speakers and 4 speakers in the top four corners of the room. This model was chosen as the sweet spot for the LOUNGE, enough power to be able to play loud signals if required or for demo purposes but smallest possible to be able to (visually) blend in with the room decoration and furniture as much as possible. The system is complemented with a Genelec 7370 Subwoofer with a frequency response of 19Hz-100Hz (± 3.0 dB). The whole sequence is presented in Figure 2. This audio system is also capable of calibrating the frequency and loudness of each speaker, based on a separate audio sweeps and measurement using a microphone for a specific position in the LOUNGE. Each speaker is then compensated internally with the calibration values for sweeps. In this way, by changing the microphone position, presets can be defined in case participants of a study sit at different positions in the room.

3. Pilot studies

To examine the usability of the LOUNGE for upcoming audio perception studies, two pilot studies were set up to test the facility as a whole, but also test the process of developing scenarios for the audio reproduction system and to test it with actual participants. Both studies were done with the same group of participants, who effectively participated in both studies. This reduced the effort for recruitment and for reducing effects of prolonged sound exposure, measures were taken to ensure an equal group of participants started each of the two studies.

3.1 Study 1: effect of aircraft noise on two cognitive tasks

Annoyance of aircraft sounds is strongly related to loudness of the event, but it is also influenced by sound characteristics. To examine the annoyance of different aircraft sounds, a participants study was conducted to measure perceived annoyance while conducting a math task and a colouring task during playback of these sounds in the LOUNGE [12]. Participants of the study were assigned to work on one of two pre-selected tasks: a relatively low cognitive task (colouring a mandala) and a relatively high cognitive task (math exercises). While doing the task, the participants were exposed to five different aircraft sounds: two conventional aircraft, two helicopters, and one drone. All these sounds differed in loudness and sound characteristics, where the drone and Boeing 737 MAX were the lowest with 64 dBA peak sound level, and the Airbus A330 the highest with 81 dBA. After each sound that appeared in a 90-seconds time window, one disturbance question from the Multiple-Item Annoyance Scale (MIAS) [13] and a variation on the ISO/TS 15666:2021 [14] annoyance question were asked: "Thinking about the noise you just heard, how much does it bother, disturb or annoy you? "and ''During the session, the noise disturbed my ability to focus on the task''. After each task, 5 questions from the MIAS [13] on disturbance and coping were asked. The participants consisted of 14 males and 19 females, in total 33 participants between 21-59 years of age. Results for perceived annoyance were that there was a significant main effect of aircraft sound found, suggesting that there is a difference of annoyance in between the presented aircraft sounds. However, there was no significant main effect of the task, and no significant interaction between task and aircraft sound. This demonstrates that the annoyance did not differ between math and colouring tasks, nor that the annoyance of the aircraft sound did depend on the task performed. Results for perceived task disturbance were that a significant main effect was found, demonstrating higher disturbance scores during the math task than the colouring task. Furthermore, a significant main effect of aircraft sounds was found, indicating that the participants' disturbance differed across the five different aircraft sounds. No significant interaction effect was found between the task and aircraft sound, indicating that the difference in disturbance does not change between the colouring and math task depending on the aircraft sound. Concluding,

Figure 3. A test person wearing the NLR Virtual Community Noise Simulator (VCNS) as an alternative to the LOUNGE as noise simulator.

the study found that task type and different aircraft sounds significantly influenced participants' disturbance. Specifically, participants were more disturbed by the aircraft noise during the math task as compared to the colouring task. However, no differences were found in coping with the noise between the two tasks. The study did conclude that the indoor aircraft noise was indeed more disturbing during the relatively higher cognitive task. However, there was no support found that the indoor aircraft noise was more annoying during the math task than during the relaxed task. Also differences in annoyance was found between the different aircraft sounds.

3.2 Study 2: comparison VCNS and LOUNGE

This study examined the link between aircraft noise and annoyance across indoor and outdoor environments inside two contexts: A simulated living room laboratory setting using the LOUNGE facility and the Virtual Reality-based noise simulator of NLR (VCNS, See Figure 3), using a within-subjects design with the same participants as in study 1. The study was aimed at examining perceived annoyance based on the following independent variables:

- aircraft type,
- laboratory environment,
- peak sound level (64-84 dB(A)), and
- indoor versus outdoor noise.

For the aircraft type, three different sounds were evaluated: jet engine aircraft, multirotor drones and helicopters. For the laboratory environment, tests were done using the VCNS simulator with sounds made audible using a headset, or the LOUNGE using the speaker system as sound reproduction. Two different peak sound levels were tested, as we know from prior research that louder sounds cause higher annoyance. Finally, both the original outdoor-recorded sound samples were played, or the modified sound samples according to an outdoor-to-indoor propagation filter (inside a house with an open window setting) for a typical Dutch house [15].

To compare the two different laboratory facilities (VCNS vs. LOUNGE), and to ensure the visual perceived environment does not have an effect on noise annoyance, in the VCNS, the indoor noise events were played while a visual of the LOUNGE room was presented in the Virtual Reality environment. This visual was recorded using a 360-degrees camera that made a picture in the lounge. In this way, it looked like participants sat in the LOUNGE when doing the indoor test cases using the VCNS facility.

Results of this studies are still under investigation and will be reported in later publications by the authors.

4. Conclusion

A new laboratory called LOUNGE is presented with the purpose to provide a domestic setting for participants of noise perception studies. An audio reproduction system is installed and allows for positional audio playback to simulate different sound events, such as overflying aircraft, helicopters or drones. This facility is designed to help the institute's capabilities to investigate the effect of noise annoyance within indoor households. To assess the technical feasibility and effectiveness of the LOUNGE laboratory, two pilot studies were conducted. These studies not only evaluated the technical execution of experiments within the facility, but also explored the impact of noise in an indoor setting while participants engaged in different tasks. The LOUNGE facility offers a more suitable environment for such research compared to the VCNS, which relies on wearing a Virtual Reality headset and headphones. Future improvements that are foreseen for the facility are the integration of software platforms for both VCNS and LOUNGE that would allow easier configuration and set up for new experiments. Additionally, supplementary absorption measures are anticipated to further mitigate reflection of lower frequencies. These advancements will contribute to follow-up research in the LOUNGE to better comprehend the topic of noise perception and annoyance in a domestic setting.

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