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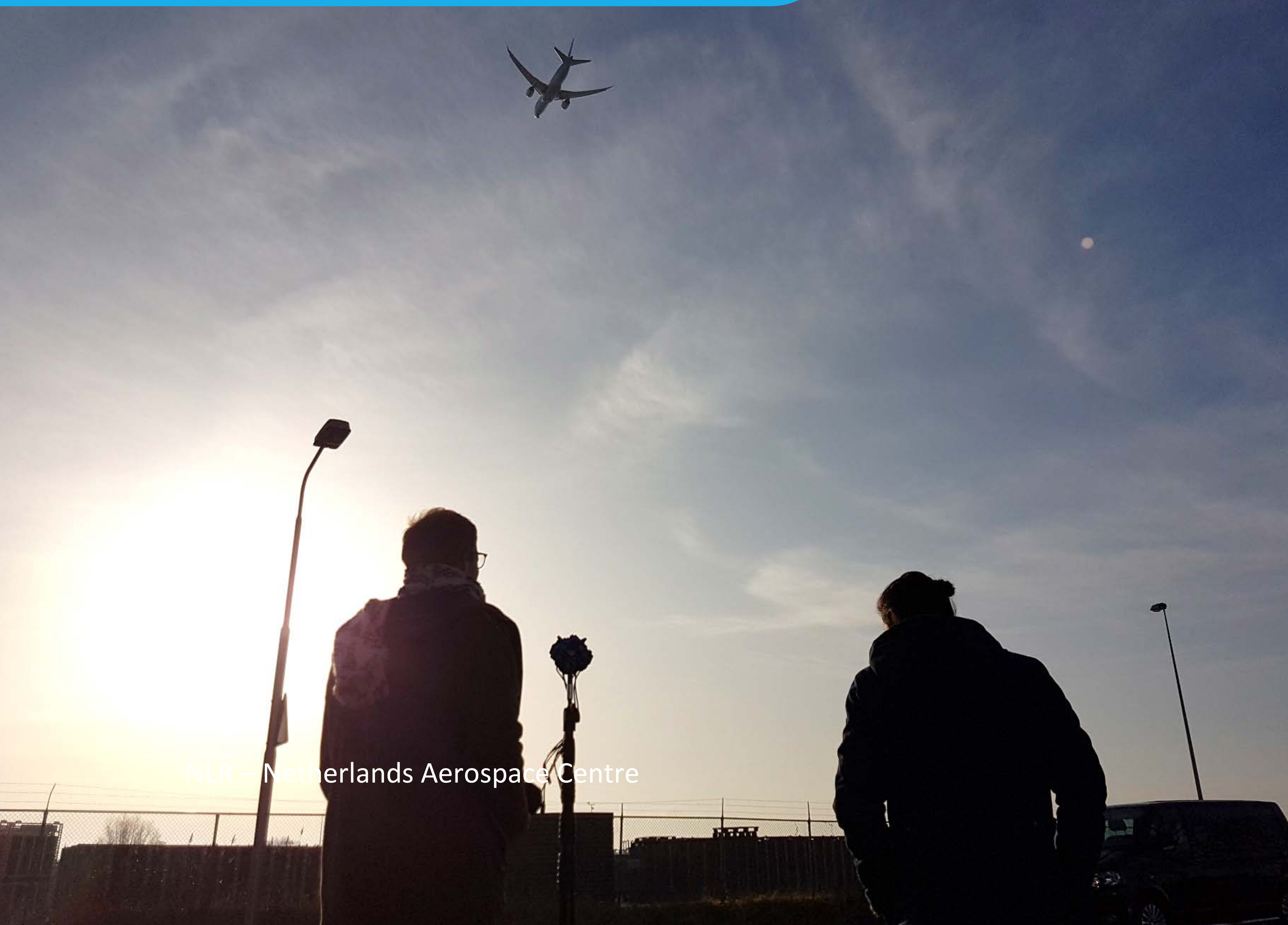
NLR-TP-2018-432 | November 2018

Perception and Presence in Virtual Reality for Simulated Aircraft Noise

CUSTOMER: Netherlands Aerospace Centre



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EXECUTIVE SUMMARY

UNCLASSIFIED

Perception and Presence in Virtual Reality for Simulated Aircraft Noise

Problem area

A realistic noise simulation can provide reliable results and confidence in the results compared to paper studies and means of information transferral that not involves visual and audio simulation. Field experts, who made use of the VCNS, reported that aircrafts were not experienced as ‘real’ because the aircrafts were experienced as smaller than in reality. This is surprisingly because the perceptual characteristics in the virtual world are physically the same as in the physical world. The current study assessed the subjective perception of the VCNS to validate subjective *presence.*

Description of work

This present study consists of two experiments. The participants adjusted the perceived characteristics of a virtual environment until they were congruent with the real characteristics within both experiments. The visual and the auditory characteristics of an aircraft were subjectively matched in both experiments.

REPORT NUMBER
NLR-TP-2018-432

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REPORT CLASSIFICATION
UNCLASSIFIED

DATE
November 2018

KNOWLEDGE AREA(S)
Aircraft Noise
Training, Mission Simulation and Operator Performance

DESCRIPTOR(S)
aircraft noise
perception
virtual reality
community engagement

Experiment 1 consisted of a size-expectancy test. The participants had to adjust the expected size of a simulated aircraft in climbing flight to the sound level of the aircraft. The aircrafts sound level was the only cue to estimate the size. Experiment 2 consisted of a sound level-expectancy test. The participants had to adjust the sound level of the climbing aircraft by the size of the aircraft. The size of the aircraft was the only cue to estimate the sound level. This means that the visual and auditory characteristics match each other according to the participant.

Results and conclusions

Experiment 1 demonstrated that the participants overestimated the size of the aircrafts presented in the virtual reality simulator compared to the real size at both tested locations. Aircrafts were estimated to be more than 1.5° (factor of 1.4) in visual angle larger Cohen's effect size value suggests a moderate effect size. Our second hypothesis was that the sound level of the aircraft in the virtual reality simulation would be perceived as similar as in the physical world. This hypothesis had no expectation due the lack of scientific and anecdotal evidence. It can be concluded that there is no significant difference between the expected sound level and the actual sound level at both locations separately and overall.
This study provides interesting directions for future research direction for analysing presence in virtual environments. The difference between expectation of the size of aircrafts and the size in the physical world is a new finding. It is interesting and necessary to research if this phenomenon applies to other objects as well.

Applicability

Virtual environments can differ in the subjective perception and experience of "being present" of the user. It is essential to present visual and auditory information as persuasive as possible to enable the user to feel present in the virtual environment. Consequently, better interaction with the community can be obtained and project plans can be adapted accordingly to improve the acceptance by the local stakeholders.

GENERAL NOTE This report is based on a presentation held at the 47th International Congress and Exposition on Noise Control Engineering Impact of Noise Control Engineering (INTERNOISE 2018), Chicago, Illinois, USA, 26-29 August 2018.

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The Proceedings are published by the Institute of Noise Control Engineering of the United States of America, Washington DC, USA

CUSTOMER	**Netherlands Aerospace Centre**
CONTRACT NUMBER	**- - -**
OWNER	**Netherlands Aerospace Centre**
DIVISION NLR	**Aerospace Operations**
DISTRIBUTION	**Unlimited**
CLASSIFICATION OF TITLE	**UNCLASSIFIED**

APPROVED BY :																				
AUTHOR							**REVIEWER**							**MANAGING DEPARTMENT**						
R. Aalmoes							A. Maij							AOEP						
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Content

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INTER-NOISE 2018
Impact of Noise Control Engineering
26-29 AUGUST
CHICAGO, ILLINOIS

Perception and Presence in Virtual Reality for Simulated Aircraft Noise

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ABSTRACT

The Virtual Community Noise Simulator is used to inform communities on the effects of aircraft noise on their environment. It allows the user to experience different environmental impacts of aircraft flyovers visually and acoustically, with a video and binaural audio presentation. The present study aims to examine the effectiveness of the simulator by assessing presence in the virtual environment. Two experiments were conducted to test whether the expected size (in the video presentation) and the expected sound level (in the acoustical presentation) of an aircraft in the simulated world corresponds to the same characteristics in the physical world. Our first hypothesis was that simulated aircrafts are larger perceived than they actually are in the physical world. We hypothesized that a virtual environment, which matches the expected perceptual characteristics enhances the reported presence in the acoustic domain.

The results for the visual presentation indicate that aircrafts appear significantly larger in the virtual environment than aircrafts in the physical world. The results for the acoustical experiment indicate that there is no significant difference between the expected sound level and the actual sound level of the aircraft. In summary, creating virtual aircrafts that are 1.4 times larger than the actual size, can bring the subjective perception of the aircraft closer to the objective reality of the simulation.

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1 INTRODUCTION

The Netherlands Aerospace Centre (NLR) makes use of a noise simulator to demonstrate the impact of the aircraft on the environment. The system was adopted from the National Aeronautics and Space Agency (NASA)[1-2]. The visual part of the system was later on improved by NLR, by making use of the latest virtual reality technology created by the Oculus Rift. Further improvements made the system portable, for easier transportation and usage at different locations. This system is called Virtual Community Noise Simulator (VCNS).

The VCNS is used as a tool to inform the user about changes in the local environment, where noise annoyance is a main concern. The local environment is recorded using a 360 degrees camera recording system. The environmental sound is recorded with a spatial audio recorder. This is combined within a virtually generated aircraft flyover, where both the visual aircraft model and the aircraft sound are added. Application of the VCNS can help to create better understanding of the impact of new or modified aircraft procedures for residents. The VCNS is an important tool to address fear and uncertainty of the residents. Consequently, better interaction with the community can be obtained and project plans can be adapted accordingly to improve the acceptance by the local stakeholders.

1.1 Presence

A realistic noise simulation can provide reliable results and confidence in the results compared to paper studies and means of information transferral that not involves visual and audio simulation. Virtual environments can differ in the subjective perception and experience of “being present” of the user. According to Slater and Wilbur (1997), *presence* is used to illustrate the experience of actually being present. In the current study, *presence* is being used according to Slater and Wilbur[3] as: “a state of consciousness, the (psychological) sense of being in the virtual environment.” When the *presence* is high in a virtual environment, the behaviour of a person in the virtual environment is expected to be consistent with the behaviour in the physical world. The term physical world is used to describe the world one is physically present in.

It is essential to present visual and auditory information as persuasive as possible to enable the user to feel present in the virtual environment[6]. According to IJsselsteijn et al[4] a “single, accepted paradigm for the assessment of presence” does currently not exist. Recently proposed methods to assess *presence* in virtual reality have not been able to provide a concept of validated objective measurements[5]. However, the feeling of subjective *presence* provides an important validation for a virtual simulation tool. The current study assessed the subjective perception of the VCNS to validate subjective *presence.*

1.2 Objective versus subjective reality

Field experts, who made use of the VCNS, reported that aircrafts were not experienced as ‘real’ because the aircrafts were experienced as smaller than in reality. This is surprisingly because the perceptual characteristics in the virtual world are physically the same as in the physical world. The discrepancy between the expectation of the same characteristics in virtual reality and in the physical world might influence the degree of reported presence of the particular participant.

Based on expert judgment by operators of the VCNS, it is likely that the expected perceptual characteristics in the virtual environment differ from the characteristics in the physical world. When the perceptual characteristics in the virtual environment are adjusted to what is expected, the virtual environment appears more alike to what the participant thinks is realistic, which enhances the *presence.* In other words, when perceived and real world characteristics of a visual environment differ, subjective reality and objective reality differ from each other. The virtual environment should be adjusted to the subjective reality, to enhance the presence[7-10] and thus improve the transfer of information[6].

1.3 Aim of the study and hypotheses

This present study consists of two experiments. The participants adjusted the perceived characteristics of a virtual environment until they were congruent with the real characteristics within both experiments. The visual and the auditory characteristics of an aircraft were subjectively matched in both experiments. Experiment 1 consisted of a size-expectancy test. The participants had to adjust the expected size of a simulated aircraft in climbing flight to the sound level of the aircraft. The aircrafts sound level was the only cue to estimate the size. Experiment 2 consisted of a sound level-expectancy test. The participants had to adjust the sound level of the climbing aircraft by the size of the aircraft. The size of the aircraft was the only cue to estimate the sound level. This means that the visual and auditory characteristics match each other according to the participant.

According to earlier personal experiences with VCNS, a phenomenon was encountered where objects should be simulated larger than in the physical world. There is, however, no scientific evidence which invalidates or supports this phenomenon; therefore we expect that the size of the flying aircraft in Experiment 1 is estimated larger than in the physical world. Experiment 2 is included for exploratory purposes; there is no literature or personal experiences which can help to predict the outcome. The first hypothesis, which is tested in experiment 1, is that the size of the flying aircraft in the simulated environment is estimated larger than in the physical world. The second hypothesis, tested in experiment 2, is that the sound level of the flying aircraft in the simulated environment is perceived as similar as in the physical world. If a difference is found between these expected perceptual characteristics and the perceptual characteristics in the physical world, and this influences the presence, all the assumptions which virtual reality is based on, especially concerning perception, need to be reconsidered.

2 METHODOLOGY

2.1 Participants

A total of 45 participants took part in this study (n=15 female participants). Their age ranged from 16 to 57 years (M= 24.57, SD =7.28). Data from six participants were (partly) excluded due to different reasons: Three participants did not fill in the scale of the questionnaire correctly; the sound level of the VCNS was not calibrated correctly for two participants and one participant did not understand the adjusting of the perceptual characteristics correctly. All signed an informed consent.

2.2 Apparatus/Materials

The visual stimuli were presented using the VCNS running the Unity 3D gaming engine (version 5.4.1f1) on an Intel Core i5-6600 CPU with a NVIDIA GTX-970 graphic card. Virtual reality was presented on an Oculus Rift CV1, with a refresh rate of 90 Hz. The auditory stimuli were presented by a Bose QC 25 headphone.

2.3 Stimuli

The visual stimuli that were presented in the virtual environment were filmed by six different GoPro Hero 4 Black Edition with a refresh rate of 60 Hz on a 6 rig camera tripod. The videos were combined together in a single-stereospheric video using Kolor autopano software, so they could be replayed in the virtual reality headset. Two different takes of departing aircrafts were used, both filmed in Aalsmeer but on different locations. One location (Aalsmeerdijk) is very close (500 meter) to the runway (Aalsmeerbaan). The other location (Middenweg) is approximately two kilometres away of the runway (Aalsmeerbaan), both under the flight path of the starting aircraft.

Fig. 1 – Screenshot of a simulation of a climbing aircraft at the Aalsmerdijk in the VCNS.

The audio stimulus was recorded by a calibrated high-end microphone (B&K) and a 2-channel binaural audio recorder Zoom H2n to record the environmental noise. Through Unity 3D software, the recordings were transformed in 360 degrees videos with sound and artificial aircraft noise. In the 360 video the aircraft was replaced by a virtually added (3D) aircraft, so that the size could be adjusted.

At both locations, an aircraft appeared behind a building and flew over until it disappeared in the horizon. For this purpose, a background mask was added in the visualisation software. This allowed the software to determine if the virtual aircraft was in front or behind an object in the 360 recorded video, and could accordingly obscure (part of) the aircraft. This was present at both locations.

2.4 Experimental setup

First the participants perceived a few irrelevant, but comparable, virtual environments to habituate to the VCNS. After the habituation-phase the participants entered the experiment-phase. The following two experiments were counterbalanced between participants and the experiments were presented in random order.

Experiment 1 consisted of a size-expectancy test. In the virtual environment a climbing aircraft was presented to the participant. The participants were instructed to adjust the size of the aircraft to the physical world by judging the sound level of the aircraft. The only cue to estimate the size of the aircraft was the auditory information. The adjusting of the size of the aircraft was done by pressing the “up”-button (larger) or “down”-button (smaller) on the Oculus remote. One step larger or smaller corresponded to a change of 10 percent in the visual presentation. The size adjustment was carried out with respect to the ‘actual‘ size (objective reality). The sound that the aircraft produced in the virtual environment was the sound that was recorded during the corresponding take-off at either the Aalsmeerdijk or the Middenweg. The presented size of the aircraft differed per trial. In randomized order, seven different sizes were presented, whereas the actual size was presented twice. Each location (Aalsmeerdijk or the Middenweg) were simulated eight times. The experiment consisted of 16 trials and lasted for approximately 15 minutes.

Experiment 2 consisted of a sound level-expectancy test. The participants were exposed to a climbing aircraft in the virtual environment, as done in Experiment 1. The participants were told that the sound level of the aircraft is possibly incorrect relative to the physical world. The task was to adjust the sound of the aircraft until it would match the size of the aircraft. The size of the aircraft was the only cue to estimate the sound level. The adjusting of the sound level of the aircraft was done by pressing the “up”-button (louder) or “down”-button (softer) on the Oculus remote. By adjusting the sound level, the whole sound level of the virtual environment was adjusted. One step larger or smaller is two decibels (A-weighted) louder or softer than the previous step. The sound level of the aircraft in the virtual environment was the sound level that was recorded during the concerned take at either the Aalsmeerdijk or the Middenweg. The sound level of the aircraft differed per trial. Each location (Aalsmeerdijk or Middenweg) were simulated eight times. In randomized order, seven different sound levels were presented, whereas the correct sound level was presented twice. After 16 trials, which took approximately 15 minutes, Experiment 2 was finished.

3 RESULTS

For each of the six one-sample t-test, we did also one-way between subjects Analysis of Variance (ANOVA) to check whether there was an effect of the order of presenting the two different experiments on the expected sound or size level of an aircraft in virtual reality. It will only be noted if the result was significant, otherwise the result was not significant.

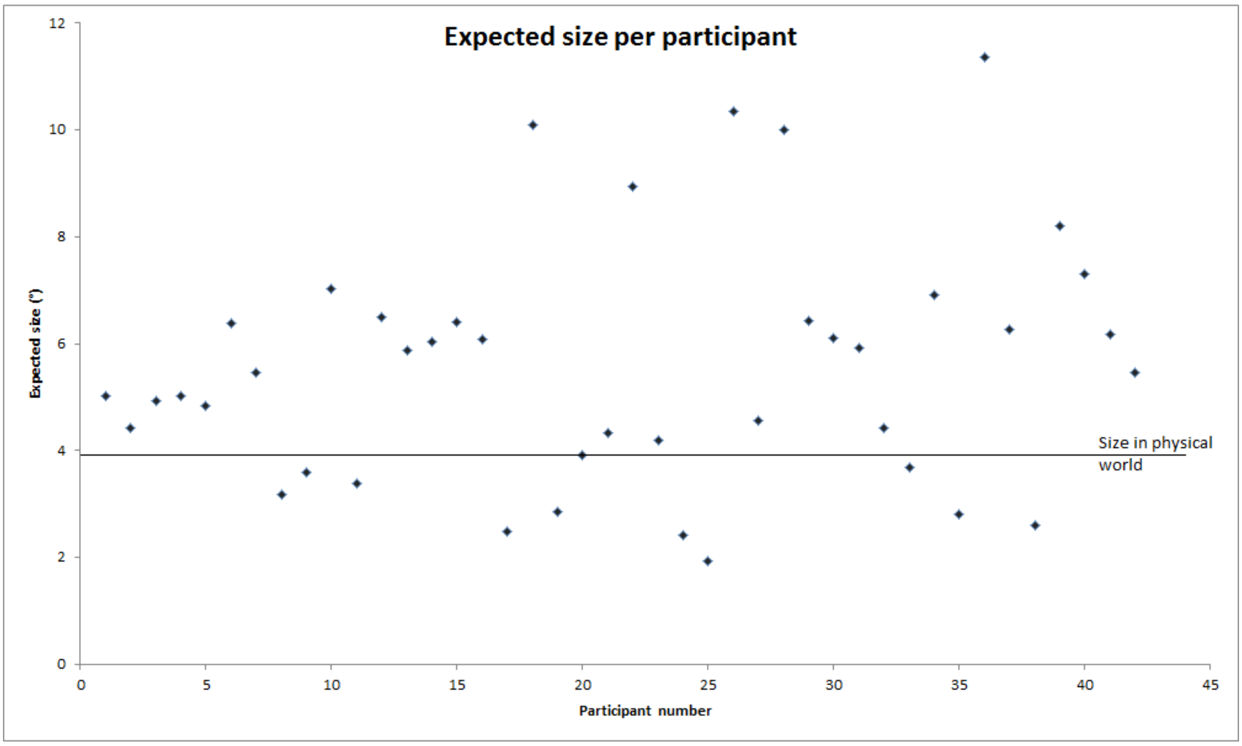

Fig. 2 – Average expected size (°) per participant at both locations. Actual size in the physical world is 3.933°.

3.1 Experiment 1 – size expectancy

Overall

A one-sample t-test was run to determine whether the expected size of an aircraft in virtual reality is larger than the actual size in the physical world. The estimated sizes were normally distributed, as assessed by Shapiro-Wilk's test (p >.05). There were no outliers in the data, as assessed by inspection of a boxplot. Mean estimated size in visual angle (M = 5.59, SD = 2.28) was significantly higher than the actual average size (3.93 °) in the physical world $t(41)$ = 4.66, p < .001. d = 0.72.

Location Aalsmeerdijk

A one-sample t-test was run to determine whether the estimated size of an aircraft at the location Aalsmeerdijk in virtual reality differs from the actual size in the physical world at the Aalsmeerdijk. The estimated sizes were normally distributed, as assessed by Shapiro-Wilk's test (p >.05). There were no outliers in the data, as assessed by inspection of a boxplot. Mean estimated size in visual angle (M = 3.53, SD = 1.50) was significantly higher than the actual size (2.53 °) in the physical world $t(41)$ = 4.34, p < .001. d = 0.67.

Location Middenweg

A one-sample t-test was run to determine whether the estimated size of an aircraft at the location Middenweg in virtual reality differs from the actual size in the physical world at the Middenweg. The estimated sizes were normally distributed, as assessed by Shapiro-Wilk's test (p >.05). There were no outliers in the data, as assessed by inspection of a boxplot. Mean expected size in visual angle (*M* = 7.60, *SD* = 3.53) was significantly higher than the actual size (5.34 °) in the physical world $t(41) = 4.16$, $p < .001$. $d = 0.64$.

3.2 Experiment 2 – sound level-expectancy

Overall

A one-sample t-test was run to determine whether the expected sound level of an aircraft in virtual reality differs from the actual sound level in the physical world. The expected sound levels were normally distributed, as assessed by Shapiro-Wilk's test (p>.05). There were no outliers in the data, as assessed by inspection of a boxplot. Mean expected sound level in decibel (*M* = 76.03, *SD* = 5.55) was not significantly different than the actual sound level (75 dB) in the physical world $t(41) = 1.20$, $p = .236$.

Location Aalsmeerdijk

A one-sample t-test was run to determine whether the expected sound level of an aircraft in virtual reality differs from the actual sound level in the physical world at the Aalsmeerdijk. The expected sound levels were normally distributed, as assessed by Shapiro-Wilk's test (p>.05). There were no outliers in the data, as assessed by inspection of a boxplot. Mean expected sound level in decibel (*M* = 73.29, *SD* = 5.37) was not significantly different than the actual sound level (73dB) in the physical world $t(41) = .35$, $p = .727$.

Location Middenweg

A one-sample t-test was run to determine whether the expected sound level of an aircraft in virtual reality differs from the actual sound level in the physical world at the Middenweg. The expected sound levels were normally distributed, as assessed by Shapiro-Wilk's test (p>.05). There were no outliers in the data, as assessed by inspection of a boxplot. Mean expected sound level in decibel (*M* = 78.77, *SD* = 6.11) was not significantly different than the actual sound level (77dB) in the physical world $t(41) = 1.88$, $p = .068$.

A one-way between subjects ANOVA was conducted to compare the effect of the order of presenting the two different experiments on the expected sound level of an aircraft in virtual reality at the Middenweg. In Order of Presenting 1 (OP1) (*M* = 76.83, *SD* = 4.31), participants first get the vision-related test and secondly the audition-related test. Participants in Order of Presenting 2 (OP2) (*M* = 81.19, *SD* = 7.19) first experience the audition-related test and afterwards the vision-related test. There was a significant effect of the order of presenting the two different experiments on the expected size of an aircraft in virtual reality at the p <.05 level for the two orders of presenting $F(1,40) = 5.72$, p =.022, $\eta^2 = .13$. Despite the differences between the two orders of presenting, the expected sound level of one order of presenting does differ significantly from the actual sound level in the physical world. The condition where the vision-related test is done at first (OP1) is not significantly different than the actual sound level $t(22)$ =-.19, $p = .848$. The other condition (OP2) which starts with the audition-related test is significantly higher than the actual sound level $t(22) = 2.50$, $p = .022$. $d = 0.57$.

4 DISCUSSION

The aim of this study was to improve the transfer of information of the VCNS: the higher the presence in the virtual environment, which is simulated by the VCNS, the better the transfer of information[6]. The authors reasoned that a person in a virtual environment, which matches the expected perceptual characteristics (subjective reality), has a higher degree of presence than in a virtual environment which contains the perceptual characteristics as in the physical world (objective reality).

In this study, two experiments were conducted to test two hypotheses, respectively. Our first hypothesis was, that the size of aircrafts is overestimated (subjective reality) compared to the real size of the aircraft. Experiment 1 demonstrated that the participants overestimated the size of the aircrafts presented in the virtual reality simulator compared to the real size at both tested locations. Aircrafts were estimated to be more than 1.5° (factor of 1.4) in visual angle larger Cohen’s effect size value suggests a moderate effect size. At the location Aalsmeerdijk, where aircrafts are relatively closer to the ground (423 metres at the closest position), aircrafts are overestimated by a factor of 1.40 in visual angle. At the location Middenweg, where aircrafts are a relatively further away from the ground than at the location Aalsmeerdijk (756 metres at the closest position), aircrafts were expected 2.27° (factor of 1.43) larger in visual angle. No significant interaction was found between the two locations, indicating that the expected size of the aircrafts at the two different locations did not differ significantly. It can be concluded that aircrafts are expected larger by a factor of ±1.4. It was tested whether the subjective reality in virtual reality differs from the objective reality as registered with film cameras. The results showed that the size of an aircraft in a virtual environment is expected larger than the size of the same aircraft in the physical world as hypothesised. These findings contradict the findings of Wu et al[11]; they claim that objects in virtual reality, only with visual cues, are perceived smaller than their actual size when the objects are farther away. An explanation of the difference in results found in this study and the study of Wu et al[11] is that Wu et al. used objects in a virtual environment which are in reach of the participant, whereas in this study the objects (aircrafts) are much farther away. Follow-up studies should test if the factor of ±1.42 remains constant on other locations, distances and types of aircrafts.

Our second hypothesis was that the sound level of the aircraft in the virtual reality simulation would be perceived as similar as in the physical world. This hypothesis had no expectation due the lack of scientific and anecdotal evidence. It can be concluded that there is no significant difference between the expected sound level and the actual sound level at both locations separately and overall. There was a significant effect of the order of presenting Experiment 1 and 2 on the expected sound level of an aircraft in Experiment 2 on the location Middenweg but not on the location Aalsmeerdijk or in Experiment 2 overall. In contrast to the expected size, the expected sound level of an aircraft (sound level-expectancy test) did not differ from the sound level in the physical world. Although there was no significant difference on sound level, there was a trend towards significance which suggested that the sound level of an aircraft is expected higher than in the physical world at the location Middenweg. A possible explanation for the lack of significant results is that the sound level of the whole virtual environment was adjusted, not solely the sound level of the aircraft. Because the scenes had some frames of reference, like passing cars, participants had indications of the sound level, which were not related to the aircraft.

The results show that only a visual characteristic was significantly expected different and that there was no difference between expected sound level in the virtual environment and the sound level in the physical world. On the other hand, other visual and auditory characteristics, for example brightness or sound localization, should be tested in future presence research to conclude if there is a difference between the presence in an environment in accordance with subjective and objective reality. What also should be taken in consideration is that the difference that is found in the size-expectancy test, between the size in the physical world and the expected size, can either be assigned to the expectation of the participant or it can be assigned to the virtual reality technique that has its limitations compared to the physical world. The improvement of virtual reality and follow-up research should clarify whether the results in the size-expectancy test were a result of expectation or the virtual reality techniques that are used. The resolution of the virtual reality headset is, due to technical limitations, lower than the human eye resolution, and this may also impact the perception of size of the aircraft. This hypothesis is also a topic for further study. Also important to note is that the difference found between size in the physical world and the expected size cannot yet be generalized into other objects. If, by doing follow up studies, it turns out that other objects are expected larger as well, then the conclusions made in experiment 1 can be generalized to other objects.

For both experiments a control analysis was done to check whether there was a learning effect due the order of presenting the first two experiments, the order of presenting the experiments was done randomly but counterbalanced between participants. The results show that there was no learning effect for the size of the aircraft, but there was a difference between the two opposed orders of presenting the experiments on the expected sound level. The group who started with adjusting the sound level, who had no chance to learn anything from a previous experiment, expected a louder aircraft than the other group, who could learn from size-expectancy test. Although the two groups differed on expected sound level, both groups did not differ significantly from the actual sound level in the physical world. Still a trend towards significance was found: if a participant had no chance of learning the sound level from previous experiments, he/she expects a louder aircraft than the sound level is in the physical world. Future research, where sound level adjustments solely feature the sound level of the aircraft and not of the entire virtual environment, should be able to test whether this trend is an actual phenomenon.

This study provides interesting directions for future research direction for analysing presence in virtual environments. The difference between expectation of the size of aircrafts and the size in the physical world is a new finding. It is interesting and necessary to research if this phenomenon applies to other objects as well. As soon as a stable and validated measure of presence[12] is found, the previous question can be easily answered.

5 ACKNOWLEDMENTS

The authors would like to thank dr. Anouk Koster from the Social Studies faculty at the University of Utrecht, dr. Barbara Ohlenforst, Anneloes Maij, and Henk Lania, all from NLR, for their support during this research.

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