# Occurrence of Simulator Sickness in Spatial Sound Spaces and 3D Auditory Displays

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## ABSTRACT

This paper describes an investigation into the effect of movement patterns in a spatial sound space on the perceived amount of simulator sickness, the pleasantness of the experience, and the perceived workload. Our user study indicates that predictable left to right movements lead to a perceived unpleasantness that is significantly higher than the unpleasantness experienced for unpredictable or no movements at all. Approx. 48 percent of all participants showed mild to moderate symptoms of simulator sickness, with a trend towards stronger symptoms for the left to right movements. Our data suggest that neither of the movement patterns has an effect on the perceived cognitive load for simple tasks.

## 1. INTRODUCTION

Virtual (auditory) environments and 3D auditory interfaces have been an ongoing research topic for many years. So-called binaural rendering systems can evoke the compelling illusion of one or more sound sources positioned around a listener. Recent trends in consumer audio show a shift from stereo to multi-channel audio content, as well as a shift from stationary to mobile devices. Especially in the field of communication and entertainment, virtual auditory scenes show a high degree of realism aiming at inducing a sense of presence in the virtual environment.

However, several investigations have shown a correlation between spatial presence/immersion and vection. Vection is the illusory perception of self-motion, which can, for example, be experienced when watching a moving train through the windows of a stationary train [1] [2]. Vection has been attributed by Hettinger and Riccio [3] and McCauley and Sharkey [4] to be one of the major candidates for causing simulator sickness. Studies concerning vection often assume a link between the vection measured and the potential for the device or environment producing the vection to cause sickness.

Simulator sickness has been identified as a form of motion sickness, in which users of simulators or virtual environments develop symptoms such as dizziness, fatigue, and nausea, which are also characteristic of motion sickness. Simulator, as well as motion sickness, often has a variety of different symptoms, many of which are internal, non-observable, and subjective and therefore difficult to measure.

One of the most popular theories to explain motion sickness, is the sensory conflict theory by Reason and Brand [5]. It states, that motion sickness occurs if there is a conflict between visual, vestibular, and proprioceptive signals in response to a motion stimulus. This disconcordance between the different cues leads the brain to conclude that the conflict is due to poison ingestion [6]. As a defense mechanism the brain responds by inducing sickness and even vomiting to clear the supposed toxin.

The occurrences and effects of vection have been well studied over the past decades. We will therefore summarize the most important findings in the related work chapter. Only very few researchers have addressed the problem of simulator sickness in simulators or interfaces exclusively using spatial audio, like spatial auditory interfaces or 3D sound spaces. With our experiment we will address questions concerning the influence of movement patterns within the sound space on the perceived pleasantness of the experience and the perceived cognitive load. We also hope that our findings will lead to a better understanding of the occurrences of simulator sickness in spatial sound spaces.

## 2. RELATED WORK

In recent years a large body of research has been focused on vection elicited by visual stimuli. Vection has been shown to occur for all motion directions and along all motion axes. In a typical vection experiment, participants are seated inside a optokinetic drum. Most participants quickly perceive vection in the direction opposite to the drum's true rotation. Depending on the type of simulator used, over 60% of participants can experience motion sickness-like symptoms under optokinetic conditions [7] [8].

Brandt et al. [9] and Pausch et al. [10] found that visual stimuli covering a large part of the field of view induce stronger circular vection with shorter onset latencies, and that stimulation of the entire field of view results in strongest vection.

There has been less work on auditory vection. The first research in this areas was described long time ago [11], but recently there has been an increased interest in the phenomenon [12] [13] [14]. For a detailed review of research on auditory vection, see [15].

Lackner [16] demonstrated that a rotating sound field generated by an array of six loudspeakers, or a rotating sound field created by dichotic stimulation can both induce illusory self-rotation with nystagmus[1]. Neither the illusory self-rotation nor the nystagmus occur when the subject has his or her eyes open and a stable visual environment is present, suggesting that visual information dominates auditory information in determining apparent body orientation and sensory localization [17].

Al'tman et al. [18] present results from an experiment addressing the effects of moving sound images on postural response and the illusion of head rotation in humans. In their

[1] Involuntary eye movement which can be caused by subsequent foveation of moving objects. Foveal centration of an object of regard is necessary to obtain the highest level of visual acuity.

study the subject closed their eyes and sat on a stool placed on a rotating platform with their head fixed in an immobile position. Impulse series were presented binaurally via headphones and the moving sound image affected postural reactions and the head rotation illusion. Vection effects (such as the perceived rotation speed) were particularly strong when there were changes in the sound source movement. Thus, higher perceived sound source movement speeds were associated with increases in the sensation of head rotation.

Larrson et al. [12] found that in a rotating sound field sound sources associated with immovable objects (such as church bells) are more likely to induce vection than both moving (e.g. cars) and artificial sound sources. They also found that a realistically rendered environment may increase perception of self-motion. Playing multiple sound sources to a listener induces significantly more vection responses than playing only a single sound source.

As summarized above, several studies show that vection can be evoked by auditory stimuli. It is important to keep in mind, however, that vection is only one possible cause for simulator sickness and that often symptoms are non-observable, subjective, and temporal. The experiment depicted in this paper did not aim at reproducing the findings summarized above. Our primary intention was to investigate the general effects, including effects similar to simulator sickness, on a human listener of exposure to a binaural listening experience, characterized by predictable and unpredictable movement in the audio scene.

## 3. EXPERIMENT

### 3.1. Design Rationale

Our experiment was designed to induce motion sickness or a certain degree of unpleasantness in participants through playback of binaural recordings of movements between several competing sound sources. Having a mobile user in mind, we consider applicable scenarios for spatial sound to be:

- Navigation support systems that create and make use of a sound space moving relative to the user.
- Binaural media consumption such as listening to binaural recordings of concerts or audio books, etc.
- Spatial mobile conferencing with attendants being located in a spatial sound space.
- A binaurally recorded sound feed from one person is fed live to another person and vice versa.
- Spatial auditory interfaces that support navigation between and interaction with different sound items.

We are explicitly interested in the effect on mobile users, so we refrained from blindfolding the participants of our study or restricting the participants' body positions to a special pose. In a mobile setting users will have a visual stimulus and it unlikely that they cannot freely determine their body positions.

The following conditions were used:

Condition 1: Left-right movements, simulating predictable, exploratory movements as may occur while navigating, crossing a street, or interacting with a spatial audio interface.

Condition 2: Random movements, with an unpredictable sound space as may occur during media consumption or live feeds from other users.

Condition 3: No movements, control condition.

The following task was used: Participants were asked to identify random, nonsensical numbers in a text read to them (see 3.4 for a detailed description). This task was designed to create a cognitive workload similar to the cognitive challenges of orientation or navigating and/or focusing on a particular primary task.

The study was designed to test the following hypotheses:

H1: Participants would feel more discomfort, sooner, by random, unpredictable audio movements.

H2: The distraction generated by random audio movements affects the cognitive load and decreases task performance.

### 3.2. Participants

Eighty-two participants volunteered for the experiment ranging in age from 15 to 54 years (M = 33 years), and were recruited within the Nokia community and several sport clubs. Forty-nine participants were male, thirty-three female. All participants were native Finnish speakers. Participants were randomly allocated to the three conditions: left-right movements (N=28), random movements (N=25), and control, no movements (N=27). Three participants reported minor hearing problems.

### 3.3. Audio material

Twenty minutes of binaurally recorded sound was used for the experiment. The recording was produced by the experimenter wearing an ARA (Augmented Reality Audio) headset, which consists of binaural microphones, an amplifier/mixer, and in-ear headphones [19]. We chose to use the ARA headset instead of a manikin as it allowed the experimenter to move freely during the recording, which was especially important for recordings of random, 3-DOF movements. We opted for binaural recordings instead of binaural synthesis to grand the reproduction of authentic head and body movements. During the recording the experimenter sat on a swivel chair and was surrounded by five Genelec 6020A bi-amplified active loudspeakers fixed at face level. The recording was made in a soundproof studio with room acoustics. As can be seen in Fig. 1, the loudspeakers were set up in a circular layout with a diameter of approx. 3 meters. The sound field created by the loudspeakers playing the following:

- Music, easy listening (Loudspeaker 1)
- Male reading Finnish text for task (LS 2)
- Street noise (LS 3)
- Finnish podcast, male and female speakers (LS 4)
- Environmental noise, birds, river (LS 5)

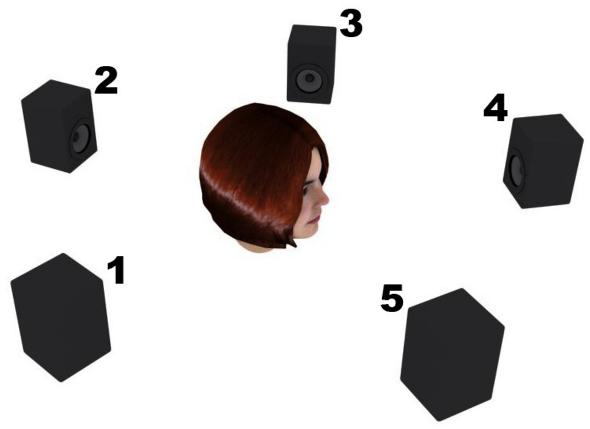


Figure 1: *Setup used for binaural recordings. Experimenter surrounded by five loudspeakers.*

For the left-right condition (condition 1) the experimenter, wearing the ARA headset, moved her head from left to right through an angle of 80 degrees over approximately 0.8 seconds. During this the sound source the participants were asked to concentrate on was played on the back speaker (conf. Fig 2.).

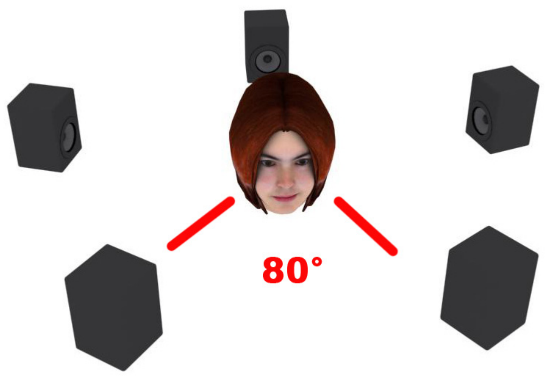


Figure 2: *Illustration of orientational movements made for the recording of the left-right condition*

For the random condition the experimenter moved her head in random, unpredictable movements. This included approaching or withdrawing from a sound source, rotations on her x- ,y-, and z-axis, and rapid changes of acceleration during movements. For the control condition the experimenter did not move at all, always facing the target sound source.

Preliminary testing indicated that having the target sound source appearing in the back is perceived as less natural and hence more annoying than sensing it to be in front.

### 3.4. Experiment Task

All participants were asked to concentrate on one of the sound sources, a male voice talking about dogs and horses. The script was read by a professional male speaker and consisted of adaptations of Wikipedia Finland [20] entries on dogs and horses. At random positions in the text numbers between 1 and 120 were placed out of context. Participants were asked to write down chronologically all the numbers that did not make sense in the text.

The task required participants to concentrate on only one of the sound sources, process the received information, and to identify numbers out of context. It was designed to investigate the differences in cognitive load placed upon the participants over the three conditions. It also required participants to focus their attention on one fixed spot in space and hence perceive changes in position as additional challenge.

### 3.5. Procedure

Before their first trial, participants were familiarized with the listening booths and were instructed on how to put on and adjust the Sennheiser HD580 headphones. After these instructions they were asked to fill the Simulator Sickness Questionnaire (SSQ) [21]. They were then given an oral and written explanation of the task. After the trial participants were asked to fill the SSQ again, followed by a second questionnaire on reactions to various aspects of the experiment. After completing the questionnaire, participants were debriefed, compensated, and dismissed.

### 3.6. Experimental Design

A between-subjects design was used for this experiment. Eighty-two participants were randomly assigned to one of three groups. Group 1 was given condition 1 with left-right movements, group 2 given condition 2 with random movements, and group 3 given condition 3, the control condition, with no movements. Group 1 consisted of twenty-eight participants, group 2 of twenty-five and group 3 of twenty-seven participants.

## 4. RESULTS

The dependent measures were: the pleasantness of the experience (including simulator sickness), the perception of the sound space, and perceived cognitive load. The data from the various dependent measures were mostly analyzed using a one-way analysis of variance (ANOVA) with a fixed confidence level (p-value = .05). A seven-point Likert scale has been used in the questionnaire handed to participants after the trial (1 = ”I totally agree to the statement” and 7 = ”I totally disagree”).

#### *4.1.1. Simulator Sickness Questionnaire (SSQ)*

The SSQ introduced by Kennedy et al. [21] was used as a measure in this experiment. The symptoms used, and their weightings, are given in table 1.

| | | | | |
|---|---|---|---|---|
| General discomfort | None | Slight | Moderate | Severe |
| Fatigue | None | Slight | Moderate | Severe |
| Headache | None | Slight | Moderate | Severe |
| Eye strain | None | Slight | Moderate | Severe |
| Difficulty focusing | None | Slight | Moderate | Severe |
| Increased salivation | None | Slight | Moderate | Severe |
| Sweating | None | Slight | Moderate | Severe |
| Nausea | None | Slight | Moderate | Severe |
| Difficulty concentrating | None | Slight | Moderate | Severe |
| “Fullness of the head” | None | Slight | Moderate | Severe |
| Blurred vision | None | Slight | Moderate | Severe |
| Dizzy (eyes open) | None | Slight | Moderate | Severe |

| | | | | |
|---|---|---|---|---|
| Dizzy (eyes closed) | None | Slight | Moderate | Severe |
| Vertigo (Giddiness) | None | Slight | Moderate | Severe |
| Stomach awareness | None | Slight | Moderate | Severe |
| Burping | None | Slight | Moderate | Severe |

Table 1: The Simulator Sickness Questionnaire (SSQ) used as a measure in this experiment, the symptoms used, and their weightings.

The SSQ has three major subscales: nausea, oculomotor, and disorientation. Participants report the degree to which they experience each of the symptoms shown in table 1 as one of ``None", ``Slight", ``Moderate" and ``Severe" before and after the trial. These are scored respectively as 0, 1, 2 and 3. The subscales of the SSQ were computed by summing the scores for the component items of each subscale. Tables 2 and 3 show pre-exposure scores, post-exposure scores and differences between post- and pre-scores. To adapt the results to the requirements of measuring simulator sickness induced by a purely auditory stimulus, we neglected the scores for oculomotor problems.

| **Cond.** | **Nausea Pre Mean** | **Nausea Post Mean** | **Nausea Post-Pre Mean** |
|---|---|---|---|
| Left-right | 1.26 | 2.56 | 1.3 |
| Random | 1.08 | 1.6 | 0.52 |
| Control | .81 | 1.69 | 0.81 |

Table 2: Pre- and post exposure SSQ scores for nausea over all three conditions.

| **Cond.** | **Disorientation Pre Mean** | **Disorient. Post Mean** | **Disorient. Post-Pre Mean** |
|---|---|---|---|
| Left-right | 1.04 | 1.52 | .48 |
| Random | .36 | 1.12 | .76 |
| Control | .42 | .69 | .26 |

Table 3: Pre- and post exposure SSQ scores for disorientation over all three conditions.

**Nausea**

There was a near significant difference in subjective nausea scores.

A paired t-test showed a significant difference ($t(26) = -4.24$, $p < .001$) between pre ($M = 1.26$, $SD = 1.56$) and post ($M = 2.56$, $SD = 2.13$) exposure scores for nausea in the left-right condition.

A paired t-test showed a near significant difference ($t(24) = -1.83$, $p = .079$) between pre ($M = 1.08$, $SD = 1.29$) and post ($M = 1.6$, $SD = 1.58$) exposure scores for nausea in the random condition.

A paired t-test showed a significant difference ($t(26) = -2.76$, $p = .01$) between pre ($M = .081$, $SD = .8$) and post ($M = 1.69$, $SD = 1.95$) exposure scores for nausea in the control condition.

However, the results from an analysis of variance on the scores for each condition shown in table 2 did not indicate significant differences in perceived nausea between the conditions.

**Disorientation**

A paired t-test showed a significant difference ($t(24) = -2.28$, $p = .032$) between pre ($M = 0.36$, $SD = .57$) and post ($M = 1.12$, $SD = 1.81$) exposure scores for disorientation in the random condition.

However, the results from an analysis of variance on the mean scores for each condition shown in table 3 did not indicate significant differences in perceived disorientation between the conditions.

**SSQ Total**

The total SSQ score is obtained by adding the scale scores across the three columns and multiplying by 3.74. For the left-right condition the SSQ total is 6.65, for the random condition it's 4.79 and for the control condition 4.02.

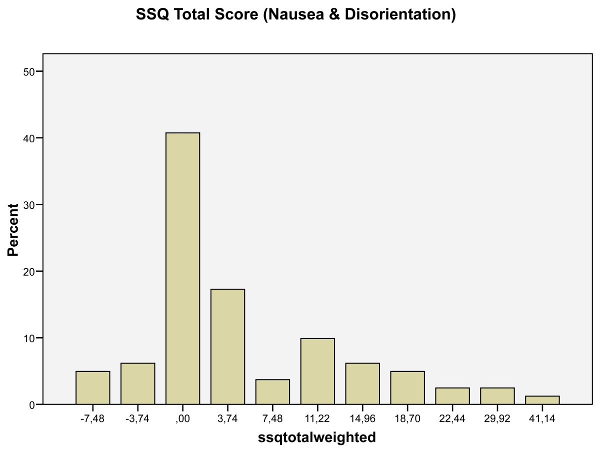


Figure 3: Frequencies for SSQ Total for all participants (N 81).

As can be seen in figure 3, 51.9 percent of all participants had a score of zero or below zero for the SSQ Total, indicating that they did not show any symptoms of simulator sickness.

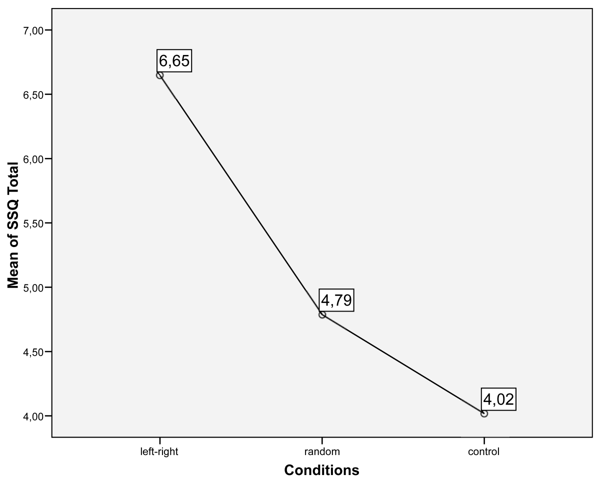


Figure 4: *Mean scores for SSQ total over all conditions.*

As illustrated by figure 4, no significant difference for SSQ Total could be found between the three conditions, but here is a trend towards a higher total score for the left-right condition.

### *4.1.2. Pleasantness*

In the post-study questionnaire we asked participants to agree or disagree to statements around the general pleasantness of the experience. This included statements as:

1. The task was pleasant.
2. The task was boring.
3. The listening experience was good.
4. I could have continued to listen to this for a longer period of time.
5. I would have liked to quit the test before the end.
6. The sound volume was just right.

Mean scores and standard deviations are summarized in table 4.

| Condition / Statement | N | Mean Score | SD |
|---|---|---|---|
| "The task was pleasant." | | | |
| Left-right | 28 | 4.89 | 1.6 |
| Random | 25 | 5.0 | 1.36 |
| Control | 27 | 3.74 | 1.5 |
| "The task was boring." | | | |
| Left-right | 28 | 3.71 | 2.12 |
| Random | 25 | 3.08 | 1.55 |
| Control | 27 | 2.85 | 1.38 |
| "The listening experience was good." | | | |
| Left-right | 28 | 5.25 | 1.65 |
| Random | 25 | 4.68 | 1.91 |
| Control | 27 | 4.04 | 1.74 |
| "I could have continued to listen to this for a longer period of time." | | | |
| Left-right | 28 | 6.29 | 1.15 |
| Random | 25 | 5.85 | 1.28 |
| Control | 27 | 5.15 | 1.82 |
| "I would have liked to quit the test before the end." | | | |
| Left-right | 28 | 4.32 | 1.87 |
| Random | 25 | 4.8 | 2.1 |
| Control | 27 | 4.85 | 1.9 |
| "The sound volume was just right." | | | |
| Left-right | 28 | 2.25 | 1.18 |
| Random | 25 | 1.72 | .74 |
| Control | 27 | 2.22 | 1.25 |

Table 4: Results from the post-study questionnaire on single items concerning the pleasantness of the experience.

Participants in the control group were on average indifferent about the pleasantness of the task. Participants from the left-right and the random group found the task to be significantly more unpleasant (F(2,77) = 5.39, p=.006, confirmed by a post hoc Bonferroni test with p=.022 for left-right and .014 for random) compared to the control group (cf. Figure 5).

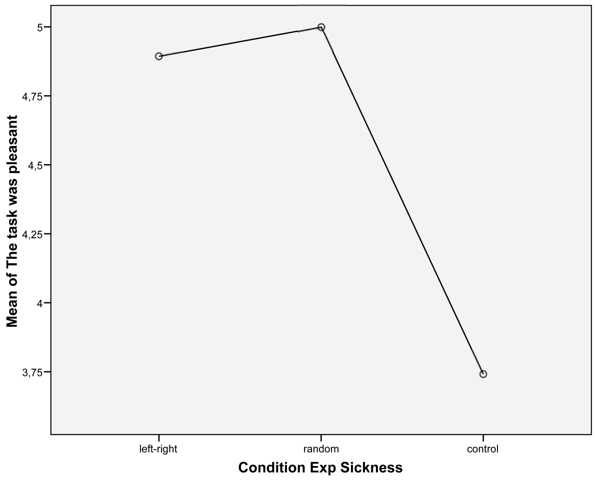


Figure 5: *Differences in mean scores for answers to the statement "The task was pleasant."*

Participants in the left-right group found the listening experience significantly worse (F(2,77) = 3.251, p=.044, confirmed by a post hoc Bonferroni test with p=.38) than participants in the control group (cf. figure 6).

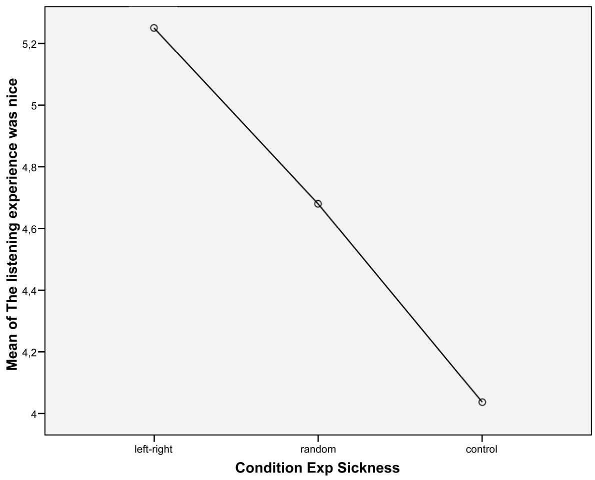


Figure 6: *Differences in mean scores for answers to the statement "The experience was nice/good."*

Both participants in the control group and the left-right group did not feel like they would want to listen to the sound space for a longer period of time. Though participants from the left-right group showed a significantly stronger (F(2,77) = 4.32, p=.017, confirmed by a post hoc Bonferroni test with p=.014) rejection (cf. figure 7).

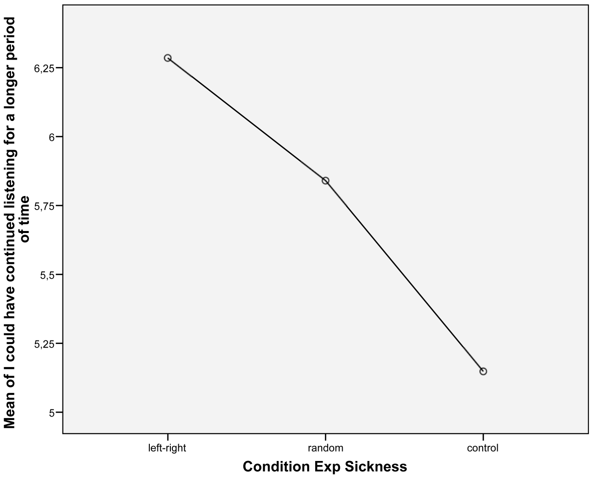


Figure 7: *Differences in mean scores for answers to the statement "I could have continued to listen to this for a longer period of time."*

Overall the results indicate, that the left-right condition was perceived to be significantly less pleasant than the random and control conditions.

#### 4.1.3. *Perception of the soundspace*

We also asked participants if they perceive the soundspace to be chaotic. As can be seen in figure 8, participants in the control group (N = 27, M = 3.37, SD = 1.85) found the soundspace to be significantly less chaotic (F(2,77) = 6.67, p=.002, confirmed by a post hoc Bonferroni test with p=.03) than participants in the left-right group (N = 27, Mean = 2.07, SD = 1.12).

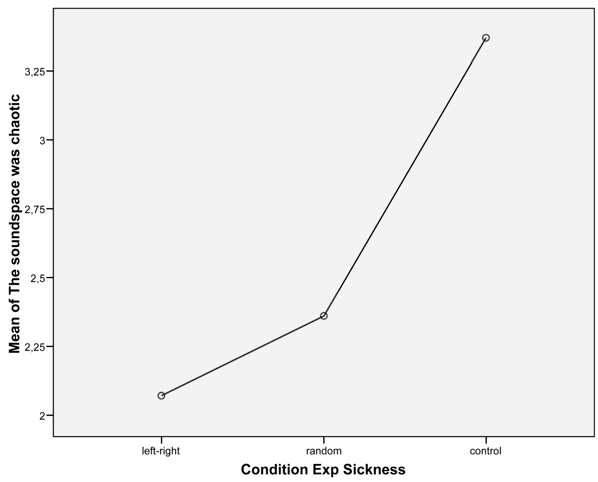


Figure 8: *Differences in mean scores for answers to the question whether the sound space was perceived to be chaotic.*

#### 4.1.4. *Cognitive load*

To measure the cognitive load of participants during the trial we evaluated the results from the listening task. Thirty-three nonsensical numbers were randomly inserted into the text. We could not identify a difference between the conditions (F(2,74) = .072, p=.931), in fact, the results are almost identical. For control (N = 25) the mean of detected nonsensical numbers is 31 (SD = 2.4), for left-right (N = 27) the mean is 30.67 (SD = 3.11) and for random (N = 25) the mean is 30.88 (SD = 3.96).

We also asked participants whether they found it difficult to concentrate on the task. The results shown in table 4 mirror the results from the evaluation of the task – participants were rather undecided, but showed a tendency in the random and control conditions towards having more difficulties concentrating on the task. Overall participants did not have difficulties completing the task. This appraisal is supported by low (with 1="I totally agree") mean scores for the statement "The task was easy" for all three conditions can be seen in table 4.

| Condition / Statement | N | Mean Score | SD |
|---|---|---|---|
| "It was difficult to concentrate on the task." | | | |
| Left-right | 28 | 4.04 | 1.67 |
| Random | 25 | 4.4 | 1.5 |
| Control | 27 | 4.41 | 1.82 |
| "The task was easy." | | | |
| Left-right | 27 | 3.22 | 1.55 |
| Random | 25 | 3.08 | 1.58 |
| Control | 27 | 2.44 | 1.5 |

Table 5: Results from the post-study questionnaire on how difficult participants rated the task.

#### 4.1.5. *Gender differences*

We found evidence for different perceptions of task and the sound space between men and women in this study:
Women (N = 33, M = 3.85, SD = 1.72) found it significantly more difficult (F(1,80) = 4.149, p = .045) to concentrate on the task than men did (N = 49, M = 4.59, SD = 1.55).
Both women and men did not want to listen to the sound space for a longer period of time. But women (M = 6.27, SD = .94) rejected significantly stronger the statement "I could have continued to listen to this for a longer period of time." (F(1,80) = 6.75, p=.011) than men (M = 5.43, SD = 1.7).

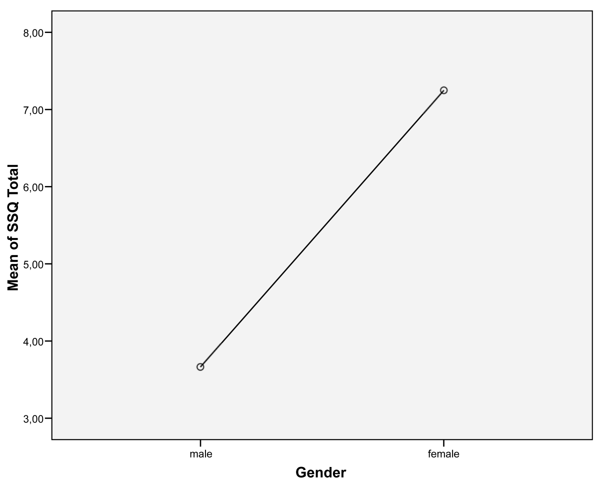


Figure 9: *Differences in mean scores for SSQ Total between men and women.*

As illustrated by figure 9, results from an ANOVA show a strong trend towards a significant difference (F(1,79) = 3.1, p = .082) between men (M = 3.66, SD = 6.89) and women (M = 7.24, SD = 11.44) in perceived simulator sickness (SSQ Total).

We also found a significant difference in ratings for the sound volume. Men and women found it to be very good, nevertheless men (M = 1.84, SD = .80) perceived it to be significantly better ($F(1,80) = 5.408$, $p=.023$) than women (M = 2.39, SD = 1.36).

## 5. DISCUSSION

Our first hypothesis (H1), that random, unpredictable spatial sound movements would make the experience more unpleasant could not be supported. Rather surprisingly, we found that predictable left-right movements generated stronger irritations and resulted in a higher perceived unpleasantness than did random or no movements. The sound space was also perceived to be more chaotic in the left-right condition. Again, this is surprising as random and unpredictable movements should have caused a delay in forming a correct mental model of the sound space and hence should have lead to the perception of a more chaotic sound space. One possible interpretation of this result is that because the left-right condition was generally thought to be less pleasant, participants associated the rather negative attribute "chaotic" with this condition. One explanation for why predictable movements scored high in terms of general unpleasantness may be that participants found it particularly annoying and boring to listen to these regular, predictable movement patterns for a rather long period of time (20 minutes), compared to the random patterns, which may have offered more challenge and hence more positive distraction.

Furthermore, our results did not support the hypothesis (H2) of a difference between the conditions in terms of distraction generated by the sound space. Our results do not support the assumption that unpredictable movements in the sound space have a different effect on the ability to concentrate on one sound source than have predictable or no movements at all. Participants found the task to be rather easy and made fewer errors than expected. This might indicate, that the low difficulty of the task may have clouded existent differences between the conditions. Further investigation is needed to fully understand if there is a difference in cognitive load between the conditions and to which extend.

Results from the SSQ showed significant differences between scores from before and after the trial throughout all conditions, especially for the sub-score nausea. An analysis of variance did not indicate significant differences in perceived nausea or disorientation between the conditions, but the SSQ Total showed a trend towards a higher total score for the left-right condition. This is supported by results from the post study questionnaire.
Our data indicated that women tend to be more susceptible to simulator sickness. This agrees with earlier findings by Kennedy et al. [22] and Biocca [23].

## 6. CONCLUSIONS AND FUTURE WORK

With our experiment we investigated whether there is an influence of movement patterns within a spatial sound space on the perceived pleasantness of the experience and the perceived cognitive load on a listener. Our user study indicates that predictable left to right movements lead to a perceived unpleasantness that is significantly higher than the unpleasantness experienced for unpredictable or no movements at all. Approx. 48 percent of all participants showed mild to moderate symptoms of simulator sickness, with a trend towards stronger symptoms for the left to right movements.

Keeping in mind that the experiment was designed with the intend to evoke symptoms of simulator sickness, the current data suggest, that even under these extreme conditions the perceived unpleasantness did not exceed an amount that would have lead to an abortion of the trial. Considering that unpredictable movements of sound sources in the sound space seem not to reduce the listening experience to a critical degree and that we could not provide evidence of a negative effect on cognitive load for simple tasks, we are rather optimistic about the use of spatial audio in mobile applications, such as navigation support systems, spatial auditory interfaces or entertainment applications.

There are several directions for future research. Although we tried to acknowledge some criteria of a mobile usage scenario, (eyes open, no fixed posture) we also neglected others. For this study we have not been able to include a realistic mobile setting, as for example an outdoors navigation task or task that forces the participant to react to an unpredictable environment.
It would also be very interesting to study the effects of a more consistent and realistic spatial sound space on a listener, like for example a sound stream that is binaurally recorded (using the ARA headset) by one person and listened to by another.
Furthermore it would be interesting to investigate the effects of spatial augmented reality audio applications, where a real sound environment is extended with virtual auditory environments, on the user experience.

## 7. ACKNOWLEDGMENTS

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