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Viewing experience of 3DTV: An exploration of the feeling of sickness and presence in a shopping mall

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ABSTRACT

The adoption and deployment of 3DTV can be seen as a major step in the history of television, comparable to the transition from analogue to digital and standard to high definition TV. Although 3D is expected to emerge from the cinema to peoples' home, there is still a lack of knowledge on how people (future end users) perceive 3DTV and how this influences their viewing experience as well as their acceptance of 3DTV. Within this paper, findings from a three-day field evaluation study on people's 3DTV experiences, focusing on the feeling of sickness and presence, are presented. Contrary to the traditional controlled laboratory setting, the study was conducted in the public setting of a shopping center and involved 700 participants. The study revealed initial insights on users' feeling of presence and sickness when watching 3DTV content. Results from this explorative study show that most of the participants reported symptoms of sickness after watching 3DTV with an effect of gender and age on the reported feeling of sickness. Our results further suggest that the users' previous experience with 3D content has an influence on how realistic people rate the viewing experience and how involved they feel. The particularities of the study environment, a shopping mall, are reflected in our findings and future research directions and action points for investigating people's viewing experiences of 3DTV are summarized.

1. Introduction

The new wave of 3D movies being released in cinemas makes the industry scramble to expand distribution into the home, whereby the overall excellence of 3D is influenced by several factors, such as content production, required high-level of compression, requirements set by transmission channel, and finally, by the quality of the display. A number of TV manufacturers, including Panasonic, Sony, and Samsung, are active in the development of 3DTV systems [26]. Different display technologies are available on the market at the moment, stereoscopic displays based on different techniques as well as autostereoscopic displays. However, as Chen et al. state [5], none of the existing 3D systems are ideal yet. Regardless what system is used, the final quality is determined by the users' perception [16], and the manufacturers still do not really know how consumers truly feel about 3DTV [32].

Research on users' needs and expectations for 3DTV has been conducted for mobile 3DTV and video (e.g., [16,18]). The quality of experience (QoE) of different stereoscopic content was evaluated by Häkkinen et al. [12] in a qualitative study, showing that stereoscopic projection technique enhances the emotions conveyed by the film material. Moreover, Jin et al. [15] compared the qualitative user experiences based on various auto-stereoscopic 3D displays.

Typically, 3D movies are still mainly available in the cinema. In the home context however, 3D content is sparsely used. We further assume that 3D games arrive sooner in the home context than 3D movies. The requirement for 3D glasses might be less of an issue for gamers in comparison with TV consumers. Given the willingness of gamers to adopt peripherals such as 3D glasses presents some unique issues around3D for this user group. Regarding the home context there are two more issues negatively influencing the deployment and adoption of 3DTV, namely the required change of the technical equipment by households (they have to buy a new 3D screen) as well as the only slowly growing availability of 3D content for private usage.

Despite the sparse availability of 3D content outside the cinema at the moment, we are convinced that 3D will find its way to public contexts like shops, malls, corporate buildings, etc. in the near future (e.g., for delivering information and displaying advertisements). The pervasion with 3D content will take place simply

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due to its more appealing nature, and its resulting positive effect on advertisement and sales numbers. Especially auto-stereoscopic displays, once available on the market at high prices in the beginning, will lend themselves to this form of deployment.

The focus of this paper is to investigate the feeling of sickness and presence when consuming 3D content. Providing people a good viewing experience, without any negative physical effects (e.g., feeling nauseous), is the goal of industrial efforts (see Section 2 for ongoing research efforts). As 3DTV aims to reach a high level of realism and involvement, we also measured the feeling of presence when watching 3DTV. Due to the limited availability of 3DTV-equipped households for performing a field evaluation study, we set up a public evaluation study in a shopping center as part of a bigger three-day science event of the University. Empirical data on 3D experience is also relevant for the utilization of 3D setups for different purposes (e.g., simulating real situations to study users' interaction with interactive technologies).

Within this paper, we first review the related work on 3DTV, focusing on sickness and presence as two aspects of the 3D viewing experience. Subsequently, the study set-up, including challenges posed by the public context, as well as the used methods, are described in detail. Next, the main study results are presented and discussed in detail. Last, we give a conclusion on the results as well as an outlook on future work.

2. Related work

In recent years, the amount of 3D content has steadily grown and studios are producing more and more 3D movies that are spreading across the market and appreciated in dedicated cinemas. According to a recent study from NPD display research[1], the spreading of 3D HDTV technology rose 27% until September 2011. The pervasion of the home theatre market in the US with 3D technology, for instance, reaches a number of 16% and grew 21% in the third quarter of 2011. These numbers indicate the importance of 3D technology in the current entertainment market and pinpoint the two most important technologies.

3D HDTV devices provide a high-resolution 3D image with high levels of brightness and good contrast, which allows viewing 3D content in brightly lit rooms. 3D projectors on the other hand can produce a bigger image and are usually applied in home theatre settings where lower ambient light settings apply. The prices of projectors are significantly lower than for 3D HDTV devices. However, due to the already broader pervasion of 3D HDTV devices and the availability of traditional TV devices which may be more easily replaced by 3D technology enabled TV sets, 3D HDTV is gaining importance. Another advantage of 3D HDTV devices is that they not only support glasses-based 3D projection based on shutter-glasses (active 3D) or anaglyphic or polarization glasses (passive 3D) but also auto-stereoscopic 3D that allows the viewing of 3D content without glasses [6].

Another type of device stemming from a different area are small handheld devices like smartphones (e.g., the HTC EVO 3D Sprint[2]) that do not only allow the viewing but also the capture of 3D content. Another device that was built by Nintendo introduced 3D technology (Nintendo 3DS) also in the mobile gaming area by using a glasses-free auto-stereoscopic visualization approach. Regardless of the new technological developments and innovations, the final quality of a 3D system and content depends on the users' perception and experiences. Most studies still focus on the image quality, on technical aspects of the device, or on physiological factors of the user (e.g., [1,6,7,13,19,22,23,25,34,35]). There are only a few studies that focus on the user/viewer experience when watching 3DTV.

Jumisko-Pyykkö et al. [18] highlight that in 2008 no field study investigating users' experience with 3DTV was available. Until now, most studies have dealt with mobile 3DTV (e.g., [4,9,16–18,31]). There are only a few studies exploring 3DTV in general [27]. Furthermore, we found no studies considering the future deployment of 3DTV screens in a living room environment.

Jumisko-Pyykkö et al. [16] present a descriptive model of the quality of experience for mobile 3DTV. Thereby, the viewing experience and the visual quality (depth-naturalness, spatial, motion) are main components of the quality of experience. Further components are content and audiovisual quality. The viewing experience itself is primarily described by the following four components: ease of viewing, pleasantness of viewing, enhanced immersion and visual discomfort [16]. Ease of viewing and pleasantness describe how easy it is to concentrate on 3D content and whether it is comfortable or not to watch 3D content. Enhanced immersion refers to a high level of involvement and realism. This mainly represents the positive effects of viewing 3DTV. Visual discomforts as eyestrain, and other related discomforts as sickness or headache, summarize the negative effects that can possibly occur whilst viewing 3DTV. Further aspects of the viewing experience are the comparison to familiar technology (if the user perceives the 3D technology as an improvement compared to existing technology) and an overall impression of quality. In order to find improvements for mobile 3DTV devices, Shibata et al. [31] compared the viewing experience of watching 3D content on a mobile device with watching on a large 3D screen, highlighting the effect of smaller screen size on felt discomfort, such as visual fatigue.

In general, most of the studies on 3D experience focus on the negative experiences that may come along with watching 3D content, such as eyestrain, nausea, vertigo, etc. Sickness is one of the main discomforts that may arise after or during watching 3D content. Häkkinen et al. [12] also points out the possible influence of the digital content on the experienced sickness level. Moreover, Ijsselsteijn [14] raises the discussion on the effects of the used production techniques for 3D movies on the users experience.

A questionnaire investigating users' sickness is the simulator sickness questionnaire (SSQ), which was originally developed to investigate sickness symptoms in flight simulators (see [20,21]). This questionnaire has already been proven to be appropriate for exploring sickness symptoms in environments such as driving simulators, head-mounted displays, virtual games displays and mobile screens (see [10,11,17,24,27]). The SSQ has also been used for 3D content (see e.g., [10,11,17,27]), but only in an experimental laboratory setting and not in field studies. For example, Jumisko-Pyykkö et al. [17] used the SSQ to analyze the effect of time on the appearance of sickness symptoms after watching 3DTV on portable devices. They conducted five experiments where 3D content of different length was displayed to participants. Similar to previously cited studies, their results show an increase of sickness symptoms caused by watching 3DTV. In their study they especially investigated how long sickness symptoms remain after watching 3DTV. They found that this takes less than four minutes for a short viewing time (till 15 minutes), and slightly more for a longer viewing time. Additionally they found out that symptoms did not increase significantly with a longer viewing time.

Häkkinen et al.[12] and Jumisko-Pyykkö et al. [18] claim that next to negative effects such as sickness, positive experiences created by watching 3D content should also be taken into account, as they motivate people to watch 3D content. In a laboratory study, Häkkinen et al. [12]compared the different experiences viewers have after watching stereoscopic and non-stereoscopic clips. Their findings show a wide spectrum of both positive and negative experiences (e.g., realism and presence).

[1] See http://www.displaysearch.com/
[2] See http://www.htc.com/us/products/evo3d-sprint/

"Presence is generally defined as a users' subjective sensation of 'being there' in a scene depicted by a medium" [1]. Gotchev et al. [9]describe presence as the main motivation for users to watch 3D content on large mobile screens. In addition, the users' feeling of presence was found to be a relevant influencing aspect on the user's experience of 3DTV. Based on a focus group study, Freeman and Avons [8] stated that users described presence as a feeling of "being there". Reasons mentioned were that content in 3D looks more real than in 2D, and that user involvement and immersion are increased when watching 3D content. According to their study results, live events (sport events, music concerts, theatre) and action movies are the best-suited content for 3DTV, providing the highest level of presence.

When investigating a range of non-interactive and interactive media, Lessiter et al. [24] found that the medium influences peoples' rating of different presence components. Following the study results of Rajae-Joordens [27], involving a small sample of 20 participants, 3D displays lead to a higher feeling of presence compared to 2D displays in a gaming application. However, they found no significant differences between 3D and 2D in a TV context on the overall presence level, but significant increase of realism while watching 3DTV. Additionally, Riva et al. [29] found that presence was higher in emotional environments and that the level of presence influences the emotional state of the user.

With this paper, we aim at closing current research gaps by (1) investigating the users' experience of 3DTV beyond mobile devices and mobile 3DTV, and by (2) moving out from a laboratory setting into a field context for exploring people's viewing experiences with 3DTV. The latter is mainly defined due to the fact that we don't have access to households equipped with 3DTV technologies and the limit availability of 3DTV content, which would be necessary for investigating the people's viewing experiences as part of study in the home context. Thus, we opted for a public setting, a local shopping mall, to collect peoples' initial experiences with 3DTV.

3. Field evaluation study

Within this section we provide a detailed description of the study set up, contextual circumstances and methods used for the conducted field study. The study took place during a three-day science event at the University of Salzburg, Austria, in November 2010. The University board selected a couple of projects for different departments to present their research to the public in the largest shopping center in the city. The event was open for everybody for the whole three days.

Our main research goal was to investigate people's feeling of presence and sickness while watching 3DTV movies in the above described public setting. With regard to the previous research conducted by Häkkinen et al. [12], we investigated both negative and positive aspects of the user experience. Special attention was paid to users' feeling of sickness, as sickness is one of the main discomforts that may arise after or during watching 3D content.

The main research question was: *How do people perceive 3DTV?*In detail, we investigated

(1) How can the viewing experience be described withregard to the factors "feeling of sickness" and "feeling of presence"?
(2) What factors influence the viewing experience (e.g., are there effects of gender, age, or from previous experiences)?

Performing a user evaluation in a public environment like a shopping center brings several contextual particularities with it. For the study set up and the choice of methods we had to consider the following circumstances: high and low frequency of people at the booth (e.g., rush hours versus idle time) over the three days – that means that methods should not demand too much time from the participants; a busy environment with possible background influences (e.g., visual distraction, people chatting), and no influence on the selection of participants (all shopping center visitors were potential participants in the study and voluntarily became involved).

Contrary to a lab-based study, such a public study environment did not allow a controlled set up with fixed duration of exposition to the 3DTV, however it did enable us to get in contact with a huge amount of participants, normally unreachable in a laboratory context. People were recruited by passing-by and were free to watch 3DTV as long as they wanted. We estimate that the approximate viewing time for the 3D movies varied between 3 and 10 min between the study participants.

3.1. Study objects and set up

In cooperation with an industrial partner, four of their produced 3D movies were used for the study. The following four movies were displayed randomly on two 3D screens (JVC 3D LCD Monitor/GD-463D10E) for three days:

(1) Skiing (3 min).
(2) Space Jumping (3 min).
(3) Breakdance/two parts (30 s and 2 min).
(4) Body painting (3 min) – see Fig. 1.

Traditional high quality 3D projection settings require more space and are more sensitive to environmental light. The abovementioned 3DTV technology was used to be able to watch 3D visualizations in a public setting. Each of the two TV screens was connected to a Sony Playstation for a random playback of one of the movies. At the booth, 40 polarization 3D glasses were available and provided to people for watching 3DTV and getting engaged in our study.

The booth was set up with two armchairs and a table positioned in front of the 3DTV to simulate a kind of living room atmosphere (see Figs. 2 and 3) as often done in laboratory studies for iTV [2]. Participants were asked to sit down in a comfortable position while watching the 3D content. Behind the armchairs, two flat screens were positioned to visualize data collected from participants while watching for a potential audience.

The 3DTV on the right side was set up in a way to simulate a public viewing scenario, so people were standing in front of the TV screen. Feedback from people was collected by using a combination of different questionnaires, which are described in more detail in the following section.

Fig. 1. Example screenshot of the 3D movie "Body Painting" used in the study.

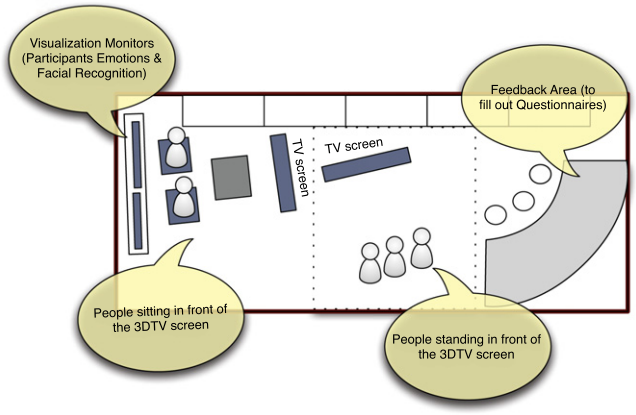

Fig. 2. Booth setup at the field evaluation study.

Fig. 3. Shopping mall as context for the field study with two set ups: on the top "sitting in front of the 3DTV screen" and on the bottom "standing in front of the 3DTV screen".

3.2. Used Methods

Different materials had been prepared at the booth in order to get people involved in the study. We used two different questionnaires, namely the Simulator Sickness Questionnaire (SSQ) [20] and the iGroup Presence Questionnaire (IPQ) [30], of which one was handed out to the participants. Both questionnaires included a sheet for collecting some basic demographic data, such as age and gender, need for visual aids and eye related problems, pre-experiences with 3DTV and additional information on previously experienced discomforts when watching 3D content.

The **Simulator Sickness Questionnaire (SSQ)** [20] was originally developed for evaluating computer-based simulator systems. It consists of a checklist of 16 symptoms from which three subscales (***nausea***, ***oculomotor related symptoms, disorientation***) and an ***overall score*** are computed. All symptoms are rated with regard to their severity on a 4-point scale, ranging from "none" (scored as 0), to "slight" (scored as 1), to "moderate" (scored as 2), and to "severe" (scored as 3). The subscales are computed involving a summing of the ratings and multiplying the resulting score by a weight score. Details about the values of the weight scores and how they were derived can be found in Kennedy [20]. The SSQ has already been applied successfully for evaluating 3DTV content (e.g., [17,27]) and thus was considered as appropriate for measuring the feeling of sickness. For our field study, we translated the items of the SSQ into German. Participants in our study were asked to fill in the SSQ before (pre) and after (post) they hadwatched the 3DTV content (participants received the 3D glasses after they filled out the first part of the SSQ).

The **iGroup Presence Questionnaire (IPQ)** [30] is a three-component self-reporting scale for measuring the sense of presence experienced in a virtual environment (VE). The items of the IPQ are originally defined and validated in German.

The sense of presence itself is defined as the sense of being there in the virtual environment. According to the authors, presence is a subjective experience similar to a feeling and has to be distinguished from the technological quality of the VE (often referred to as "immersion").

The three presence components of the IPQ are *Spatial Presence* – the sense of being physically present in the VE and directly interacting with it; *Involvement* – the attention devoted to the VE and the residual awareness of the real world; *Realness*–how real the virtual world is judged to be in comparison to the real world.

The additional general item (high loadings on all three components) assesses the general "sense of being there" and thus corresponds to the general definition of presence ("In the virtual environment, I had a sense of being there…").

In our field study, we used an adapted version of the IPQ for evaluating the feeling of presence when watching 3DTV. The adaption can be characterized by (1) leaving out the Spatial Presence subscale (i.e., all items loading on this component), as well as by (2) replacing the word "virtual environment"/"virtual world"/"computer-generated world" with the word "3D environment". The reason for leaving out the subscale on Spatial Presence was the public setting, which we thought would heavily influence and distract from a real feeling of spatial presence. Moreover, a study showed that Spatial Presence is more likely to be influenced by interactivity than Involvement and Realness (see [28]). As watching 3DTV is rather passive reception than active interaction, we decided to leave out the Spatial Presence component. The reason for changing some specific wordings was that the new phrasing applies better to 3DTV and leads to less confusion among our participants.

The focus of the adapted IPQ was thus on peoples' feeling of involvement and experienced realism when watching 3DTV in the public.Therefore, people were asked to fill in theIPQ after having watched the 3DTV content.

We used further materials at the booth to investigate other research questions we are not dealing with in this paper. We had prepared a special short questionnaire for children, who visited the science event with their school classes and families. Moreover, open feedback cards were provided to the children for collecting positive and negative experiences with 3DTV. As mentioned in the study setup, people's facial expressions and data on people's emotional status before and after watching the 3D content were collected using Fraunhofer's Shore Demo Software and an iPad application (called the EmotionPad). All this additional data is not included in this paper, but is in undergoing further analysis and publication. The focus of this paper is on the results from the sickness and presence measurements, which are presented and discussed in more detail in the following sections.

4. Results

In what is to follow, the main revealed insights on the people's feeling of sickness and presence are provided.

4.1. Participants

Overall, 700 participants took part in our study and filled in either the simulator sickness questionnaire (SSQ) or theiGroup Presence Questionnaire (IPQ)[3].

The mean age of the participants was 32.37 ($N = 618$; SD = 15.43), with the youngest participant 11 years old and the oldest 81 years old. 43% of the participants were female, 57% were male ($N = 623$). 55% of the participants do not use any visual aids. The remaining 45% indicated to either use contact lenses (12%) or glasses (34%) during watching the 3DTV movies ($N = 602$). 4% of the participants suffered from color blindness ($N = 609$). 20% of the participants indicated to have problems with their eyes ($N = 597$), for example different diopter power or dry eyes. 79% of the participants have already watched a 3D film or video ($N = 616$). Thereof, 19% had seen a 3D movie once, 57% 2–5 times, and 24% more than 5 times ($N = 482$). The largest group indicated to have watched 3D content in the cinema (92%; $N = 489$). We found a weak correlation between age and previous 3D experience: the younger the participant, the higher is the previous experience, Pearson's $r(607) = -0.23$, $p < 0.001$. 26% of the participants reported that they had already suffered from discomfort during or after watching a 3D movie before they took part in this study ($N = 700$). The most often indicated symptoms were eyestrain (48%), feeling of dizziness (44%), and headache (43%).

4.2. Feeling of Sickness

In order to investigate if discomforts arise after watching 3DTV, the SSQ (see Section 3.2) was handed out to participants before and after watching 3DTV at our booth. The questionnaire comprised 16 items in total, covering the nausea (N), disorientation (D), and oculomotor(O) subscale as well as a total score. Further, demographic data was collected with the questionnaire.

In our three-day field study, 229 simulator sickness questionnaires (SSQ) were filled in. The SSQ symptom scores (immediately after watching the 3D movies) were calculated according to Kennedy et al. [20], with the post scores not being subtracted from the pre scores (before watching the 3D content). For the total sickness score (post), an average value of 23.70 ($N = 219$, SD = 24.72) was found.[4]

Figs. 4 and 5 show the distribution of the total sickness scores that were obtained for the 219 cases before and after watching 3DTV. Fig. 5 illustrates that 27 participants (about 12%) reported no symptoms after watching 3DTV (total score post = 0), whereas the other part (88%) reported various symptoms of sickness from mild to severe. Before watching 3DTV (see Fig. 4), about 21% ($N = 229$) reported no sickness symptoms, these are 49 participants. 79% reported various sickness symptoms before watching the 3D content.

Concerning the subscores of the SSQ (Nausea-related (N), Oculomotor-related (O), Disorientation-related (D) symptoms), participants reported highest values for the Disorientation-related subscore ($M = 29.87$, SD = 35.94), followed by the Oculomotor-related subscore ($M = 21.39$, SD=20.73). The lowest values were reported for the Nausea-related subscore ($M = 13.07$, SD = 19.57).

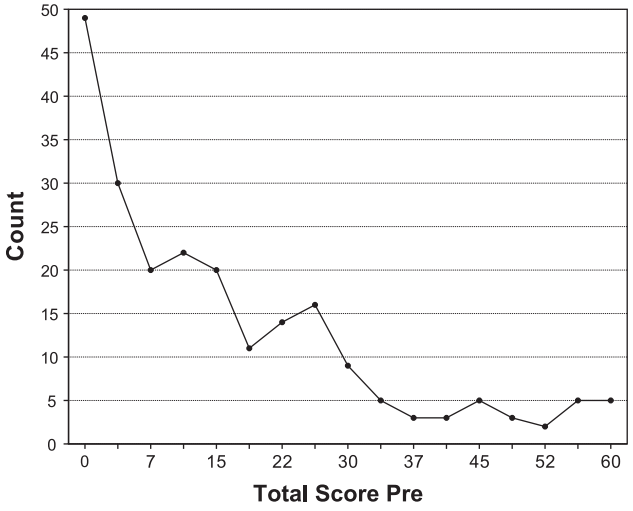

Fig. 4. Frequency distribution of total sickness score before watching 3DTV, with 21% reporting no symptoms.

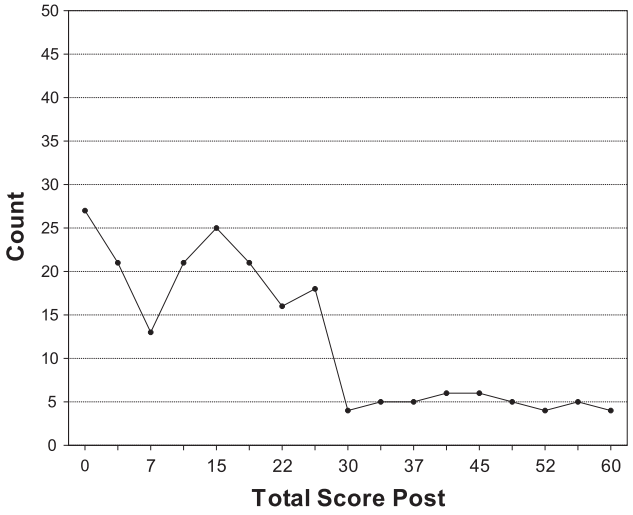

Fig. 5. Frequency distribution of total sickness score after watching 3DTV, with 12% reporting no symptoms.

A paired-samples t-test was conducted to compare pre- and post-task symptom scores (Fig. 6 shows the distribution of the subscores). For the total score, we found a significant difference before ($M = 16.75$, SD = 18.46) and after watching 3DTV ($M = 23.70$, SD = 24.72); $t(218) = -4.49$, $p < 0.001$. A significant difference was also found for the Disorientation-related sub-score before ($M = 15.45$, SD = 23.54) and after watching 3DTV ($M = 29.87$, SD = 35.94); $t(218) = -6.36$, $p < 0.001$. Another significant difference was found for the Oculomotor-related sub-score before ($M = 16.65$, SD = 16.43) and after watching 3DTV ($M = 21.39$, SD = 20.73); $t(218) = -3.50$, $p = 0.001$. No significant difference before and after watching 3DTV was found for the Nausea-related subscore:Nausea pre ($M = 11.20$, SD = 16.82), Nausea post ($M = 13.07$, SD = 19.57); $t(218) = -1.51$, $p = 0.134$. The difference between the means of the scores before and after watching 3DTV was highest for disorientation, with the mean score twice as high after watching 3DTV than before. Furthermore, disorientation had the highest average score after watching 3DTV compared to the nausea, oculomotor, and total score. In general, more symptoms occurred after

[3] Not all participants completed the short demographic section attached to both questionnaires – e.g. some participants were not willing to name their age or report on previous 3D viewing experiences.

[4] This number is smaller than the total number of returned questionnaires as 10 participants did not fill in the second part of the SSQ (post scores missing).

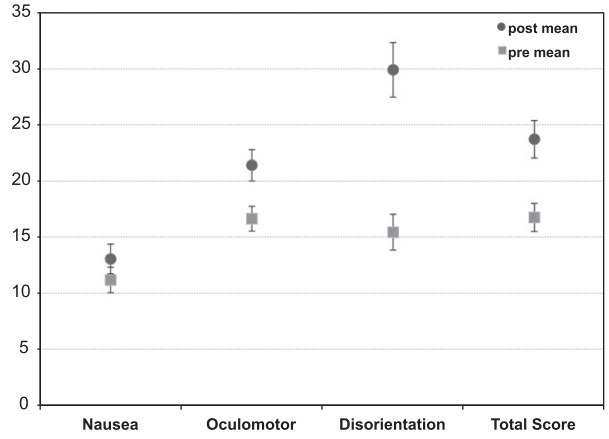

Fig. 6. Difference in the sub-scores and total score of the SSQ before and after watching 3DTV (the error bars represent the standard error).

watching 3DTV than before. Before watching 3DTV, 676 symptoms had been denoted by 180 persons. After watching 3DTV, 842 symptoms were denoted by 192 persons.

When regarding the occurrence of single sickness symptoms of the SSQ, fatigue is the symptom that was mentioned most frequently both before and after watching 3DTV (before: 81%, after: 54%). A paired-samples *t*-test showed that the decrease in mentioning this symptom after watching 3DTV is significant (see Table 1). Furthermore, fatigue was the only symptom decreasing significantly after watching 3DTV.

Table 1 shows the average rating of the severity of sickness symptoms before and after watching 3DTV. Fatigue is the only symptom with a significantly lower score after watching 3DTV. Significant increases in mean scores after watching 3DTV were found for the following symptoms: headache, eyestrain, difficulty focusing, blurred vision, nausea, dizzy eyes open, dizzy eyes closed, vertigo. Highest differences in means before and after watching 3DTV can be found for fatigue, blurred vision, eyestrain and dizziness. These results indicate that watching 3DTV mostly affects symptoms related to the eyes (regarding both frequency of occurrence and average differences before and after watching 3DTV). Except of the symptom nausea, the rating of the nausea-related items (N) before and after watching 3DTV does not change significantly. The nausea-related items increased salivation, sweating, stomach awareness, burping, difficulty concentrating, and general discomfort remain stable after exposure to 3DTV (see Table 1) and thus do not seem much affected by 3DTV.

Table 2 shows a ranking of the most frequently mentioned symptoms after watching 3DTV. Symptoms related to the eyes (e.g., fatigue, difficulty focusing, blurred vision, eyestrain, dizziness with eyes closed) occurred most often. When comparing the frequencies of symptoms before and after watching 3DTV, dizziness (eyes open) and nausea show the highest increase regarding their incidence, which appear more than twice as often after watching 3DTV than before. The incidence of eyestrain and blurred vision is also almost doubled after watching 3DTV.

Regarding the sub-scores and the total score, significant differences and correlations for the sub-scores and total score were identified. An independent-samples *t*-test revealed a difference in the scores for gender, with females reporting significantly higher symptom levels in the total score as well as in the oculomotor-related and disorientation-related sub-scores before and after watching 3DTV (see Table 3). The highest difference was found for the oculomotor score, with females reporting almost as twice as high mean scores (both before and after watching 3DTV) than males. The lowest difference was found for the nausea-related

Table 1
Mean Differences for single Sickness Symptoms comparing Pre and PostScores (paired-samples *t*-test).

	Symptoms			
	Pre	Post	*t*	df
Fatigue (O)	0.88 (0.82)	0.61 (0.73)	5.91***	218
Headache (O)	0.16 (0.41)	0.29 (0.54)	−3.83***	218
Eyestrain (O)	0.18 (0.43)	0.42 (0.60)	−5.48***	217
Difficulty focusing (O,D)	0.29 (0.59)	0.43 (0.60)	−2.92**	216
Nausea (N,D)	0.07 (0.27)	0.14 (0.38)	−2.88**	218
Blurred vision (O,D)	0.20 (0.48)	0.48 (0.72)	−5.56***	217
Dizzy (eyes open) (D)	0.07 (0.28)	0.26 (0.54)	−5.40***	218
Dizzy (eyes closed) (D)	0.20 (0.45)	0.40 (0.67)	−5.04***	218
Vertigo (D)	0.08 (0.30)	0.18 (0.46)	−3.05**	217
General discomfort (N, O)	0.20 (0.53)	0.27 (0.55)	−1.48	218
Increased salivation (N)	0.13 (0.40)	0.14 (0.43)	−0.16	218
Sweating (N)	0.25 (0.52)	0.24 (0.55)	0.46	217
Difficulty concentrating (N, O)	0.29 (0.53)	0.32 (0.58)	−0.70	217
Stomach awareness (N)	0.16 (0.44)	0.18 (0.46)	−0.60	217
Burping (N)	0.07 (0.36)	0.08 (0.40)	−0.43	216
Fullness of head (D)	0.20 (0.49)	0.25 (0.51)	−1.36	216

Note: $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. Standard Deviations appear in parentheses below means. Beside symptoms the sub-score to which they belong is denoted in parentheses.

Table 2
Ranking of "Post" symptoms appeared according to frequency (see "Pre" symptoms for comparison in the rightmost column).

Ranking	Frequency post (percent of cases)	Frequency pre (percent of cases)
Fatigue	104 (54%)	146 (81%)
Difficulty focusing	82 (43%)	52 (29%)
Blurred vision	80 (42%)	42 (23%)
Eyestrain	79 (41%)	40 (22%)
Dizzy (eyes closed)	70 (37%)	47 (26%)
Difficulty concentrating	57 (30%)	64 (36%)
Headache	56 (29%)	33 (18%)
General discomfort	50 (26%)	38 (21%)
Fullness of head	46 (24%)	44 (24%)
Dizzy (eyes open)	46 (24%)	18 (10%)
Sweating	42 (22%)	49 (27%)
Vertigo	33 (17%)	18 (10%)
Stomach awareness	33 (17%)	34 (19%)
Nausea	29 (15%)	14 (8%)
Increased salivation	24 (13%)	26 (14%)
Burping	11 (6%)	11 (6%)
	N = 192	*N* = 180

Table 3
Differences in Mean Scores of sickness between females and males (independent-samples *t*-test).

	Gender			
	Females	Males	*t*	df
Nausea-related sub-score				
Pre	12.04 (19.43)	8.55 (13.17)	1.43	178
Post	14.31 (15.74)	9.74 (17.44)	1.82	175
Oculomotor-related sub-score				
Pre	20.12 (17.90)	11.21 (12.30)	3.84***	144
Post	28.38 (22.25)	15.64 (17.33)	4.20***	152
Disorientation-related sub-score				
Pre	18.73 (25.43)	11.17 (17.56)	2.29*	145
Post	39.21 (37.70)	21.10 (28.78)	3.55**	150
Total score				
Pre	19.68 (20.54)	11.88 (14.23)	2.99**	178
Post	30.15 (23.93)	17.20 (20.90)	3.80***	162

Note: $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. Standard Deviations appear in parentheses below means.

score, where we found only slight differences in the mean scores of females and males, which were not statistically significant.

We further found a correlation between age and the reported symptom scores (see Table 4), where age was negatively correlated with the symptom levels. This means that the total score, the oculomotor-related sub-score (both before and after 3DTV exposure), as well as the nausea-related sub-score (before 3DTV exposure) significantly decreased with increasing age of the participants.

Finally, an interesting finding was that the mean scores of participants having previous experience with 3DTV were always higher than the scores of those without any previous experience. However, an independent-samples *t*-test revealed only significant differences for the oculomotor-related sub-score after watching 3DTV, ($M_{previous\ experience} = 22.97$, SD = 21.40, $M_{no\ experience} = 16.24$, SD = 18.00; $t(81) = -2.01$, $p = 0.048$). Participants with previous 3D experience showed significantly higher oculomotor-related sub-score compared to participants without previous experience. These results let us assume that people with previous 3D experience are more affected with eye-related discomforts after watching 3DTV compared to people who watch 3DTV the first time.

The main results from the SSQ can be summarized as follows:

- Symptoms reported most often concerned the visual system (eyes). These symptoms significantly increased after exposure to 3DTV.
- Symptoms concerning the gastric system (stomach) were reported least; these symptoms remained relatively stable (i.e., do not change significantly after exposure).
- There is a difference between male and females in the reported symptom level (symptom level higher for females in TS, D, O).
- The reported symptom levels decreased with increasing age.

4.3. Feeling of presence

In order to investigate the feeling of presence when watching 3DTV, an adapted version of the IPQ (see Section 3.2) was handed out to participants after watching 3DTV at our booth. The questionnaire comprised 9 presence items in total, covering the three presence components general presence, realism, and involvement. Further, demographic data was collected. In total, 471presence questionnaires were filled in during the three-day field study. When watching the 3D movies, most of the participants were standing in front of the TV screen ($n = 427$); only a minority was sitting in an armchair ($n = 44$).

When conducting an independent-samples *t*-test, significant differences were found in the ratings of people who had already seen a 3D movie before watching 3DTV at our booth ($n = 350$) and those who had not ($n = 89$), see Table 5[5]. The latter indicated to have higher general presence compared to those who had already seen a 3D movie. Those who had not seen a 3D movie before felt more involved compared to those who had already seen such a movie. Participants who had no previous experience with 3D movies perceived the movies as more realistic compared to participants with previous experience. These results suggest that people who watch a 3D movie the first time feel higher general presence, perceive the movie as more realistic, and feel more involved than people who have seen 3D movies before.

Table 4
Pearson's product moment correlations for scores of sickness with age and gender.

	Age	Gender
Nausea-related sub-score		
Pre	−0.22**	−0.11
Post	−0.13	−0.14
Oculomotor-related sub-score		
Pre	−0.18*	−0.28***
Post	−0.18*	−0.31***
Disorientation-related sub-score		
Pre	−0.08	−0.17*
Post	−0.11	−0.26***
Total score		
Pre	−0.18*	−0.22**
Post	−0.16*	−0.28***

Note. $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. $N(\text{Age})_{pre} = 181$, $N(\text{Age})_{post} = 178$, $N(\text{Gender})_{pre} = 180$, $N(\text{Gender})_{post} = 177$.

Table 5
Differences in means between people with and without previous experience with 3DTV (independent-samples *t*-test).

	Previous experience			
	No	Yes	*t*	df
General Presence	3.75 (1.82)	3.25 (1.72)	2.44*	437
Involvement	3.21(1.04)	2.84(1.25)	2.83**	159
Realism	3.57 (1.05)	3.23 (0.91)	2.73**	124

Note: $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. Standard Deviations appear in parentheses below means.

We further observed a slight correlation between the number of 3D movies already seen and the general presence perceived, Pearson's $r(435) = -0.10$, $p = 0.038$, as well as between the number of 3D movies seen and the rated realism, Pearson's $r(435) = -0.11$, $p = 0.022$. This suggests that the higher the number of already seen 3D movies is, the lower is the rating of general presence and realism.

When having seen a 3D movie before, the place of reception also had an influence on the rating. An independent-samples *t*-test showed that people who had already watched a 3D movie in the cinema perceived the 3D movie(s) presented in the shopping mall as less realistic ($M = 3.23$, SD = 0.88) than those who had never seen a 3D movie in the cinema before ($M = 3.51$, SD = 1.12); $t(158) = 2.34$, $p = 0.020$. Such a significant difference was not found for other places where a 3DTV movie was seen (e.g., TV, computer, mobile phone, others).

An independent-samples *t*-test showed no differences in the ratings of the three presence components (general presence, realism, involvement) for (1) participants who used visual aids and those who did not as well as for (2) participants who suffered from defective vision sight and those who did not. Further, we found no differences in gender for the general presence item as well as for the realism and involvement scores. A slight correlation between age and realism was found for age, showing that the older the participants, the more realistic they experienced 3DTV, Pearson's $r(435) = 0.16$, $p = 0.001$.

Concerning previously experienced discomforts and 3DTV (question in the demographic questionnaire part: "Have you ever suffered from any of the discomforts (listed below) during or after watching a 3D movie?"), an independent-samples *t*-test showed a significant difference in the ratings of people who had suffered from headache when watching a 3D movie before and those who had not. Those who had never suffered from headache rated the general presence item higher ($M = 3.39$, SD = 1.67) than those who had already suffered from headache when watching a 3D movie ($M = 2.44$, SD = 1.78), $t(347) = 3.86$, $p < 0.001$. The factor involvement was also rated higher by the participants who did not indicate headaches when watching a 3D movie ($M = 2.90$, SD = 1.24) compared to those who did ($M = 2.53$, SD = 1.23); $t(347) = 2.03$, $p = 0.043$. Concerning the factor realism, those who had never suffered from a headache when watching a 3D movie

[5] The relatively high number of missing values is caused by the fact that some participants did not fill in the second part of the questionnaire (demographic part).

Table 6
Differences in means between people standing and sitting during watching 3DTV (independent-samples *t*-test).

	Position standing	sitting	*t*	df
General Presence	3.34 (1.77)	3.25 (1.75)	0.31	468
Involvement	2.84 (1.19)	3.30 (1.28)	−2.42*	468
Realism	3.28 (0.95)	3.52 (0.84)	−1.57	469

Note: $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. Standard Deviations appear in parentheses below means.

rated this factor higher ($M = 3.30$, SD = 0.91) than those who had already suffered from headache when watching a 3D movie ($M = 2.89$, SD = 0.81), $t(347) = 3.06$, $p = 0.002$. These findings suggest that people who had not suffered from headaches when watching a 3D movie experienced higher levels of involvement, realism and general presence. Previously experienced headache when watching 3DTV seems to affect general presence most, as the difference between means is highest (compared to involvement and realism).

Reports of eyestrain are also related to the feeling of realism indicated: Conducting an independent-samples *t*-test, we found that participants who had never experienced eyestrain when watching a 3D movie rated the 3D movie as more realistic ($M = 3.29$, SD = 0.89) than those who had experienced eyestrain ($M = 2.96$, SD = 0.94); $t(347) = 2.59$, $p = 0.010$. However, no significant differences were found between previously experienced eyestrain when watching 3DTV and general presence as well as involvement.

Regarding discomforts in general (subsuming any symptoms experienced during or after watching a 3D movie), an independent-samples *t*-test showed that those participants who reported no discomforts at all when having watched a 3D movie rated the movies as more realistic ($M = 3.31$, SD = 0.90) compared to those who did ($M = 3.09$, SD = 0.91); $t(347) = 2.21$, $p = 0.028$. Based on these findings we assume that previously experienced discomforts have an influence on the feeling of presence (particularly on the factor realism). No significant differences were found between previously experienced discomforts and general presence as well as involvement.

The position in which the 3D movie was watched also had an influence on the viewing experience: An independent-samples *t*-test revealed that participants who were sitting in an armchair during watching the 3D movie(s) felt more involved than those who were standing when watching the movie. No significant differences were found between position and general presence as well as realism (see Table 6).

The main results from the IPQ can be summarized as follows:

- People who watch a 3D movie the first time feel higher general presence, perceive the movie as more realistic, and feel more involved than people who have seen 3D movies before.
- People sitting in front of the 3DTV screen experience a higher feeling of presence (i.e., involvement) compared to people standing in front of the 3D screen.

5. Discussion

Sickness or discomforts when watching 3D movies are important aspects to consider when designing or developing for a good viewing experience. This is reflected by the high number of participants (26%) who indicated that they already suffered from discomforts like eyestrain, feeling of dizziness or headache during or after watching a 3D movie (before participating in this study). Participants indicated this previous experience for 3DTV, but also for 3D in the cinema or on other devices. Interestingly, these previously experienced discomforts have an influence on future 3D experiences. We found that such previously experienced discomforts when watching 3D movies influenced the perceived realism of the movie in a negative way. Thus, the perceived sickness also affects other viewing experience factors, such as presence, and needs to be studied in more detail. In the following discussion, the findings from this explorative study are presented and discussed more thoroughly with respect to the feeling of sickness and presence.

The revealed profile for 3DTV sickness – the disorientation (D), oculomotor (O), and nausea (N) sub-scores – (D > O > N) differs from the profiles emerged in other application fields. We found that the exposure to 3DTV causes more disorientation (D) than oculomotor-related (O) disturbances, and even fewer nausea-related (N) symptoms. In contrast, simulator sickness causes an O > N > D profile, virtual environment sickness a D > N > O profile, space sickness an O > D > N profile and airsickness an N > D > O profile (see summary in [33]). Based on these findings, it can be assumed that 3DTV sickness is constituted in a special way. For verifying this assumption, however, further studies are needed.

Our findings support previous work on viewing experiences [16], listing visual discomforts as important negative effect when watching 3DTV. 3DTV seems to put most strain on people's eyes. This can be indicated as the most frequently mentioned symptoms are strongly related to the visual system. Interestingly, there were no significant differences in gastric symptoms (stomach awareness, increased salvation, burping) before and after watching 3DTV, indicating that the stomach is not affected very much by watching 3DTV. Possibly, the gastric system needs more time to experience the symptoms. However, as the study results on mobile 3DTV of Jumisko-Pyykkö et al. [17] show, the sickness scores did not increase with a longer viewing time.

A possible explanation for the finding that people feel less tired after watching 3DTVcould be the distraction from typical activities in the shopping context and the exceptionality of the novel technology people were confronted with during the science event in the shopping center. Compared to 2DTV viewing, it could be further assumed that a higher presence level due to watching 3DTV leads to a decreased fatigue level. The influence of 3DTV on perceived fatigue needs to be investigated in more detail in future studies (taking initial study results from [27] into account).

Similar to Häkkinen et al. [10], our results also revealed a difference in the scores of sickness regarding gender. Compared to male participants, females are reporting significantly higher symptom levels in the total score as well as in the oculomotor-related and disorientation related sub-scores before and after watching 3DTV.Especially regarding oculomotor-related symptoms, females have as twice as severe symptoms on average as male participants.

However, we differ from previous work [10] when comparing our study results regarding the influence of age on the feeling of sickness. We found a correlation between age and the reported symptom scores, where age was negatively correlated with the symptom levels. Our results showed that the feeling of sickness significantly decreased with increasing age of the participants, whereas Häkkinen et al. [10] stated an increase of the symptoms with increasing age. They assumed that the correlation between the increase of eyestrain and age are caused by age changes of the oculomotor system. Their study, however, focuses on stereoscopic experiences with head mounted displays. In contrast, this study focused on experiences with stereoscopic displays watched at a certain distance. This might explain the differences in the correlation of age and symptoms. Age also has a slight influence on the realness component of presence: the older the more realistic participants rated the 3D movies.

Watching 3DTV the first time has an effect on the rating of 3DTV in a positive way, as people feel more involved and report less

symptoms of sickness. This "first experience effect" could explain the decrease of symptoms with increasing age as a consequence of watching 3DTV the first time. Thus, when developing 3DTV entertainment, it has to be kept in mind that involvement decreases with increasing usage.

People who had already watched a 3D movie in the cinema perceived the 3D movie(s) presented in the shopping mall as less realistic than those who never had. This could be due to the more immersive setting of the cinema context where a dark environment, a big screen, spatial audio, etc. provide a stronger feeling of presence (compared to the3DTV setting in the public context). This results support the viewing experience component of Jumisko-Pyykkö et al. [16], in particular the "comparison to existing technology" aspect.

The viewing setup (i.e., sitting or standing) influences the viewing experience in terms of perceived involvement. Those who are sitting while watching the 3D movies feel more involved than the participants standing in front of the screen. However, this could be alternatively explained by the fact that the participants of the living room setting spent more time watching the 3D contents. Time is a relevant aspect to consider in future studies in order to better understand user engagement related to different influential aspects, such as content and viewing set up. Longitudinal studies will also support the transportation of emotions, since higher presence leads to a stronger emotional involvement ([12]).

Finally, the pre scores of sickness in our study are relatively higher than in related studies using the simulator sickness questionnaire (see [10,17]). We assume that this is caused or influenced by the study environment (high frequency of people, noisy and exhausting shopping mall context).

As implication for the future design of 3DTV, we propose the creation of target group specific 3DTV programs, at least until 3DTV is state of the art in every home. Similar to content and theme suitability for certain audiences (e.g., MPAA – Motion Picture Association of America – rating), 3DTV content can be rated on the likelihood for certain target groups to experience sickness. To support viewers in avoiding sickness, we suggest to use a scale based on the experience viewers have with 3D content. 3DTV programs with calm content and less usage of 3D effects can then be recommended for less experienced viewers, while other programs might be suitable for users with more experience. Since less experienced users experience a higher level of presence with 3DTV, their programs can be less visually exciting while still creating a sufficient level of immersion. More experienced users, who require a higher level of 3D experience to be immersed, also will not suffer from sickness that much.

A further area that shows potential in the area of 3DTV research is the area of recommender systems. Bjelica [3] focuses on recommender systems for specific user groups while 3DTV has still not been included in research in this area. Our results may contribute to this new direction in research by the inclusion of sickness likelihood into modern personalized TV recommender systems focusing on 3DTV. Based on previous content, viewing duration and a personal profile of the viewer, 3DTV contents can be recommended, which fit each individual in terms of sickness potential. The support through this kind of technology will lower the barrier of 3DTV adoption in modern homes caused by sickness.

6. Conclusions & future work

While the production of 3D content is still focusing on the cinema context, there exist other promising areas for the application of 3D. The home context represents a especially promising future market, industry has shown interest in this area and a technological push can be observed towards 3DTV production and marketing. 3D technology has become more affordable and has begun penetrating into households, with 3D enabled becoming more pervasive. However, in entering the home context, a better understanding of the users and their perception of 3D content is needed. Many studies on 3DTV focus on the image quality, technical aspects of the device, or the physiological factors of the user. However, there are only few studies that explore the user experience when watching 3D content.

Within this paper we investigate people's perception of 3DTV focusing on the feeling of sickness and presence while watching 3DTV movies in a public setting. The decision for 3DTV technology was made based on the rapidly growing penetration of 3DTV devices in nowadays households. Another reason was that the higher brightness of 3DTV devices in comparison to projection devices better fit the requirements of a public setting where the light could not be dimmed. In the paper we presented the results of a three-day field study involving 700 participants. The evaluation revealed interesting initial insights on the users experiences with and perception of 3DTV in a public context, and provides a solid starting point towards future research on 3DTV.

The main conclusions with regard to our main research question How do people perceive 3DTV?and its sub-questions (1) how can the viewing experience be described with regard to the factors "feeling of sickness" and "feeling of presence"? and (2) what factors influence the viewing experience (i.e., the feeling of sickness/presence)? can be summarized as follows (see overview in Fig. 7):

- Most of the participants filling in the SSQ (in total 88%) reported sickness symptoms. Symptoms reported most often concern the visual system (eyes). Symptoms reported least concern the gastric system (stomach).
- Previously experienced discomfort influences presence (i.e., perceived realism) negatively.
- The experience of 3DTV (feeling of sickness and presence) is influenced by age and previous experience with 3D content.
- The feeling of sickness is influenced by gender.
- The feeling of presence is influenced by the viewing set up, e.g., standing or sitting in front of the 3D screen.

Although we could not influence the selection of participants regarding age, prior experience, gender, and number of participants for the different prepared methods, we reached a quite well balanced sample in terms of gender and age.

The presented study results have to be seen in light of the particular study environment. A shopping mall is not a typical research environment and is restricted with regard to the set up, usage of methods and feedback mechanism. This particular study environment is limited with respect to controllability, which has to be reflected in the collected data as well. We cannot exclude

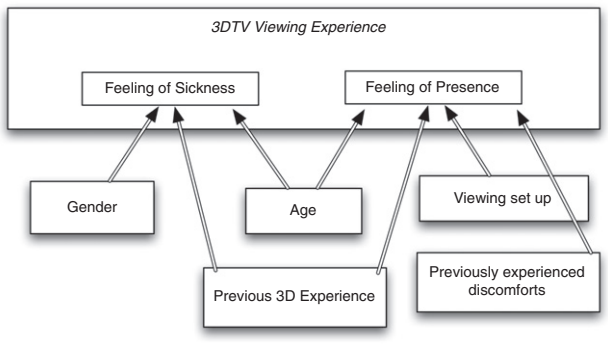

Fig. 7. Factors influencing the 3DTV viewing experience based on our field study focusing on the two major factors "feeling of sickness" and "feeling of presence".

the influence of contextual aspects (e.g., light conditions, angle of viewing, time of viewing, social context) on the final results of this study. We were also not able to control the perception of sound, since the environment was noisy and the position of participants did not allow the installation of high quality surround sound devices. Yet our study was designed for the public space, with content that has to attract attention. In this space, sound also cannot be controlled as it is possible in a home environment. Moreover, the viewing time in particular has to be considered as a relevant influence factor. We estimate that the time span of watching the 3D movies varied approximately between 3 and 10 minutes between the study participants (also influenced by the two viewing set ups, standing or sitting in front of the TV screen).

Additionally, we were not able to control the effect of the content on the feeling of presence and sickness. The movies we used (skiing, space jumping, breakdance, body painting) were produced to exploit the full potential of 3DTV technology, partly to create awareness of its potential and following the study results revealed by Freeman and Avons [8], that live events (sport events, music concerts, theatre) and action movies are the best-suited content for 3DTV. Based on our results we cannot be sure, whether the findings are also applicable on calmer content, such as nature documentaries, if they are explored for 3D viewing purposes. Further studies would be also needed to differentiate our findings with respect to the different movies.

Overall, the study results on 3DTV viewing experiences collected in the public space imply different future research directions. Some immediate action points are summarized below:

- Selected experience factors, such as physical symptoms of nausea and disorientation (part of feeling of sickness) or the feeling of presence need further investigation in controlled settings. Lab studies could be promising to obtain deeper insights in specific facets of factors like e.g., fatigue and presence when investigating 3DTV-viewingexperiences. In such a controlled setting, it is also important to provide a comfortable TV watching environment (e.g., arranging the lab as a living room).
- Contextual influences, such as the viewing angle, light conditions, sound level, social context (absence or presence of other people) should be further investigated in controlled environments. Thus, the assumptions on pre- and post-effects revealed in our study can be deepened.
- Demographic influences on the 3D viewing experience should be further examined in lab-based and complementary longitudinal studies. The latter should in particular support the research on the temporality of user experience based on selected factors (e.g., presence). However, the setting has to be well elaborated and approved with respect to ethical concerns when investigating sickness as a relevant factor.
- Different 3D system and screen settings (i.e., 3DTV, mobile 3D, 3D cinema) could be explored with respect to selected viewing factors. This could be part of a controlled, large-scale user study, which we are currently trying to realize with in an industrial cooperation.
- The effect of the content on the 3DTV experience, considering different viewing settings, should be investigated in order to reveal insights on users engagement and emotional involvement over time.
- Finally, as 3DTV is foreseen as a relevant technology to enter the future homes, field-based research with different users/user groups is needed with respect to their viewing experiences. A smooth integration and adoption of 3D technology has to be ensured in order to be successful.

We are convinced that the above research directions could provide valuable contribution to the findings we revealed through our initial explorative study. We are currently setting up an experimental laboratory (as part of the Christian Doppler Laboratory for "Contextual Interfaces") enabling controlled study environments, where we can follow up our action points listed above.

Apart from this research streams, there is one more research direction, which is worth mentioning even though we did not address it in our study, namely the usage of 3D glasses. The viewing experience of 3D content, having the home environment in mind (e.g., sitting together in the living room), is disturbed by the fact to wear 3D glasses. Thus, auto-stereoscopic 3D systems not requiring glasses would be an interesting field for studying the resulting viewing experience and represent further areas regarding the user's experience related to the perception of 3D content.

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