Immersive Experiences in the Home: A Field Trial on Stereoscopic 3DTV

Jonas De Meulenaere
iMinds-SMIT,
Vrije Universiteit Brussel
Pleinlaan 9, 1050
Brussels, Belgium
jdemeule@vub.ac.be

Koen Willaert
iMinds-SMIT,
Vrije Universiteit Brussel
Pleinlaan 9, 1050
Brussels, Belgium
kwillaer@vub.ac.be

Wendy Van den Broeck
iMinds-SMIT,
Vrije Universiteit Brussel
Pleinlaan 9, 1050 Brussels,
Belgium
wvdbroec@vub.ac.be

Lizzy Bleumers
iMinds-SMIT,
Vrije Universiteit Brussel
Pleinlaan 9, 1050
Brussels, Belgium
lbleumer@vub.ac.be

ABSTRACT
Announced as an immersive technology stereoscopic 3D (S-3D) is actively implemented in consumer electronics. S-3D is capable of producing a sense of presence for the viewers, yet bottlenecks such as visual discomfort still exist. This research investigates the experiences of presence and visual comfort when watching S-3D content in the home, hereby focusing on both user characteristics and environmental factors, in particular light circumstances. This was researched using a mixed method design, involving in-depth interviews, diary study, quantitative survey as well as three subjective tests. Sensations of presence as well as the S-3D visualizations in itself can motivate viewers to watch S-3D. Moreover, there is a clear trade off between these positive sensations and discomforts derived from the nature of S-3D and the S-3D glasses. In addition, both visual comfort and presence are significantly influenced by the given light circumstances.

Categories and Subject Descriptors
J.4 [**Social And Behavioral Sciences**]: Sociology

General Terms
Human Factors.

Keywords
Stereoscopic 3D, 3DTV, Ambilight, Presence, Human Factors, Mixed method

1. INTRODUCTION
The S-3D technology is increasingly entering the homes in the form of 3DTV, with every manufacturer implementing the S-3D functionality in its new TV-sets. S-3D is believed to induce a more immersive, lifelike viewing experience compared to 2D viewing. In this respect, watching an S-3D movie may cause the viewer to experience higher levels of presence [3], yet bottlenecks such as visual discomfort and the little appreciated S-3D glasses [9,10] exist.

ImmersiveMe'13, October 22, 2013, Barcelona, Spain.

http://dx.doi.org/10.1145/2512142.2512145

In this paper we report on a research regarding the immersive character of S-3D in the context of a real-life home setting. Existing user research often investigates S-3D in an isolated fashion and studies are often conducted in a lab setting only. The research on practices and experiences of S-3D in a home context on the other hand is non-existent. The purpose of our study was to surpass the drawbacks of a lab setting (i.e. the absence of context) by entering the homes and test in the wild. The following research questions were investigated:

RQ1: *To what extent do viewers experience sensations of presence when watching S-3D in the home? What is the nature of these sensations?*

RQ2: *To what extent do light circumstances affect the S-3D viewing experience?*

2. RELATED WORK
2.1 Presence
Previous research has indicated that S-3D has the quality to enhance the viewer's sense of presence. S-3D is believed to lead to a more immersive experience and to higher levels of presence than 2D images are capable of. Presence can be defined as:

"… a psychological state or subjective perception in which even though part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience." [14]

Presence is a subjective state of an individual, caused by the immersive form, content and/or usage of a medium or technology [14]. In this respect, watching an S-3D (form) movie (content) may cause the viewer (user) to experience higher levels of presence. As a consequence the viewer can be more aroused, feel more enjoyment or feel more connected to other (virtual) people [14]. Early research on the experience of presence while watching S-3D showed that this was the case [6] and that viewers refer unprompted to sensations of presence, caused by the augmented realism of the scenes, the naturalness of the perceived depth and the extent to which one felt involved [3].

Discernable types of presence include spatial presence, sensory presence, psychological immersion or social presence. Literature on S-3D and presence has – directly and indirectly – referred to various types of presence, making it rather fuzzy to ascertain which types apply to S-3D and to what extent. For instance both Freeman & Avons and Häkkinen, et al, allude to sensations of spatial presence [3, 4]. A viewer may experience spatial presence when he or she perceives to be in a physical location and environment that is distinct from his or her location and

environment in the physical world [14]. Häkkinen, et al, also indicate that S-3D can enhance the atmosphere and emotional themes of the presented content [4], which hints at the fact that viewers feel more engaged with and involved in the S-3D content compared to 2D counterparts. These sensations occurs when part or all of a person's perception is directed toward objects, events and/or people created by the technology, and away from objects, events and/or people in the physical world. An important remark here is that the perception is not directed to the technology itself but the technology is rather a means to an end [14].

2.2 The discomforts of watching S-3D

2.2.1 Visual discomfort

Visual discomfort is often used as an umbrella concept. Typical experiences of visual discomfort include, among others, eyestrain, headaches, tiredness, and nausea [15]. It is clear that stereoscopy is inherently a consequence of the human perceptual system. However, significant differences exist between the way the three spatial dimensions are perceived in reality and on an S-3D screen. A major difference is the unnatural decoupling of accommodation and convergence, which refers to a mismatch in focus and perception; one focuses on a vertical flat plain (the screen) but perceives different depths, in front of or behind the screen, depending on the presented images. This phenomenon inherent to the perception of S-3D images is often referred to as the main cause of eyestrain while watching S-3D video content [2, 7]. Recent work indicated, however, that the accommodation-convergence mismatch only leads to eyestrain when 1) this mismatch is large and 2) the viewer is susceptible to it [5]. Therefore, it is concluded that rather than the discrepancy between accommodation and convergence, the hampered fusion of the left and right image is central to the eyestrain [5]. More important from our perspective is that this mismatch feels unnatural and as such can influence the immersive experience of watching S-3D.

2.2.2 S-3D glasses

Another major bottleneck is the required pair of S-3D glasses. The principle of S-3D is that two images are shot under a slightly different angle, which corresponds to the pupillary distance. These two images are then displayed in such a way that the images intended either for the left or the right eye, only reach the predetermined eye. Finally, the brain merges both images into one stereoscopic image. To achieve this, different techniques have been developed. Generally these techniques can be divided in techniques with (aided viewing) or without (free viewing) the need for viewers to wear glasses [11]. Currently only the aided viewing techniques are widely commercialized in TV-sets. As research has indicated, users are averse to these glasses [10]. According to a Nielsen study [9], this aversion is nurtured by the expectation that these glasses will transform Television viewing into a stressful rather than a relaxing activity.

2.3 Ambilight

Issues such as visual discomfort can be mitigated or solved through technological advances. Apart from technological enhancement on the display and device side of the S-3D technology (e.g. more responsive displays), visual discomfort also appears to be benefiting from alterations of the viewing environment. Experimental research has indicated that subjects are less likely to be fatigued or to experience eyestrain if the viewing environment is illuminated. Yet, the found effects were modest [1]. One application that taps on to this is Ambilight (developed by Philips and available as feature on their TV-sets). Ambilight is "an ambient lighting system that generates dynamic light effects around the television set that correspond to the video content. This results in an extension of the display colors and leads to a larger perceptual view" [13].

Earlier research on the combination of Ambilight and S-3D [13] has indicated that Ambilight enhances the sense of presence for the viewer. It was found that a significant difference in levels of presence exists between conditions with Ambilight compared to conditions without Ambilight. Yet, no significant results were found in terms of intensity of Ambilight and presence.

3. METHODOLOGY

In order to study presence and visual comfort in a context of S-3D viewing, we applied a mixed methods research approach. We placed commercial 3DTV-sets in the homes of 17 households (N=40) for a period of three months in order to give the respondents sufficient time to get used to S-3D viewing. We conducted in-depth interviews, diary research, and a questionnaire with three subjective tests of which one controlled in a lab environment (N=30) and two in a home environment (N=17 and N=27).

3.1 Applied methods

3.1.1 Immersive sensations in the home

During these three months the households were interviewed thrice. These interviews were based on the respondent's diaries in which they kept track of their S-3D viewing practices by means of an event and a time based diary. As a follow up we administered an online questionnaire that comprised a list of statements that was based on a grounded analyses of both the interviews and the diaries and was used as a confirmation of these qualitative findings. The statements could be answered on a 5-point Likert scale and inquired the respondent's S-3D viewing behavior, the experienced sensations, the use of the S-3D glasses, visual comfort as well as the potential of S-3D for certain types of content and the expected future of 3DTV. This survey was distributed online to the 40 respondents of this research; 35 of the 40 respondents completed this survey.

3.1.2 Influence of environment on viewing experience

The influence of light circumstances on S-3D viewing was studied in a threefold way: in a controlled lab setting with short-form content, in the home with short-form content and in the home with long-form content. In all three of the tests, viewers watched S-3D content in 4 different lighting conditions (cf. Table 1). The controlled and the short-form test in the home used the same sequence; the test with the long-form content in the home used a full feature S-3D movie (Avatar 3D, Titanic 3D, or The Adventures of Tintin: The secret of the unicorn 3D). In this test, subjects had to change the lighting circumstances four times throughout the movie. The order of the different lighting circumstances was altered in all three of the tests.

Table 1 The four light conditions

Condition 1: Environment Light on + Ambilight on	**Condition 2:** Environment Light off + Ambilight on
Condition 3: Environment Light on + Ambilight off	**Condition 4:** Environment Light off + Ambilight off

The subjects had to rate each condition on the following parameters on a 5-point scale:

1) Presence: *the sense of being immersed in the viewing experience*
2) Visual Comfort: How comfortable was the experience to you? Additionally: indicate *any uncomfortable experience while watching 3D*
3) Overall Viewing Experience: *Overall quality assessment of the viewing experience*

3.2 Sample

3.2.1 Sample home test

The respondents were recruited along a set of criteria for the composition of the household sample. We achieved a maximum variation in terms of household type and age, and phenomenological variation in terms of interest in and attitude towards S-3D and 3DTV [12]. In total 17 households – totaling 40 respondents – were recruited through snowball sampling, taking into account the aforementioned criteria. During the first contact with potential households we tried to get sufficient information about both the basic and socio-demographic criteria in order to determine whether the household would fit in this research or not.

The average age was 26,3, with the oldest respondent being 43, the youngest being 10 and a standard deviation of 7,3. Of the 17 participating households there were five families, two singles, six couples and four households existing of co-housing friends. Except for one respondent, all of the respondents had experiences with S-3D content before. Whereas most of the respondents (N=37) had seen S-3D in cinema, also experiences in theme parks (N=22) and on TV-devices (N=15) were counted. Regarding the latter, these encounters are generally traceable to a "showroom experience" such as seeing it briefly in a shop. As such, these households varied in composition and in attitude towards S-3D as well as in the previous experiences they had had with S-3D.

3.2.2 Sample lab tests

The sample for the controlled lab test existed of 30 research participants (12 females, 18 males), which were all employed in an academic environment. All participants had a stereo acuity of 40 seconds of arc or lower tested with the Randot Stereotest. The majority of the research participants reported having experiences with S-3D before the experiment, predominantly from cinema (86%). A majority of the participants reported to have previously experienced discomforts while watching S-3D. A majority of the participants knew what Ambilight was, however, little of them had seen it in action in a natural (home) environment for an extended period of time; most experienced it (briefly) in a showroom of a shop or at other people homes. Yet, 10% owned an Ambilight-enabled TV-set.

4. RESULTS

4.1.1 Viewer profiles

Through triangulation of the quantitative and qualitative data we were able to create S-3D viewer profiles for the respondents participating in the home user study that completed the final survey (N=35). We found four viewer profiles in our sample that engaged differently with the S-3D technology in a TV-context. This engagement differed in terms of the experienced sensations, the perceived invincibility of the S-3D visualization and the extent to which one is focused on these, and the extent to which discomforts are experienced. The four profiles are:

- Viewers seeking immersion (P1), (n = 14)
- Viewers focusing on the S-3D effects and visualizations (P2), (n=6)
- Viewers experiencing uncomfortable sensations while watching S-3D content (P3) (n = 11)
- Viewers being indifferent about S-3D (P4), (n=4)

Table 2 shows the results of a k-means cluster analysis; the survey items that allowed differentiating the four profiles are listed. The mean scores are indicated as well as the significance level. In our sample 40% belonged to P1, 17% to P2, 32% to P3 and 11% to P4. Due to the small sample size (n=35) and the way the sample was recruited, we do not claim any representativeness on population level as far as the distribution over the 4 profiles is concerned.

These different viewer profiles help to understand and nuance the various attitudes, motivations, thresholds and limitations viewers experience when watching S-3D in a home environment. Each of these profiles will be further discussed in the remainder of this section using qualitative interview data.

Table 2 Segmentation of S-3D TV viewers

Segmentation (mean scores)	P1	P2	P3	P4	F value
	n = 14	n = 6	n = 11	n = 4	
Successful 3D makes the viewing experience more intense.	4,36	4,17	3,36	4,00	6,22**
When watching a 3D movie, I'm looking for the 3D effects.	3,43	4,33	4,18	3,50	4,30*
I do not mind to wear 3D glasses, this part of the 3D experience.	3,07	3,67	1,82	3,75	8,96***
The 3D glasses bothers me all the time while watching 3D.	2,07	1,67	3,64	1,75	15,37***
I don't like watching 3D because I have to wear 3D glasses.	2,14	1,83	4,00	2,50	16,25***
Once I'm watching 3D, I forget that I'm wearing 3D glasses.	3,07	3,50	1,64	3,00	7,68***
I like to wear 3D glasses.	1,86	3,00	1,55	3,00	8,80***
The 3D glasses bothers me because it gives a feeling of pressure in the nose and / or ears.	3,14	1,83	4,36	3,00	9,94***
Wearing 3D glasses makes me feel disconnected from my environment.	2,57	3,17	3,00	4,00	3,11*
The 3D glasses helps me to focus on the film.	2,36	3,33	1,91	2,75	5,33**
It's an effort to watch an entire movie in 3D.	2,14	2,17	3,55	4,00	9,02***
I feel not the slightest problem when watching 3D.	2,79	3,00	2,09	1,50	3,08*
Watching 3D gives me a headache.	1,79	2,00	3,09	4,00	10,43***
I do not feel that watching 3D is tiring.	3,43	2,00	2,27	2,50	6,28**
I expect that in the future every TV set will have a 3D function.	4,07	3,17	3,09	2,25	5,27**
Within a few years, 3DTV will almost completely disappear.	1,57	2,17	2,36	2,00	2,90*
3DTV is likely to remain a niche product.	2,07	3,67	3,09	3,00	6,34**
3DTV is a gadget and will remain a gadget in the future.	2,00	4,00	3,09	4,25	19,84***

· * p<0.05, **p<0.01, ***p<0.001

4.1.2 Viewers seeking immersion (P1)

For this viewer profile S-3D is considered a means of attaining immersive sensations. S-3D is watched because viewers get more easily involved with the characters and immersed in the story.

> *"And I wondered whether there are wild life documentaries or deep sea documentaries or about birds in the air in* [S-]*3D.* […] *Because I think it will give a nice effect. That you have the feeling of flying with the birds or that the fishes are swimming around you."* (Sandra, female, 43)

We noticed that respondents in this viewer profile also can experience discomforts, albeit only to a modest extent. The same applies for the S-3D glasses. These viewers are not bothered by the S-3D glasses, moreover they tend to forget about these glasses when watching S-3D glasses. Stated differently, they are considered and inherent part of watching S-3D content.

4.1.3 Viewers focusing on the S-3D effects and visualizations (P2)

This viewer profile has, similar to the first profile, a positive attitude regarding S-3D viewing. Both profiles consider it a pleasant viewing experience and are motivated to watch S-3D content, yet for different reasons. For this profile, the S-3D effects are the reason why S-3D content is watched in the first place. These viewers enjoy the S-3D generated depth and tend to search actively for these effects when watching S-3D content:

> *"Well, those depth cues… sometimes you are really searching for what's done in* [S-]*3D. And when you find something, I enjoy how they have done it. I really think it's awesome."* (Kenny, male, 21)

This type of S-3D viewers is thus more interested in the technology itself, more so than they are willingness to suspend disbelief.

In terms of discomforts neither the S-3D visualization or the S-3D glasses are considered problematic by this profile. The motivation and curiosity about the S-3D visualizations for viewers in this profile is stronger than any possible visual discomfort. We observed that for instance viewers that watched S-3D content on a regular base could also experience visual discomforts:

> "*I can only take in something for maybe at most an hour, or little more than an hour.* […] *Sometimes I feel like there are things that I have to strain my eyes to really… to enjoy it.* [I] *really felt like* [I] *had to stop at certain points, because* […] *it really, I don't know, kind of tires you, watching* [S-]*3D.*" (André, male, 30)

This quote illustrates that the experienced visual discomforts affects André's viewing behavior, yet only in a minor way. Given these findings, it appears that visual discomfort affects the S-3D viewing practices via the extent to which viewers are able to enjoy the S-3D visualization and effects.

Different from the first viewer profile, however, is their idea about the future about the S-3D technology in a home context. They have the idea that S-3D is more a gadget and a niche, whereas the first profile beliefs every TV-set will have S-3D functionality.

4.1.4 Viewers experiencing uncomfortable sensations while watching S-3D content (P3)

In general this profile has a negative opinion about S-3D, predominantly caused by the strong dislike for the S-3D glasses and the many discomforts they experience.

Similar to the previous profile they indicate to be searching actively for the S-3D effects. Yet, whereas the first and second do so to be amazed by this, the S-3D effects are emphasized for the uncomfortable viewers because of the discomfort it causes. For instance the intensity of the S-3D is too important here. Notwithstanding the fact that an intense viewing experience can be regarded as a driver for watching S-3D content, the interview data indicates that it affects watching S-3D in a restrictive way. This restriction is twofold, namely regarding the frequency with which one will watch S-3D content (e.g. is it suited for everyday usage) and what type of content will be watched in S-3D:

> *"It's more intense, your [viewing] experience is more intense and that's not always what you're looking for. Because we often watch "Thuis" (a daily soap opera broadcasted on the PSB channel Eén). "Thuis" is definitely not a great program, but is a relaxing moment. It's a continuing story and it's rather easy and comfortable to follow. Whereas an [S-]3D movie, that is being totally immersed in the story, immersed in the images… much more than you would do in other occasions. And that… well, it's not very well suited for an everyday relaxing moment."* (Anita, female, 44)

Moreover, the intenseness of the viewing experience may hinder the viewer to forget about the S-3D technology while watching, making it less convenient to have a non-mediated experience.

We did found confirmation that experiencing visual discomforts can be insurmountable and may annul any positive sensation. In this case viewers will avoid watching S-3D. For instance Roxanne voiced she experienced severe discomforts and only watched S-3D twice during the entire research period. In the following quote she briefly states why:

> "*I know upfront that afterwards I'll still have a headache for 30 minutes even though the film has already finished.*" (Roxanne, female, 32)

As the quantitative data also indicates, the S-3D glasses are a significant and insurmountable threshold. Not everyone is capable of forgetting about the S-3D technology while watching, making it less convenient to have a non-mediated experience. Notwithstanding the fact that the importance of the S-3D glasses cannot be neglected in this context, it also must be emphasized that the processing of S-3D images requires more effort than 2D images, even without taking into account possible visual discomforts:

> "*Sometimes I didn't know how or on what to focus, because so many things happened at the same time. Or, sometimes you have the feeling that your brain is trying to create depth or tries to grasp what happens, that it doesn't really work out that well. […] And the more you try to think about this, the more irritating it becomes. […] The trick is trying to think as less as possible about the [S-]3D-effect…"* (Roel, Male, 26)

4.1.5 Viewers being indifferent about S-3D (P4)

For this type of indifferent viewers, the motivation to watch S-3D is very low. They are not searching for any S-3D effects nor are they are interested in the 3D content itself. Moreover, they consider watching S-3D not an intense viewing experience, in contrast to the other profiles. A possible explanation is that these viewers are somewhat disappointed by the visualization compared to what they are used to from S-3D cinema.

> "*Well I expected more actually. I had seen it once in the cinema, and those effects, how it really comes towards you… you don't get the same experience on a 3DTV set. That 3D-effect [on a 3DTV] is too limited. Well, it is still*

fun to watch, but not as spectacular as I expected and how I experience it in cinema." (Wouter, male, 30)

Interestingly this type of viewers seems to have little problems with the S-3D glasses, yet they do admit to have problems to watch an entire S-3D movie. It is considered to be tiring and to be causing headaches. The interesting point is that this is more the case than for the uncomfortable viewers. A hypothesis might be that these sensations are strong because they do not see any added value in watching S-3D on a TV-set and lack the motivation to watch a entire movie in S-3D. It yields little surprise that these viewers see little future for S-3D in TV-sets. To them S-3D is a gadget that will most likely disappear in a few years.

"*Well, the S-3D effect is way to insufficient. For instance in the cinema, with Avatar, you see many fluffs coming from the screen and flying past you… and that's over the entire screen. Whereas here… there's perhaps one thing that you see and that see and that's it.*" (Laurens, male, 23)

4.1.6 Light circumstances

Our research showed that the experience of immersion presence and visual comfort is not only impacted by the profile of a 3DTV viewer as described above, but equally by the light circumstances in witch the S-3D content is being watched. Previous research (cf. supra) already showed that lighting conditions while watching S-3D TV influence the S-3D viewing experience. This was clearly confirmed in our research, however the effect of Ambilight was not yet investigated in a long running trial in a home context.

Next series of tables show how the viewing experience parameters were assessed under the different lighting conditions for both short content (clips) and longer content (full movie). The assessment of the viewing experience with short content took place both in a controlled lab environment (N=30) and in the home environment (N=17). The results within these two settings were analyzed separately and were then compared. As no significant differences were found between those two samples, they were merged into one sample (N=47). The assessment with longer content took place in the home environment (N=27).

Presence

Regarding presence, conditions with Ambilight do score systematically higher than conditions without Ambilight (Table 3) for long content. For short content, the results indicate that presence is only positively impacted when the environment light is switched off. For longer content this effect is nearly significant.

Table 3: Presence

Presence				
	Mean short-form	**Std. Dev. Short-form**	**Mean Long-form**	**Std. Dev. Long-form**
C1	5,8	1,7	6,2	1,6
C2	6,7	1,6	7,2	1,5
C3	5,7	1,6	6,5	1,6
C4	6,5	1,7	6,4	1,7
Short-form content		***Value***	***F***	***Sig.***
Environment light		.354	25.172	.000***
Ambilight		.021	.990	.325
Environment light* Ambilight		.003	.125	.726
Long-form content		***Value***	***F***	***Sig.***
Environment light		.132	3.943	.058
Ambilight		.202	6.578	.016*
Environment light* Ambilight		.079	2.227	.148

· * p<0.05, **p<0.01, ***p<0.001

Visual comfort

The results indicate that Ambilight leads for both types of content to significant higher levels of visual comfort (Table 4). For long content the interaction effect of Ambilight and environmental light is significant, this means that the specific combination of Ambilight and the absence of environmental light leads to more visual comfort. For short content, these findings are in line although the interaction effect is not significant.

Table 4: Visual Comfort

Visual Comfort				
	Mean short-form	**Std. Dev. Short form**	**Mean Long-form**	**Std. Dev. Long-form**
C1	6,6	2,1	6,0	2,1
C2	7,1	1,54	7,0	1,5
C3	6,5	1,99	6,0	1,9
C4	6,6	1,7	6,2	2,0
Short-form content		**Value**	**F**	**Sig.**
Environment light		.054	2.634	.111
Ambilight		.113	5.843	.020*
Environment light* Ambilight		.063	3.071	.086
Long-form content		**Value**	**F**	**Sig.**
Environment light		.044	1.185	.286
Ambilight		.198	6.436	.018*
Environment light* Ambilight		.160	4.971	.035*

· * p<0.05, **p<0.01, ***p<0.001

Overall viewing experience

In terms of overall viewing experience for longer content, both Ambilight and interaction between Ambilight and (the absence of) environment light create significant positive effects on the overall viewing experience (Table 5).

Table 5: Overall viewing experience

Overall viewing experience				
	Mean short-form	**Std. Dev. Short-form**	**Mean Long-form**	**Std. Dev. Long-form**
C1	7	1,5	6,4	1,5
C2	7,4	1,4	7,6	1,0
C3	6,5	1,4	6,3	1,6
C4	6,9	1,4	6,7	1,6
Short-form content		***Value***	***F***	***Sig.***
Environment light		.113	5.846	.020*
Ambilight		.209	12.166	.001***
Environment light* Ambilight		1.000	.009	.926
Long-form content		***Value***	***F***	***Sig.***

Environment light	.054	1.471	.236
Ambilight	.436	20.115	.000***
Environment light* Ambilight	.254	8.974	.006**

p<0.05, **p<0.01, ***p<0.001

These results are partly different from the results we observe with short content. For both lengths of content, Ambilight does have a significant positive effect whereas the effect of (the absence of) environment light is only significant with shorter content.

5. DISCUSSION

Our study revealed two different motivations for enjoying 3DTV viewing. One group of users (P1) referred to their experience of presence, while another group pointed out they actively searched for 3D effects (P2). This finding is in line with how the role of user characteristics in determining presence has been previously discussed in the literature. Lombard and Ditton [8], for instance, note that some people are less willing or able to suspend disbelief than others due to their curiosity about how the medium operates. This leads them to focus on the technology and its effects rather than to get immersed in the content and engaging in a flow-experience, which is typical for movie viewing. They also refer to findings on an inverse relationship between familiarity with the medium and the degree of presence that one experiences. It is not unlikely that in our study, viewers focusing on the S-3D effects and visualizations were unable to experience a strong sense of presence, due to their interest in the technology, but derived their enjoyment from observing the medium's properties instead.

The visual discomfort experienced by a third group of users (P3) may have had a similar negative effect on presence. Wirth [16] states: "Suspension of disbelief is defined as not paying attention to external stimuli and internal cognitions that (might) distract from the enjoyment of the mediated story and environment. Such distractions may be of technological kind or of the contents. For example, technologically they may stem from the weight of the head-mounted display or sweaty gloves (VR)…" (p.513-514). In our study, participants experienced discomfort caused by the S-3D glasses and the S-3D visualization, which focused their attention on the technology, this time in a negative way.

Our study shows that the feeling of presence and the level of experienced discomfort were equally impacted by the light circumstances while watching 3DTV. Both Ambilight and environment light do impact different parameters of the viewing experience. Watching S-3D with Ambilight and without environmental light is beneficial in terms of overall viewing experience. Furthermore the specific combination of 'Ambilight on' and 'the absence of environment light' lead to the highest levels of visual comfort.

Ambilight does not affect any of the viewing parameters that were investigated in a negative way whereas environment light can negatively impact the experience of presence. Hence, on the basis of these results the condition 'Ambilight without environment light' can be recommended as the most suited condition for watching S-3D and can lower the threshold for the segment of S-3D viewers that does experience substantial discomfort (P3), lead to even higher levels of presence for the segment of immersed viewers (P1) and accentuate the 3D effects for the segment of 3D focused viewers (P2).

6. CONCLUSION

Our research showed that there is a clear potential for experiencing a sense of presence while watching S-3D content on a TV-set in a home setting if viewers are not disturbed by the visual discomfort related to the current technology. Important is that presence can be positively influenced by adapting the lightning conditions while watching S-3D content and combining S-3D with the Ambilight technology. Of course the content (i.e. the movie itself) will remain an important factor, (if not the most important factor) in creating a sense of presence and engagement.

7. ACKNOWLEDGMENTS

This research was done within the framework of the iMinds 3DTV 2.0 project. This project is co-funded by iMinds, a research institute founded by the Flemish Government. Companies and organizations involved in the project include among others iMinds-SMIT, Vrije Universiteit Brussel and TP Vision, with project support of IWT.

8. REFERENCES

[1] Bullough, J.D. et al. 2006. Impact of Surrounding Illumination on Visual Fatigue and Eyestrain while Viewing Television. *Journal of Applied Sciences*. 6, 8 (2006), 1664 – 1670.

[2] Fortuin, M.F. et al. 2011. An exploration of the initial effects of stereoscopic displays on optometric parameters. *Ophthalmic and Physiological Optics*. 31, 1 (2011), 33–44.

[3] Freeman, J. and Avons, S.E. 2000. Focus group exploration of presence through advanced broadcast services. (2000), 530–539.

[4] Häkkinen, J. et al. 2008. Measuring stereoscopic image quality experience with interpretation based quality methodology. (2008).

[5] Howarth, P.A. 2011. Potential hazards of viewing 3 D stereoscopic television, cinema and computer games: a review. *Ophthalmic and Physiological Optics*. 31, 2 (2011), 111–122.

[6] Ijsselsteijn, W. et al. 1998. Perceived depth and the feeling of presence in 3DTV. *Displays*. 18, 4 (1998), 207–214.

[7] Lambooij, M. et al. 2010. Visual discomfort associated with 3D displays. (2010).

[8] Lombard, M. and Ditton, T. 1997. At the heart of it all: The concept of presence. *Journal of Computer Mediated Communication*. 3, 2 (1997).

[9] Nielsen 2010. Purchase Intent for 3DTV Varies Around the Globe.

[10] Nielsen 2010. U.S. Consumers Show High Interest in 3DTV, but Cite Some Concerns.

[11] Ostnes, R. et al. 2004. Visualisation techniques: an overview-part 2. *Hydrographic Journal*. (2004), 3–10.

[12] Sandelowski, M. 1995. Sample size in qualitative research. *Research in Nursing & Health*. 18, (1995), 179–183.

[13] Seuntiens, P. et al. 2007. Visual experience of 3D-TV with pixelated ambilight. (2007), 339–344.

[14] The Concept of Presence: Explication Statement: 2000. *http://ispr.info/*.

[15] Ukai, K. and Howarth, P.A. 2008. Visual fatigue caused by viewing stereoscopic motion images: Background, theories, and observations. *Displays*. 29, 2 (2008), 106–116.

[16] Wirth, W. et al. 2007. A process model of the formation of spatial presence experiences. *Media Psychology*. 9, 3 (2007), 493–525.