

# Effect of image scaling on stereoscopic movie experience

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## ABSTRACT

Camera separation affects the perceived depth in stereoscopic movies. Through control of the separation and thereby the depth magnitudes, the movie can be kept comfortable but interesting. In addition, the viewing context has a significant effect on the perceived depth, as a larger display and longer viewing distances also contribute to an increase in depth. Thus, if the content is to be viewed in multiple viewing contexts, the depth magnitudes should be carefully planned so that the content always looks acceptable. Alternatively, the content can be modified for each viewing situation. To identify the significance of changes due to the viewing context, we studied the effect of stereoscopic camera base distance on the viewer experience in three different situations: 1) small sized video and a viewing distance of 38 cm, 2) television and a viewing distance of 158 cm, and 3) cinema and a viewing distance of 6-19 meters. We examined three different animations with positive parallax. The results showed that the camera distance had a significant effect on the viewing experience in small display/short viewing distance situations, in which the experience ratings increased until the maximum disparity in the scene was 0.34 - 0.45 degrees of visual angle. After 0.45 degrees, increasing the depth magnitude did not affect the experienced quality ratings. Interestingly, changes in the camera distance did not affect the experience ratings in the case of television or cinema if the depth magnitudes were below one degree of visual angle. When the depth was greater than one degree, the experience ratings began to drop significantly. These results indicate that depth magnitudes have a larger effect on the viewing experience with a small display. When a stereoscopic movie is viewed from a larger display, other experiences might override the effect of depth magnitudes.

**Keywords:** Image scaling, viewing distance, stereoscopic quality, stereoscopic film, image quality

## 1. INTRODUCTION

The purpose of a good stereoscopic movie is to integrate effective storytelling with stereoscopic depth to produce an engaging immersive experience for the viewer. Depth should be used skillfully, as too little depth is not interesting and too much depth irritates and possibly hurts the viewer.<sup>1-3</sup> The depth magnitude of objects depends on their horizontal disparity, and the range of depth in a scene can be controlled by changing the distance between stereoscopic cameras<sup>2</sup>. The safe distance between the cameras can be determined, for example, by the 3% rule, which states that the interocular distance should be set to 1/30th of the distance from the camera to the foreground.<sup>2</sup>

The planning of depth effects is complicated since the viewing context significantly affects the perceived depth. If a movie intended for the cinema is shown in another context, both the viewing distance and the size of the screen will change. The viewing distance for television at home is a couple of meters, and that for a mobile device is 30-40 centimeters. The viewing distance also changes the perceived depth, as the depth effect grows with the size of the display and the viewing distance.<sup>4</sup> These changes present a challenge for stereoscopic content creation, as the cumulative effects of simultaneous changes in image size and depth magnitude are unknown. There are several possible consequences to changing the viewing context. First, if the depth magnitudes are too small, the viewers find the added experiential value to be insufficient, and if the magnitudes are too large, they experience the adverse perceptual consequences of excessive depth magnitudes. Second, if the depth range changes significantly, people and objects in the scenes might appear distorted, which would diminish the quality experience and distract the viewers from the narrative. In this study we investigated the ability of viewers to notice changes in camera base distance for different viewing contexts, and whether those changes had an effect on their viewing experience. We showed three different types of animation in three different viewing contexts and compared the effects of camera base distance changes in each animation.

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## 2. METHODS

### 2.1 Experimental setups

#### Experiment 1: Small size video

We conducted three experiments for showing animations. In experiment 1 (Figure 1a), the animations were shown on a Hyundai 24-inch stereoscopic display (W240S) with circular polarization. The display had a resolution of 1920x1200 pixels (60 Hz) and brightness of 500 cd/m<sup>2</sup> in 3D mode (row interlaced). The viewing distance was 38.6 cm. The height of the video was 17.32 degrees of visual angle (11.67cm / 240 pixels) and the width was 30.71 degrees of visual angle (20.69cm / 432 pixels), which mimicked the screen of a mobile device. The pixel size was 0.049 x 0.048 cm. The display was connected to a 12 GB HP Z600 Intel Xeon system unit. Videos were played with a Stereoscopic Player. The experiment and the assessment interface were implemented by Matlab (version R2010a). The room was lit with 5080K light varying between 95 lux (sides of the display) to 135 lux (above the display).

#### Experiment 2: Television

In experiment 2 (Figure 1b), the display was a Sony 40" Full HD 1080 LCD-TV (Sony KDL-40HX800, 240 Hz) with a resolution of 1920x1080 pixels (half height) in 3D mode (over-under). A 3D Sync transmitter (TMR-BR100) and active shutter glasses (TDG-BR100) were used. The viewing distance was 158 cm. The height of the video was 18.06 degrees of visual angle (49.8cm / 1080 pixels) and the width was 32.13 degrees of visual angle (88.60 cm / 1920 pixels). The pixel size was 0.046 x 0.046 cm. The display was connected to a 12 GB HP Z600 Intel Xeon system unit. Videos were played with a Stereoscopic Player. The experiment and the assessment interface were implemented by Matlab (version R2010a). The room was lit with 5080K light varying between 95 lux (sides of the display) to 135 lux (above the display).

#### Experiment 3: Cinema

In experiment 3 the animations were shown in a cinema over two separate sessions. The cinema had a capacity of 276 seats (12 rows x 23 seats). The seats for the first 23 participants were determined prior to the experiment so that the cinema would fill evenly (Figure 3). Thus, the first participant was seated in the middle of the cinema, as indicated by number 1 in Figure 3, the second participant was seated in the front left corner (number 2 in Figure 3), and so on until the first 23 participants were seated. The distances from the screen to the backseat of the first row and the backseat of the last row were 6.03 m and 19.23 m, respectively. The width of the cinema was 12.23 m. Videos were shown with a Dolby Cinemeccanica CMC3 projector, Dolby DSP100 player, showStore Dolby DSS100, and XpanD 3D-system. The projection distance was 19.60 meters, and the height of the video ranged from 79.34 (front row) to 24.88 (back row) degrees of visual angle (835.0 cm / 1080 pixels). The width ranged from 141.10 (front row) to 44.25 (back row) degrees of visual angle (1485.0 cm / 1988 pixels). The pixel size was 0.75 x 0.77 cm.



**Figure 1.** a) Small size video setup, b) Television setup.



**Figure 2.** Cinema setup.

Seat		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Row	12	4					12						8						17					3
	11																							
	10	10					20												19					15
	9																							
	8																							
	7	6					22						1						23					7
	6																							
	5																							
	4	16					18												21					13
	3																							
	2																							
	1	2					14						9						11					5
		Screen																						

**Figure 3.** Seating order in the cinema setting. The seats of the first 23 participants were determined prior to the experiment so that the cinema would fill evenly. The first participant was seated in the middle of the theater, as indicated by number 1, the second participant was seated in the front left corner (indicated by number 2), and so on until the first 23 participants were seated.

## 2.2 Contents

We used three stereoscopic animations without sound in the experiments. The first animation, of a male dancer next to the Helsinki Cathedral, was produced using the motion capture technique (Length: 16 seconds). There was a slow camera movement towards the dancer (Figure 4). The second animation depicted sneakers running in a street. First, a pair of sneakers came from behind the corner; this was followed by a group of sneakers. In the background there were cars, traffic signs, and buildings. There was no camera movement (Figure 5). In the third animation, the camera flies through an old western town. The scene starts with a bird's-eye view of the town, after which the camera quickly flies down to the town, goes through a street, and stops at a scene where two men face each other in a shootout. The scene ends with the camera placed just behind the back of one of the two men (Figure 6). The contents were produced by Undo Ltd ([www.undo.fi](http://www.undo.fi)).

The animations had positive parallax, i.e., they appeared completely behind the screen. Table 1 shows the maximum disparity in pixels, followed by the maximum disparities in degrees of visual angle for the different experiment settings for each animation.

**Table 1.**

Scene	Separation (mm)	Max disp (px)	Max disp Small size (°)	Max disp TV (°)	Max disparity Cinema mid (°)	Max disp Cinema back (°)	Max disp Cinema front (°)
Dancer	6.0	3.0		0.06	0.10	0.06	0.19
Dancer	13.0	7.0	0.08	0.13	0.23	0.15	0.45
Dancer	26.0	15.0	0.17	0.28	0.50	0.31	0.96
Dancer	52.0	27.0	0.30	0.50	0.90	0.56	1.74
Dancer	104.0	54.0	0.60	1.01	1.80	1.13	3.47
Dancer	208.0	108.0	1.21				
Ghost Town	3.4	5.5		0.10	0.18	0.11	0.35
Ghost Town	6.8	11.0	0.12	0.21	0.37	0.23	0.71
Ghost Town	13.5	22.0	0.25	0.41	0.74	0.46	1.41
Ghost Town	27.0	44.0	0.49	0.82	1.47	0.92	2.83
Ghost Town	54.0	88.0	0.98	1.64	2.94	1.84	5.65
Ghost Town	108	176.0	1.97				
Sneakers	2.4	3.75		0.07	0.13	0.08	0.24
Sneakers	4.8	7.5	0.08	0.14	0.25	0.16	0.48
Sneakers	9.5	15.0	0.17	0.28	0.50	0.31	0.96
Sneakers	19.0	30.0	0.34	0.56	1.00	0.63	1.93
Sneakers	38.0	60.0	0.67	1.12	2.01	1.25	3.85
Sneakers	76.0	120.0	1.34				

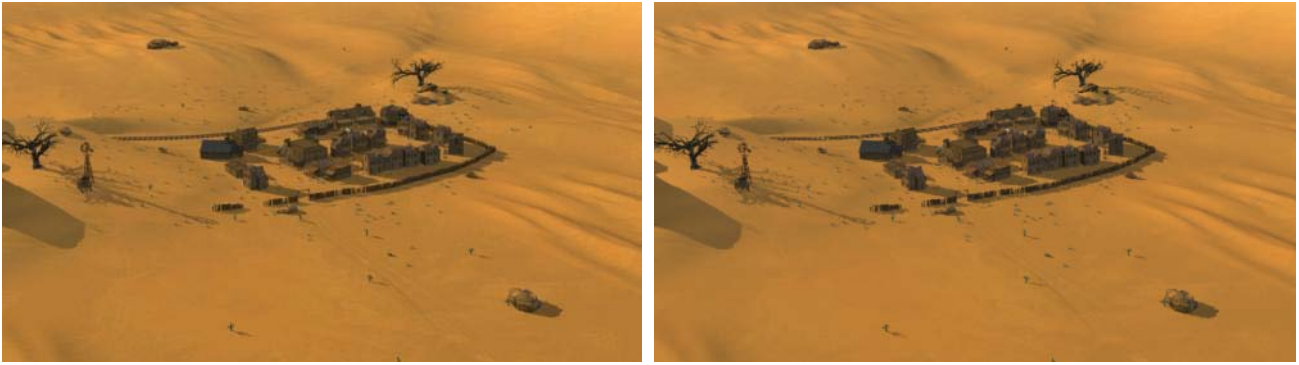


**Figure 4.** Scene from a video showing a man dancing in front of a Helsinki cathedral: separation 52 mm, frame 116 (3.7 seconds / 16 seconds). The stereo pair is intended for parallel viewing, so the left image is for the left eye and the right image is for the right eye.

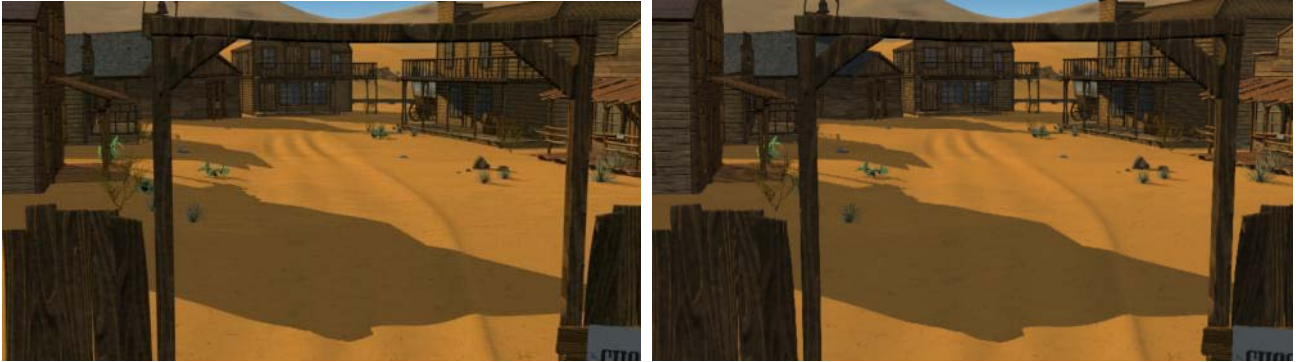


**Figure 5.** Scene from a video showing a group of sneakers running in a street: separation 38 mm, frame 402 (16 seconds / 20 seconds). The stereo pair is intended for parallel viewing, so the left image is for the left eye and the right image is for the right eye.





a.



b.



c.

**Figure 6.** Scenes from the Ghost Town video, starting with a bird's-eye view of the town (a: separation 13 mm, frame 1, 0.2 seconds / 20 seconds). Next the camera flies down to the town through the town gate shown in stereopair b (separation 13 mm, frame 256, 10.2 / 20 seconds). The camera then moves to a scene where two men face each other in a shootout. The scene ends with the camera placed just behind the back of one of the men (c: separation 13 mm, frame 500, 20 seconds / 20 seconds). The stereo pairs are intended for parallel viewing, so the left image is for the left eye and the right image is for the right eye.

Multiple versions of each animation were produced using six different camera base distances (Table 1). Five distances were used in each experimental setup, as overly small or large camera base distances were omitted from each experimental setup (the smallest separation was omitted from the small size/short viewing distance experiment and the largest separation was omitted from the television and cinema setups). The reason for the omission was to eliminate potential subjective effects: too small depth values would be insignificant for the viewers in a small size setting, and too large depth values would be so clearly bad looking that the ratings of the other camera separations would be skewed. We noticed this effect in pilot setups, in which the inclusion of extremely high depth values compressed the evaluation scales in other cases. This effect is quite logical, because if one of the scenes is clearly bad looking, the other scenes appear

quite satisfactory by comparison, making it difficult for the viewers to distinguish between the smaller differences due to the other separations. Thus, extremely large separations were omitted from the television and cinema settings.

## **2.3 Participants**

All participants were required to be age 18 or older, fluent in Finnish, and have normal or corrected vision. The test supervisor ensured that the subjects met these requirements, and viewers who were found not to have normal visual acuity and stereopsis were rejected. At the beginning the subjects were given a brief introduction to the experiment (the rundown of the procedure, duration, privacy protection, and compensation).

### **Experiment 1: Small size video**

There were 20 participants (13 males / 7 females) with average age of 22.5 years (range 20-26 years). Most of the participants (17/20) were engineering students from Aalto University. The participants were familiar with stereoscopic contents, as 17 of them had seen stereoscopic 3D movies and 11 had used other equipment to watch 3D content or otherwise view stereoscopic images. One participant had never seen stereoscopic contents.

### **Experiment 2: Television**

There were 21 participants (16 males / 5 females) with average age of 22.5 years (range 18-27 years). Most of the participants (19/21) were engineering students from Aalto University. The participants were familiar with stereoscopic contents, as 17 of them had seen stereoscopic 3D movies and 10 had used other equipment to watch 3D content or otherwise view stereoscopic images. Two participants had never seen stereoscopic contents.

### **Experiment 3: Cinema**

There were 36 participants (29 males / 7 females) with average age of 27.3 years (range 18-57 years). Most of the participants (25/36) were engineering students from Aalto University, and four of the participants worked in the information technology field. The participants were familiar with stereoscopic contents, as 26 of them had seen stereoscopic 3D movies and 18 had used other equipment to watch 3D content or otherwise view stereoscopic images. Five participants had never seen stereoscopic contents.

## **2.4 Procedure**

### **Visual screening in experiments 1 and 2**

Prior to the experiment a visual screening was conducted. The screening consisted of the following tests:

1. The far and near visual acuity of the participants were examined from the distances of 3 meters and 0.4 meters using Lea-numbers.<sup>5</sup> Both the left and right eyes were tested separately in each case. For near visual acuity the binocular vision was also assessed. The criteria were an acuity of 0.50 for both distances and for all combinations (left eye, right eye, and binocular).
2. The stereoscopic vision was assessed using the TNO test (Laméris Ootech BV, Nieuwegein). The viewing distance was set to 0.4 meters, and only plates V-VII of the TNO were used. The exclusion criterion was 60 minutes of arc (plate VI).
3. The participants' interpupillary distance was examined using a Digital Pupillometer BRT-II. The criterion was that the value acquired had to be in the range of 51-71 millimeters.
4. The near horizontal and vertical phoria of the participants was assessed using the Maddox wing test.<sup>6</sup> For near horizontal phoria the criteria were 13 D for exophoria and 7 D for esophoria. The criterion for near vertical phoria was 1 D.
5. The near point of convergence (NPC) was measured using the RAF gauge test keeping both eyes open (binocularly), and the near point of accommodation (NPA) was measured for both eyes separately.<sup>7</sup> There was no exclusion criterion in these tests.

### **Visual screening in experiment 3**

The cinema testing session began with a stereoscopic acuity test which was performed to ensure that the participants had sufficient stereoscopic vision for the test. The testing was done with random-dot stereograms. Participants were instructed to mark a cross on their answer sheets if they did not see anything in the test figures, thereby indicating their complete inability to see stereoscopic contents.

### **Background questionnaire in experiments 1, 2 and 3**

After the visual screening the subjects filled out a short preliminary questionnaire consisting of demographic questions (gender, age, profession, study major) and questions on computer skills, technology attitude, and experience with stereoscopic movies and technologies. They were also asked multiple medical questions related to susceptibility to motion sickness, headache, and illnesses related to the visual system.

### **Content evaluation in experiments 1 and 2**

The experimental session began with an introduction to the experiment. Instructions were provided both verbally and on paper. In addition, the rating scale and brief definitions of the assessment attributes (viewing experience, naturalness, and depth impression) were presented on paper. The participants were allowed to ask questions at this point. Afterward the participants put on passive circular polarized glasses or active shutter glasses (Sony TDG-BR100). The participants were showed a 1 min 11 second live action stereoscopic video to familiarize them with stereoscopic contents (energy drink commercial by Stereoscape Inc., [www.stereoscape.com](http://www.stereoscape.com), available on YouTube by searching “ED Special FX”). The video was not shown during the actual experiment.

The participants were also familiarized with the evaluation interface used in the experiment. This consisted of three scales (viewing experience, naturalness, and depth impression) with sliders that could be changed by a mouse. The rating scales for the viewing experience and naturalness followed the ITU recommendations on subjective quality assessment; a numeric scale represented the adjective terms, from 1 (bad) up to 5 (excellent). The depth impression was rated from 1 (weak) to 5 (strong). The participants were also allowed to choose a value halfway between two integers. The participants were encouraged to make use of the entire scale. The numbers from 2 to 4 were not specifically described by any adjectives. The rating was performed by moving the rating sliders to the preferred values shown above them.

The experimental stimuli consisted of the short animations (16-20 seconds) discussed above, produced as a series using five baseline separations. Each video was presented three times, so the total number of videos was 45. The video clips were played using a Stereoscopic Player, and the experiment and the assessment interface was implemented by Matlab (version R2010a) and Psychophysics toolbox (Version 3).

After the training session the video clips were presented to the subjects one by one. The display order of the video clips and the order of the rating sliders were randomized using Matlab. Prior to each clip, a black square (27 x 27 pixels) was shown in the middle of the screen for 6 seconds. After the video clip was played, the subjects were shown the assessment interface with the sliders. In experiment 1 (small size video) the sliders appeared in the same display as the video, but in experiment 2 (television) the sliders appeared in a separate display lying on top of a table in front of the participant. When the participants had completed their evaluation of the current video clip, they could continue the experiment by pressing the "next" button. During the assessment/evaluation, the participants had to click/touch every rating slider before being allowed to continue to the next video. In other words, they could not continue quickly just by pressing the “next” button. In total, the participants rated the viewing experience, naturalness, and depth impression 45 times.

### **Content evaluation in experiment 3**

After the stereoscopic acuity test a training session was conducted. The purpose of the training session was to familiarize participants with the stereoscopic 3D content and the evaluation settings. Instructions were provided both verbally and on paper. Participants viewed a stereoscopic video (ED commercial) without sound and were instructed to evaluate it.

The rating scales for the viewing experience and naturalness ranged from 1 (bad) to 5 (excellent). The depth impression was rated from 1 (weak) to 5 (strong). The participants were allowed to choose a value halfway between two numbers. Numbers 2 to 4 were not specifically described by any adjectives. The rating was performed by crossing the preferred value on an answer sheet.

Each of the 15 different clips was shown twice in random order. In total, the participants rated the viewing experience, naturalness, and depth impression 36 times. The first six clips were hidden references that included disparity extremes for all three scenes. Before each video a ten second countdown from 10 to 1 was shown in the middle of the screen to prepare the participants for the next video. After the video, a text "Rate Video X" appeared for 20 seconds, where X indicated the most recently viewed video.

### **Questionnaire after the experiments 1, 2 and 3**

The participants filled out a questionnaire after the experiment. First, they had to indicate the lowest viewing experience and naturalness that they would accept in the current experimental setting, using the same scales as in the experiment. They also indicated the smallest and largest acceptable depth using the depth impression scale. These values were compared to the evaluated values in the data analysis. After completing these ratings, the participants filled out the Simulator Sickness Questionnaire<sup>8</sup> and the Visual Symptoms Questionnaire,<sup>9</sup> as well as answered questions related to their opinions regarding stereoscopic 3D.

## **3. RESULTS**

### **3.1 Experiment 1: Small size video**

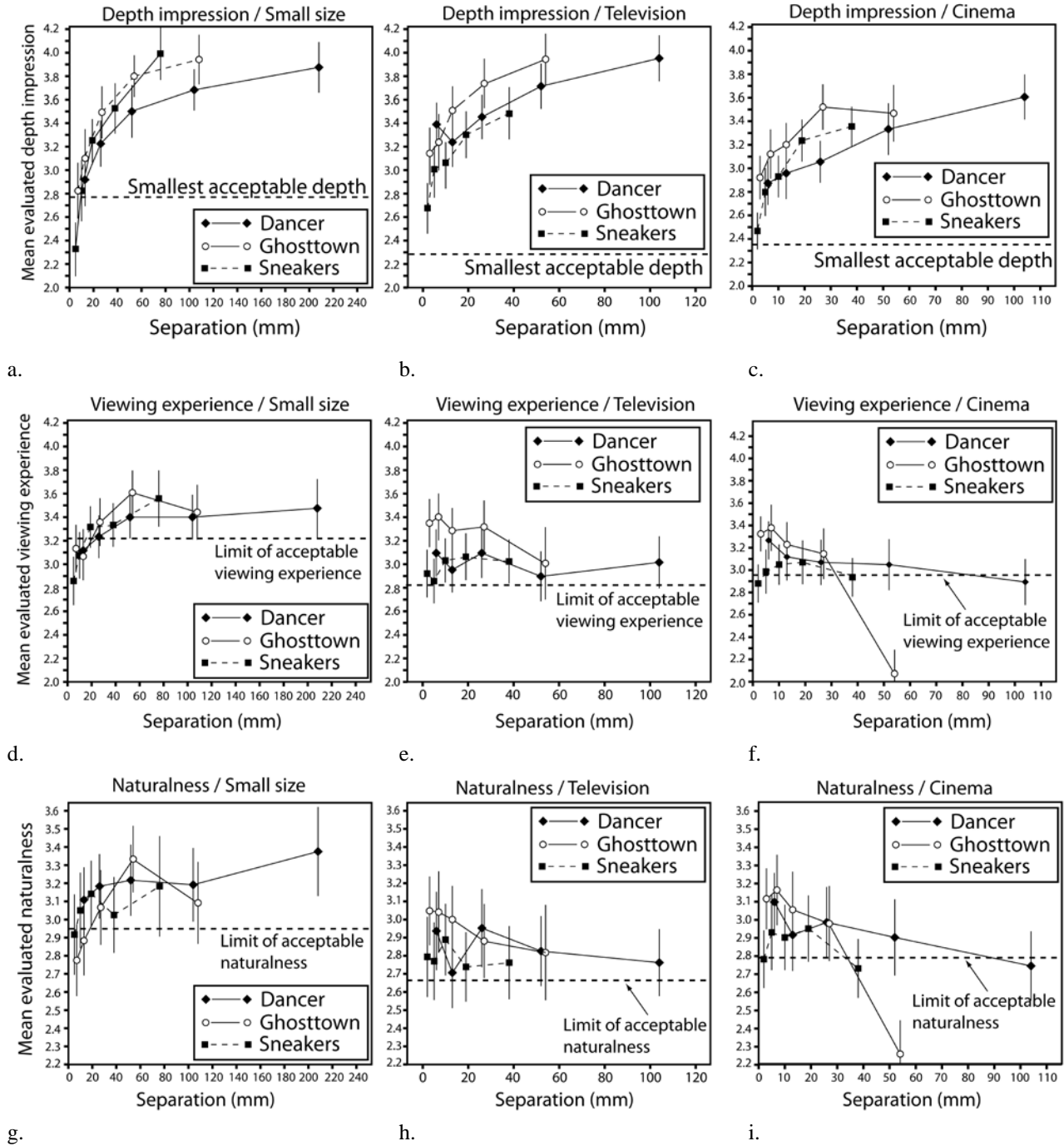
The depth impression scales were used to rate the magnitude and quality of depth in the contents as perceived by the participants. It also served as a control question which showed how well the participants were able to distinguish a change in depth caused by camera separation changes. Figure 7a shows the mean evaluated depth as a function of camera separation, and Figure 8a shows the mean evaluated depth as a function of the maximum disparity of the scene. The effect of camera separation on the perceived depth was highly significant with all contents (Oneway Anova (4,295),  $p < 0.001$ ), which indicated that depth changes due to changes in camera separation were easily perceived. All but the smallest separations (5 mm) were greater than the smallest acceptable depth threshold defined by the participants.

The evaluated general viewing experience indicates a correspondence between the perceived changes in depth and the experienced quality of the contents (Figures 7d and 8d). In experiment 1 there was a clear relationship between the camera base and the evaluated viewing experience (Dancer:  $F(4,295)=2.177$ ,  $p < 0.10$ , approaching significance; Sneakers:  $F(4,295)=7.071$ ,  $p < 0.001$ ; Ghost Town:  $F(4,295)=7.071$ ,  $p < 0.001$ ). The significance values were the same when differences between disparity values were compared. Post-hoc testing showed that in the small sized video there was a steep and significant rise in the evaluations, from 0.08 degrees of visual angle to 0.34 degrees through the limit of lowest acceptable viewing experience. After this point the evaluated values stopped increasing and remained constant (Figure 8d).

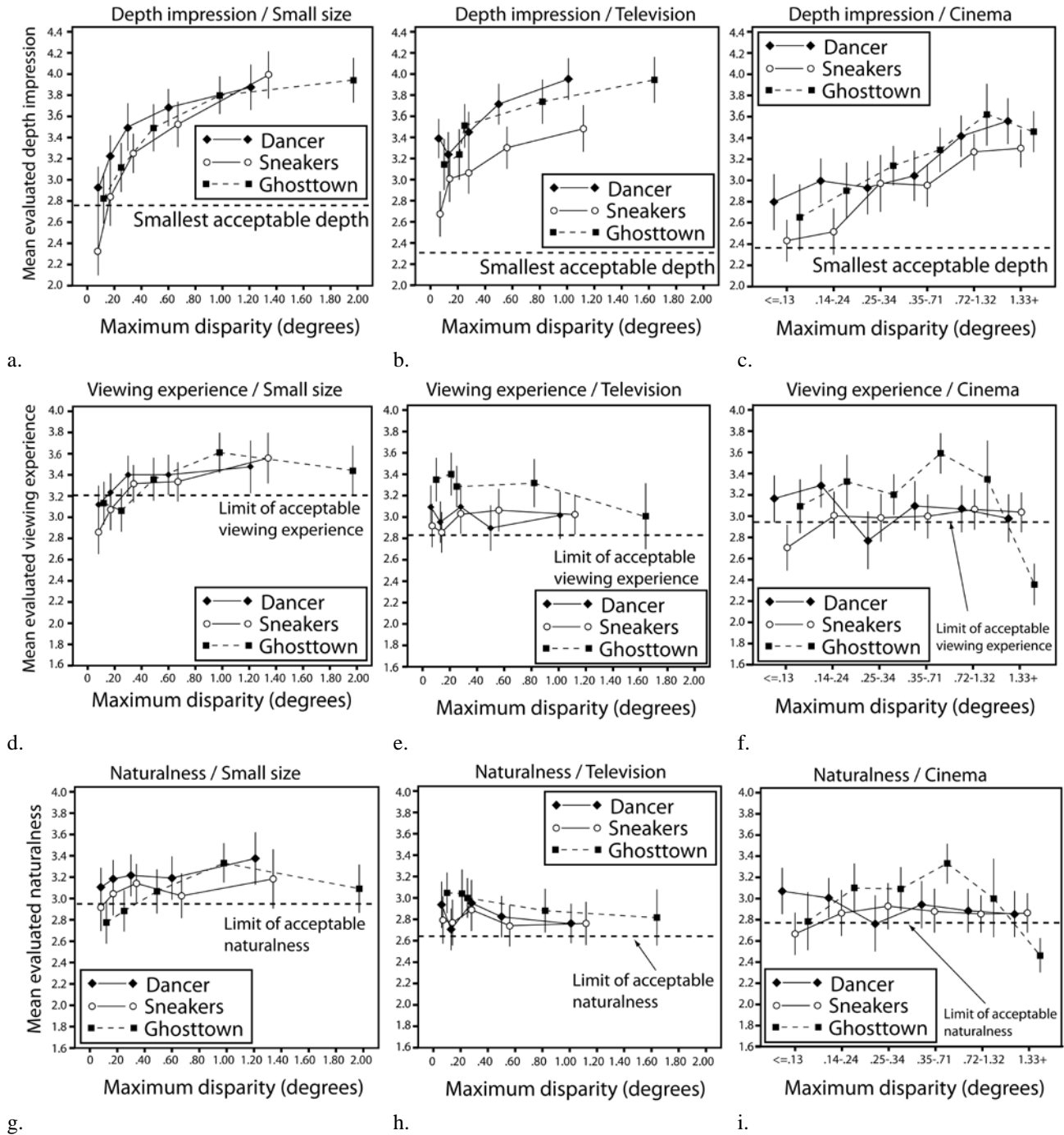
The naturalness values evaluated for the Sneakers and Ghost Town contents (Figures 7g and 8g) show a significant ( $p < 0.001$ ) dependence on both the separation and the maximum disparity. The results show an increasing trend until 0.34 degrees of visual angle in Sneakers and between 0.25 and 0.45 degrees in Ghost Town.

The three evaluation scales were highly correlated in the experiment; the viewing experience had a correlation of 0.703 ( $p < 0.001$ ) with naturalness and a correlation of 0.594 ( $p < 0.001$ ) with the evaluated depth impression. Naturalness had a correlation of 0.459 ( $p < 0.001$ ) with depth impression.





**Figure 7.** The evaluation results as a function of camera separation. a)-c) show the evaluated depth impression in experiments 1-3, d)-f) show the viewing experience, and g)-i) show the evaluated naturalness of the contents. Each data point represents an average from all participants for specific content and camera separation. The error bar represents the 95% confidence interval.



**Figure 8.** The evaluation results as a function of maximum disparity. a)-c) show the evaluated depth impression in experiments 1-3, d)-f) show the viewing experience, and g)-i) show the evaluated naturalness of the contents. Each data point represents an average from all participants for specific content and camera separation. The error bar represents the 95% confidence interval. With the cinema format, the seating of the participants affects the disparity in the scene, so the maximum disparities have been calculated according to the actual viewing distance. Next the disparity values were categorized into six groups with equal percentiles in each group.

### 3.2 Experiment 2: Television

Figure 7b shows the mean evaluated depth as a function of camera separation, and Figure 8b shows this depth as a function of maximum disparity in the scene. The effect of camera separation on the perceived depth was highly significant with all contents (Oneway Anova (4,295),  $p < 0.001$ ), which indicated that depth changes due to various camera separations were easily perceived. All separations and disparity values were above the smallest acceptable depth threshold defined by the participants.

The evaluated general viewing experience is shown in Figures 7e and 8e. There are fairly flat curves for experiment 2, showing that the viewing experience did not change as a function of camera base or as a function of maximum disparity in the scene. The evaluated naturalness showed a similar flatness. There was a moderate decrease in the viewing experience as a function of camera separation, but this effect was not statistically significant.

### 3.3 Experiment 3: Cinema

Figure 7c shows the mean evaluated depth as a function of camera separation, and Figure 8c shows this depth as a function of maximum disparity of the scene. With the cinema format, the seating of the participants affects the disparity in the scene, so the maximum disparities have been calculated according to the actual viewing distance. Next the disparity values were categorized into six groups with equal percentiles in each group. The effect of camera separation on perceived depth was highly significant with all contents (Oneway Anova (4,295),  $p < 0.001$ ), which indicated that depth changes due to various camera separations were easily perceived. All separations and disparity values were above the smallest acceptable depth threshold defined by the participants.

The evaluated general viewing experience is shown in Figures 7f and 8f. There are fairly flat curves, showing that for the most part the viewing experience did not change as a function of camera base or as a function of maximum disparity in the scene. The evaluated naturalness showed a similar flatness. However, with the Ghost Town contents the viewing experience and naturalness clearly decreased with the highest disparities above 1.35 degrees; this is significantly different than the other data points (Tukey Post-hoc test in One-way Anova,  $p < 0.001$ ).

## 4. CONCLUSIONS

Stereoscopic camera separation and the associated changes in depth magnitude had an effect on the viewing experience when the stereoscopic video was viewed in a small format (11.67 x 20.69 cm) with a short viewing distance (38.6 cm). In this case the viewing experience benefited from a disparity increase, from 0.08 degrees of visual angle to 0.30 – 0.49 degrees of visual angle, after which there was no further increase in the viewing experience or naturalness with increased depth. The results also showed that with camera separations less than 20-40 mm, the viewing experience increased as a function of separation; however, after 20-40 mm the separations were perceived as equally good in the small sized video format.

Interestingly, the camera separation and its related depth change had only a small effect on the viewing experience and naturalness evaluations in the television and cinema cases. Only very large depth values of more than 1.35 degrees decreased the viewing experience significantly, which agrees with earlier results.<sup>10</sup> Thus, it appears that changing the total depth range of a stereoscopic video within acceptable limits has little effect on the viewer experience. One possible explanation is that an increase in immersive experiences, like presence,<sup>11</sup> enabled by a large television or cinema projection might override the effects of depth change. In a smaller display these additional effects might be less visible; consequently, the participants might pay more attention to depth values. In other words, since the smaller-sized video is less immersive and less interesting to watch, the added value of stereoscopic depth to the viewer experience could be higher; thus, changing the depth would also have a larger effect on the viewer experience.

There are possible alternative explanations for this result. First, it is possible that the method by which the participants rated each stereoscopic video individually was difficult in the case of the cinema and television formats, and thus the viewers would not have been able to distinguish between the different videos. However, this interpretation is not

supported by the fact that the participants were easily able to differentiate between the depth differences in scenes, as shown in Figures 7a-7c and 8a-8c.

Second, it is possible that the different technologies employed in the experiments might have affected the observed results. The technology differences probably affected the absolute levels of the subjective ratings, making them not completely comparable. However, it is more difficult to find a technological explanation for the effect of camera separation on viewing experience in each case, so it is probable that this is not a significant variable here.

The third significant issue is the animation content we used in the experiment, which probably reduced the naturalness ratings significantly. Furthermore, it might be easier to notice unnatural depth ranges in live action contents, since that would enable an easier reference to the natural world. This effect is so significant that we are currently conducting a follow-up experiment with live action contents.

To summarize our results, we conclude that a changing camera separation had a significant effect on viewer experience with a small size stereoscopic video. However, changing the depth within the range of acceptable values had little effect on the viewer experience in the television and cinema formats.

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## REFERENCES

- [1] Lipton, L., [Foundations of the stereoscopic cinema], Van Nostrand Reinhold Company, New York (1982).
- [2] Mendiburu, B., [3D movie making], Focal Press, Oxford, UK (2009).
- [3] Häkkinen, J., Kawai, T., Takatalo, J., Leisti, T., Radun, J., Hirsaho, A. and Nyman, G., "Measuring stereoscopic image quality experience with interpretation based quality methodology," Proc. SPIE 6808, (2008).
- [4] Kishi, S., Kim, S.H., Shibata, T., Kawai, T., Häkkinen, J., Takatalo, J. and Nyman, G., "Scalable 3D Image Conversion and Ergonomic Evaluation," Proc. SPIE 6803, (2008).
- [5] Hyvärinen, L., "Lea Numbers 15-Line distance chart instructions," Web page: [lea-test.net/en/vistests/instruct/2711/index.html](http://lea-test.net/en/vistests/instruct/2711/index.html) (Accessed 01.01. 2011, Created 2009).
- [6] Rosenfield, M., Logan, N., [Optometry: science, techniques and clinical management], Elsevier, (2009).
- [7] Neely, J.C., "The R.A.F. near-point rule," British Journal of Ophthalmology 40, 636-637 (1956).
- [8] Kennedy, R.S., Lane, N.E., Berbaum, K.S. and Lilienthal, M.G., "Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness," The International Journal of Aviation Psychology 3, 203-220 (1993).
- [9] Howarth, P.A., Istance, H.O., "The association between visual discomfort and the use of visual display units," Behaviour and Information Technology 4, 135-149 (1985).
- [10] Lambooij, M., IJsselsteijn, W. and Heynderickx, I., "Visual discomfort in stereoscopic displays: A review," Journal of Imaging Science and Technology 53, 030201-030201-14 (2010).
- [11] Lombard, M., Ditton, T., "At the Heart of It All: The Concept of Presence," Journal of Computer-Mediated Communication 3, (1997).