PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

Viewing stereoscopic images comfortably: the effects of whole-field vertical disparity

Speranza, Filippo, Wilcox, Laurie

Filippo Speranza, Laurie M. Wilcox, "Viewing stereoscopic images comfortably: the effects of whole-field vertical disparity," Proc. SPIE 4660, Stereoscopic Displays and Virtual Reality Systems IX, (23 May 2002); doi: 10.1117/12.468047

SPIE.

Event: Electronic Imaging, 2002, San Jose, California, United States

Viewing stereoscopic images comfortably: the effects of whole-field vertical disparity

Filippo Speranza* and Laurie M. Wilcox**
York University, Toronto, Canada

ABSTRACT

Stereoscopic images while providing enhanced depth and image quality can cause moderate discomfort. In this paper, we present the results of two experiments aimed at investigating one possible source of discomfort: whole-field vertical disparities. In both experiments, we asked viewers to rate their comfort level while viewing a 3D feature film in which the left and right images were vertically misaligned. The feature film was presented on a large theater type screen. In Experiment 1, the vertical offset was changed randomly on a scene-by-scene basis resulting in an average vertical disparity of 31 minutes of arc at the closest viewing distance. The results showed that whole-field vertical disparities produced a marginal increase in discomfort that became only slightly more pronounced with time. In Experiment 2, we alternated periods of low, medium and high levels of whole-field vertical disparity. At the closest distance, the mean vertical disparity was 15, 30, or 62 minutes of arc for the low, medium, and high disparity conditions, respectively. In this experiment, discomfort increased with vertical disparity, but again only marginally even after prolonged exposure. We conclude that whole-field vertical disparities cannot be a major contributor to the discomfort experienced by observers when viewing stereoscopic images.

Keywords: stereoscopic viewing, comfort level, whole-field vertical disparity, large screen.

1. INTRODUCTION

Stereoscopic video is expected to play an important role in future video technologies. When compared to 2D images, stereoscopic (i.e., 3D) images appear to greatly improve the viewing experience of the observer. Not surprisingly, a great effort has been devoted in recent years in developing technological solutions that will facilitate the introduction of stereoscopic video to the general public. Of particular relevance is the introduction of devices specifically designed for capturing and displaying stereoscopic video as well as the inclusion in video coding standards, such as MPEG-2, of capabilities suitable for stereoscopic video compression and transmission[1].

However, the rate at which consumers will embrace stereoscopic video systems will strongly depend on appropriately addressing concerns regarding viewer comfort. Indeed, some evidence[2-8] suggests that stereoscopic images while providing enhanced depth and image quality can also cause moderate discomfort. Finding the causes of this discomfort will hopefully lead to solutions which eliminate them either through appropriate filming and display methods[4,5] or via software techniques [9].

It is known that the size of the binocular parallax is one source of discomfort. Indeed, horizontal disparities in excess of about 70 minutes of arc are judged as uncomfortable by viewers[8]. This effect of parallax might be in part due to the conflict between accommodation and vergence responses of the eyes[2,3,6]. Under natural viewing conditions, accommodation and vergence effortlessly co-vary so that the point (or plane) the eyes converge to is always in focus. With stereoscopic displays, accommodation tends to remain on the screen's plane where the object is displayed. Vergence, on the other hand, changes with horizontal disparity; that is, the eyes tend to converge to the perceived depth

*Address correspondence to Filippo Speranza, <Filippo.Speranza@crc.ca>, who is now with the Communications Research Centre Canada, 3701 Carling Avenue, Ottawa, Canada K2H 8S2, phone: +1 613 9987822, fax: +1 613 9906488; **Laurie M. Wilcox, Department of Psychology, York University ,4700 Keele St., Toronto, Canada M3J 1P3, phone: +1 416-736-2100 x66494 , fax: +1 416-736-5814.

Stereoscopic Displays and Virtual Reality Systems IX, Andrew J. Woods, John O. Merritt, Stephen A. Benton, Mark T. Bolas, Editors, Proceedings of SPIE Vol. 4660 (2002)

of the fixated object in the display, and therefore, in most cases, away from the plane of the screen. Accommodation might be changed as to coincide with the plane of fixation thereby reducing the conflict[2,3]. However, this change is limited to small horizontal disparities and, when it occurs, causes the images on the screen to be blurred[2,3,6]. Discomfort might also be caused by the presence of vertical disparities between left and right images. To date, investigators have focused on one type of vertical disparities: namely, vertical disparities that result from the geometrical distortions (e.g., keystone distortions) introduced by toed-in cameras. The magnitude of this type of vertical disparities varies across the stereoscopic image increasing from the center to the periphery of the image. It has been suggested[4,5,7] that these disparities contribute negatively to viewing comfort.

In this study, we investigated the effect on viewing comfort of a second type of vertical disparity: whole-field disparity. In this case, the vertical disparity is a constant difference for all corresponding points throughout the stereoscopic image. Under natural viewing conditions, whole-field vertical disparity can only arise as a result of a vertical misalignment of the eyes. In stereoscopic systems, whole-field vertical disparities might be produced, for instance, by misalignment along the vertical dimension of cameras and/or projectors used to capture and display stereoscopic images.

To determine what effect, if any, whole-field vertical disparities have on viewing comfort we conducted two experiments. The results of these experiments allowed us to examine how important whole-field vertical disparities are in determining viewer comfort, and consequently how important the correction or elimination of whole field disparities is for the stereoscopic display industry.

2. EXPERIMENT 1

In Experiment 1, we asked viewers to rate their comfort level while viewing a 3-D feature film, which contained whole-field vertical disparities varying on a scene-by-scene basis. Viewers were seated at one of two distances from the screen and asked to rate their comfort periodically. Since vertical disparity scales with viewing distance, we hypothesized that discomfort level would be higher for the closer than for the farther distance; furthermore, this difference would increase with time.

2.1 Method

2.1.1 Viewers

Thirty-five viewers (Mean Age = 20.5 years; SD = 3.74) participated in this experiment. Of these, nineteen had viewed stereoscopic images at least once previously. All viewers had normal stereopsis.

2.1.2 Procedure

The 3-D feature film had a duration of 35 minutes. To vary whole-field disparity, the right eye image was offset vertically, always directed upwards, using a programmable dual-projector system. The magnitude of the vertical offset was changed randomly on a scene-by-scene basis for a total of 85 changes. Viewers wore shutter glasses and looked at the screen from a distance of 11.80 or 16.50 meters. The size of the screen was 25 x 19.5 meters. At the closest distance, the screen subtended 64.7 x 58.3 degrees of visual angle. The average vertical disparities were 31 (SD = 4.6) and 22 (SD = 3.3) minutes of arc for the far and near distance, respectively. Figure 1 shows how vertical disparity, expressed in minutes of arc of visual angle, changed as a function of scene number at the viewing distance of 11.80 meters. Viewers rated their comfort level at five-minute intervals during the film using a ten-point scale (see Figure 2) for a total of 7 ratings. Discomfort was defined as any uncomfortable feeling such as for example moderate levels of eyestrain, slight headache, or queasiness. Viewers were informed that they could terminate the experiment at any time.

2.2 Results

Figure 3 shows the variations in comfort level reported during the presentation of the 3D feature film. Note first that whole-field vertical disparities produced, overall, only a marginal increase in discomfort. Furthermore, there was no difference between the results obtained at the two viewing distances which, as noted, corresponded to average vertical disparities of 31 (SD = 4.6) and 22 (SD = 3.3) minutes of arc. However, it should be noted that discomfort became slightly more pronounced after prolonged exposure.

To evaluate the significance of these results, a 2x2 Analysis of Variance (ANOVA) with Distance (i.e., mean disparity level) as between factor and Time as within factor was performed on judgments of comfort. The analysis indicated no significant effect of Distance (i.e., mean disparity level), $F(1,33)=0.019$, $p = 0.889$, but a significant effect of Time, $F(6,198) = 6.190$, $p = 0.00005$. The Distance x Time interaction was also not significant $F(6,198) = 0.477$, $p = 0.824$.

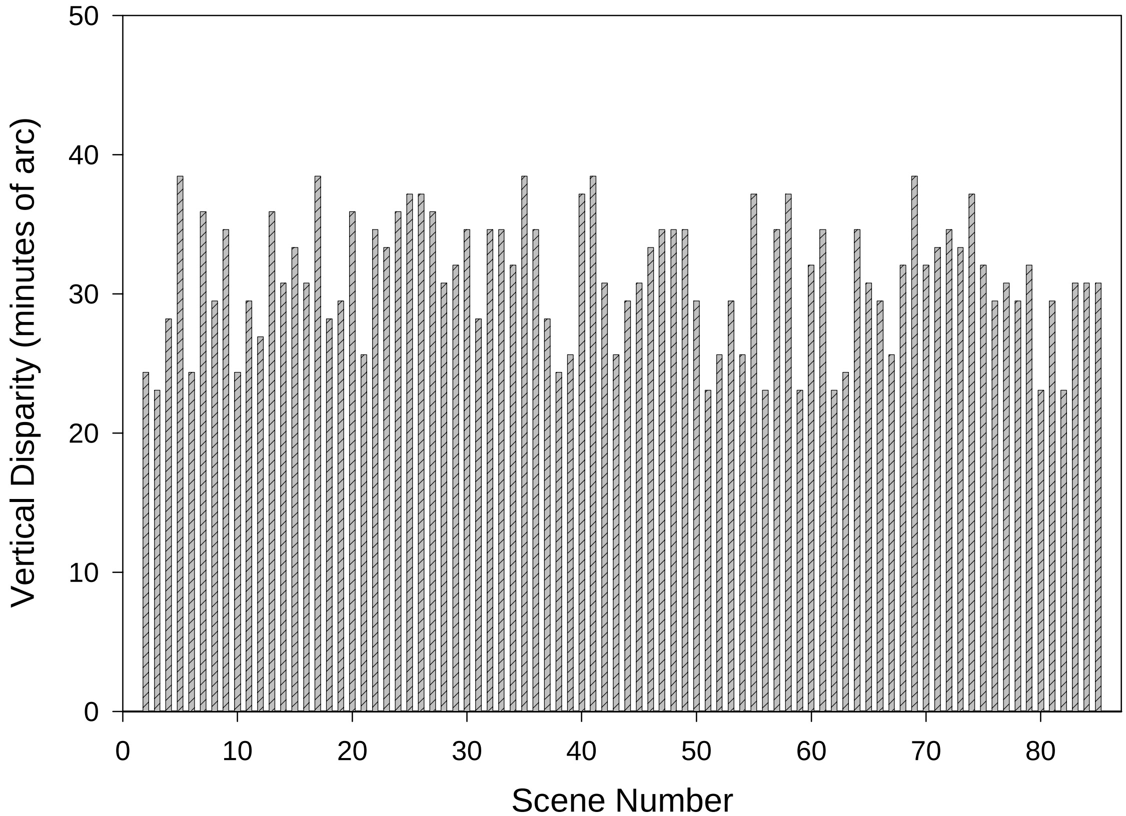

Figure 1. Changes in whole-field vertical disparity, expressed in minutes of arc of visual angle, as a function of scene number at the viewing distance of 11.80 meters (Experiment 1).

COMFORT	NORMAL	SLIGHT DISCOMFORT			MODERATE DISCOMFORT			STRONG DISCOMFORT		
RATING	1	2	3	4	5	6	7	8	9	10

Figure 2. Rating scale used to measure the degree of discomfort.

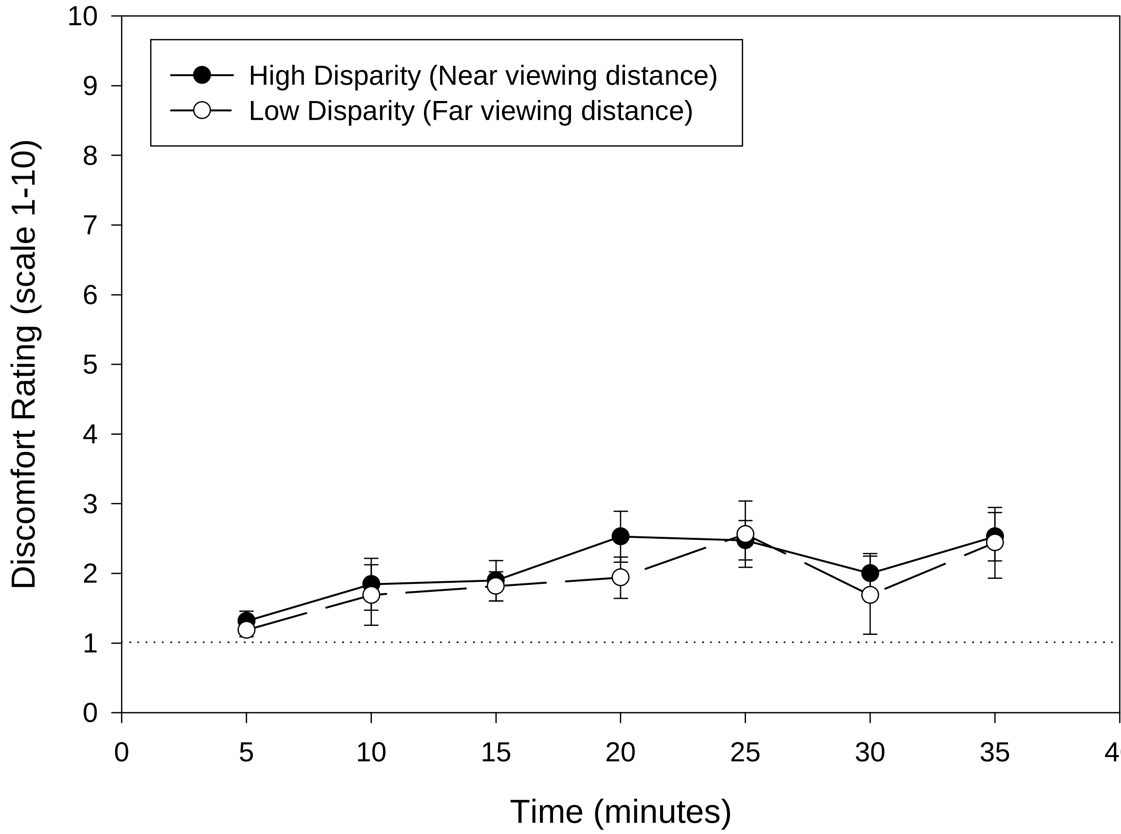

Figure 3. Changes in comfort level as a function of time for the high disparity (i.e., near viewing distance) and low disparity (i.e., far viewing distance) conditions used in Experiment 1. The dotted line represents the no discomfort level.

3. EXPERIMENT 2

The marginal effects on comfort observed in Experiment 1 might have been due to the relatively small vertical offsets employed. To evaluate the effect of larger variations in vertical disparity, in Experiment 2 we alternated periods of low, medium and high levels of disparity variability during the course of the 3D film. To avoid degradation of stereoscopic information with high vertical disparity levels, disparities were kept below the 1.5 - 2 degrees of visual angle limit that can be compensated by vertical vergence eye movements[10-11].

3.1 Method

3.1.1 Viewers

Thirty-three viewers (Mean Age =22 years; SD = 5.29) participated in this experiment. Twenty-six had viewed stereoscopic images at least once previously. All viewers had normal stereopsis.

3.1.2 Procedure

The 3-D film used in this experiment had a duration of approximately 38 minutes. Vertical offsets between the left and right images were introduced as in the previous experiment. However, in this experiment the magnitude of the offset was varied randomly every 25 seconds. The total duration of the feature film was divided into three temporal segments. Within each segment, the disparity level was first low (low mean average and low standard deviation), then medium (medium mean average and medium standard deviation), and finally high (high mean average and high standard deviation).

Viewers wore shutter glasses and were seated in different rows with the closest and farthest rows at 11.80 and 21.00 meters from the screen. The average offset corresponded at the closest distance to a mean vertical disparity of 15 (SD = 13.2), 30 (SD = 21.4), and 62 (SD = 44.2) minutes of arc for the low, medium, and high conditions, respectively. Corresponding values for the farthest distance were 9 (SD = 7.4), 17 (SD = 12.0), and 35 (SD = 24.9). Figure 4 shows how vertical disparity, expressed as minutes of arc of visual angle, changed over time at the viewing distance of 11.80 meters. All other aspects of the experimental procedure were identical to those used in the first experiment.

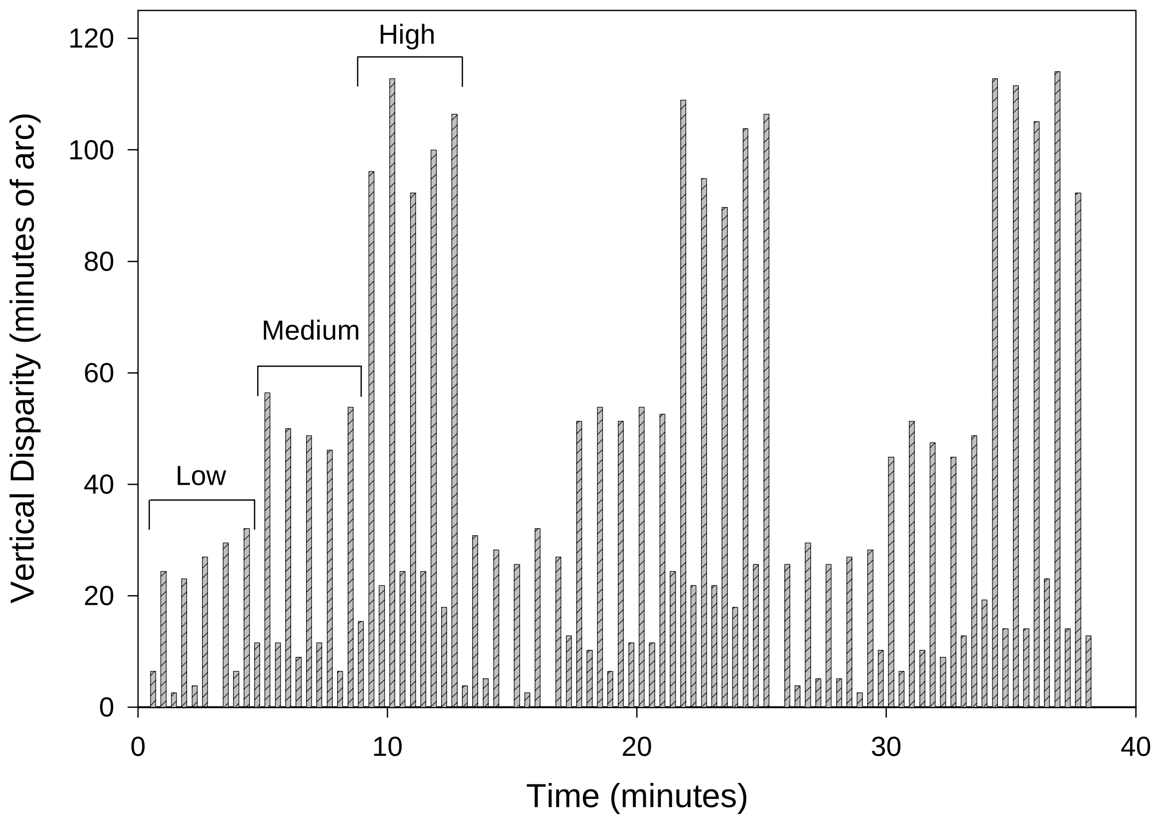

Figure 4. Changes in whole-field disparity as a function of time at the viewing distance of 11.80 meters, Experiment 2.

3.2 Results

The results of Experiment 2 are shown in Figure 5. It can be appreciated that discomfort increased directly with vertical disparity level though very marginally even at the largest vertical disparity. Furthermore, there appears to be little evidence of an increase in discomfort with time as observed in the previous experiment. Recall, however, that in Experiment 1 whole-field vertical disparity remained at a relatively sustained medium level throughout the entire presentation, whereas in this experiment periods of low disparity were intermixed with periods of medium and high disparity. This difference suggests that the effect of exposure duration observed in Experiment 1 is contingent upon the presence of a sustained level of whole-field vertical disparity.

These observations were evaluated with a repeated measures ANOVA, with Intensity Level and Time as factors, performed on judgments of comfort. The analysis indicated a significant effect of Intensity Level, $F(2,64) = 22.457$, $p = 0.0004$, but no effect of Time, $F(2,64) = 0.645$, $p = 0.527$. The Intensity Level x Time interaction was significant $F(4,128) = 6.070$, $p = 0.0001$.

In this experiment, we manipulated vertical disparity so that an increase in average disparity was accompanied by an increase in variability as well. Therefore, the significant effect of disparity intensity level observed in this experiment could be due not to the changes in average disparity but rather to the changes in variability. However, a comparison of the results obtained in Experiment 1 for near distance with those obtained in this experiment for the medium disparity level suggests that changes in variability are not the main determinant of comfort. In Experiment 1, the average and standard deviation for the near distance were 31 and 4.6 minutes of arc, respectively, whereas in this experiment the average for the medium level was about 30 minutes of arc and the standard deviation was 21.4 minutes of arc. Despite the larger standard deviation, the medium level condition in Experiment 2 resulted in a discomfort level of 1.87, which was actually smaller than the discomfort level of 2.02 observed in Experiment 1 for the near distance condition.

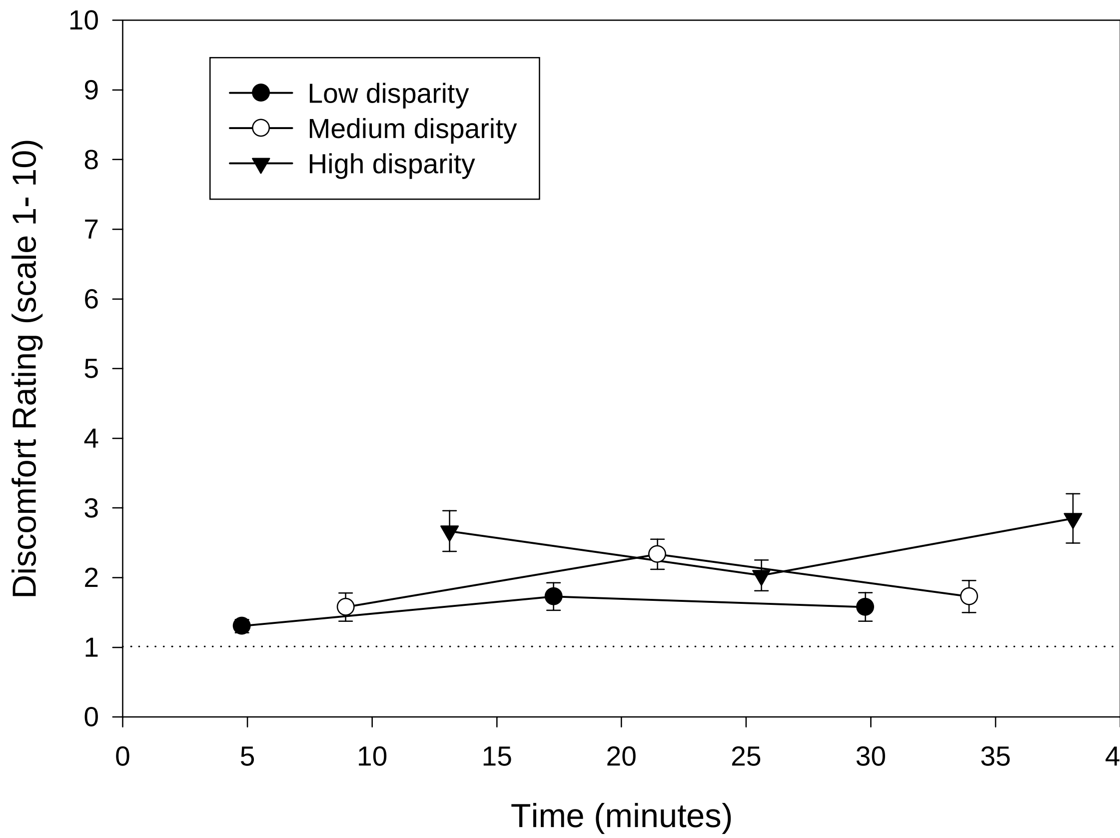

Figure 5. Changes in comfort level over time for the low, medium, and high disparity conditions in Experiment 2. The dotted line represents the no discomfort level.

4. SUMMARY AND CONCLUSIONS

In this study, we conducted two experiments to determine the effect of whole-field disparities on viewing comfort. In Experiment 1, we found that whole-field vertical disparities produced a marginal increase in discomfort that became only slightly more pronounced with time. In Experiment 2, we alternated periods of low, medium and high levels of whole-field vertical disparity and found that discomfort increased with vertical disparity level, but again only marginally even after prolonged exposure.

The disparity change we introduced was always in one direction. That is, the right eye image was always misaligned in the up direction with respect to the left one. It might be argued that this choice, which was motivated by technical limitations of the apparatus, could have helped the viewers to reduce the amount of vertical displacement, thereby reducing discomfort. Indeed, it is possible that the viewers attempted to counter the whole-field disparity by maintaining an intermediate vergence state. However, it is unlikely that this strategy would have been effective in reducing vertical disparity, since the latter changed randomly over time. Further research, examining the effect of vertical disparity offsets in equal and opposite directions, is needed to fully evaluate this possibility.

It is worth stressing that our conclusions are limited to the range of whole-field disparity employed, that is up to about 1-1.5 degrees of visual angle. In fact, it is reasonable to expect that larger whole-field vertical disparity changes would result in a more pronounced level of discomfort. Some indication that this might indeed be the case is found by examining the percentage of viewers who did report an appreciable change in viewing comfort. To this end, we have reported the percentage of viewers that experienced a degree of discomfort equal or higher than 4 in Table 1.

Table 1. Percentage of viewers that experienced a degree of discomfort equal or higher than 4 in Experiment 1and 2.

	Condition	Average Vertical Disparity (Standard Deviation) in minutes of arc	Percentage
Experiment 1	Far	22 (SD = 3.3)	6%
Experiment 1	Near	31 (SD = 4.6)	11%
Experiment 2	Low	9 (SD = 7.4) to 15 (SD = 13.2)	0%
Experiment 2	Medium	17 (SD = 12.0) to 30 (SD = 21.4)	6%
Experiment 2	High	35 (SD = 24.9) to 62 (SD = 44.2)	21%

Note that the percentage is 0 for small whole-field vertical disparities, varies between 6% and 11% for intermediate vertical disparities, and rises to about 21% for large vertical disparities. Clearly, the number of viewers experiencing discomfort increases with increasing whole-field disparity level. This increase suggests the existence of individual differences in the capacity to compensate for whole-field vertical disparities.

The data obtained in this study are important for they reveal that whole-field vertical disparities smaller than about 15-20 minutes of arc do not cause any noticeable discomfort for the average viewer. It is noteworthy that these results were obtained with non-expert viewers, i.e., viewers with limited or no stereoscopic experience, and under applied conditions, e.g., commercial movie theater. Thus, we are confident that our data are representative of the general population. However, it is also important to note that our data were obtained with a theater type screen subtending a large visual angle. Future research will have to confirm these findings for small screens (e.g., computer screens) which typically subtend a much smaller visual angle. If our results were confirmed, then it might be of limited benefit for the 3D display industry to spend additional time/funds to refine either camera systems or projection/display technology to reduce whole-field vertical disparity below the 15-20 minutes of arc range.

5. ACKNOWLEDGMENTS

We would like to thank Gord Harris for his assistance in designing and conducting these experiments. We also thank Dr. W. J. Tam and Dr. L. Stelmach who provided helpful comments on an earlier version of this manuscript.

6. REFERENCES

1. A. Puri, B.G. Kollaritis and B.G. Haskell, “Basics of stereoscopic video, new compression results with MPEG-2 and a proposal for MPEG-4," *Signal Processing: Image Communications*, **10**, pp. 201-234, 1997.

2. N. Hiruma, “Accommodation response to binocular stereoscopic TV images,” in *Human Factors in Organizational Design and Management III*, K. Noro and O. Brown, Eds., pp. 233-236, 1990.

3. N. Hiruma and T. Fukuda, “Accommodation response to binocular stereoscopic Tv images and their viewing conditions,” *SMPTE Journal*, **102**, 1993.

4. W.A. Ijsselsteijn, H. de Ridder, and J. Vliegen, “Perceptual factors in stereoscopic displays: the effects of stereoscopic filming parameters on perceived quality and reported eyestrain,” *Proc. of the SPIE Human Vision and Electronic Imaging III*, **3299**, pp. 282-291, 1998.

5. W.A. Ijsselsteijn, H. de Ridder, and J. Vliegen, “Effects of stereoscopic filming parameters and display duration on the subjective assessment of eye strain,” *Proc. of the SPIE Stereoscopic Displays and Virtual Reality System VII*, **3957**, pp. 12-22, 2000.

6. T. Miyashita and T. Uchida, “Cause of fatigue and its improvement in stereoscopic displays,” *Proc. of the SID*, **31**, pp. 249-254, 1990.

7. A. Woods, T. Docherty, and R. Koch, “Image distortions in stereoscopic video systems,” *Proc. of the SPIE Stereoscopic Displays and Applications IV*, **1915**, pp. 36-48, 1993.

8. M. Wopking, “Visual Comfort with stereoscopic pictures: An experimental study on the subjective effects of disparity magnitude and depth of focus,” *J. of the SID*, **3**, pp.101-103, 1995.

9. J. Konrad, “Enhancement of viewer comfort in stereoscopic viewing: parallax adjustment,” *Proc. SPIE Stereoscopic Displays and Virtual Reality System VI*, **3639**, pp. 179-190, 1999.

10. R.S. Allison, I.P. Howard, and X. Fang, “Depth selectivity of vertical fusional mechanisms,” *Vision Research*, **40**, pp. 2985-2998, 2000.

11. I.P. Howard, R.S. Allison, and J.E. Zacher, “The dynamics of vertical vergence,” *Exp. Brain. Res.*, **116**, pp. 153-159, 1997.