PERCEPTUAL COMPENSATION MECHANISMS WHEN VIEWING STEREOSCOPIC 3D FROM AN OBLIQUE ANGLE.

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ABSTRACT

Mathematically, 3D content should appear distorted unless viewed from the position the content was produced for. However, 3D content regularly gets viewed from incorrect angles, not perpendicular to the screen as intended. This distortion is not noticed, or at least does not affect the impression of 3D. This may be because a compensation mechanism known to exist with 2D content extends to 3D.Using canonical-form testing, we show that 3D content can appear warped when viewed from oblique angles, but the effect is small and non-stereo cues help to restore the effect.

Index Terms — Stereoscopy, Binocular, Vision, Oblique, Viewing, Correction.

1. INTRODUCTION

Small disparities between retinal images in each eye being detected by the brain, even in the absence of other depth cues, suffice to create a vivid perception of depth [1]. This is used in stereoscopic displays, which present separate images to the two eyes. Appropriate disparities result in the impression of depth [2, 3]. Passive 3-dimensional (3D) stereovision has been utilised in the displaying of content for a long time.

When considering the angles involved in projecting the correct impression of depth, the viewer must be positioned with each eye exactly where that eye's image was intended. Once not at that position, the disparity cues will become mathematically incorrect[4]. This should lead to distortions in perceived depth and object shape. We can distinguish two main ways in which viewers can move away from the intended position: incorrect viewing distance and incorrect viewing angle. In this paper we consider the viewing angle.

Almost all S3D content is created to be viewed on a screen perpendicular to the viewer. However, in cinemas many viewers will be viewing the screen obliquely. This can also happen in the home: with only one correct position, whenever there is more than one viewer somebody is certain to be viewing from an incorrect angle.

This in itself is a problem as 3D displays should look distorted from any viewing angle other than a perpendicular one. These problems also apply to 2D images, however from an early age the visual system seems to learn to compensate, keeping the 2D image from appearing deformed by correcting for the position the image is viewed from[5, 6], resulting in the image being viewed always being the same.

This compensation seems to depend on the brain calculating the orientation of the screen plane. Accordingly, manipulations which make it harder to locate the screen plane – removing the visual cue provided by the frame, viewing monocularly, or using a pinhole to remove the accommodation – tends to make this compensation less effective, and make the images appear warped at oblique angles[6, 7].

This process appears to be somewhat disrupted in 3D[7, 8]. This may be because in 2D accommodation and disparity [9] tell you where the screen plane is, but in 3D they do not: disparity is now inconsistent with the true orientation of the screen plane[7]. This means that it could potentially be that the very thing that makes 3D a powerful visual experience is, ironically, the reason that the compensation methods learned by the visual system do not work as well.

2. AIMS OF THE STUDY

In this paper, we used a canonical-form task to examine distortions caused by incorrect viewing angle. We compared stereoscopic 3D and binocular and monocular 2D stimuli to examine whether the visual system is less able to compensate for oblique viewing in S3D than in 2D. To determine the extent to which compensation depended on knowledge of screen orientation, we compared results when the edge of the screen was occluded versus when it was visible.

3. MATERIAL AND METHODS

3.1. Apparatus

Stimuli were presented on a 50inch 3D TV (LG 47LD920 – ZA) using passive stereo technology. Participants were instructed to sit on a chair at a perpendicular viewing distance 120cm from the screen of the television, which could be rotated between ±45°. We define θ_{sit} to be the angle between the perpendicular viewing of the screen and the participant's line of sight (figure 1). The television screen was rotated so that angle θ_{sit} was either 0^o, -45^o or $+20^o$ (see sec 3.3). A chinrest was used to ensure the subject's head and eyes were at the correct height and distance from the television. In some experimental blocks, a

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curtain was pulled across which occluded the edges of the screen from the view of the participant (see sec 3.3).

3.2 Stimuli and task

In each trial, the participant viewed two wire-frame cubes. The participant was asked to choose which cube looked the "most cube-like".

In each trial, one of the two cubes was rendered for perpendicular viewing, and one was projected for a different viewing angle that varied between -45° and +45°. Angles were measured from the perpendicular viewing distance V. Occasionally the obliquely-rendered cube was rendered for the actual viewing angle of the participant, i.e. in the S3D condition, each eye saw the retinal image which would have been created by a physical cube in space. Each virtual cube was rotated through a random angle about all three axes in succession before being rendered. In each trial the cubes were randomly assigned a size.

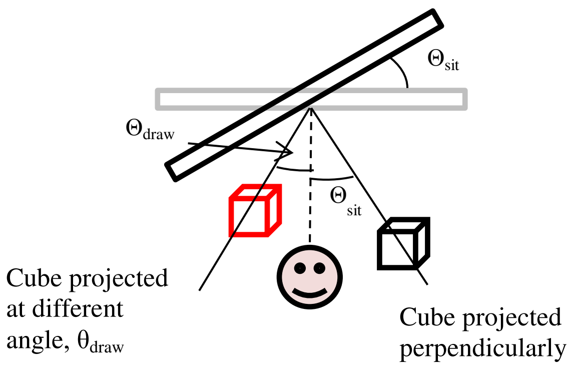

Fig. 1. How the experiment was set up. The television is rotated from its original (grey) position by θ_{sit} The black cube is projected perpendicularly and the red cube projected for θ_{draw}. Occasionally a curtain is pulled across so that the angle by which the television is rotated is not available information to the participant.

3.3 Experiment design

The experiment was composed of six blocks. In each block the participant was sat at one of three viewing angles: -45°, 20° and 0° and had a curtain occluder either present or not to obscure the edges and remove any knowledge of the angle the stimuli were being viewed at in that particular block. The six blocks were randomly interleaved using a random number generator. There were eight values for the angle with which θ_{draw} was projected. It was also randomly interleaved whether the cubes were to be viewed in S3D, 2D binocularly or 2D monocularly. These parameters were displayed in each block resulting in 24 distinct parameter sets repeated 8 times. In each block the angle that the obliquely-rendered cube was projected from, $\theta_{draw,}$ changed in each trial, with eight distinct values: ±45°, ±35°, ±20° and ±10°. The normal-rendered cube was always projected at 0°. Each trial (n=384) was randomly interleaved in each of the six blocks. The six blocks were randomly interleaved for viewing position, i.e. θ_{sit} being either 0°, 20° or -45°, and whether or not a curtain occluder was present.

3.4. Stimulus Generation

Stimuli were generated and the experiments run using the computer programming environment Matlab and the Psychtoolbox extension [10-13]. The cubes (Fig 2) were rendered by calculating the position of the vertices on the screen from projection.

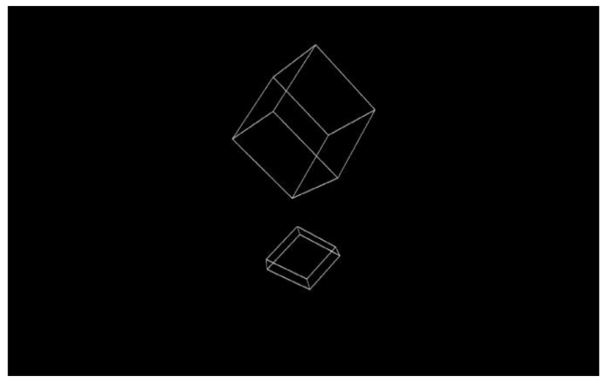

Fig. 2. How the cubes were displayed to the participant. Here the bottom cube is the perpendicular cube and the top cube the obliquely rendered cube, here rendered for a viewing angle of 45°.

3.5. Participants

Participants were recruited via an internal volunteer scheme and were recruited on the basis they had no visual problems other than wearing glasses or contact lenses. The work was approved by Newcastle University Faculty of Medical Sciences Ethics Committee. 11 participants (8 female, naïve to the study, 3 males, 2 naïve and 1 author) were used in the study.

4. RESULTS AND DISCUSSION

To display the results, we show the proportion of trials on which the perpendicular cube was selected as being "more cube-like". We plot this as a function of θ_{draw}, the viewing angle for which the obliquely-rendered cube was drawn. For θ_{draw}=0, both cubes would be rendered for perpendicular viewing, so performance would necessarily be at chance. The three panels in Figs 3 and 4 show results for the 3 different viewing angles actually used by the observers, θ_{sit}. For the top and bottom panels where $\theta_{sit}\neq 0$, the vertical dashed lines mark the case $\theta_{draw}=\theta_{sit}$.

Fig 3 shows the results in the unoccluded condition where subjects could see the television screen and thus were aware when they were viewing it obliquely. We first consider the central panel, Fig 3B, where $\theta_{sit}=0^o$, i.e. the screen was perpendicular to the participant. As the obliquely-rendered cube is drawn at more extreme angles subjects become more likely to choose the perpendicular cube. There is no difference between performance with 2D binocular vs. monocular viewing. However, there is a small but significant difference with S3D. When viewing the cubes in S3D, subjects are significantly more sensitive to incorrect rendering.

Fig 3A and C show results where subjects were viewing the screen obliquely. In Fig 3C, the viewing angle was $\theta_{sit}=20^o$. The asymmetry of the results about the line $\theta_{draw}=\theta_{sit}$ indicates the operation of a compensation mechanism which corrects for oblique viewing and makes subjects more likely to perceive the normally-rendered cube as "cube like", even if it in fact projects a distorted image on their retina.

This fits with previous work suggesting that subjects compensate for oblique viewing. If the compensation were perfect, then Figs 3A and C would be identical to Fig 3B. As it is, our results suggest the compensation is imperfect.

Comparing the S3D results (red squares) in Fig 3 to the 2D results, it is clear that S3D weakens the compensation mechanism and gives more weight to whether rendered objects create the correct image on the retina. This is particularly clear in Fig 3A, where the viewing angle is extreme ($\theta_{sit}=-45^o$). When the obliquely-rendered cube produces close to the correct retinal image (θ_{draw} close to θ_{sit}), subjects perceive it as more cube-like than the normally-rendered cube when it is viewed in S3D.

We expected the compensation for oblique viewing to be less effective when the screen is occluded such that viewers cannot tell its orientation. Results for this condition are shown in Fig 4. In fact, very little difference is apparent between these occluded results and the unoccluded data in Fig 3.

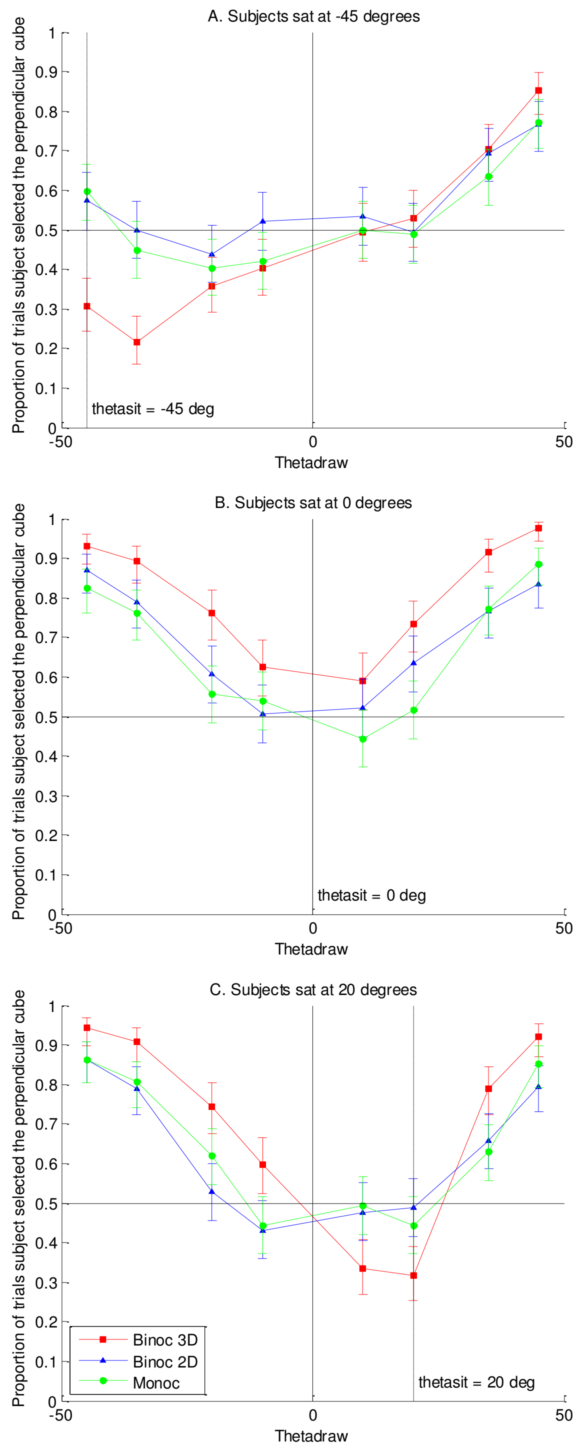

Fig. 3. Results from unoccluded condition. Results are plotted as a function of θ_{draw}. Subjects would therefore necessarily be at chance at $\theta_{draw}=0$. Each data-point represents 176 trials from 11 subjects. Error-bars show 95% confidence intervals using simple binomial statistics.

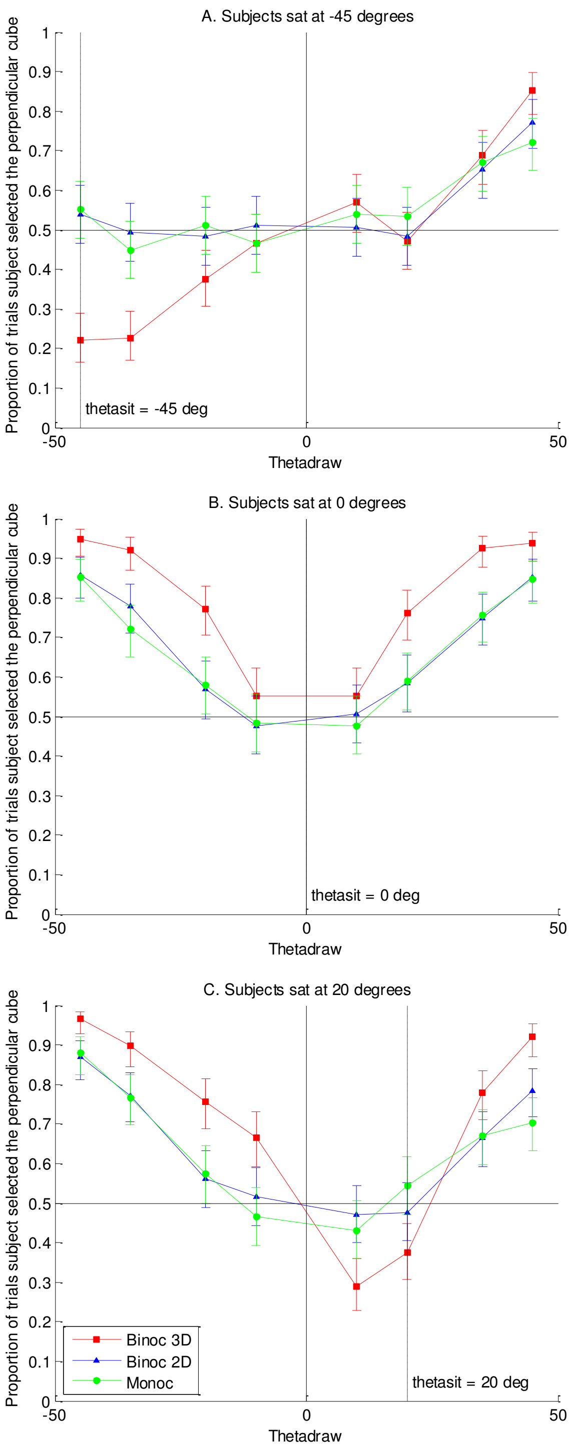

Fig. 4. Results from occluded condition. A curtain prevented the subject from seeing the edges of the screen. Other details as for Fig 3.

5. DISCUSSION

The compensation mechanism known to exist for 2D binocular viewing of displays has been relied upon for the production of S3D content. This compensation mechanism ensures that an image viewed on a screen is perceived as if the screen is frontoparallel to the observer.

There are good reasons to imagine that this compensation mechanism might be weaker for stereoscopic 3D content, mainly due to the disruption of the disparity cue to the screen plane.

Our results confirm previous work showing that the human visual system compensates for oblique viewing angles [6-8]. Additionally, viewers are relatively insensitive to distortions caused by inappropriate viewing angles. Most viewers cannot tell the difference between a stimulus rendered for perpendicular viewing and a stimulus rendered with up to 20^{o} error in viewing angle.

At the most extreme viewing angles ($\theta_{sit}=45^{o}$), the compensation mechanism does work better in 2D images. At these extreme viewing angles, geometrically correct cubes are more likely to appear correct than cubes rendered for perpendicular viewing. The preference for geometrically correct retinal images is stronger in S3D viewing than for 2D viewing. A plausible reason is that, in binocular 2D viewing, the true orientation of the screen can be deduced from disparity cues. This makes it possible to apply the appropriate compensation [6].

However, these differences only apply at the most extreme viewing angles. For many S3D display systems, these viewing angles already cause other problems such as increased cross-talk or contrast changes.

6. CONCLUSION

The recent surge in popularity of 3D content over the past decade has brought with it many questions with regards to its successful delivery. This study has questioned basic assumptions made by producers of content for cinema and television, namely the assumption that the angle the content is viewed at has no effect on the image perceived.

Fortunately for the producers of 3D technology and content, our results suggest that viewers are very nearly as tolerant to oblique viewing in S3D as in 2D. Similar compensation mechanisms seem to apply. This may help explain why S3D content is popular and effective even though it is usually viewed from the “wrong” position.

7. ACKNOWLEDGEMENTS

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