Abstract

Stereoscopic cinema is a recently resurrected trend in the film industry. While most audiences enjoy the vivid effect stereoscopic cinema creates, negative side effects, such as visual fatigue, has been cited as a significant issue. Some people report that viewing a stereoscopic film causes severe discomfort and visual fatigue. An experimental study designed to investigate the contributing factors would reveal whether those negative components could be eliminated via the image content. In the thesis it was hypothesised that one element only, moving in the depth of field would cause less visual fatigue and discomfort than multiple elements.

Two experiments were carried out in order to find evidence in support of the hypothesis, if any. Each experiment consisted of two versions of stereoscopic video, one containing a single element and the other multiple elements. The first experiment contained fully stereoscopic stimuli, and the second experiment contained only partially stereoscopic stimuli meaning not all elements were stereoscopic. The experiments were conducted with repeated measures where each participant watched videos that contained single and multiple elements and rated his or her discomfort and fatigue on a five point rating scale.

The results did not support the hypothesis. It was evident that any differences between experiment stimuli did not affect the perceived discomfort.

Numerous speculations regarding the hypothesis are considered. The experimental stimuli were very short and the display method was not optimal, both factors deemed likely to have affected the result from the experiment. With that said it could be concluded that visual fatigue and discomfort are more physiological issues and that image content is most likely not a significant factor.

Preface

This study was conducted at Aalborg University Copenhagen spring semester 2010. It was written as a 10th semester project which also serves as a Master Thesis, M.Sc Medialogy. The thesis is worth 30 ECTS which span over 4 months period.

The content of the thesis is written in relation to stereoscopic cinema and negative perceptual affects that it can lead to.

The report is accompanied with a CD containing electronic version of the report in addition to the stimuli used for Experiment I and II.

The report consists of 11 sections. Following the *Introduction* which outlines the motivation for the thesis, a section on *binocular vision and stereoscopy* serves to clarify the terminology for the prject. The next sections presents *related work and hypothesis* which form a grounding for an experiment. *Design and production pipeline* outlines the creation of the experimental stimuli followed by a section on *Experimental Design* where the setup and procedure for the investigation is outlined. *Results I* represents the outcome from experiment 1 followed by a *discussion* of the results which conclude that *experiment II* is in order. *Results II* specify findings during the latter experiment. The project as a whole is discussed and concluded in *Discussion and Conclusion.*

Aalborg University Copenhagen, May 2010

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I would like to thank Daniel Grest for his supervision during the project period. Furthermore, I would like to thank Halla B. Ólafsdóttir for her assistance with treating the data.

Contents

1 Intoduction

3D cinema is currently a very growing trend. The technique is seen as the holy grail to combat piracy and to create new, exciting and even more immersive cinema experience [19, p 14]. At first glance it seems sublime to add the third dimension but as the technique is becoming more widespread, complaints have arisen. Some audiences claim that the 3D gives them discomfort in the form of a headache, motion sickness and general eye fatigue.

What triggers this discomfort? Is is possible to dodge it in any way? How do visual effects affect the perceived discomfort?

The goal of the current project is to come closer to answer those questions by means of a short, stereoscopic film clip that has been enhanced with simple visual effects. The visual effects will serve as a medium to investigate the eye fatigue they may take part in causing.

2 Binocular Vision and Stereoscopy

2.1 Brief History of Motion Pictures in 3D

This chapter outlines the history of stereoscopic cinema, where it comes from and why it has not been more popular in the past.

Stereoscopy has been known for centuries, in 1833 Sir Charles Wheatstone invented a way to project two images in order to create stereoscopic experience. [7, p.1] The technique continued to progress over the years and around the American Civil War stereoscopic viewing device could be found in many homes. In 1862 an inexpensive dual lens cameras came to the market which enabled even easier access to create stereoscopic imagery. [7, p.1] The stereoscopic effect was solely used for still images at the time but the technique was later adopted to create 3D for motion pictures.

The first device to view 3D films was so called *peep-show* where only one person could watch at a time. In 1915 a more theatre friendly version of the 3D projection was invented, namely the red and green anaglyph technique. This technique consists of two pair of footage that is printed over each other in two different colours and viewed with glasses in corresponding colours [7, pp. 3-4].

Although Stereoscopic techniques have been around for ages, it took a long time for it to become a real hype within the movie industry. It was not until 2007 that *Variety* magazine covered speculations about 3D cinema in Hollywood that it really took off and producers started to invest in full featured stereoscopic films[14, p 518].

The current stance of the 3D cinema and the hype it is currently creating has some parallels to when the cinema introduced both sound and colour which are today considered an obvious part of the experience. The addition of sound to the cinema required complete synchronisation between two machines, similarly to the stereoscopic projectors that are used in 3D cinema, the technology was expensive and resulted in higher ticket prices for cinema goers [14, p 519]. Thus it is an viable consideration whether the 3D cinema is not only going to be a hype but become a part of traditional cinema experience. However, it is estimated that four to five percentage of the population are stereoblind [20, p 708] and around ten percent is experiencing extensive difficulty with viewing 3D movies [24, p 380]. For that reason it is arguable if stereoscopy is here to stay or if it is a hype that will settle again.

2.2 The Human Vision - Terminology

When viewing the world multiple cues that indicate depth, distance and shape are used. Most of those cues are monocular but knowing and understanding the terms is important to create a convincing 3D scenario. In the following chapter those terms are discussed briefly, along with general description of the functionality of binocular vision in the natural world on one hand and the 3D world digital cinema can create on the other.

The human eye is a complex organ. Along with the brain it does an astonishing job helping to determine distance and location. Fundamentally the vision is a combination of reflected light on the retina which is then interpreted into recognisable images by the brain [27, p 2]. Area in the back of the brain called occipital lobe processes the information from the eyes. Although the eyes are two and have equally as many points of view, that are approximately 6.35 centimetres apart, they are interpreted as only one image [18, p 19]. This is due to certain fusion that happens in the brain where the optic tracts give stimuli from each eye to both visual cortex. This process is more commonly known as *binocular* vision.

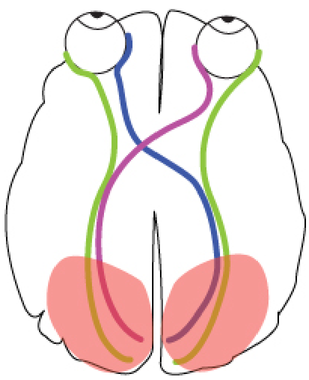

Figure 1: *The inputs from the eyes is processed in the occipital lobe.*

The brain uses several depth cues to localise objects in space. Although binocular depth cues are the most accurate, the brain also uses monocular components to determine depth and location. Monocular vision is provided through one eye only.

Monocular depth cues make a traditional 2D motion picture look as it has some depth and not be flat as it essentially is. To understand fully how depth is determined by two dimensional depth cues several terms should be coined. By reviewing the following elements monocular depth cues are clarified. By implementing some of those principles into a stereoscopic scene that contains visual effects, more depth can be created without necessarily having all elements in stereo.

The fist term is *occlusion*, also known as *interposition*, it refers to when objects in the foreground overlap the objects in the background [15, p 167]. This gives important information when determining spatial relations between objects displayed in a 2D image.

Size cue can also give an information about how far or close an object is in space [15, p 167]. The size of the object has to be somewhat known or be set in relation to another object of known size, for instance when a man and a house seem to be of the same size in a photograph, the house might be very small, the man might be a giant or, most likely, that the house is further away from the point of view.[18, pp 11-12].

The size cue can be aided with a *texture gradient*, but that pertains to when distance makes pattern and texture appear more dense [15, p 169]. For instance when one stands at a meadow filled with flowers the pattern of the flowers appears to be a solid colour in the distance. Figure 3 illustrated some of the depth cues including texture gradient. *Atmospheric perspective* obeys similar laws, meaning that remote objects become less distinguishable. More specifically atmospheric perspective refers to when distant objects appear more misty than objects that are closer [18, p 13], again this is illustrated in figure 3.

Both *Linear perspective* and *height cues,* relate to the horizon. The prior refers to when two lines that are perpendicular to the horizon lead to the same spot. For instance, when the two edges of a road seem to meet at the horizon [15, p 170]. The latter pertains to when distance is determined by the height of objects in the horizon, objects close to the horizon are perceived to be further away than objects that are lower [15, p 172] [18, p 14].

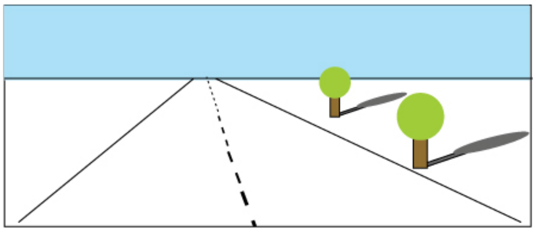

Figure 2: *The road illustrates linear perspective. The trees appear of different distance because of the height cues.*

Shape, texture and position can be determined by the *shading* of an object. It also helps to determine the height of objects relative to the surrounding objects [18, p 14] [15, p. 170].

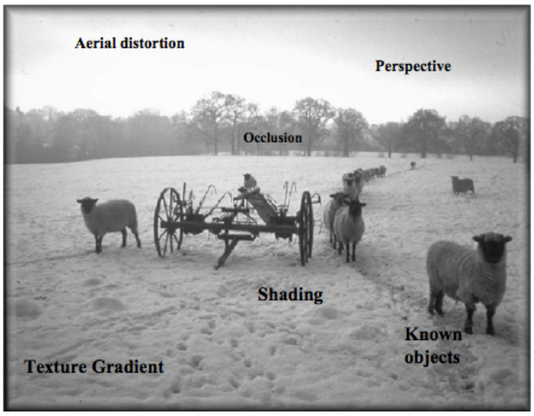

Figure 3: *Monocular depth cues, the figure illustrates several of the different cues. [8, p 5].*

All of priorly mentioned depth cues are fairly obvious to the perceiver. Although it seems like it is stating the obvious, one should keep in mind that understanding those cues is a learned behaviour that is developed since infancy.

Accommodation on the other hand is the part of depth perception the perceiver is not aware of. This means that when looking at an object the eye is accommodating or focusing on that spot. The ciliary muscles in the eye enable the lens that controls accommodation to tighten and relax according to the location of the viewed object [15, p 167]. Figure 4 illustrates how accommodation works.

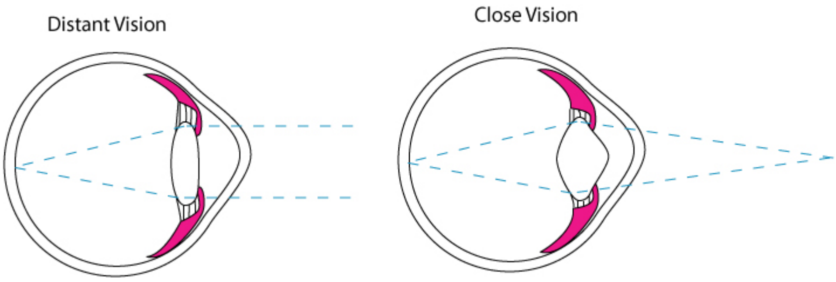

Figure 4: *The process of accommodation. The muscles in the eye help adjusting the "lens" in the eye in order to accommodate. The figure is inspired by [22]*

The ability to accommodate makes 3D possible [18, p 22]. Studies have shown that the eye accommodates on the nearest virtual point when viewing a stereoscopic movie thus using the functionality to aid the perception of 3D effects[6, p 4]. This is perhaps the only monocular depth cue that is not learned and interpreted by the perceiver.

All previously mentioned depth cues depend on monocular vision for non moving objects. As the real world takes place more actively and the perceiver is seldom completely static, awareness of other motion dependent cues is very useful for the creation of a 3D cinema. Here *motion parallax* is one of the most important terms to understand. The term refers to when objects of different distance appear to be moving past one another at different velocities [15, p 174]. Meaning that objects that are further away seem to move slower than objects that are closer to the perceiver. This technique was popular in video games during the 80's and was commonly used to create a feeling of depth to otherwise flat and pixelated surroundings [18, pp 16-17].

The above mentioned depth cues insure that traditional cinema does not look flat. So what about 3D cinema, what are the attributes for that?
Josh Greer the CEO of RealD stated that *"Stereopsis is more like a feeling than a perception "*[18, p 25]. 3D cinema is precisely just that, a feeling of 3D. The process of seeing 3D happens in the brain. Before going deeper into 3D perception the terminology should be clarified. *Stereopsis* and *binocular vision* is the same phenomenon. It refers to when the two different inputs from both eyes are merged together to create a 3D representation[15, p 183]. By mixing the two images from the eyes, location and depth can be determined. Figure 1 depicts

how the optic tracts from the eyes interconnect to both of the visual cortexes, this connection is what makes binocular vision possible. Another term is *stereoscopy*, this is essentially the same as 3D but it refers to the technology where the image material has two different angles, each seen with one eye each.

The eyes react differently to the real world than to a stereoscopic cinema. The difference is how the eye accommodates. Figure 5 illustrates vision in the real world.

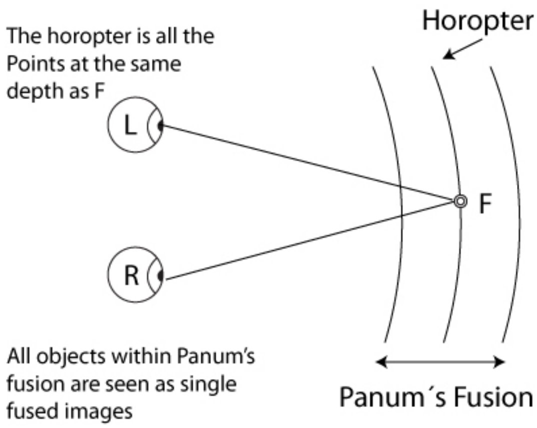

Figure 5: *Vision in natural environment, illustration from [8, p 6].*

Figure 5 depicts when both eyes are focusing at point F. Both of the eyes are directed towards F that is located on so called horopter, that term is used for all points that have the same depth and therefore same accommodation for the eyes to focus on. The eyes verge or rotate the visual axis horizontally in order to alter its accommodation and reach focus [8, p 6]. When stereoscopy is perceived the fixation points are not the same for both eyes. To clarify, the illustration depicts F with zero retinal disparity. Points that would be in front or behind F would create some retinal disparity via mismatching images for left and right eye which the brain interprets as a stereoscopic depth cue [8, pp 6-7].

Understanding binocular vision in natural surrounding clarifies the functionality 3D cinema creates for the visual system. While the real world allows the eyes to verge[1] and accommodate at the same spot, 3D pulls the two apart. This means that the eyes convergence at a different

[1]Rotate horizontally, when watching near objects the eyes converge and diverge for distant objects, this behaviour is referred to as vergence [25].

spot then they are essentially accommodating at [18, p 22]. Figure 6 illustrates how the 3D cinema affects eye system.

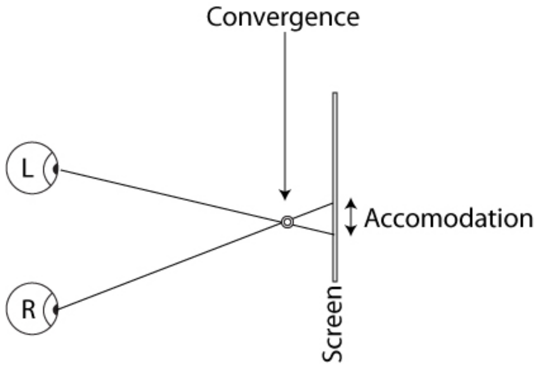

Figure 6: *Stereoscopic perception occurs when the eyes are accommodating beyond the converging spot [18, p 22] [32, p 10].*

The parallax between two spots determines the depth in the scene. Increased parallax forces the eyes to convergence and less parallax enable divergence. It is evident that depth perception is combination of several contributive factors. The process of interpreting depth is a cognitive process in the brain and thus can be perceived and interpreted differently between individuals [27, p 6]. Some individuals are very sensitive to stereoscopy and are likely to experience discomfort such as eye fatigue, motion sickness and headache. The common word for those symptoms is *asthenopia* which is collectively used for eye strain or weakness of the eye. The condition causes severe tiredness in eyes that sometimes leads to headache and general discomfort [13, p 3]. Those symptoms can be traced to the unnatural eye movement 3D cinema requires. The brain gets confused when the eyes have converged at a spot but lack the accommodation since 3D is merely a visual illusion [21].

2.3 Stereoscopic Display Technology

There are several stereoscopic display methods. Following is a listing of variant technology and methods and the pros and cons that follow each technology.

The basic principle behind stereoscopic display is that there are two separate images for left and right eye that depict slightly different point of view. Stereoscopic displays imitate the binocular disparity functionality in the visual system which the brain construe as depth signals [4, p 1]. "*The horizontal distance on the display screen between corresponding points in the left and right eye view is called the screen parallax. When the screen parallax for a certain point in the image is zero this point will be seen at the screen plane.* " [27, p 9]. This means that when both eyes have the same point of view the image is two dimensional but as soon as there are negative or positive screen parallax the third dimension can be perceived [27, p 9]. Figure 7 depicts this phenomenon.

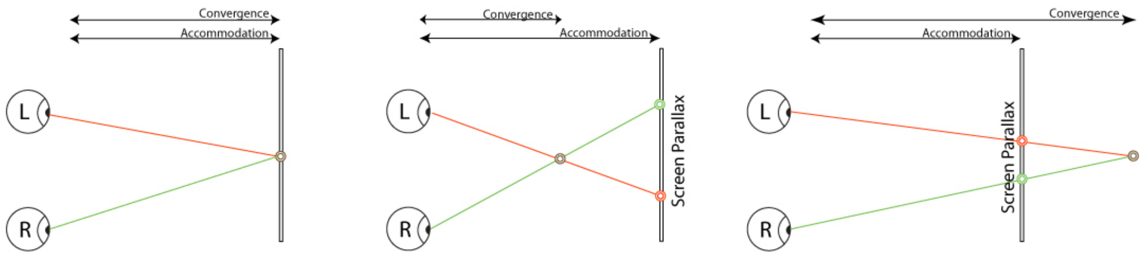

Figure 7: *Three different states of convergence and accommodation. Screen parallax is the distance between the red and green dot in order to create a binocular perception of the brown dot.*

To be able to view the depth 3D movies create, display technology that makes a distinction between right and left eye is utilised. There are *active stereoscopic* devices and *passive* devices, also referred to as *auto stereoscopic* displays. The term *stereoscopy* is usually paired with shutter glasses, anaglyph colour glasses and polarized glasses. The anaglyph glasses and the polarized glasses are commonly used for 3D cinemas. The latter is more complexed system.

The anaglyph technique is probably the most known technique. Anaglyph is when coloured gel, often red and cyan, is used to distinguish between the left and right image [8, p 15]. Stereoscopy using this technique is very easy to create. The left and right images are layered on top of each other where left has filtered out specific colour and right another. In this project red and cyan anaglyph glasses were utilised thus the red and the cyan colour filtered accordingly.

Several variations of stereoscopic systems require polarized glasses, It can for instance be *light polarization* -where the waveform is oriented by neutral grey filters and paired with silver coated screen or *RealD* which is commonly used in cinemas [18, p 172]. Its biggest advantages is that the glasses are circularly polarized, which allow the user to tilt his head without any loss of depth effect. The image for left and right eye are separated by so called *Z-filter*, which is placed between the projector itself and the porthole of the projector. The image is distinguished between the eyes by circularly polasizing, clockwise for one eye and counter-clockwise for the other [18, pp 172-173], [16].

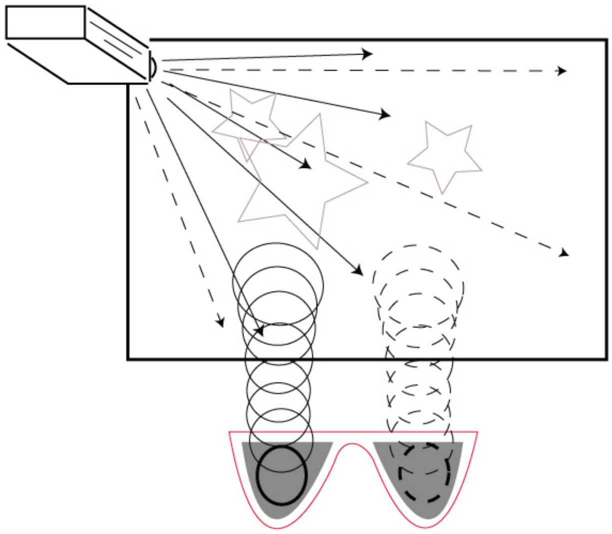

Figure 8: *RealD makes use of circular polarisation where left eye sees frames that are polarized counter clockwise and the right eye clockwise. Figure inspired from [26]*

Instead of polarization the *Dolby* system utilises colour separation, special glasses with twenty to thirty filter- and tint coatings aid to distinguish between the RGB values for left and right eye. More specifically, the left eye takes in certain value of, for instance, green and the right eye takes in another value for the same colour thus creating binocular vision. Figure 9 illustrates the different wavelength for each eye.

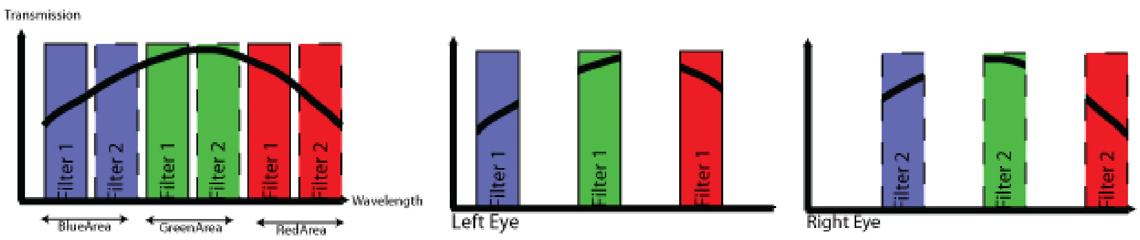

Figure 9: *Each only sees colours of a specific wavelength. Illustration from [18, p 174]*

Dolby projectors are equipped with a colour wheel that is located between the light source and the DLP[2] in the projector [18, p 174][16].

Shutter glasses are also an example of active stereoscopic device. The glasses run in synchronisation with the display where the left and the right side of the glasses flicker rapidly in beat with the image on the display and thus creating binocular perception [16][27, p 9].

When display technique is *auto-stereoscopic* or *passive*, the division between the visuals for the left eye and the right eye is integrated into the display itself. *Parallax barrier* is an example of an auto-stereoscopic system, it functions somewhat like the polarized glassed since it divides the light from the display between left and right eye [29]. This is done via "*alternating transmissive and non-transmissive columns aligned with the columns of the LCD pixels*" [10, p 2]. The most obvious disadvantage of this technique is that the viewer has to be at a very specific position in front of the screen to perceive the 3D properly.

The common denominator for all stereoscopic and auto-stereoscopic devices is that it imitates binocular vision by separating the left and right point of views. Up to date, there is no technique that is considered completely flawless but the stereoscopic active systems are more commonly used than the auto-stereoscopic systems. With that said it should be noted that active stereoscopic systems will be used for the current study.

2.4 3D as a Resent Trend

3D cinema is currently the hot topic in the industry. Some compare the trend to when colour and sound were added to the cinema. The recent success is owing to the improved display technology for stereoscopic cinema. Older 3D techniques such as coloured anaglyph glasses have been to a great extent replaced by polarisation which gives better result in terms of colour and eye comfort.

Although the stereoscopic cinema is currently a big hit, there are many that claim this

[2] A light switch that can produce very fine quality in an image, it consists of microscopic mirrors that can reflect up to 35 trillion colours[9]

is a trend that wont stick around and that it is a pointless gimmick. Those negative voices arise from the obvious disadvantage of stereoscopic cinema, namely the discomfort it can lead to. Previously, at the end of the section *The Human Vision - Terminology* the discomfort is referred to as an eye fatigue and headache.

A huge media fuzz has been about 3D cinema. Amongst others, the british *Telegraph* published an article stating that in addition to the three million of the british population that are stereoscopically impaired, substantial amount of people experiences extensive discomfort while watching 3D [21]. The article lists testimony from number of people that claim to have become sick after visiting a 3D cinema. Stories of people that had to leave the auditorium during a 3D movie due to symptoms like nausea, headache and dizziness. Some even describe the experience as "vomit-indulging" [21].

And the negative voices go on, Richard Cobbett at TechRadar.com expressed his opinions regarding 3D cinema through the TechRadar website. The title of the post says it all, but it is called "*Why 3D TV is just a pointless gimmick.*" In the post Cobbett describes how annoying he finds 3D cinema. "*I quite often lift up the glasses just to compare the two images and every time it's the same: any power that the 3D version of the film has ultimately comes from the 2D version being exquisitely made. I've never wanted for that extra half a dimension as much as I craved the brighter colours and a lack of intense eye-trauma after leaving the cinema.*" [2] Here Mr. Cobbett is talking about how little he thinks 3D adds to the scene, that he lifts his glasses and realises that the reason for the scene to be impressive is not owing to the 3D but something that would also be enjoyed in 2D version he also misses the vivid colours that polarized glasses dampens in a stereoscopic cinema.

The assorted attitude 3D cinema is receiving is largely to be blamed on the eye fatigue it can cause. To make 3D properly it has to obey different principles than traditional 2D movie. For instance it can take the brain up to 1000ms to perceive the 3D depth [31, p 57]. This was found in a research on a stereoscopic depth discrimination where participants were asked to detect dots that appeared on the display. This study showed that editing a 3D movie obeys to different principles than a traditional 2D movie. That is, each clip should be displayed longer in order to allow the eyes to adjust to the perceived depth [18, p 26]. Movie makers have to be cautious how they use the 3D medium. Dave Walton at JVC Professional pointed out that "*no 3D is better than bad 3D*" [5]. This means that when film makers decide to create stereoscopic cinema they better do it properly in order not to do damage the quality of the movie.

Professor Martin Banks from UC Berkley, California, has been researching on 3D eye fatigue. He claims that 3D can enhance films in a way 2D movies can not. Banks continued saying that 3D cinema is here to stay as it works as a nice sensory experience for most viewers [25]. According to him the risk of causing eye fatigue can be lessened by doing 3D properly and take notice to the strain it puts on the brain. By making the audience focus on only one entity at a time the strain of stereoscopic cinema is likely to be decreased [25].

3 Related Studies and Hypothesis

This study makes use of composited video with stereoscopic effect to investigate the visual discomfort sometimes experienced while viewing stereoscopic cinema. This will form a basis for a comparative study where the difference between stereoscopic film clips that contain one focus element on one hand, and multiple on the other is investigated.

It is hypothesised for the current project that the experienced visual discomfort would differ between a stereoscopic film clip that contains multiple focus elements that swarm around in all directions, including the depth of field, and a scene where the audience can focus on one element only.

The following chapter will explain how the hypothesis was derived at and how it connects to previous studies conducted in related areas.

3.1 Visual Discomfort caused by Stereoscopy

Several studies have been conducted to investigate the affect of stereoscopic cinema in relation to eye fatigue and visual discomfort. The common denominator for those studies is that they mention that the cause for visual fatigue is not well known despite much research in the area [33, p 141].

3.1.1 Causes For Visual Discomfort

Studies have shown that viewing of stereoscopic motion images can lead to discomfort in the form of eye fatigue, motion sickness, headache and other symptoms. Researchers claim that those symptoms are caused by a"*conflict [...] between convergence or divergence eye movement and the accommodation function*" [34, p 191]. In addition other studies claim that visual discomfort can be caused by many factors. In *Two factors in visual fatigue caused by stereoscopic HDTV images,* it is stated that the visual discomfort relates to the "*geometrical distortions between the left and right images, differences between the electrical characteristics* *of the left and right images, [...] and excessive binocular parallax.*" [33, p 141].

3.2 Related Work

Many of the studies that concern stereoscopic perception are very abstract in regards to the hypothesis which forms the goal of this study.

Several studies have been conducted in order to investigate eye fatigue. *Lens Accommodation to the Stereoscopic Vision on HMD*[6] is investigating viewers accommodation while watching a sphere that moves in the depth of field. Test subjects watched the video clip for 40 seconds where the sphere travelled back and forth on the z-axis. The study showed that the ciliary muscle that controls the accommodation tensed up as the sphere came closer. Hence the study concluded that virtual environment triggers the same response as the real world. [6]

Furthermore, technical factors related to stereoscopic cinema are investigated in *A Survey of Perceptual Evaluations and Requirements of Three-Dimensional TV* [17] which investigates perceptual issues that may come up when stereoscopic movie is displayed on a 3D TV. Issues such as the difference between the screen parallax in stereoscopic movies created for cinema displays on one hand and TV on the other, are addressed in this study. [17]

Many studies regard specific display technique for stereoscopic image content and other technical issues 3D is facing. As this study does not take specific interest in display techniques it was chosen not to discuss them further.

However three studies deemed of particular interest and are reviewed in the following. Those studies were chosen due to the experiment methodology and the content of the study.

3.2.1 A study of visual fatigue and visual comfort for 3D HDTV/HDTV images

The paper carries out, as the name suggests, an evaluation of visual fatigue [34]. In the study it is hypothesised that by increasing screen brightness and viewing distance, visual discomfort can be decreased. Participants were thus asked to keep viewing distance at 4.5 meters from the display[34, p 191].

Method

Participants were asked to evaluate visual comfort continuously while participating in the experiment by filling in a questions presented on a rating scale, this was done to insure that participants were looking at the image during the whole study. Two videos were displayed called Africa and Waffen. The main difference between the two was the camera setup. One was filmed with so called *toed-in system*, where the distance between the cameras were adjusted in correspondence to the converged point. The other image sequence was filmed with two parallel cameras that were aligned 65mm apart. [34, p 192] Furthermore, participants were asked to view the same video in 2D [34, p 195].

The formal video was shown three times fifteen minutes with five minute interval. The latter was shown five times, ten minutes each time with five minute interval. By showing the videos with intervals it was easier to break down when, if ever, the viewer began to experience visual discomfort. In the study the accommodation response was measured before and after viewing a stereoscopic image and a 2D image. [34, p 193]

Visual fatigue was measured via evaluation scale ranking from one, my eyes are very tired, to five, my eyes are not tired. This was done in addition to an accommodation response measurements which were carried out by a special equipment optimised for the task. Five test subjects were used for this study, all with normal vision, meaning they had no severe visual impairment. [34, p 193]

Results and conclusion

The results confirmed that visual discomfort is very subjective, some encountered it, while others that were exposed to the same stimuli, did not experience any. Visual fatigue was assessed by the change of accommodation response -where reactions in the ciliary muscle is measured- but as there is no standard technique to evaluate visual fatigue the change of amplitude of accommodation response was used as a measure. [34, p 195] Most visual discomfort was experienced during scenes that contained an object that appeared to be in front of the screen and had rapid movements [34, p 196]. Here it is stated "*that the limit of binocular fusion is reduced if the target moves fast, and if a gazed point is located besides the moving objects in the stereoscopic image, the limit of binocular fusion is further reduced.*" [34, p 197]. Meaning the study suggests that stereoscopic objects that move rather fast may appear double ("ghosting") since the brain cant handle the very rapid fusion [34, p 197].

3.2.2 Two factors in visual fatigue caused by stereoscopic HDTV images

The study was conducted with special concern for depth of focus when viewing stereoscopic images. Here so called *Donders' line* is taken under consideration. This term refers to the rotation of the eyeballs in relation to the position of an object, that is being gazed at, in the depth direction (z-axis) [33, p 142]. According to the study Donders' line shows that the accommodation functionality in the eye and convergence eye movement coincide with one and other [33, p 142].

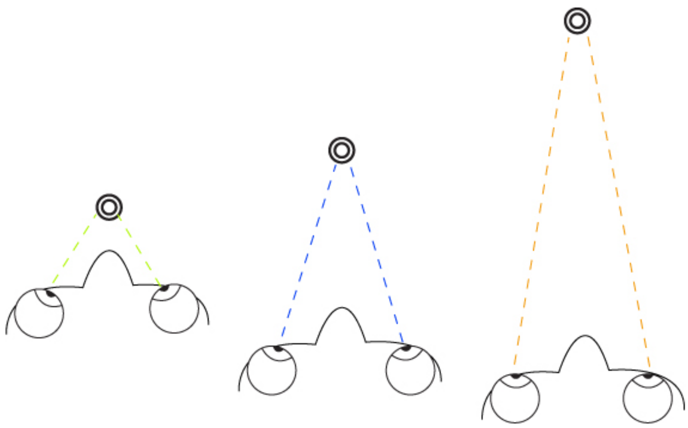

Figure 10: *Tthe eyeballs rotate in accordance to the focus points position on the x-axis from the head.*

It is pointed out that although visual discomfort can be blamed on a conflict between accommodation functionality and convergence of the eye, it is not the only reason. Additionally it is pointed out that in previous studies it was established that static stereoscopic images often did not cause any visual discomfort but rapidly changing motion images seemed to precipitate visual discomfort [33, p 143].

Method

The study was divided between static stereoscopic images and stereoscopic motion images. First, test participants were to view stereoscopic static images and read text that appeared on them. The viewing distance was 108 centimetres and participants were required to conduct the task for three times fifteen minutes with three minutes intervals for rest. At the end of the experiment additional ten minutes were added resulting in sixty four minute total test time. Between each interval the screen parallax was adjusted to three different values, meaning that the distance between the image for left eye and the image for right eye was increased between intervals. [33, p 144] Next, test participants were asked to watch motions stereoscopic image. Two kinds of motion direction were utilised for the test, depth direction and lateral direction [33, p 147]. The test was conducted on six participants [33, p 144].

Both subjective and objective measures were used to evaluate visual fatigue. Like in previously reviewed study, *A study of visual fatigue and visual comfort for 3D HDTV/HDTV images*, participants were asked to evaluate their eye fatigue via self reported measures ranking from one, very tired, to five, not tired. Additionally accommodation response (how fast the ciliary muscle that controls accommodation reacts) was measured before and after viewing the stereoscopic images. [33, p 144]

Results and conlusion

The study showed that extreme parallax increased visual fatigue, interestingly remarkable difference was between screen parallax of -1.36 degrees which shows the stereoscopic image behind the screen and screen parallax of +1.36, which appears in front of the screen[33, p 146]. According to the study visual fatigue was experienced more intensely when the screen parallax caused the image to appear behind the screen.

In the test that entailed motion stereoscopic image the difference of experienced visual fatigue was explicitly more for images that contained depth motion, however the motion images using lateral motion did not seem to trigger the same visual fatigue [33, p 149].

It was shown that visual fatigue is not a significant issue for static stereoscopic images, which are primarily *"perceived by convergence eye movement,"* [33, p 149]. However, when the stereoscopic image contained a depth motion component visual fatigue was more apparent[33, p 149].

3.2.3 Measuring visual discomfort associated with 3D displays

The goal was to find empirical validation that visual discomfort varies substantially between individuals and that previously conducted clinical research may not be suited for evaluation of the matter[12, p 1]. It is hypothesised that *"[...] approximately twenty percent of the population suffer from some form of a binocular anomaly. The associated visual complaints that are not necessarily present in normal viewing situations may become acute or more severe when viewing stereoscopic content."* [12, p 1].

Method

Visual discomfort was measured via both objective and subjective measures. To gain the objective data so called fusion range measurement was utilised, this is when the maximum screen parallax that is perceived stereoscopically is measured. Additionally participants were asked to give self-reported evaluation of visual discomfort [12, p 1]. The test design consisted of one optometric screening and four varying sessions where visual fatigue and discomfort were measured. The sessions involved different display types in addition to an experiment with 2D and 3D [12, p 1].

Results and conclusion

The most interesting outcome in the reviewed study was; that individuals claiming to experience visual fatigue showed changes in their fusion range after viewing stereoscopic content. For those individuals the display type was irrelevant. [12, pp 1-2]

3.2.4 Summary and considerations regarding related work

It is commonly accepted that visual fatigue is related to conflict between the accommodation eye function and the convergence functionality that may occur when stereoscopic content is viewed. Previously reviewed studies are all homing in on investigating the boundaries where visual discomfort is more likely to transpire. The studies had the evaluation methods in common. They all utilised a combination of self-reported measures in the form of questionnaire in addition to objective measures -such as accommodation response, where a clinical device was used. Results showed that subjective measures seemed to be accurate enough to determine and validate hypothesis.

In continuation hereof, number of considerations arise. This thesis can adopt elements from the test methodology that was used for the reviewed studies. It seems like the self-reported measures gives a clear and an approximate idea of the viewers experience, thus it can be assumed that subjective measures are sufficient in order to understand visual discomfort and influencing elements.

To the authors knowledge no study has been conducted where the number of elements, that require attention from the viewer, is investigated. As stated in the *Delimitation* section on page 16, Professor Martin Banks claimed that showing only one main stereoscopic element at a time was the best way to avoid visual discomfort [25]. Furthermore it has been investigated that depth motion can increase visual discomfort [33, p 146]. Thus it is known that certain movements in the film can increase visual discomfort, but what about the amount of elements? So far the reviewed studies have not contained any composited effects and knowing that composited visual effects are very common in the film industry where stereoscopy is a current trend, it is interesting to investigate the affect of multiple elements that require attention from the viewer versus one main focus element.

4 Design and Production Pipeline

4.1 Design and production planning

In order to investigate whether the number of elements composited into a stereoscopic scene induces visual discomfort, two comparative scenes were created. The aim of the study was to gain support to the hypothesis that multiple moving elements of a variant depth of field in a stereoscopic scene, cause more visual discomfort than one element only. Thus, the two scenes included different number of computer generated elements. Following is a description of the design of the test media.

The idea was to create a scene with a stereoscopic camera setup with visible difference between foreground elements and background. Since the purpose of the study was to investigate perceptual elements in regards to the senses rather than any contextual components, there was no need for narrative. Small components were chosen to be the centre of attention. This was decided since small objects can create a large screen parallax. Dices, coins, matches or practically anything small in size could serve the purpose, but to make the shot aesthetically appealing a flowerbed with buzzing bees was chosen. This decision was made on the account of the nature of stereoscopy. As stated in the section on *Human Vision* on page 8, the eyes are on average 6.35 cm apart [18, p 19]. To get the the binocular effect stereoscopic cinema is expected to create, two synchronised cameras with parallax were utilised.

The reason for having both the real footage and the 3D model in stereo, was to mimic industry standards. Meaning, to the authors knowledge, most stereoscopic movies created for the cinemas are fully stereoscopic where both background and foreground are in stereo. Furthermore the cameras were configured in parallel, the approach is easier to conduct than toed-in camera configuration which can cause geometrical distortion [17, p 382].

When there is more parallax it is perceived so that the object appears to be close by. This is due to the nature of binocular vision, meaning, objects that are close by require more convergence than objects that are far away. When binocular perception is created with a stereoscopic camera setup, the parallax can be exaggerated. This exaggeration is sometimes referred to as a *hyper stereo* [18, p 19]. However, when the parallax of the cameras is very small, it has the opposite effects, that is, it magnifies the distance. This phenomenon is sometimes called *hypo stereo* [18, p 19]. In other words, the parallax causes objects to appear either very close by or very far away, depending on the magnitude of the difference between the left and right images. When an object takes up more space on the retina it appears to the viewer to be closer than an object that takes up less space. When stereoscopic camera is zoomed in on an object, the parallax is not as large as when the camera is fully zoomed out.

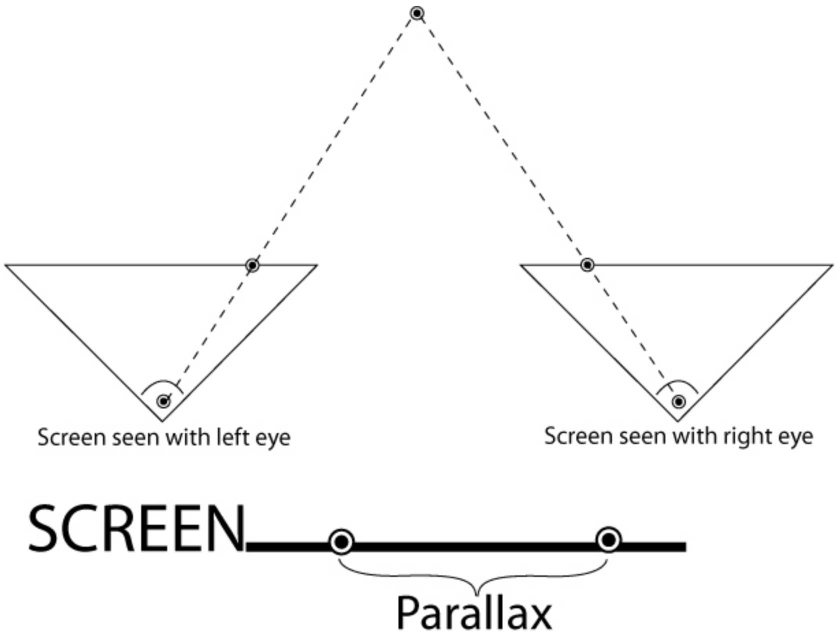

Figure 11: *Parallax, a spot in space takes up different space in the retina of each eye. The eyes converge on the spot causing binocular perception.*

According to investigations reviewed in the *Related Work* section on page 20, test subjects experienced more visual fatigue when a stereoscopic object moved in the depth of field, more specifically the z-axis, compared to when the object was completely stationary. This prompted the question whether multiple elements moving in different depth of field cause more visual fatigue than one element only. For the study, a composition of a real footage and a 3D model was used. Both elements were stereoscopic from a static point of view. To get a good depth of field, small objects, flowers and bumble bees were chosen. One scene displayed one bee flying among flowers while the other scene included multiple bees swarming around in the same environment. The bumble bees flew in an arbitrary manner in all direction, including along the z-axis, but did otherwise not perform any meaningful actions.

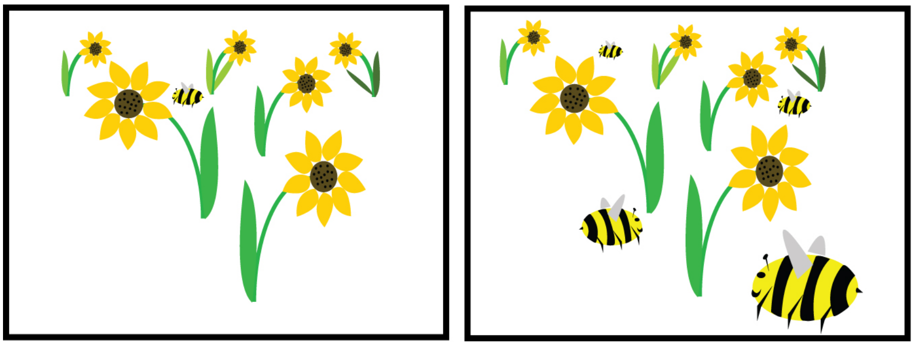

Figure 12: *Design of the test products. The only changing variable between the two is additional bees in the scenario to the right.*

A 3D model of a bee was composited with the real footage. The model of the bee was kept relatively simple and not ecologically realistic since its appearance was not important to the experiment. The bee was rather large relative to the real footage but as previously mentioned, ecological appearance was not an issue of interest for the study.

4.2 Pre-Production

4.2.1 Camera Setup

As stated in the *Design* section on page 26, the scene was filmed using a stereoscopic camera. A stereoscopic device was not available at the facility of AAUK during the project period and therefore a stereoscopic camera rig had to be created. Two Canon MD215 Mini-camcorders were attached together in parallel using a clamp. To ensure the stability of the two cameras, a small plate was mounted under them. In order to imitate the parallax of human vision, the camera lenses were fixed approximately 6.35 cm apart, which is the same as the avereage distance beteween the two eyes in humans [18, p 19]. This parallax was used since neither *hyper stereo* nor *hypo stereo* was of interest in this particular study.

Figure 13: *Material and camera rig for stereoscopic camera setup.*

4.2.2 3D modelling and Animation

The bumble bee was modelled in Maya (Autodesk Inc). The model was kept fairly simple since, as stated in the *Design* section on page 26, its appearance was not of great importance for the study. The bee was sculpted from a sphere and texture, made in Photoshop (Adobe Systems Incorporated), was added to the body. A simple skeleton was constructed in order to simplify the animation process and a simple rig eased the process of animating basic movements such as flapping the wings.

For each scene, only one bumble bee was animated and rendered with the stereoscopic camera setup that was manually created in Maya and had the same parallax as the cameras that filmed the real footage.

The scene that contained multiple bees was rendered out several times. Each time with different animation of the bee. The renders were then composited together during post production in After Effects (Adobe Systems Incorporated). Figures 14 and 15 show the bumble bee during the working process.

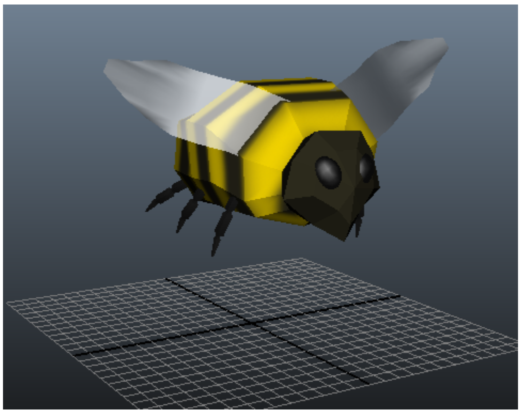

Figure 14: *The bumble bee after it has been sculpted and textured.*

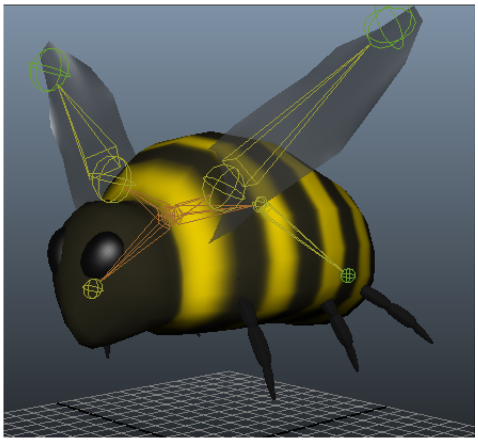

Figure 15: *The bee smoothened and rigged.*

4.3 Production

4.3.1 Filming

According to the plan, a stereoscopic camera-setup was utilised for the filming. For stereoscopy to function properly the two feeds from the cameras had to be in perfect synchrony. To ensure straightforward synchronisation in post production, a flash from a photo camera was used, thus in the beginning of each filming session the cameras were exposed to a flash.

The cameras (Canon MD215 mini-camcorders) have an automatic focus and white balance. In order to get the best synchronisation relative to image quality, the two cameras had exactly the same settings. A *beach* setting was used as the filming took place outside, on a very bright day. Choosing pre-defined settings on the camera was the only way to control the appearance of the outcome in regards to focus and white balance since both cameras had to be perfectly synchronised the whole time.

Figure 16: *Shots from the filming session.*

According to the design outlined on page 26 the shots were environmental with flowers in the foreground. Due to the time constraints of the project, the scene had to be relatively easy to work with in post production. Apart from that no specific requirements were made for the filming. Therefore, in spite of being shot with a handheld camera rig, the scenes were relatively static since that simplified the process of adding the bumble bee to the scene afterwards.

4.3.2 Maya Camerawork

A brief description of the camerawork in Maya can be read in the section *3D Modelling and Animation* on page 29. To review what was stated previously, the bee was rendered through two different virtual cameras which had the same parallax as the video cameras used for the video footage. The two cameras were set up manually in Maya. Using a built-in stereocamera function was attempted but that did not give the desired results in regards to rendering.

4.4 Post Production

The experiment did not require extensive or complex post production and the main challenge was the combination of the stereoscopic video footage and the stereoscopic 3D model. A proper stereoscopic image has a correspondence between the left and the right stimuli. Due to this the post production was kept as simple as possible since creating stereoscopic effects is a delicate process.

To create the stereoscopic scenes the left and right image from the video footage was separated into two individual clips. The appropriate render from the virtual camera in Maya was composited with the correspondent video footage using After Effects. Additionally, masking effects were introduced when the bee was travelling behind the flowers. This process requires precision as both left and right clips need to have the effects with the exact same parallax as the video footage.

The video was prepared for two different viewing techniques, anaglyph and shutter glasses. The anaglyph version was constructed in Final Cut Pro (Apple Inc.). Anaglyph technique is based on blocking out one side from the other using colour filters for the video, and glasses with coloured gel. For this project the anaglyph glasses were red and cyan. The red filter blocked out the cyan image and the cyan filter blocked the red image. Figures 18 and 17 show the output images that were compound via screen mode when the red image allowed the cyan one to show through. Figure 19 displays the outcome.

Figure 17: *The red colour value is filtered out leaving the scene with a cyan tint.*

Figure 18: *The green and cyan colour values are filtered out.*

Figure 19: *Left and right image compound for anaglyph viewing with red and cyan glasses.*

To display the stereoscopic video with shutter glasses the left and right video footages were separated into two independent videos of the exact same length. Unlike for the anaglyph version, this technology did not require any additional post processing after the video had been edited.

A Program called *Stereoscopic Player* from a company called *3DTV.at* [1] can be used to display a movie for various 3D display methods including shutter glasses. The program requires separate video inputs for right and left side and the viewing method can be chosen via drop-down menu.

Figure 20: *The left output image.*

Figure 21: *The right output image.*

5 Experimental Design

Throughout the previous chapters the groundings to conduct an experiment to investigate the validity of the hypothesis has been established. In this chapter the experimental design and setup will be described. The experimental design was based on the methodology of studies regarding similar topics which can be reviewed on page 20.

The hypothesis this experiment addressed is whether displaying multiple stimuli at variable depth of field in a stereoscopic scene induces more visual discomfort and fatigue than when only one stimuli is presented. In order to investigate if the hypothesis can be supported or not, the two main variables of interest, visual discomfort and fatigue, need to be defined.

Previous studies have defined visual fatigue, rather vaguely, as *"physiological strain or stress resulting from excessive exertion of the visual system"* [13, p 11]. Inspection of articles and audience reviews in the popular media revealed that the most common complaints of discomfort by viewers of stereoscopic cinema include dizziness, headache, nausea and eye strain such as tiredness, feeling dry in the eyes etc. [21]. For the purposes of this study, visual discomfort and fatigue were defined as tiredness in the eyes, headache, dizziness and negative perceptual after-effects, -which is when the viewer experiences discomfort after completing the stereoscopic viewing [21] [3] [23].

5.1 Questionnaire Design

All participants were required to answer 3 questionnaires, the first two prior to viewing the videos. First, participants answered a general questionnaire regarding their age, gender and if they have normal or corrected vision. The next set of questions addressed the participants history with stereoscopic movies. The questions were if he or she had seen a 3D movie, if he or she were able to see the 3D effect and whether they experienced any discomfort while watching, in which case the participant was asked to elaborate briefly. The goal of these questions was to determine if participants suffered from stereo fatigue of some sort and if they were suitable for participation.

The third questionnaire, which the participants answered immediately after viewing each video, regarded the variables being measured. The questionnaire consisted of four questions that were presented on a 5 level *semantic differential scale*[3]. The three first questions regarded the subjects experience while watching the movie. The questions were asked in relation to the definition for visual discomfort and fatigue, *to what extent subjects were experiencing tiredness of the eyes, headache* and *dizziness.* The answers from those variables should give fairly clear idea of the discomfort, if any, experienced while watching a stereoscopic video sequence. As previously stated, these variables were chosen as they were among commonly described symptoms of the discomfort viewers experienced. Figure 22 illustrates an example of the way the questions were presented and the whole questionnaire can be seen in the *Appendix* seen on page 58.

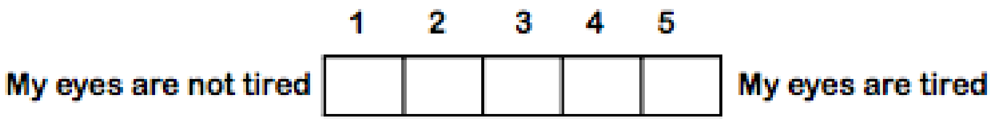

Figure 22: *An example of the 5 point rating scale used for the questionnaire.*

The usage of the rating scale is based on the methodology used in previously conducted studies which are reviewed in the *Related Work* section on page 20.

The last question regarded perceptual after effects, that is, how the subject was feeling *after* viewing the stereoscopic video sequence. The question was phrased; *to what extent do you experience discomfort after viewing the video sequence.*

5.2 Experimental setup

The experiment was conducted at Aalborg University Copenhagen. The experimental stimuli was displayed on a 13 inch, fully lit, glossy LCD display. To obtain stereoscopic effect, red and cyan anaglyph glasses were utilised. The test subject was asked to take a seat approximately 80 cm away from the display. This was determined to be sufficient distance for a relatively

[3] Explores participants attitude between bipolar variables on a rating scale [28, p 314]

small display such as the one used in this experiment.

5.2.1 Experimental Stimuli I

The experimental stimuli were two fully stereoscopic clips. That means that all elements in the clip had stereoscopic depth of field including the surrounding environment. The clips were identical apart from the changing variable, which was the number of bees that swarm around. Experimental condition video 1 (V1) consists of one bee flying around in all directions, including z-axis, for depth of field and condition video 2 (V2) contains multiple bees swarming around. The viewing order of the two was randomised between participants.

The two video sequences were approximately 2:33 minute long and consisted of a loop of three different shots.

5.2.2 Experimental Procedure

The illustration to the right in figure 24 shows a time estimation for the experiment. The questions were all subjective evaluation of how the test participant were feeling at the given moment, hence were not time consuming to answer. It was estimated that each subject could complete the experiment in approximately 7-10 minutes.

As stereoscopic perception can induce very different experience between individuals a paired design was used. That is, all participants viewed both experimental videos. To control for the possible additive effects of order, participants were randomly divided in one of two groups. Group 1, viewed video 1 first and then video 2 while group 2 viewed the experimental videos in opposite order.

Participants were given verbal directions for the experiment and before being exposed to the experimental stimuli they were asked to provide background information that determined whether they were suitable for the test. Individuals with stereo impairment (cannot see 3D) were excluded from the study.

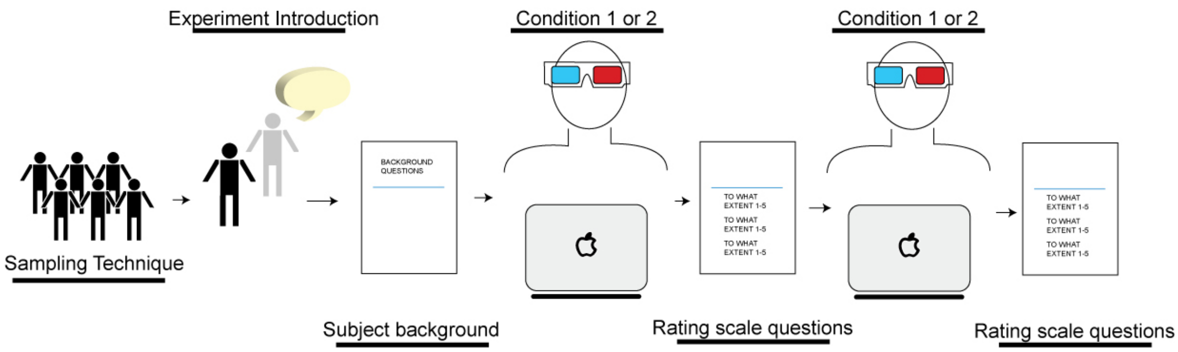

Figure 23: *Diagram illustrating the whole experimental process.*

Subsequently participants were asked to put on the provided anaglyph glasses and watch the designated video clip. After the viewing, the participants answered the 4 question post testing questionnaire that aimed to quantify the level of visual discomfort and fatigue induced by the video. Each participant viewed both videos and therefore followed the presented procedure twice. To avoid additive effects of the video viewing, sufficient time was allowed to pass between the two viewings for the participants to recover completely. The time depended on individual need of each participant, this was confirmed by asking the participant if he or she felt ready to view another video sequence. Figure 23 illustrates the experimental design.

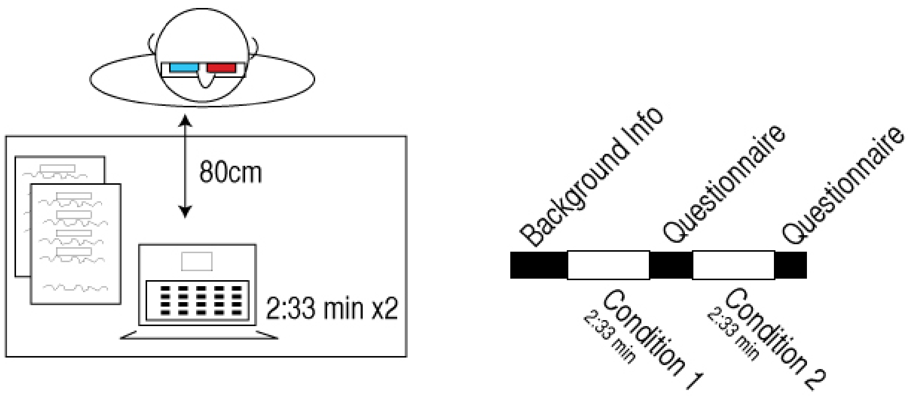

Figure 24: *Illustration of the experiment setup. The diagram to the right displays the procedure in regards to time.*

5.2.3 Sampling technique

The experimental subjects were chosen with a non-probabilistic sampling, that is, fellow students at AAUK and IHK were randomly approached and asked to join the experiment. Since most subjects are students within Medialogy the approach can be categorised as a convenience sampling. The reason for the using convenience sampling was, as the name implies, convenient since the experiment setup remained within the facility of AAUK and the subjects were at the location. The disadvantage of this approach is that the subjects all have similar backgrounds and are of similar age, thus, it is hard to generalise the test results. However, as the experiment does not focus on any technical specifications the sampling technique is regarded valid.

5.2.4 Statistics

The data was analyzed using Excel (Microsoft corporation) and SPSS 18 (SPSS Inc, Chicago, Illinois, USA) statistical software. Discriptive statistics (mean and standard deviation) were calculated for for all test conditions. Due to the discrete nature of the experimental variables, nonparametric test (Kruskal-Wallis one-way ANOVA[4]) was used to determine the significance of the difference between the conditions tested. Level of significance was set at 0.05.
The following comparisons were made for the results of each question, using one-way ANOVAS

- The results for V1 and V2 were compared, for group 1 and 2 separately
- The results for groups 1 and 2 were compaired, for V1 and V2 separately
- The results for V1 and V2 were compaired, when the data had been pooled over the two groups.

[4]A nonparametric test, used for comparison of 3 or more data sets. Has similar function as the ANOVA test but does not make any assumption about the distribution of the data, unlike ANOVA[30].

6 Results I

The following details the data obtained in experiment 1. For this test *stimuli I* was utilised, which, as described on page 36, consisted of two fully stereoscopic video sequences, V1 and V2. *V1* refers to the video where *one bee* was swarming around and *V2* refers to *multiple bees*. Each test participant viewed both video sequences. To clarify the the results, a division between participants that viewed V1 as a first movie and the group viewing V2 as a first movie is made. The groups are referred to as *group 1* for the subjects that viewed V1 first and *group 2* for the subjects that viewed V2 first.

During the experiment, participants were randomly assigned to one of two groups who viewed the experimental videos in opposite order. This was done to avoid the additive effects of order in case the visual stimulus of the two videos. First will be presented the results of the ratings for the two videos separately for each group (thus looking into if it mattered for the results which order was used) and second when the order is ignored.

A total of 20, randomly chosen individuals (16 male and 4 female) participated in the experiment. Their average age was 22±3 years for group 1 and 24.5±2 years for group 2. All of the participant have normal or corrected vision. All of them had seen a 3D movie in the past and claimed to see 3D and 7 out of 20 had experienced discomfort of some sort when previously viewing a stereoscopic movie. One individual who volunteered had to be excluded from participation due to his inability to see 3D.

6.1 Results I in Regards to Viewing Order

Question 1: My eyes are not tired - my eyes are tired

For video sequence V1, the average score for group 1 was 3.4±1.27 while group 2 rated V1 on average 4±0.82. Video sequence V2 was rated on average of 3.6±1.26 by group 1 and 3.4±1.07 by group 2.

One-way non parametric ANOVA (Kruskal-Wallis) found no significant difference between the videos for neither group 1 ($p = 0.811$) nor group 2 ($p = 0.261$).

Question 2: I experienced no headache - I experienced headache

Group 1 rated V1 with the mean of 1.7±1.25 while group 2 rated the same video 1.6 ±0.97. Video sequence V2 was rated 1.9±0.99 by group 1 and 1.3 ±0.67 by group 2.

One-way non parametric ANOVA (Kruskal-Wallis) found no significant difference between the videos for neither group 1 (p =0.357) nor group 2 (p =0.373).

Question 3: I experienced no dizziness - I experienced dizziness

Group 1 rated V1 with the mean of 2 ±1.05 while group 2 rated V1 2.5±1.58. Group 1 rated V2 on an average 2.1±0.99 while group 2 rated V2 on average 2.4±1.58.

No significant difference between the videos for neither group 1 (p =0.779) nor group 2 (p =0.969) was found.

Question 4: I experienced no discomfort - I experienced discomfort

Group 1 rated V1 with the mean of 2.7±1.16 while group 2 rated on average 3.1±1.29. On average group 1 rated V2 2.8±1.4 while group 2 rated 3.1±1.2.

No significant difference between the videos for neither group 1 (p =0.876) nor group 2 (p =0.969).

The results of the four questions for the two videos is shown in figure 25 for group 1 and figure 26 for group 2.

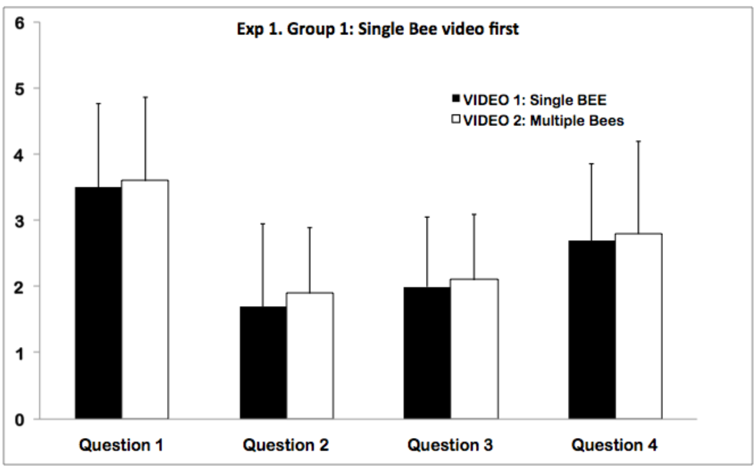

Figure 25: *Comparison of the answers for both videos in group one.*

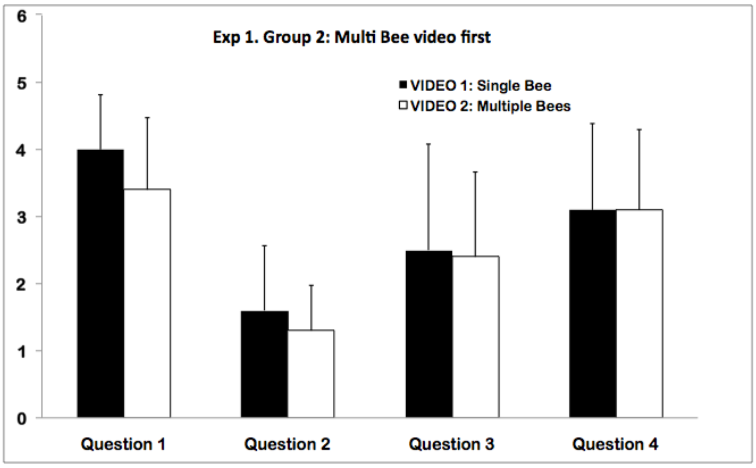

Figure 26: *Comparison of the answers for both videos in group two*

6.2 Results I Regardless to Viewing Order

When the viewing order is disregarded the results for each video sequence is the following:

Question 1: Eye tiredness

The average rating for V1 was 3.75±1.07 but 3.5±1.15 for V2. One-way non parametric ANOVA (Kruskal-Wallis) found no significant difference between the videos ($p = 0.561$).

Question 2: Perceived headache

Average score of V1 was 1.65±1.09 and 1.6±0.88 for V2. No significant difference between the videos ($p = 0.863$).

Question 3: Perceived dizziness

This question received an average rating of 2.25±1.33 for V1 and 2.25±1.12 for V2. No significant difference between the videos ($p = 0.888$).

Question 4: Perceptual after effect

V1 received the average score of 2.9±1.21 and V2 an average score of 2.95 ±1.28. No significant difference between the videos ($p = 0.911$).

Figure 27 shows the average score of the two videos for each question with standard deviation bars.

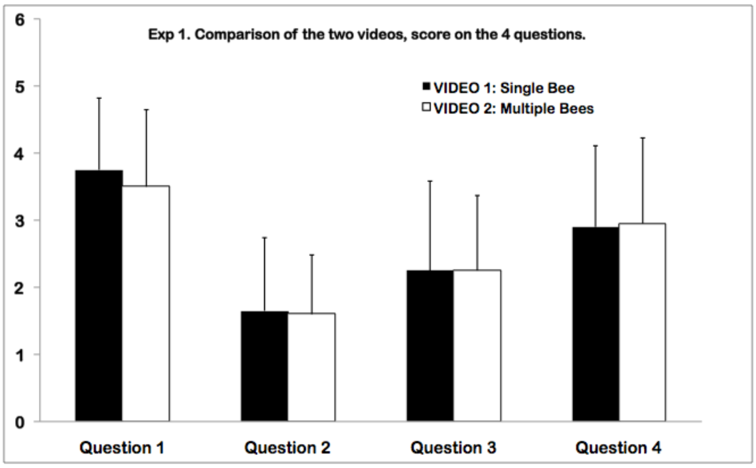

Figure 27: *The results from the four questions compared*

6.3 Results I Rating of video relative to order

Furthermore, I investigated for each video separately if its average rating on the four questions was different depending if it was viewed first or second. This was done using a one-way Kruskal-Wallis ANOVA but no statistical difference was found for any of the four questions between the two groups for either video ($p<0.05$).

The results are shown in figures 28 and 29.

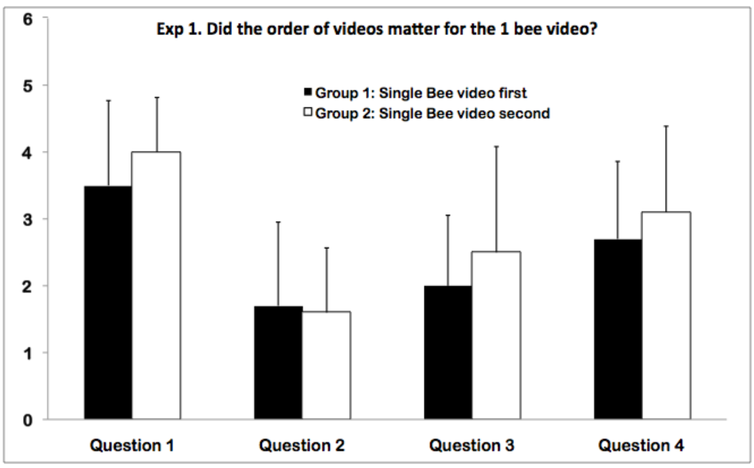

Figure 28: *Chart that illustrates comparison of answers V1 in relation to the order of which the video sequences were displayed.*

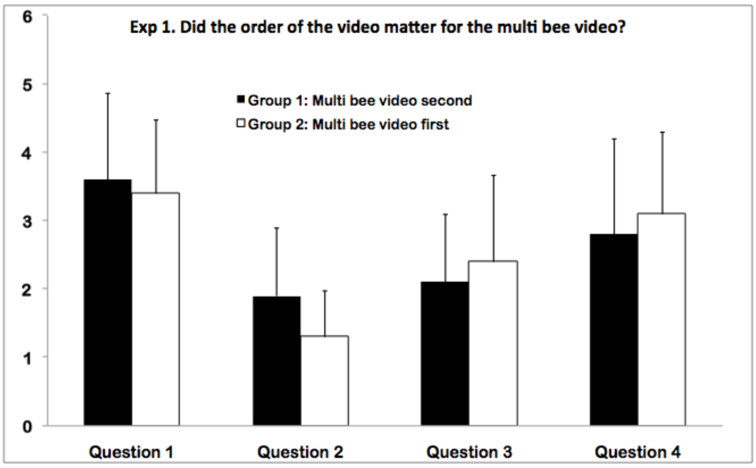

Figure 29: *Chart that illustrates comparison of answers V2 in relation to the order of which the video sequences were displayed.*

7 Discussion Experiment I

The results from experiment 1 show that there was no significant difference between the discomfort participants experienced while watching the two versions of video sequences. This was true regardless to whether the data was pooled across the two groups or not.

Figures 28 and 29 seen on page 42, show the results for the two videos separately. It can be seen that for the single bee video (V1), in 3 out of 4 questions, viewing the video second yielded in a higher score while the results for the multi-bee video showed no such pattern. However, for neither group did the order of viewing have significant effect on the rating and thus it can be concluded that here it does not make a difference for perceived discomfort. For this reason it was possible to pool the data. Figures 25 and 26 illustrate the difference of perceived discomfort within the two groups. As can be seen, the videos are fairly similar in regards to discomfort regardless if it is viewed first or second.

Several explanations to the lack of an effects can be offered. First, the display method was not optimal as the test was conducted with red and cyan anaglyph glasses. The method is known to cause visual discomfort and fatigue as the coloured gel does not completely block out the visuals intended for the other eye resulting in ghosting which leads to visual fatigue and discomfort[11, p 375]. It is therefore considered possible that the noise from the anaglyph viewing method masked out other symptoms of discomfort related to the content of the video sequences. However, as both video sequences were viewed under the same circumstances, this bias would have affected them equally and thus this explanation rendered unlikely.

Second, the design of the two video sequences may be at fault. Both clips were fully stereoscopic, meaning, the background was shot in stereo in addition to the bees being rendered with stereo. This was is to simulate the 3D used in 3D cinemas. However, this fact raises the question whether adding few more stereoscopic elements to a fully stereoscopic scene makes any difference. The bar chart on figure 27 shows that both V1 and V2 are perceived to be approximately the same. To investigate this explanation further, new versions of the two videos were created and experiment 2 conducted with new group of participants.

8 Experiment II - New Set of Stimuli

A new set of videos were created for another experiment. In this version, the background video of the flowers was no longer in stereo and only the active objects, the bees, were seen in 3D. The reason for this modification was to see if the fact that the whole scene was in stereo was indeed a factor for the hypothesis not to be supported or even show tendencies of any kind in experiment 1.

9 Results II

Experiment II was conducted in the same manner as experiment I. The results are thus presented in the in line with the outlined structure on page 38.

Twenty individuals (10 male and 10 female), participated in the study. Participants were randomly divided into one of two groups. Group 1, mean age 26.1 $\pm$3.3 years, viewed Video 1 (v1) (single bee video) first and Video 2 (v2) (multiple bee video) second while Group 2, mean age 25 $\pm$ 3.6 years viewed the videos in opposite order. All partakers claimed to have a normal or corrected vision. 4 out of 20 had never seen a 3D movie before and additional 4 individuals experienced discomfort while watching a 3D move.

9.1 Results II in Regards to Viewing Order

Question 1: My eyes are not tired - my eyes are tired

The mean for v1 by group 1 is 3.1$\pm$1.1 and 2.9$\pm$1.5 for group 2. Group 1 rated v2 on average 2.6$\pm$0.96 while group 2 had 3.7$\pm$1.34.

One-way non parametric ANOVA (Kruskal-Wallis) found no significant difference between the videos for neither group 1 ($p = 0.341$) nor group 2 ($p = 0.207$).

Question 2: I experienced no headache - I experienced headache

Group 1 had the mean of 1.4$\pm$0.7 and group 2 had the same or 1.4$\pm$0.7 for v1. For v2 group one had the mean of 1.8$\pm$0.79 and group 2 2.3$\pm$1.34.

One-way non parametric ANOVA (Kruskal-Wallis) found no significant difference between the videos for neither group 1 ($p = 0.206$) nor group 2 ($p = 0.104$)

Question 3: I experienced no dizziness - I experienced dizziness

For v1 group 1 the mean is 1.9±0.99 while group 2 had mean 2 2.4±1.26. For v2 group 1 had mean 1.7±0.67 and group 2 had mean 3.1±1.29

No significant difference between the videos for neither group 1 ($p = 0.774$) nor group 2 ($p = 0.223$) was found.

Question 4: I experienced no discomfort - I experienced discomfort

For v1 group 1 had mean 2.3±1.34 and group 2 had mean 3.2±0.79. For v2 group 1 had mean 1.8±0.79 and group 2 had mean 3.5±0.97.

No significant difference between the videos for neither group 1 ($p = 0.471$) nor group 2 ($p = 0.333$).

The results of the four questions for the two videos is shown in figure 30 for group 1 and figure 31 for group 2.

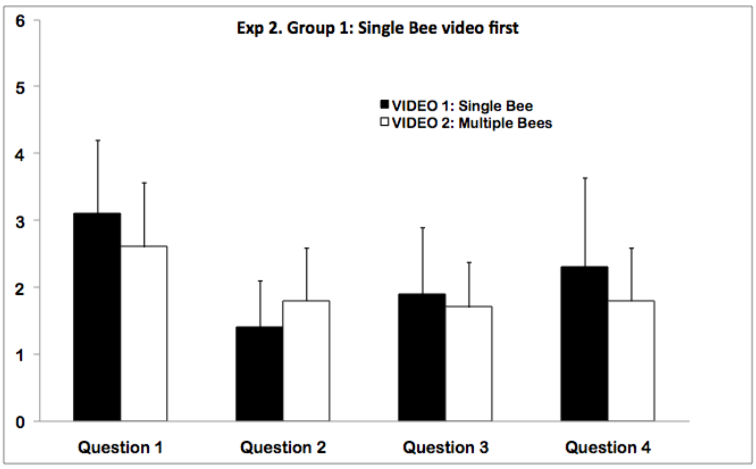

Figure 30: *Comparison of answers from group 1.*

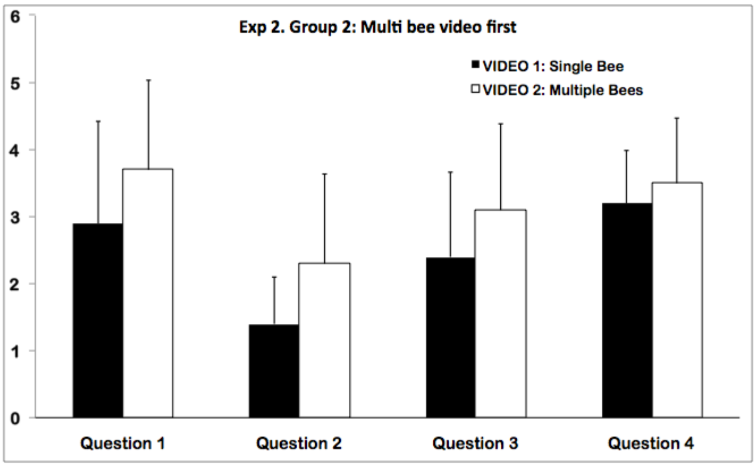

Figure 31: *Comparison of answers from group 2.*

9.2 Results II Regardless to Viewing Order

The following lists the results when all the data is pooled.

Question 1: Eye tiredness

The average rating for v1 was 3±1.3 but 3.15±1.27 for v2. One-way non parametric ANOVA (Kruskal-Wallis) found no significant difference between the videos (p =0.727).

Question 2: Perceived headache

Average score of v1 was 1.4±0.68 and 2.05±1.1 for v2. Significant difference between the videos (p =0.039) was found.

Question 3: Perceived dizziness

This question received and average rating of 2.15±1.14 for v1 and 2.4±1.23 for v2. No significant difference between the videos (p =0.506).

Question 4: Perceptual after effect

V1 received the average score of 2.75±1.16 and v2 an average score of 2.65 ±1.23. No significant difference between the videos (p =0.802).

Figure 32 shows the average score of the two videos for each question with standard deviation bars, the star denotes significant difference.

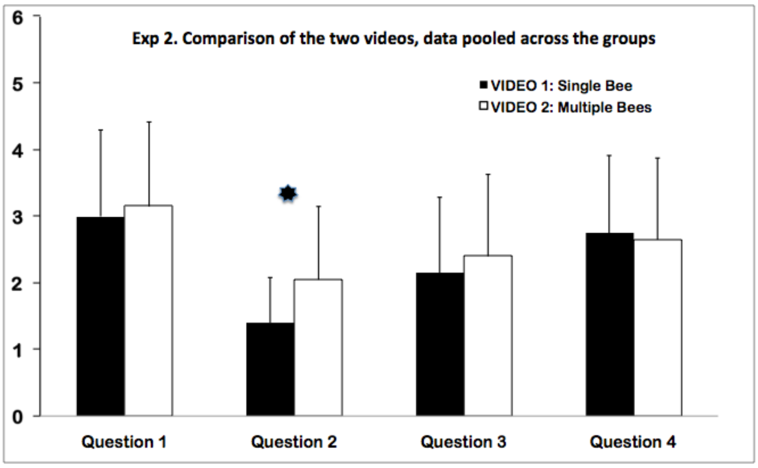

Figure 32: *Comparison of the two videos.*

9.3 Results II Rating of video relative to order

Investigation was conducted for each video separately whether its average rating on the four questions was different depending if it was viewed first or second.
This was done using nonparametric one-way Kruskal-Wallis ANOVA but no statistical difference was found for any of the four questions between the two groups for either video ($p<0.05$). The results are shown in figures 33 and 34.

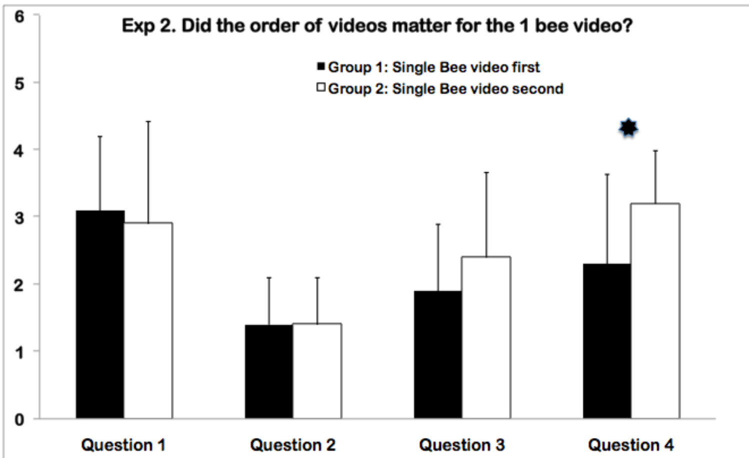

Figure 33: *Comparison of answers from group 1 and group 2.*

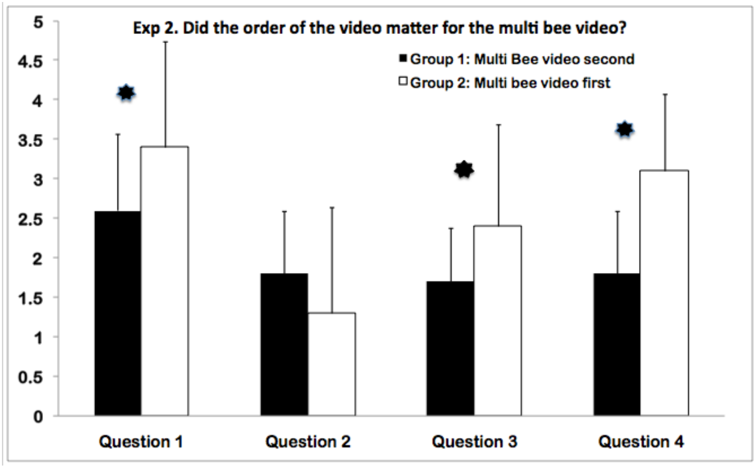

Figure 34: *Comparison of answers from group 1 and group 2.*

10 Discussion and Conclusion

10.1 Discussion

The results of experiment 1 did not show any significant difference between the two videos and thus did not support the hypothesis. However, the results also prompted concerns that the quality of the stimuli used in the experiment could have been at fault. To investigate this suspicion experiment 2 was conducted. The result from the experiment showed that even with the new stimuli the difference in perceived discomfort was minimal between the two videos. The bar chart on figure 32, page 48, shows that the only significant difference between the two videos was for question 2 (perceived headache) when all the data is pooled between groups. Other questions did not show any significant difference.

Figures 35 and 36 illustrate a comparison between the results from experiment 1 and 2. As can be seen the results show approximately the same score for all the questions.

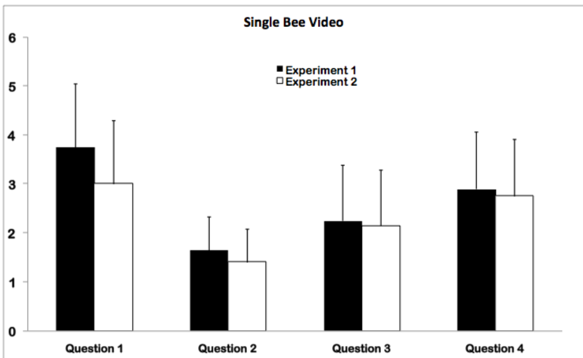

Figure 35: *Single bee video between experiments I and II.*

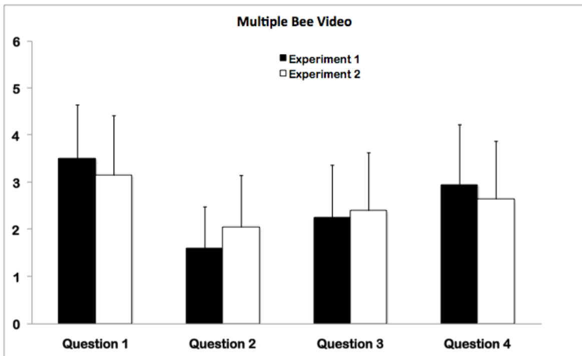

Figure 36: *Multiple bee video between experiments I and II.*

The lack of difference is not seen as a surprising outcome as it simply confirms that Experiment I was acceptable thus the initial stimuli deemed suited for the investigation. Furthermore the outcome enabled the data to be pooled for further assessment with twice as big subject group. Chart on figure 37 illustrates the difference between the single bee video and the video containing multiple bumble bees. As can be seen there was no significant difference between the two.

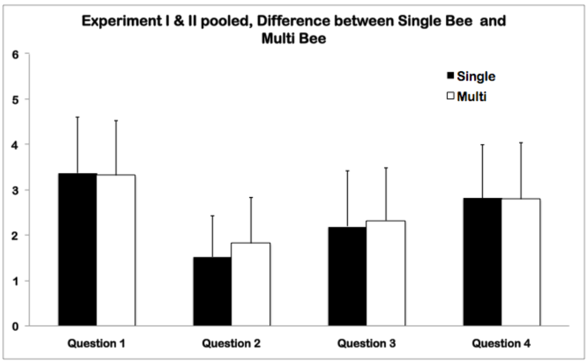

Figure 37: *Difference between the two stimuli when the data from both experiments are pooled.*

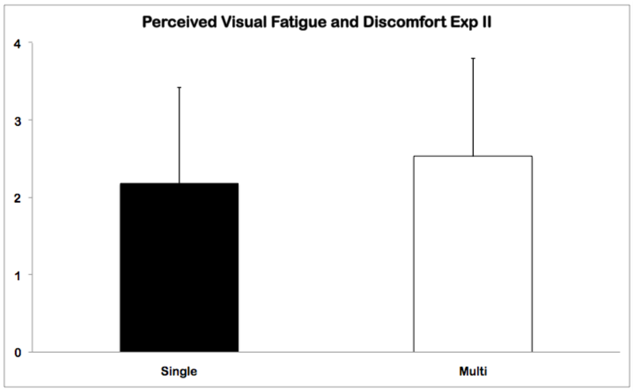

Figure 38: *Experienced eye fatigue and discomfort in Experiment II.*

Clearly the hypothesis can not be supported by these findings. However when all the data gathered in experiment II via questions 1-3, which investigate visual fatigue and discomfort during the viewing, are pooled, some difference can be detected but not at a significant level ($p=0.105$), thus it can not be used to support any tendencies or indications regarding whether more elements in a stereoscopic scene cause increased visual fatigue and discomfort.

There can be many contributing factors leading to the test results not supporting the hypothesis. First of all the definition of *visual discomfort* and *fatigue* may have been too tenacious for test participants to be able to correspond to it within the given timeframe of the experiment, which was rather short at 2:33 minutes per video. With that said, it can be speculated whether the stimuli was too short all together. Featured film is usually around 1 and a half - 2 hours long. Visual fatigue and discomfort was defined in accordance to testimony from movie goers. It was not taken under serious consideration that the discomfort may not have occurred instantly as the movie started but after the audience had been exposed for some time.

Another angle is that the hypothesis is simply wrong, that the number of moving elements has nothing to do with visual fatigue but rather the movement in regards to depth of field. Numerous studies have concluded that visual fatigue and discomfort can be provoked by a mis-match between accommodation and convergence. A moving object that is animated back and forth on the depth axis is evidently straining the eye more than a static object would.

Two out of the 40 experiment participants for this thesis claimed after viewing both stimuli that there was "something" uncomfortable about the single bee scenario and that the other scenario with the multiple bees was less straining although one of the bees was animated the same way as the single bee. It can therefore be speculated that the multiple bees allowed the viewer to chose a target to follow thus make it easier to keep within similar depth of field at all times. This speculation does completely contradict the hypothesis but for the current experiment, the number of elements do not seem to be very influencing factor for increased visual fatigue and discomfort.

As mentioned in the previous discussion on page 44 the display method was not optimal to experiment with eye fatigue and discomfort. Anaglyph glasses have been known to strain the eyes excessively. More ideal viewing methods such as a RealD system or utilisation of shutter glasses could possibly give more concise information of whether the hypothesis deems invalid as the results from Experiment I and II suggests.

The display used for the experiment is relatively small. To ensure the results from the experiment could be transferred onto a cinema display an approximation of the viewing angle was calculated.

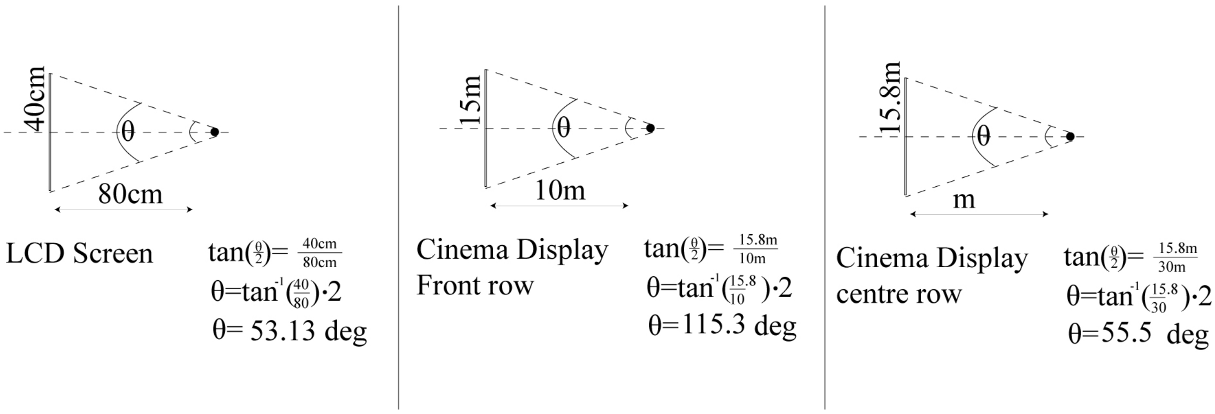

Figure 39: *Approximation of exact viewing angle for a 13 inch LCD display, front row and centre in a cinema.*

According to the calculations displayed on figure 39, the viewing angle for a small LCD display, -such as the one used in the experiment setup, and a centre seat in a cinema is similar.

Thus it can be assumed that the results from the experiment can be transferred to cinema display. This knowledge deems of interest since 3D is primarily used in movie theatres.

Future work would focus on addressing the issue with display technique to verify if the hypothesis does simply not hold regardless of the display device used . Furthermore the length of the exposure to the stimuli would have to be extended as the discomfort may not have occurred within the short amount of time that the stimuli was exposed to participants.

10.2 Conclusion

Stereoscopic cinema is a growing trend but it is not clear what the physiological factor is. This study was carried out to investigate whether the image content could be a factor. It was hypothesised that multiple elements, -moving in depth (z-axis), in a stereoscopic scene would cause more visual fatigue and discomfort than one element only.
To investigate the hypothesised area, two experiments were carried out. The first experiment made use of fully stereoscopic video footage which contained single bee on one hand and multiple bees on the other. As the results from the experiment did not show any significant difference between the experiment stimuli of one bee and multiple bees it was decided to conduct another experiment with slightly altered stimuli. For the second experiment only the bees were in stereo.

The results from the second experiment did not show any support for the hypothesis Furthermore, the two experiments showed close to identical results although participants were presented with two separate sets of stimuli.

The cause for the large similarity experiment results is not clear but numerous speculations can be made regarding the matter. It can be considered that the basis for the hypothesis was perhaps not strong enough, the experimental stimuli not sufficient in length or the display technique faulty to the extent of masking out content related discomfort. Furthermore the terms could have been defined inaccurately.

With that said, this master thesis can be concluded with an unsupported hypothesis regarding number of moving elements in a scene. However interesting speculation came up during the process, the most interesting one contradicts the presented hypothesis completely. That is, whether multiple elements can help to decrease visual fatigue and discomfort since the audience can choose more automatically to gaze at objects that are of same depth thus lessening the eye strain caused by accommodation and convergence.

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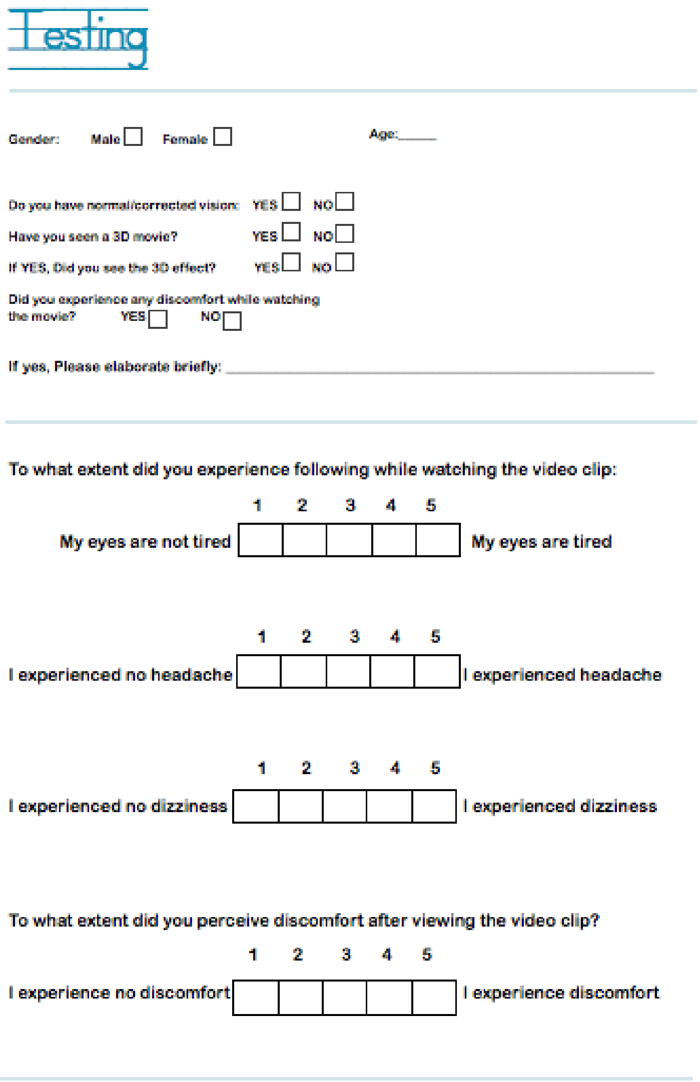
12 Appendix



Testing

Gender: Male ☐ Female ☐ Age:_____

Do you have normal/corrected vision: YES ☐ NO ☐

Have you seen a 3D movie? YES ☐ NO ☐

If YES, Did you see the 3D effect? YES ☐ NO ☐

Did you experience any discomfort while watching the movie? YES ☐ NO ☐

If yes, Please elaborate briefly: ____

To what extent did you experience following while watching the video clip:

	1	2	3	4	5	
My eyes are not tired						My eyes are tired
I experienced no headache						I experienced headache
I experienced no dizziness						I experienced dizziness

To what extent did you perceive discomfort after viewing the video clip?

	1	2	3	4	5	
I experience no discomfort						I experience discomfort

Figure 40

Testing

To what extent did you experience following while watching the video clip:

	1	2	3	4	5	
My eyes are not tired						My eyes are tired

	1	2	3	4	5	
I experienced no headache						I experienced headache

	1	2	3	4	5	
I experienced no dizziness						I experienced dizziness

To what extent did you perceive discomfort after viewing the video clip?

	1	2	3	4	5	
I experience no discomfort						I experience discomfort

Figure 41

G1				G2				G1				G2			
V1				V1				V2				V2			
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	q1	q2	q3	q4	q1	q2	q3	q4
1	1	1	1	4	4	4	4	1	1	1	1	4	2	2	3
2	1	1	2	5	1	4	5	2	1	1	2	4	1	4	5
4	1	2	3	5	2	5	4	4	1	2	4	4	1	4	4
4	1	3	3	4	1	2	2	4	2	3	3	4	1	3	3
4	1	1	2	3	1	1	2	4	2	1	2	2	1	2	4
3	1	1	1	3	2	1	4	3	1	1	1	4	3	2	3
5	4	4	4	4	1	2	4	5	3	3	4	3	1	1	4
5	4	2	3	4	1	1	2	4	4	3	2	4	1	1	2
3	1	3	4	5	2	4	3	5	2	3	5	4	1	4	2
4	2	2	4	3	1	1	1	4	2	3	4	1	1	1	1
3.5	1.7	2	2.7	4	1.6	2.5	3.1	3.6	1.9	2.1	2.8	3.4	1.3	2.4	3.1
1.2693	1.25167	1.05409	1.1595	0.8165	0.96609	1.58114	1.28668	1.26491	0.99443	0.99443	1.39841	1.07497	0.67495	1.26491	1.19722

Figure 42: *Data Experiment I*

	G1				G2				G1				G2			
Experi II	V1				V1				V2				V2			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	q1	q2	q3	q4	q1	q2	q3	q4
	4	1	3	3	5	2	1	5	3	2	2	2	5	4	2	5
	3	1	2	2	4	1	1	3	3	1	3	2	5	2	4	4
	5	3	4	5	4	2	4	3	2	1	1	1	4	4	5	4
	2	1	2	1	4	3	3	3	2	2	2	2	4	3	2	3
	2	2	2	2	1	1	1	4	3	2	2	2	4	1	4	4
	2	1	1	2	1	1	2	2	1	2	1	1	3	1	3	2
	4	2	1	4	1	1	2	3	4	3	1	3	1	1	2	3
	3	1	2	1	4	1	4	3	2	1	2	1	5	2	4	4
	2	1	1	2	3	1	4	3	2	3	2	3	4	4	4	4
	4	1	1	1	2	1	2	3	4	1	1	1	2	1	1	2
	3.1	1.4	1.9	2.3	2.9	1.4	2.4	3.2	2.6	1.8	1.7	1.8	3.7	2.3	3.1	3.5
	1.100505	0.699206	0.994429	1.337494	1.523884	0.699206	1.264911	0.788811	0.966092	0.788811	0.674949	0.788811	1.337494	1.337494	1.286684	0.971825

Figure 43: *Data Experiment II*