

The Evaluation of Selected Parameters that Affect Motion Artifacts in Stereoscopic Video

by

Saeedeh Bayatpour

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APPROVAL

Name: Saeedeh Bayatpour
Degree: Master of Science
Title of Thesis: The Evaluation of Selected Parameters that Affect Motion Artifacts in Stereoscopic Video

Examining Committee: Chris Shaw,
Associate Professor,
Chair

Tom Calvert,
Professor Emeritus,
Senior Supervisor

James Bizzocchi,
Associate Professor,
Supervisor

Steve DiPaola,
Associate Professor,
External Examiner

Date Approved: August 18th, 2014

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Abstract

This work investigates the role of various parameters on the visibility or strength of motion artifacts in stereoscopic video. The parameters examined in an experimental study were disparity, presentation protocol (double flash or triple flash), seating position of a viewer in the theatre and speed of a moving object in the scene. The results of the study suggested that disparity and presentation protocol had no significant effect on the visibility or strength of the motion artifacts. Speed of a moving object had a significant effect on both the visibility and strength of the motion artifacts. Although position does not itself have a significant effect, there was an interaction between speed and seating position that had a significant effect. The speed threshold for visibility of motion artifacts was significantly higher for viewers sitting closest to the screen, which is surprising. It is concluded that the effects of viewer seating position on the perception of movement artifacts requires further investigation.

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Chapter 1

Introduction

1.1 Overview of the problem

When the human visual system perceives a scene it receives two images, one from each eye and they are slightly different. This difference is a consequence of the separation of the two eyes and is called disparity. The brain fuses the two images and depth perception occurs based on the disparities of corresponding points in the two images. This is the basis of the stereopsis process in the Human Visual System and underlies the stereoscopic technology used in stereo 3D movie making. This technology is becoming an increasingly common approach to bring an increased feeling of realism to movies by conveying the depth and distance of objects. Along with improvements in 3D technology for the capture of stereo scenes, application of stereoscopic technology to display systems is growing fast. Stereoscopic technology can be more successful and competitive with 2D if it can provide visual comfort and acceptable image quality. The goal of this technology is to create depth while maintaining realistic feelings. Although the techniques for generating the experience of depth are successful, the experience of watching a scene in a stereoscopic movie is still not perceived as equivalent to the real world. There are a series of major and more common artifacts in stereoscopic videos that adversely affect the quality of the video and feeling of realism. The purpose of this study is to investigate parameters that affect some of these artifacts. Capture, compression and display are the most important technical stages in 3D movie production. Although the type and quality of the 3D display system is preeminent in producing a powerful and strong feeling of depth, adjusting the parameters for capture and selection of an appropriate coding and transmission system also play key roles in increasing the quality of 3D movies. These parameters need to be adjusted to particular values depending on the situation in order to minimize potential artifacts. In particular, selection of an optimal viewing position is a critical element that relies on the type and size of the presentation device. An excellent viewing position also depends on recording

geometry of the stereoscopic content. In addition to setting these parameters, it is important to notice that evaluating stereoscopic video quality can be a subjective issue. Different viewers may judge the same phenomena differently based on their prior knowledge and experiences, the ability of their visual system and the viewer's concentration on the movie. Therefore, it is challenging and complicated to determine the effect of different parameters on stereoscopic artifacts. The focus of this study is on motion related artifacts which are among the most common in a real stereoscopic video. Motion artifacts occur when the subject (or the camera) is moving. To limit the scope of this research we have chosen to study the effects of only four parameters on the visibility and strength of motion artifacts. These parameters, chosen because of their importance and ease of adjustment, are:

- Speed of the moving object: this is by definition, the fundamental driver of motion artifacts.
- Position of the viewer: this is an important choice for all viewers and has received little attention in previous studies.
- Disparity: this is an adjustment usually made at the camera.
- Presentation protocol: this is chosen at the projector.

1.2 Thesis Structure

This thesis comprises 7 Chapters and two Appendices. The next chapter, Chapter 2 contains a summary of related works in the literature. Research goals are expressed in Chapter 3. All details of the experiment are available in Chapter 4. Analysis and results of the experiments are set out in Chapter 5. Chapter 6 provides a discussion of the results and their implications. Finally conclusions and future work are presented in Chapter 7. The Appendix provides the questionnaire and the forms that are used for the experiment.

Chapter 2

Literature Review

Three-dimensional stereo (S3D) technology has the potential for a wide variety of applications in fields that include education, medicine, entertainment and science. Among these fields, entertainment has attracted the most attention with the production of movies and other material for theatre viewing and to a lesser extent for television. The history of 3D films goes back to the early twentieth century with the basic 3D methods. Then, in the 2000s 3D films had remarkable achievements for example in the “Avatar” movie [58]. In spite of the extensive research and development applied to this field there are still problems in providing viewers artifact free images that do not cause health problems. The research reported here addresses factors that affect motion artifacts in S3D video.

Although, there are different approaches to convey depth information to audiences through 3D content, stereoscopy is a widespread 3D technology. In fact, stereoscopic technology imitates the stereopsis process in the human visual system. Through this mechanism the brain extracts the depth information from the differences between the views seen by the left and right eyes. Basically, stereoscopy conveys depth information by presenting two slightly different images from a scene.

The real scene is continuous, but it will be captured as discrete frames. This discretization is a source of some 3D artifacts that result in obvious dissimilarity between watching a 3D video of a scene and watching the real scene. 3D content can be captured with three different methods [32]: first, it can be captured by two or more cameras simultaneously with a specific configuration. Second, it can be two-dimensional (2D) content with added depth information (depth map) captured by another device such as AXI-Vision and Zcam for each pixel [32]. Third, it can be captured in 2D and then converted to 3D with convertor software. Each approach may lead to a series of distinctive artifacts. Among all these approaches stereoscopic display of video shot with dual cameras is the most common approach. The configuration of the cameras can be parallel or converging (toed-in). Since the converging camera configurations cause some common artifacts like keystone distortion or depth plane curvature, the parallel configuration is more recommended in the literature [60]. Since the capture step is one of the most important stages in providing a high quality 3D video, the

video makers decisions at this step are fundamental; these decisions include: distance of camera to the target, picture size, contrast level, baseline distance, convergence distance and camera configuration (toed-in vs. parallel cameras). Also, in order to reduce the size of the content, different compression algorithms are applied to 3D videos with the goal of reducing redundant information. Some cues may be lost in the coding and decoding processes and this is the source of a series of problems [11, 32].

There are a variety of 3D display methods for cinema and home applications available on the market. 3D displays utilize different techniques to artificially re-create the depth cues. 3D display systems can be categorized into stereoscopic displays, auto-stereoscopic displays, integral imaging, holography and volumetric 3D [37, 29]. Integral imaging, holography and volumetric 3D display systems can also be considered as an auto-stereoscopic display according to Pastoor and Wopking [39]. In their definition, all eyewear free 3D display systems that only rely on the display itself are auto-stereoscopic.

2.1 Stereoscopic Displays

Stereoscopic displays are categorized into anaglyph, polarization-based filtering and shutter-based. In the anaglyph method, a 3D image is achieved by colour filtering (red and cyan filters or blue and yellow filters). Although it is a low-cost method, the usage is limited because it cannot provide a complete colour spectrum. Polarization-based filtering controls the direction of the polarized light. Polarization systems work based on linear or circular polarization and provide full-colour stereoscopy. Shutter-based systems display right and left images alternately not simultaneously. This technique usually presents 140-200 images in each second. This technique needs to be fast enough that brain can solve the delay between left and right views. This technology needs glasses to block one eye and then switch to the other eye. The Pulfrich effect is another stereoscopic method in which one eye is transparent and the other eye is semi-transparent not completely opaque [33, 37, 48, 40].

In stereoscopic display systems the left eye and right eye images can be presented to the two eyes either simultaneously (time-parallel) or in temporal alternation (time-sequential or field-sequential). Anaglyph and polarization-based display methods are time-parallel while shutter-based systems are time-sequential [32]. In both these presentation methods (time-parallel and time-sequential) several different presentation protocols can be obtained by changing presentation rate and the order and number of repetition of each frame. These protocols can influence the perceived quality of the final 3D movie.

2.2 Auto-stereoscopic Displays

Most current 3D display systems rely on glasses to filter out images into each eye. However, auto-stereoscopy is a technique for displaying 3D images without any glasses or headgear. Basically, this technology presents the left and right images on parallel planes to the screen. Direction-multiplexed (such as Lenticular systems and parallax barrier), hologram and volumetric display are examples of techniques for auto-stereoscopic viewing [32, 37, 48, 40]. Multi-view auto-stereoscopy, which is based on lenticular or parallax barrier technology, provides more than two views (two angles) generally between five to nine or even 50 views. Parallax is the ability in most multi-view auto-stereoscopic displays that covers head movements horizontally or in some cases vertically. Horizontal parallax by head tracking or an eye-tracking approach exists in some displays. For example, integral imaging is a kind of multi-view display which consists of a micro lens array (a layer of spherical lenses) to provide both vertical and horizontal parallax [37]. The hologram is another 3D presentation technique that is based on interference patterns. Hologram systems involve the intensity and direction of light. Recording image in this technology needs coherent lighting which is achieved by laser as opposed to natural lighting [50, 37, 32]. Volumetric 3D is another auto-stereoscopy technique to create 3D imagery via emission, scattering, or absorption of radiation within a physical volume with a wide range of horizontal and vertical parallax. Swept volume and static volume are two types of volumetric displays [5, 14, 32].

2.3 Stereoscopic Artifacts

There exists a great amount of effort in research on 3D stereoscopic technology aimed at finding ways to present 3D videos that look like the real world. Acceptable stereoscopic content has a pair of images (or videos) with equal quality from exactly the same scene with a proper disparity, which leads to slightly different views from the scene (in a disparity range that can be fused). There are many impairments or artifacts that may lead to unnatural stereoscopic video; some of them are in-common with 2D and some of them are specific to stereoscopic videos. These artifacts have direct or indirect influences on the quality of the stereoscopic video but this effect is stronger and more irritating in stereoscopic than conventional 2D videos [11]. The source of stereoscopic artifacts can be in the capture, compression or presentation stages. Also, due to diversity in perception of depth cues in the human visual system, different observers may have a different perception of the artifacts and experience of 3D. The most common artifacts are described in the following sub-sections.

2.3.1 Flicker

According to Huffman et al.[17] "fluctuation in the brightness of the stimulus" is called flicker. This fluctuation can either happen in the whole screen or locally at high contrast features. The first type is called large area flicker and the second type is edge flicker [59]. In the frequency domain, flicker is the result of having a sampling frequency less than the maximum temporal frequency sensitivity of the human eye. This artifact can be reduced in Liquid-Crystal Displays (LCDs) that have a sample-and-hold presentation protocol [17]. Another approach to reducing flicker is frame doubling where each left and right frames are displayed twice [59]. This approach can be extended to multi-flash protocols where one frame is shown more than once with dark frame intervals [17].

Multi-flash Protocols or multi-flashing is a method to decrease the time separation of left and right frames by increasing the presentation rate in a time-sequential protocol. The method presents a pair of frames (left and right frames) twice in a double-flash and three times in a triple flash protocol. For example if L is the left frame, R is the right frame and 1 and 2 represents frame number, then the multi-flash frame sequences are L1 R1 L2 R2 in single-flash protocol, L1 R1 L1 R1 L2 R2 L2 R2 in double-flash protocol and L1 R1 L1 R1 L1 R1 L2 R2 L2 R2 L2 R2 in triple-flash protocol [17, 15].

2.3.2 Depth Distortion

Sometimes the fusion of the left eye image and the right eye image is not successful and causes distortion in depth. Disparity gradient and disparity magnitude are two factors for checking the functionality of fusion of the left and the right eye corresponding pixels. It was first believed that only the disparity magnitude has to be smaller than a threshold (Panums fusional limit) for the brain to be able to fuse the two images [35]. However, Burt and Julesz [8] showed that disparity gradient is the determinative factor for fusion when two or more objects are very close to each other. Disparity gradient determines a critical value by considering both the visual angle and difference of disparities of nearby objects. Considering disparity gradient in addition to disparity helps to provide images with proper binocular fusion [8, 52].

Moreover, many typical stereoscopic display methods work based on a delay in transferring the image to the second eye to provide the experience of depth. This technique may provide an illusion in depth. Higher capture and presentation rates can reduce the duration of the delay and therefore result in lower distortion in depth [17].

2.3.3 Keystone distortion and depth plane curvature

Converging camera configurations result in a trapezoidal shaped picture for left and right views that are slightly different. It can cause undesired horizontal and vertical disparities. This displeasing vertical parallax is known as keystone distortion. The keystone distortion is a function of camera

base distance, convergence distance and focal length. The undesired horizontal parallax is called depth plane curvature. Depth plane curvature causes the objects at the corner to appear with a greater distance than the objects at the center of the plane [32, 60].

2.3.4 Puppet theatre effect

The puppet theatre is a stereoscopic effect in which objects appears unnaturally small. It is a distortion in size of a perceived 3D object. In other words, when the angular size of a presented object and its distance is not like their natural proportions in the real world, the object will be perceived unnaturally small [32]. This effect is built on the prior knowledge and experience of the observer about the object. The observer has to be familiar with the object and its size to find it unnaturally small in stereoscopic video or image. Usually when the puppet theatre effect occurs the object in the foreground appears unnaturally smaller when the background is the reference [62]. Yamanoue et al.[62] showed that this effect is not possible with the parallel camera configuration since the reproduction magnification of the image is fixed. However, it is more possible to occur with converging camera configuration because shooting distance is relevant to the reproduction magnification of the image.

2.3.5 Cardboard effect

This artifact results in a layered stereoscopic image. The object looks flat (or in some cases one object may appears disjointed) and the whole scene is perceived as a series of planes or layers. This problem usually happens due to insufficient adjustment of capture parameters, coarse quantization of disparity or improper depth values in compression [32, 63]. Yamanoue et al. [62] demonstrated that the Cardboard effect is not dependent on the camera configuration; it may occur with both parallel or converging configurations. In using a parallel camera, shooting angle and the viewing angle can affect this artifact. In using a converging camera configuration, the baseline distance, distance to the convergence point, and viewing distance play key roles in occurrence of this situation. Also, shading, textures, and motion parallax can affect this phenomena [62].

2.3.6 Crosstalk

Crosstalk or ghosting is a typical artifact in which left and right images cannot be matched properly on the screen and one image appears like a ghost or shadow on the other. In stereoscopic displays, this artifact usually occurs due to weak separation of left and right views. In other words the left or right image leaks to the succeeding image. It also may happen because of phosphor persistence of a CRT display or inadequate positioning of the viewer in using linear polarization techniques. Losing polarization because of scatter or time-multiplex system with deficient response time may

also result in this phenomenon [32, 11]. There are different approaches in the literature to reduce this common stereoscopic phenomenon. For example, Konrad et al. [24] suggested an algorithm to reduce perceived crosstalk in a stereo-image. Also, Kim et al. [22] proposed a new method to reduce cross-talk for active shutter glasses-type 3D LCDs. They developed a new algorithm that uses the over drive technology to minimize 3D crosstalk phenomena for 3DTV [22].

2.3.7 Shear distortion

Shear distortion is another common stereoscopic artifact. If the observer changes his position or moves his head, he feels like the stereoscopic image is following him in the same or opposite direction [32].

2.3.8 Motion Artifacts

Although, motion is an important depth cue for stereoscopic images, it can be a source of artifact. Huffman et al. define three types of motion related artifacts in stereoscopic videos: edge banding, blurring and judder. Edge banding occurs when the observer perceives more than one edge seen at the edge of the moving object. Blurring is when the edge of a moving object is not clear and sharp. Finally, judder is un-smooth motion which happens when the viewer perceives a series of discontinuous snapshots instead of a smooth motion [17]. Basically low-pass filtering and eye tracking are characteristics of the human eye visual system which help to perceive a moving image with minimum artifacts [23]. When a real object moves smoothly in a real scene, it is tracked by the human eye with the same speed. Hence, the object image remains fixed on the retina. However, the retinal speed of a moving object in a video that is a sequence of discrete stimuli in frames may not be the same as retinal speed in following an object in a real world. In general, motion blur in videos occurs because of big displacement on the retina with a fast moving object or low frame rates due to a finite number of frames per second [17]. Shooting a stereoscopic video is mainly done with synchronized camera or lenses while projection is usually multi-flash time-sequential. This procedure can result in motion artifacts when there is an object moving with a high speed. Indeed, if the shooting procedure is with a synchronized camera, then the left and right views record the object at the same time. The presentation procedure in a single-flash protocol is L1 R1 L2 R2 (where L1 is the left view of the first frame, R1 is the right view of the first frame, L2 is the left view of the second frame and R2 is the second view of the right frame). The brain expects to see the position of a moving object at R1 between its position at L1 and L2, however, the position of moving object at R1 is the same as L1 with a half frame delay [33].

In practice, LCD displays cause more motion blur as opposed to CRTs [23]. In order to decrease this problem, the response time of the LCD can be increased by either improving the material or by a video processing method called override [36].

Huffman et al. [17] show that increasing the speed of the moving object results in increasing the motion artifact and increasing the capture rate results in decreasing the motion artifact. These are primary determinants of the motion artifact. As explained above, multi-flash protocols reduce the flicker visibility to a great extent, but result in edge banding. An edge of the moving stimulus is seen as two or more edges depending on the number of flashes. On the other hand, using multi-flash does not modify judder signals. Low frame rate plays a key role in occurrence of judder; for example a 24Hz frame rate with triple flash results in noticeable judder regardless of speed. Glynn et al.[15] recently illustrated that false depth is another stereoscopic artifact that may happen when an object moves in the left to right direction or vice versa. In this situation the object appears to have more or less depth than it should have. More or less depth than the actual depth depends on the preceding frame (the starting frame sequence can be left or right) in multi-flash protocols. Glynn et al. showed that false depth could be weakened or diminished by alternately displaying multi-flash protocol with left and right precedence or selecting the preceding frame in a random order.

2.3.9 Viewing Position

One of the most important parameters that can affect artifact perception in a stereoscopic video is the viewing position. A good position depends on different factors such as the type of display system, the size of the system and lighting of the room. The best viewing position for watching a 3D video is where the reflected light from the image to the eyes is the same as the perceived lights in the real scene. However, it is impractical to only use one position for viewing stereoscopic videos. The human visual system has a strong ability to compensate the slant or orientation of the display toward the eyes. This ability provides a range of correct multi-viewing positions in 2D but not always in 3D. Since, the viewer position has a direct influence on the perceived disparity, changing viewing position may lead to misperception of the stereoscopic image. The viewing position should not be too close or too far from the screen. Viewing the scene from positions that are too close results in shifting the objects closer to the display and it seems that the scene is squeezed. When the observer is too far, the scene seems to be extended in depth and objects move farther away. When the viewer is watching a video from a left or right side position, the objects in front of the screen seem to move toward the viewer and objects behind the screen move in the opposite direction. These conditions happen when the viewer is watching parallel to the screen not with a sweeping angle. If the viewer's head has movement toward the screen, it leads to vertical disparity and causes image distortion [11]. According to Held et al. [16] when the observer's head is rotated around the vertical axis of the screen or the forward axis, it is more likely that the rays from retinal images that projected to corresponding points of left and right images do not intersect. These are called skew rays. In this situation the visual system uses vertical disparities to perceive depth. However, this situation produces an inappropriate viewing situation. From another aspect, the screen size and

viewing distance have a direct relationship together. Smaller devices need a small distance and a large screen display systems needs a longer distance. Hakkinen et al. [18] investigated the effect of camera baseline which leads to disparity and depth magnitude in three different situations: a small device (24 inches display) with 15 inches viewing distance, a 40 inches TV with 62 inches viewing distance and in a cinema with 630–748 inches viewing distance. They found that camera base distance has a significant effect on viewing experience with small displays. However, this effect is not noticeable for large screen TVs or cinema screens [18]. Regardless of the screen size there is a rule for disparity in stereoscopic videos. The rule states that a safe disparity value is 1/30 of the distance of camera from the objects in the foreground of the scene [33]. Also, another study [1] shows that for a 3DTV the distance from the screen needs to be near to 2000 pixels. Furthermore, Polonen et al. [42] assessed the sense of presence and the comfort of a viewer in a movie theatre for a stereoscopic movie. The results show that a large number of observers feel comfortable after watching the movie and have the experience of presence. Later, Polonen et al. [44] investigated the effect of sickness, visual strain, quality of the stereoscopic images and feeling of presence through another study. Also the effect of different genres of the movie and the time duration were evaluated [42]. The researchers assumed a small effect due to viewing position since all the participants were located at the middle of the cinema.

2.4 3D Visual Discomfort

Visual discomfort in 3D stereoscopic viewing is an important issue. Subjective tests show that some people are not able to continuously watch a 3D movie [27]. According to Blehm et al. [4] common vision symptoms can be categorized into four different categories: asthenopic symptoms such as eye strain, ocular surface-related symptoms such as dry eyes and watery eyes, visual symptoms such as blurred vision and double vision and extra-ocular symptoms such as neck and shoulder pain. These symptoms can be due to: environment, abnormality of vision or display issues. The home and work environment can cause visual discomfort. The ocular surface can be irritated by air flow, low humidity, aerosols and excessive heat [51]. Abnormality of vision is another important factor that causes visual discomfort. Many people have binocular vision problems or accommodation difficulty that is insignificant during every day life, but cause discomfort when they spend long amounts of time working with computers and watching TV [49]. Conflict between accommodation and convergent eye movement is an intrinsic visual discomfort issue for stereoscopic 3D movies and images [38]. Accommodation is the change in the eye lens in order to focus an object on the fovea. When the human eye is viewing a real scene, accommodation and eye convergence change in conjunction with each other [41]. However, in stereoscopic movies, the accommodation is fixed on the display system and the convergence changes. This conflict is a source of visual fatigue. Another important source of visual discomfort is excessive disparity in stereoscopic images. The

human visual system is able to fuse images with disparities beyond the Panums fusional limit [66]. However, Wopking [61] showed that disparities bigger than 70 arcmin can cause visual discomfort. This study shows that Panums fusional limit can be revisited as a comfort limit. Another major source of visual discomfort is the 3D stereoscopic artifacts. Kooi and Toet [25] have shown that crosstalk can cause visual discomfort. Blur can both increase and decrease the visual discomfort. In actual scenes, the objects that are beyond the eye fixation point are blurred; hence, blur can be a depth cue and increase visual discomfort even at high disparities [61]. This is the case of a local blur in a limited part of the image. In the case of a global blur (by applying a homogeneous Gaussian blurring operator for example), visual discomfort increases [25]. Other artifacts such as flicker and depth distortion can also cause visual discomfort. However, little is known about the underlying mechanisms [26].

2.5 Other Depth Cues

Although the focus of this work has been on stereopsis as the main mechanism in 3D perception in the human visual system, there are other factors contributing to the extraction of depth information. The role of each factor depends on the structure of the image and the real scene, the distance of the objects, the position of nearby objects, the subjective human visual system and many other parameters. In general, depth cues can be categorized into monoscopic depth cues, binocular depth cues and motion parallax. Monoscopic depth cues rely only on one eye. This category of cues includes shadow, perspective and relative size, occlusion, position relative to horizon and accommodation. Accommodation is a process of focusing on a target by changing the lens optical power. This is one of the most important depth cues that are used for an object at a short distance. Illumination and brightness are examples of monocular depth cues in 3D images [33, 3]. Cormack et al. [10] assessed the relationship between luminance contrast and the threshold of intraocular correlation. Intraocular correlation is a measure of similarity between the left eye and right eye images. This parameter is maximum when the two images are identical and disparity is zero. In fact, when intraocular correlation is less than a critical value the observer is not able to fuse the two images. They showed that the threshold for intraocular correlation decreases for low values of contrast and then becomes constant for high contrasts [10]. Binocular depth cues are involved with both left and right eyes. Binocular depth cues include vergence and stereopsis. Vergence is the process in which the left and right eyes move in opposite directions. This process results in minimum difference of projected image on left and right retinas. Stereopsis is another depth cue that works based on retinal disparity as discussed before. Between 3 and 15% of people have stereopsis problems and as a result they mostly rely on other depth cues [33].

Motion parallax is the changing parallax of a moving object that is used as a tool for depth perception in human visual system. The human brain is able to imagine a three-dimensional model

by inspecting the speed, direction and the position displacement of the moving object [33, 3].

2.6 Summary

This brief review has shown that there is a wide body of multidisciplinary research that bears on stereoscopic videos and stereoscopic artifacts. As might be expected, there are numerous questions that have not yet been investigated. Our study will address issues related to motion artifacts and how controlling a few parameters can minimize them. We are particularly interested in results relevant to projection in a theatre.

Chapter 3

Research Goals

3.1 Background

Based on our review of the literature it is clear that there are many factors that affect the presence of artifacts and thus the overall quality of stereo 3D video presentations. In this research study we were particularly interested in motion artifacts since their presence or absence is to some extent controllable in production. We were also particularly interested in how these motion artifacts manifested themselves in a realistic theatre environment where subjects are assigned a variety of seats. This is in contrast to many studies where subjects are in a laboratory environment and often sitting directly in front of a screen. This interest in theatre environments was facilitated by the presence at SFU Surrey of Lecture Theatre 2600 which seats 200 viewers and which is equipped with a late model Christie projector capable of 3D stereo projection (This projector was donated to the University by Lightyear Digital Theatre) [9]. As noted, there exists a long list of parameters that affect the capture and presentation of a stereoscopic video. Changing these parameters leads to increasing or decreasing the quality of the final stereoscopic video. To keep the scope of our study manageable, we selected a subset of parameters and observed their effect on motion artifacts. In order to do this, several stereoscopic clips were shot with different capture parameters. Specifically, the different capture parameters were disparity and angular velocity of the moving object in the scene. The presentation parameters for the video clips were double flash versus triple flash projection in a theatre equipped with an advanced 3D projector and the seating assigned to the viewer subjects in the theatre. These parameters represented the independent variables. The dependent variables were the perceived presence or absence of motion artifacts and the perceived strength of the motion artifacts.

3.2 Research Questions

The above dependent and independent variables are selected to address the following research questions:

1. Does disparity have a significant effect on motion artifacts?
 - What level of disparity causes more motion artifact and what level causes less motion artifact?
2. Does presentation protocol have a significant effect on motion artifacts?
 - Which presentation protocol results in more motion artifact and which one provides the minimum of this phenomenon?
3. Does the speed of the moving object have a significant effect on motion artifacts?
4. Does the position of the viewer in the theatre have a significant effect on motion artifacts?

Chapter 4

Experimental Design

As noted, there are numerous capture and presentation parameters for a stereoscopic video; these include screen size, presentation resolution, viewing condition (for example viewing distance, viewing angle, zone of comfort and brightness of the room), frame rate, presentation technique (which depends on the projector technology), selected disparity, shooting distance, convergence distance, camera configuration (parallel or toed-in) and characteristics of the real scene. These parameters can all potentially affect visibility of and the strength of stereoscopic artifacts in a video. This study is limited to the effects of four parameters on motion artifacts: disparity of the left and right views, speed of the moving object in the real scene, presentation techniques, and position of the viewer in a theatre. Other parameters are fixed in this study.

4.1 Independent Variables - Angular Velocity, Viewer Position, Presentation Protocol and Disparity

Angular velocity: the speed of the moving object is known to be one of the important factors for motion artifacts in both 2D and 3D videos. In order to examine the effect of speed, we captured videos from the same scene with a cyclist riding a bicycle on a roundabout (traffic circle) at four different constant speeds: 5, 10, 15 and 20 km/h. The camcorder was set at the center of a roundabout at a constant 25m distances from the cyclist (see Figure 4.1). Hence, the above four speeds correspond to angular velocities that are respectively 3.18, 6.36, 9.54 and 12.73 degrees/second as seen from the camera.

Viewer position: the angular velocity of the moving object seen by the viewers in the theatre depends on their seating positions relative to the projector and the screen. The position of the participants has three levels: the center near position, with seats at center theatre and 6.2 m from the center of the screen; the center far position, with seats at center theatre and 13.9 m from center



Figure 4.1: A screen shot from one of the clips

screen; and the side position, with seats at 7.58 m from center of the screen. For each position, two adjacent seats are considered to have the same distances from the screen. These positions are shown in a plan view of the theatre in Figure 4.2.

It is straightforward to calculate the angular velocity of the moving object as seen by viewers in either the center near or center far positions. It is assumed that the angular velocity seen from the projector position is the same as that from the camera position. This is due to the fact that the crossing time and the sweeping angle is the same in both cases (Figure 4.3). This occurs because of appropriate adjustment of the focal lengths of the camera and projector lenses.

Correction to the angular velocity of the moving object based on the viewer's position is simply:

$$V_c = V_o \frac{R_p}{R} \quad (4.1)$$

Where: V_c is corrected angular velocity as seen by a viewer in the theatre, V_o is the original angular velocity as seen from the camera position, R_p is the distance from the projector to the screen and R is the distance from a viewer to the screen. These parameters are shown in Figure 4.4. This equation is valid due to the fact that $V_c * R$ is a constant value at every position in the theatre; $V_c * R = d/t$ where d is the screen width and t is the moving object crossing time.

This correction equation does not apply directly to a viewer in a side position - in this situation we set R equal to the distance from the viewer to the center of the screen but it is recognized that one side of the screen is closer and the other further away. Also, in the literature there is discussion

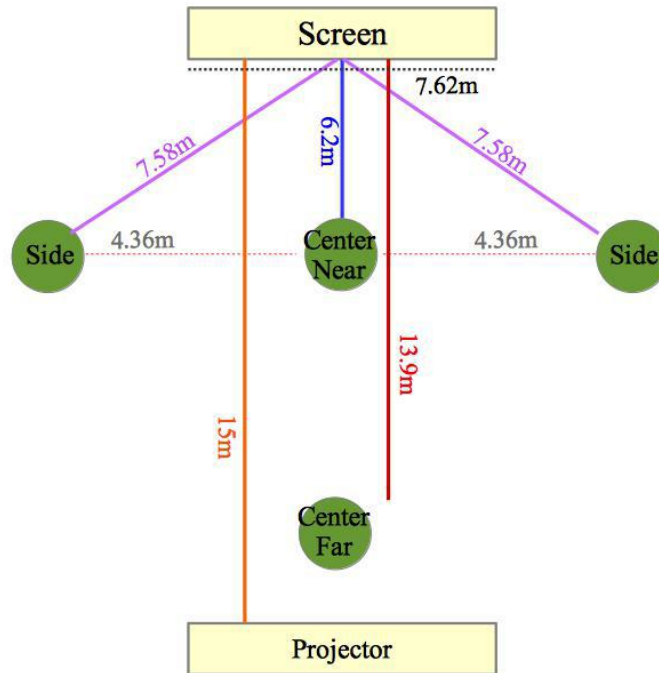


Figure 4.2: The geometric model of the theatre.

of perceptual processing when a viewer has an oblique view of a screen [64].

Presentation protocol: there are varieties of time-parallel and time-sequential stereoscopic presentation protocols. However, this study is limited just to double and triple flash protocol time-sequential presentation techniques. In double flash protocol, left and right images are presented two times and in triple flash presentation protocol left and right images are presented three times. We were not able to consider the single flash protocol since it provides a high degree of flickering. As a result, the viewer could not concentrate on motion artifact. Hoffman et al. [17] also reported a similar effect of multi-flash presentation protocol on flickering. In this experiment the frame rate was 24p (24 frame per second) and the experiment compared single flash and double flash. The dark time intervals for both double and triple flash were adjusted to 700 microseconds. The display sequence starts with left view, for example L1 R1 L1 R1 L2 R2 L2 R2 in double flash presentation protocol and L1 R1 L1 R1 L1 R1 L2 R2 L2 R2 L2 R2 in triple flash (where L is left view, R is right view, 1 represents the first frame and 2 represents the second frame).

Disparity: stereoscopic technology is based on disparity, i.e. the difference of an object location between left and right images. This is similar to the human visual system, which is based on a horizontal separation of the left and right eyes. Disparity is larger for nearby objects than distant

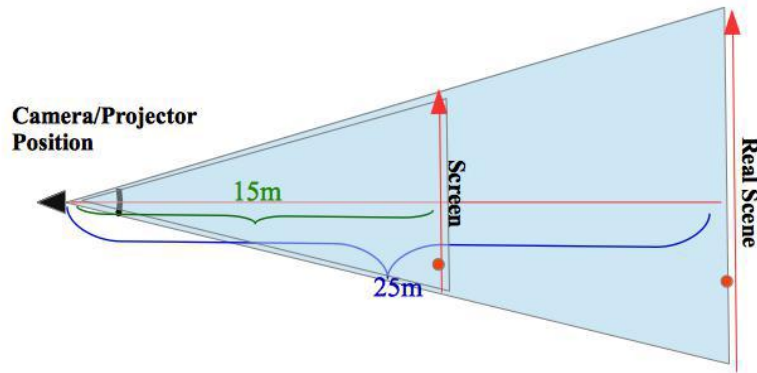


Figure 4.3: The relative positions of camera and projector.

objects with respect to transferring the true depth information. Disparity can be either adjusted in the capturing stage through the camcorder baseline or in post-production. In this work, the effect of larger or smaller disparity is examined on motion artifact. In the experiment, disparity with three levels: 1, 3 and 5 camcorder parallax values, is another dependent variable which determines the distance between left and right images in the 3D video.

4.2 Dependent Variables - Motion Artifacts

The response variables (dependent variables) were visibility and strength of motion artifacts. The visibility of motion artifacts can be determined by asking participants to report if they could see any motion artifact in each video. For artifact strength, a rating scale can be used to indicate how much the artifact adversely affected the feeling of realism while watching the 3D video. Data were collected through a questionnaire constructed such that higher scores indicate the stronger motion artifacts and lower value means weaker or no motion artifact. Viewers were asked to indicate whether the motion artifact was present (yes, no). If motion artifact was detected, they were asked to rate motion artifact on a scale of 1 to 5, where a response of 1 indicates slight motion artifact detected and 5 means the motion artifact was very strong.

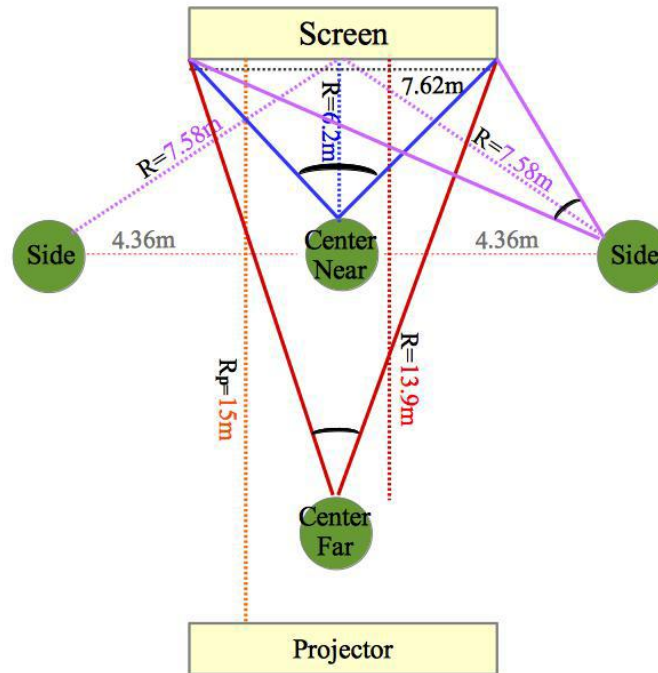


Figure 4.4: The correction factor parameters in the geometric model of the theatre.

4.3 Study Participants

Thirty-eight observers between 18-56 years of age took part in this experiment. The participants were mainly university undergraduate students. Two subjects were researchers who were aware of the research hypotheses. The stereopsis vision ability of the subjects was tested through the TNO test. As discussed before, 3% to 15% of people are stereo blind and cannot perceive depth according to a stereopsis process in their vision. Thus, we arranged a pre-test before the main test to select participants based on the TNO Stereoscopic test (Lameris Ootech BV, Nieuwegein). This test is widely used to screen out subjects who cannot perceive stereo 3D. As a result, eight subjects were found to have stereo ability problems. Thus, the analysis is based on data obtained from thirty subjects. Some of the participants received course credit to compensate for their time.

This quantitative study was conducted through user experiments in 19 sessions. Each session was 45 minutes. Thirty-eight participants registered through SFU Research Participant System (the so called SFU SONA System) for participation in one of the 19 sessions. As mentioned above the participants were seated in three different positions: center close, center far and side. In each

position two seats were selected with the same distance and angle from the screen. Thus, the maximum number of participants in each session was six. The participants enrolled for participation in the SONA system were in groups of one to five. After taking the TNO test from each participant, only the participants who had stereo-ability were included in the study. The participants were randomly assigned to one of the three positions in such a way that finally we had ten participants for each position.

4.4 Equipment Details

A JVC GY-HMZ1U Pro HD 3D camcorder (Figure 4.5) was used for recording the stereoscopic clips. The camera uses Twin f/1.2 HD lenses. The videos are recorded with a parallel configuration where the optical axes of the two cameras are parallel to each other. The capture rate was 24 frame/second and the target distance from the camera was 25m. The videos were in MP4 format with 1920 x 1080 resolution for each left and right view. The camera manual and detailed characteristics can be found at [20].

The camera output is converted to CineForm video format to be compatible with the required input format of the projector.



Figure 4.5: JVC GY-HMZ1U Pro HD 3D camcorder

The theatre room consists of 200 seats. The screen width is 7.62 meters (25 feet). During the experiment, the lighting in the theatre was dimmed. Figure 4.6 shows two different views of theatre. The projector is located at the end of the theatre room behind all the rows. The projector



Figure 4.6: Two views of the inside of the theatre.

was a CP2000-M/MR CHRISTIE 3D stereoscopic projector (Figure 4.7). The projector manual and detailed characteristics can be found at [9].



Figure 4.7: CP2000-M/MR CHRISTIE 3D stereoscopic projector

4.5 Experimental Design

The participants were selected by volunteer based sampling. In this experiment there are four speed levels, three values for disparity and two presentation protocols. For each session, a group of one to five participants watched all 24 clips. Since each subject watched all clips, and the clips

were shown in random order, this aspect of the study represents a crossover design structure. The participants are randomly assigned to one of the three positions described above. Also, each movie has a unique configuration of values of three factors (presentation, speed, and disparity). The relationship between position and the three movie factors represents a special structure known as a strip plot. [34]. All in all, this experiment has a strip plot crossover design structure.

The content consists of 24 stereoscopic real video clips. The duration of each video clip is 25 second and there is a 14 seconds interval between clips to answer the related questions. The videos are presented without sound. In each video the participants are asked to focus on the cyclist and answer the related questions. The 24 stereoscopic videos are the result of twelve clips with four different levels of moving object speed and three levels of parallax value at capturing. Then, these twelve movies are presented in both double and triple flash presentation protocols.

4.6 Experimental Protocol

This experiment consists of these steps:

- Consent form completed by the participants
- Visual TNO test
- Watching training clips
- Main test

First, all participants were asked to carefully read and sign the informed consent form. The form describes the purpose of the experiment, the procedure, data confidentiality and risks or benefits to participation. As described before, because 3% to 15% of people are stereo blind and cannot perceive depth according to a stereopsis process in their vision system, they are screened out with the TNO test (Lameris Ootech BV, Nieuwegein).

Following this, the procedure of the experiment and the nature of motion related artifacts were explained to the participants. The researcher explained motion blur, unsmooth motion and edge banding as the three types of motion artifact. Two sample videos were presented to help participants to better understand the motion artifacts. One of these samples was a worst case with maximum motion artifacts. The other video was a best case with no motion artifact at all. The participants were asked to answer the corresponding question after each video in a questionnaire. The questionnaire contained twenty four similar questions. Here is one of the questions as an example:

For each clip, in the first part of the question participants were asked whether or not they noticed any motion artifact. In case of any motion artifact, they rated the effect in a scale from one to five. One means the perceived motion artifact was very weak and five means it was very strong and noticeable.

In this clip, did you see any motion artifact? Yes No

Please rate the effect of this artifact?

Weak effect 1 2 3 4 5 Very strong effect

Figure 4.8: An example of the questions asked from the participants. The full questionnaire is in Appendix B.

4.7 Discussion of Design Issues

This design for evaluating motion artifacts has some limitations. We attempted to control these limitations as much as possible. First, a period effect may occur. For example, the participants eye fatigue generally increases with the passage of time. Or subjects may get better at detecting blurriness with practice over time. These effects would lead to potential systematic inconsistencies in average responses. To avoid eye fatigue each session of the experiment was designed to be as short as possible (maximum 45 minutes).

Secondly, a carryover effect may occur due to the effect of order of presented movies on rating the succeeding movies. For example, if movie #1 is the sharpest and clearest, movie #2 is terribly blurry, and movie #3 is somewhere in between, then a subject might judge movie #3 more harshly if she sees it following movie #1 as opposed to seeing movie #2 first. This can lead to increased variability and therefore loss of power of hypothesis tests and reporting of wrong conclusions. The fact that there was a break between movies during which the participants answered a short questionnaire is helpful to reduce the carryover effect. Each clip was 25 sec and dark interval between clips was 14 second. This is assumed to be an adequate washout between consecutive movies to reduce or remove the potential for carryover. Besides, the clips were presented in a balanced random presentation order to further prevent the carryover effect to some extent.

Chapter 5

Data Analysis

The collected data are organized into two tables: the first table contains data on the visibility/invisibility of motion artifacts and the second table consists of rating scores for motion artifacts. The data table for visibility/invisibility of motion artifact consists of binary data where a one represents the appearance of this phenomenon and zero represents the absence of it. The other data table has values from zero to five. Zero has the meaning of no motion artifact and values from one to five represent the strength of the adverse effect of the motion artifact rated from very weak to very strong. The two datasets were analyzed since we are looking for the factors that affect visibility of the motion artifact and also the factors that influence the strength of the motion artifact.

Based on the hypotheses introduced above and the nature of the available data, we performed Analysis of Variance (ANOVA) on both data sets. The purpose of using ANOVA is to determine which factors have a significant effect. The JMP 10.0 statistical software package was used to perform these analyses. In all cases, the probabilities of 0.05 or less are used to reject the null hypotheses and accept the presence of significant difference between different groups. A Tukey's honest significance test (HSD) was applied on the parameters that have significant effect in order to find which levels of a factor are significantly different from other levels.

A third analysis was performed in order to determine the speed threshold for the presence of motion artifacts. For this analysis, the best cumulative Gaussian fit approach was used to determine the threshold [17]. It is recognized that an alternate approach would be to apply a logistical model to the binary data. However, we wanted our results to be directly comparable to those of Hoffman et al. [17], who used the cumulative Gaussian approach.

5.1 Analysis of the Visibility of Motion Artifacts

In this model the Full-Factorial ANOVA was used to identify which parameters have a significant effect on the visibility or invisibility of motion artifacts. The response variable of this model is the visibility of the motion artifact. Data values are binary which are either zero (no visible motion artifact) or one (visibility of an artifact).

This is a Mixed-model that has a mixture of fixed and random effects. The first fixed effect is disparity with a base separation of one, three or five camera parallax values. The second fixed effect is presentation protocol, which is either double-flash or triple-flash. Speed of the moving object in degrees per second is the third fixed effect. The speed of the moving object in the original videos has four levels: 5km/h, 10km/h, 15 km/h and 20km/h, which is equal to 3.18, 6.36, 9.54 and 12.73 deg/sec respectively as seen from the camera.

It is important to notice for evaluating the effect of speed in ANOVA we considered the speed in the real scene for the moving object. Further, it is explained in detail that speed is corrected by considering the position of the viewer. The viewers are randomly assigned to three positions: two seats at the center of theatre with 6.2 meters distance from the screen which is referred to as center near in this text, two seats at the center of theatre with almost 13.9 meters distance from the screen which is referred to as center far, and two seats at the side of the theatre with 7.6 meters distance from the center of the screen which are referred to as side in this text. The interactions of all the fixed effects are considered in the model.

Random effects were also included in the model to account for the design structure of the experiment. The experiment was done in nineteen sessions. Within each session between one and five participants were randomly assigned to three positions. In fact, thirty participants were randomly nested in three positions. Therefore, session, the interaction of session and position and the factor that specifies participants are nested in positions per session are random effects. The combination of values of speed and disparity uniquely define a movie at the capture stage. The combination of values of speed, disparity and presentation protocol uniquely define a movie at the presentation stage. This situation resulted in interaction of session with disparity and speed and also interaction of session with disparity, speed and presentation protocol as other random effects. Finally, the positional viewing of a particular movie from combination of values of speed and disparity and the positional viewing of a particular movie from combination of values of speed, disparity and presentation protocol are two other random effects. The viewers watching a particular movie in positions per session determines the last random effect. Table 5.1 shows all the random effects with corresponding variance components.

In more detail, there was also another factor Period which determined time slots within each session in which movies are shown. It varied based on the order of presentation of movies in each session. However, since the corresponding data was not available, we ignored this parameter,

which may bias our analysis.

Table 5.1: Random effects and their corresponding variance components that are in analysis of the visibility of motion artifact

	Factors	Variance Component
1	Session	-0.0044
2	Session*Position	0.0023
3	Participant (Session*Position)	0.0161
4	Session*Speed*Disparity	-0.0102
5	Session*Presentation Protocol*Speed*Disparity	-2.742e-5
6	Session*Position*Speed*Disparity	0.0086
7	Participant*Speed*Disparity (Session*Position)	0.0193
8	Session*Position*Presentation Protocol*Speed*Disparity	-0.0043

Table 5.2: F-ratio and probabilities of the fixed effects and the interactions in analysis of the visibility of motion artifact

	Source	F-ratio	Probability
1	Speed	257.08	<0.0001
2	Presentation Protocol	0.60	0.4403
3	Speed * Presentation Protocol	0.89	0.4495
4	Disparity	0.03	0.9680
5	Speed * Disparity	0.93	0.4778
6	Presentation Protocol * Disparity	0.75	0.4747
7	Speed * Presentation Protocol * Disparity	0.77	0.5966
8	Position	1.41	0.2949
9	Speed * Position	4.17	0.0009
10	Presentation Protocol * Position	1.18	0.3111
11	Speed * Presentation Protocol * Position	0.21	0.9745
12	Disparity * Position	0.45	0.7695
13	Speed * Disparity * Position	0.43	0.9492
14	Presentation Protocol * Disparity * Position	0.95	0.4401
15	Speed * Presentation Protocol * Disparity * Position	0.50	0.9128

Table 5.2 shows that the speed of the moving object has a significant effect on visibility of motion artifacts with F ratio of 257.08 and $p < 0.0001$. The least square mean value for 3.18, 6.36, 9.54 and 12.73 deg/sec are respectively 0.23, 0.86, 0.91 and 0.95 as shown in Figure 5.1. Since speed has a significant effect on visibility of motion artifacts, a Tukey (HSD) test was applied. The results show there is not a big difference between 6.36 and 9.54 deg/sec and also between 9.54 and 12.73 deg/sec. However, there is a significant difference between 3.18 and 6.36 deg/sec, between 6.36 and 12.73 deg/sec and also certainly between 3.18 and 12.73 deg/sec. It is important to notice that 3.18, 6.36, 9.54 and 12.73 deg/sec was the constant speed of the moving object in the real scene. The object was moving around a circle with 25m radius and the camera was at the center of the

circle. In the theatre, 3.18, 6.36, 9.54 and 12.73 deg/sec are the speeds that viewer would have perceived if he was exactly at the projector location. However, these speeds are different from what was perceived at center near, center far and side positions.

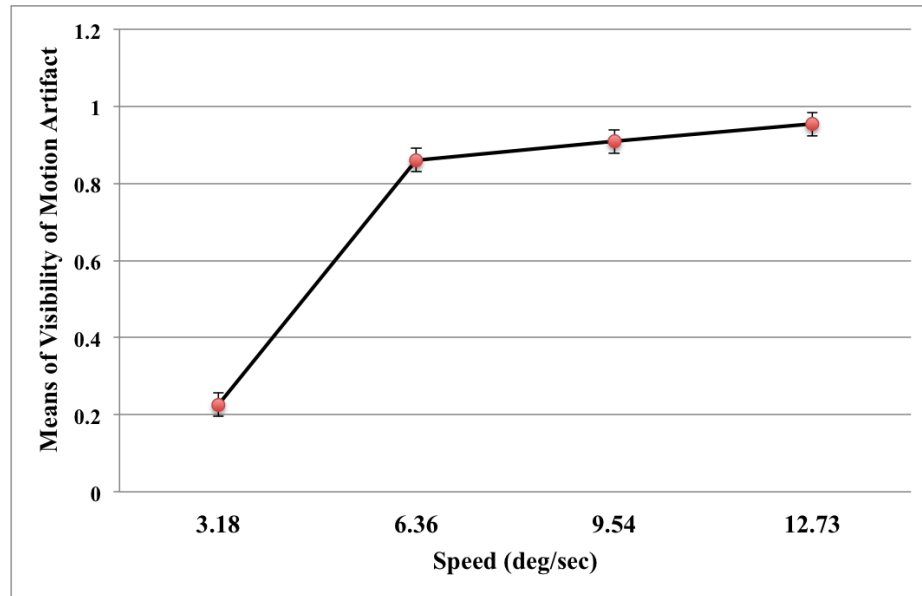


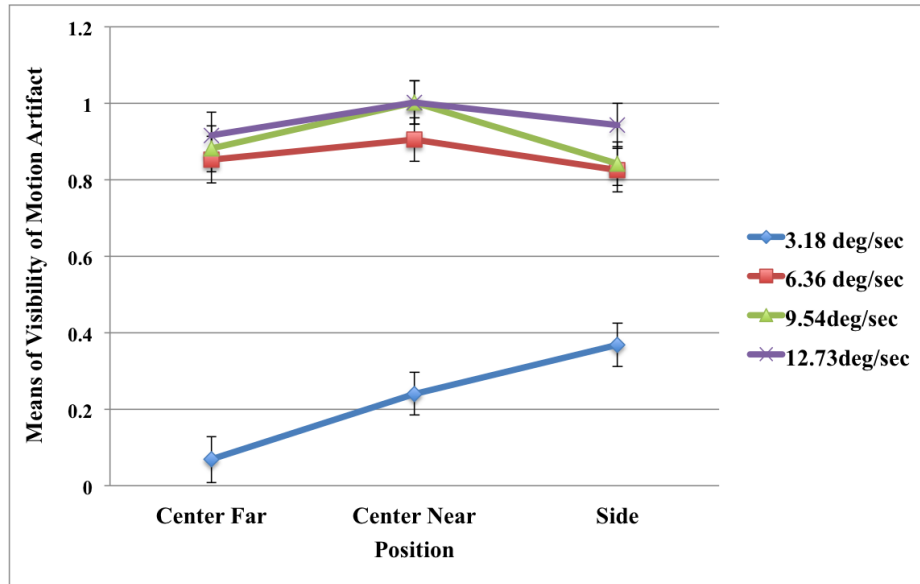
Figure 5.1: The effect of speed on the visibility of motion artifact

Although the position of the viewer does not have a significant effect on perceived motion artifacts, the position regarding the speed (the interaction between position and speed) has a significant effect. For this purpose, the mean values of three levels of position over four different levels of speeds in twelve groups are compared. Figure 5.2 depicts the interaction of speed and position. As shown in Figure 5.2a, motion artifact of a moving object with speed 3.18 deg/sec at center far, center near and side positions is mainly less than the other speeds. The Tukey (HSD) test was applied to determine which groups are significantly different. It shows there is not a big difference between motion artifact of a moving object with 6.36, 9.54 and 12.73 deg/sec at center near, center far and side positions. However, side, center near and center far positions with 3.18 deg/sec speed result in much less motion artifact. Also, for a target that moves smoothly with 3.18 deg/sec the side and center far positions result in significant differences in motion artifact. Figure 5.2b shows at high speeds such as 12.73 deg/sec the position does not play a key role in artifact perception. However, for an object that moves with a low speed of 3.18 deg/sec, it is the position of the viewer that is critical for visibility of motion artifact. Besides, center near and center far positions have almost parallel diagrams; regardless of speed, center far position results in less motion artifact than center near position. On the other hand, side position does not show such a consistent behavior with changing speed. Side position for an object with speed of 3.18 deg/sec is the source of more motion artifact

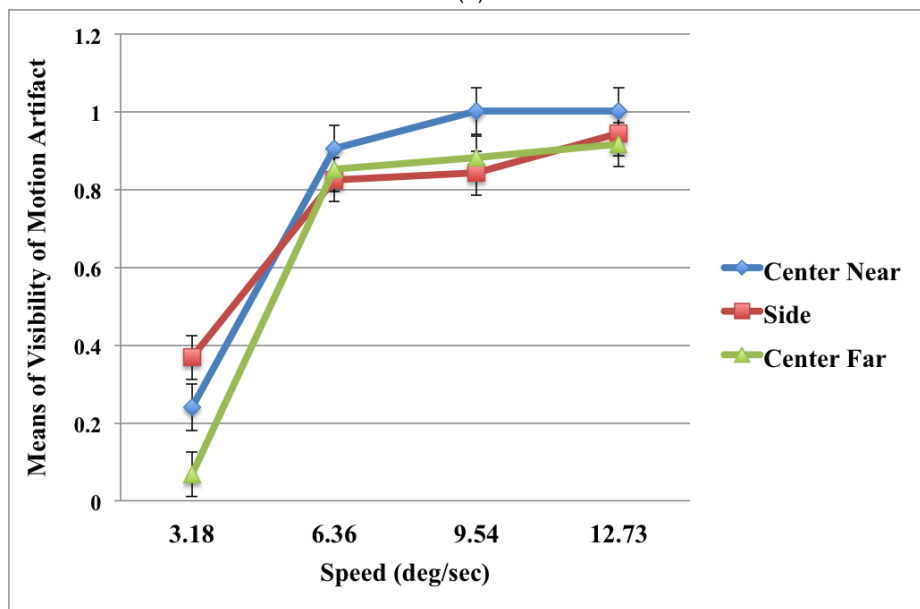
compared to an object that moves at 6.36 or 9.54 deg/sec.

Figure 5.3 displays the mean values of motion artifact at different positions. Position does not have a significant effect with F ratio of 1.41 and $p = 0.2949$. However when the means of the three positions are compared, the center far results in the minimum artifact with a mean value of 0.68. The mean value at center near position is 0.79 and at the sides is 0.75.

Also, Figure 5.4 shows that the double and triple flash presentation protocols result in almost the same level of motion artifact (0.75, 0.73 mean squares of motion artifact respectively for double and triple flash protocols). Moreover, Figure 5.5 shows that disparity does not have a significant effect on motion artifact. This is likely due to having small disparities that do not affect fusion.



(a)



(b)

Figure 5.2: The effect of interaction of speed and position on the visibility of motion artifact

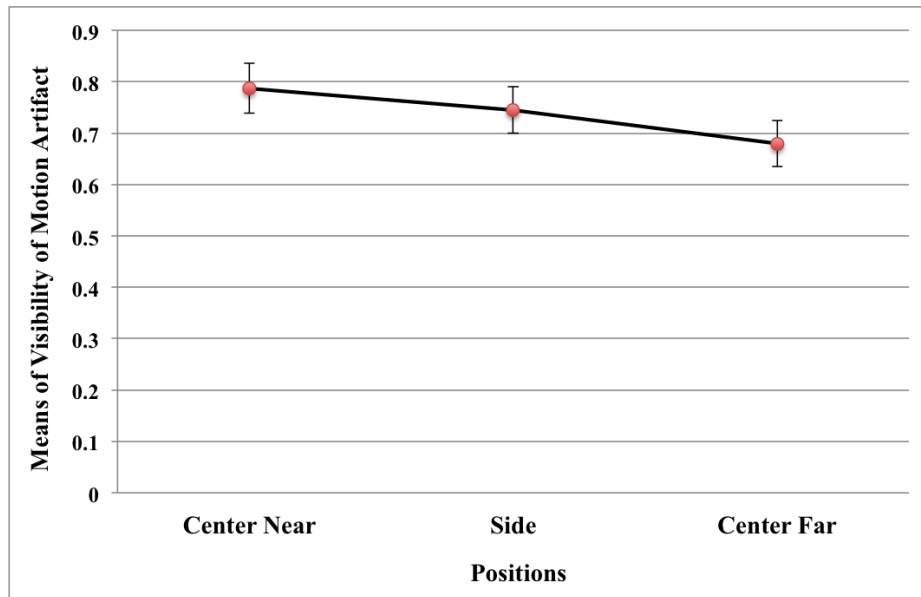


Figure 5.3: The effect of position on the visibility of motion artifact

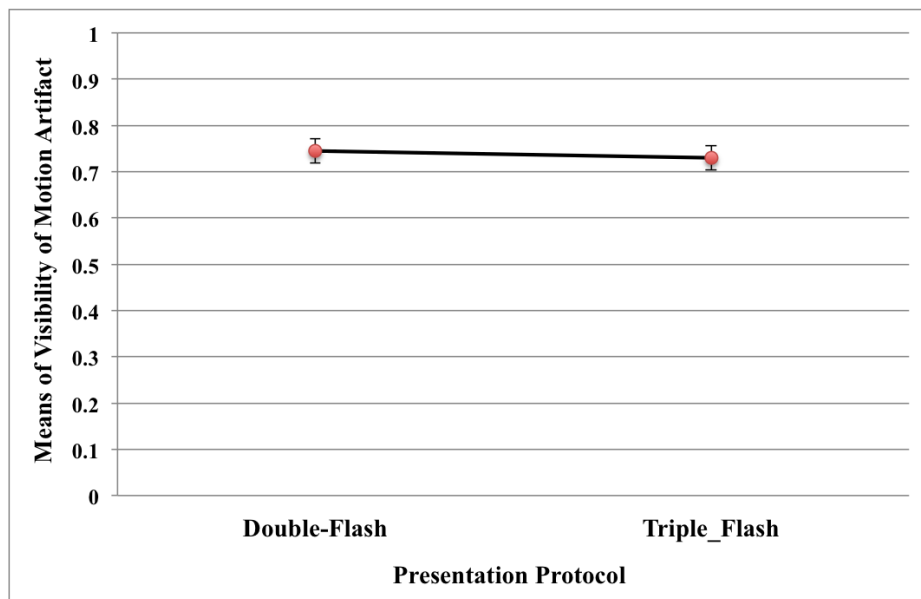


Figure 5.4: The effect of double-flash and triple-flash presentation protocols on the visibility of motion artifact

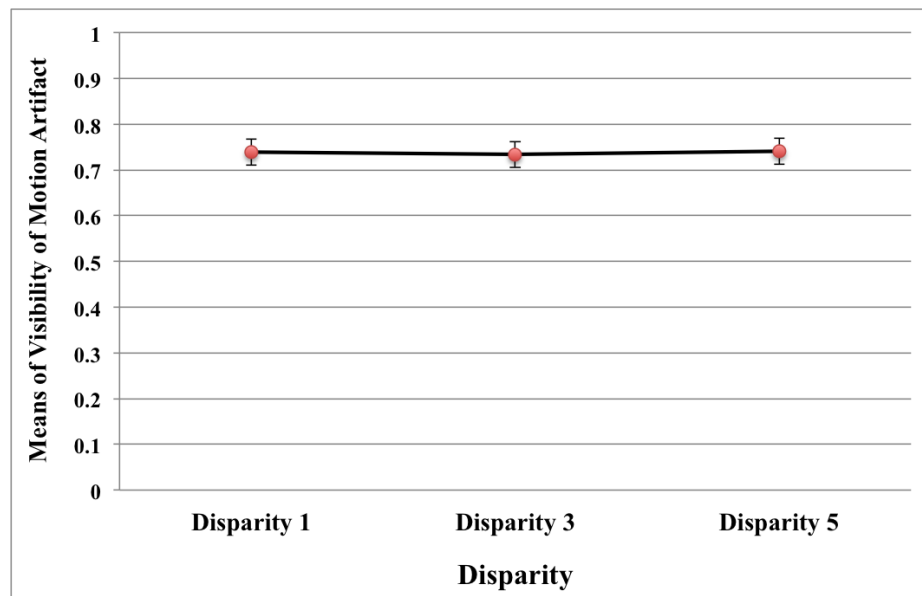


Figure 5.5: The effect of disparity on the visibility of motion artifact

5.2 Analysis of the Strength of Motion Artifacts

In this section the parameters that affect the strength of the motion artifacts are investigated. For this purpose, a Full-factorial ANOVA was performed on the rated motion artifact data table. The response variable is the perceived strength of the motion artifacts and is a numeral value between zero and five. Zero means the viewer did not perceive any motion artifact and five means the viewer perceived the maximum level of motion artifact. The parameters that were used for this model were the same as the parameters that were used in the above analysis (Analysis of the visibility of motion artifact). Table 5.3 shows all the random effects with corresponding variance component for analysis of the strength of the motion artifact

Table 5.3: Random effects and their corresponding variance components that are in analysis of the strength of motion artifact

Factors	Variance Component
1 Session	-0.1579
2 Session*Position	0.1865
3 Participant (Session*Position)	0.2719
4 Session*Speed*Disparity	-0.0410
5 Session*Presentation Protocol*Speed*Disparity	0.1250
6 Session*Position*Speed*Disparity	0.0312
7 Participant*Speed*Disparity (Session*Position)	0.2360
8 Session*Position*Presentation Protocol*Speed*Disparity	-0.0976

Table 5.4: F-ratio and probabilities of the fixed effects and the interactions in analysis of the strength of motion artifact

Source	F-ratio	Probability
1 Speed	303.67	<0.0001
2 Presentation Protocol	0.58	0.4465
3 Speed * Presentation Protocol	1.53	0.2098
4 Disparity	0.29	0.7500
5 Speed * Disparity	0.38	0.8922
6 Presentation Protocol * Disparity	0.89	0.4151
7 Speed * Presentation Protocol * Disparity	0.48	0.8209
8 Position	0.25	0.7856
9 Speed * Position	5.75	<0.0001
10 Presentation Protocol * Position	0.47	0.6263
11 Speed * Presentation Protocol * Position	0.43	0.8595
12 Disparity * Position	1.60	0.1782
13 Speed * Disparity * Position	0.30	0.9887
14 Presentation Protocol * Disparity * Position	1.01	0.4056
15 Speed * Presentation Protocol * Disparity * Position	0.28	0.9921

Table 5.4 shows the list of all fixed effects and the interactions with their corresponding F ratio

and p-values. The ANOVA analysis shows that speed had a significant effect on strength of motion artifact with an F ratio of 303.67 and $p < 0.0001$. The mean values of the motion artifact strength are 0.37, 1.61, 2.78 and 3.84 for speeds of 3.18, 6.36, 9.54 and 12.73 deg/sec respectively (Figure 5.6). The Tukey test (HSD) determines that all levels of speed are significantly different from each other. However, this analysis on the visibility of the artifact showed that there is not a big difference between 6.36 and 9.54 deg/sec and also between 9.54 and 12.73 deg/sec. Therefore, we can say that while at higher speeds the visibility of the artifact does not change very much; yet, the strength of this phenomenon significantly increases. The relationship appears to be linear.

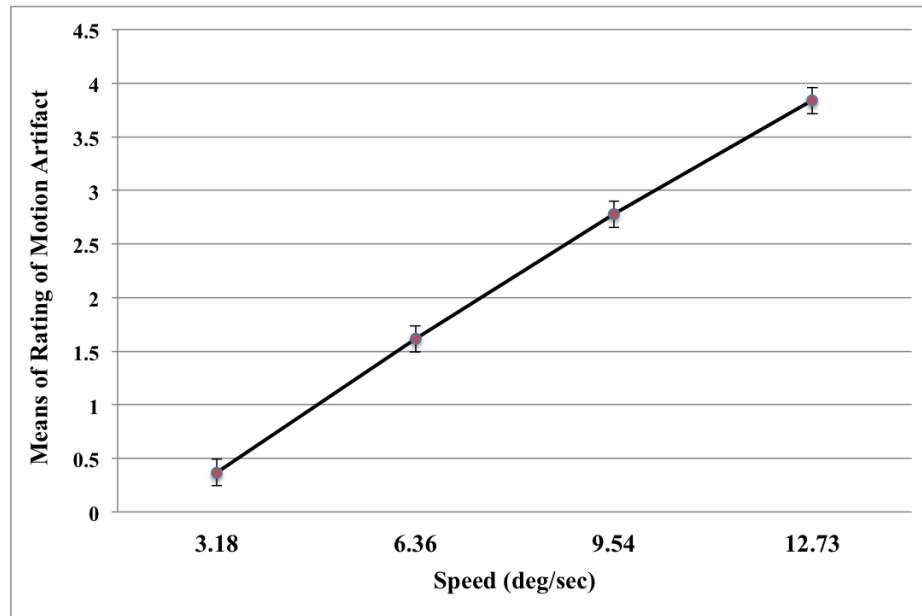


Figure 5.6: The effect of speed on the strength of motion artifact

Position does not have a significant effect. The mean values of motion artifact at Center near, center far and side are 2.23, 2.19 and 2.02 respectively (Figure 5.7).

In spite of the fact that position did not have a significant effect on the strength of motion artifacts, the interaction of speed and position had a significant effect on this phenomenon. Figure 5.8a and 5.8b show that for an object with speed 6.36 deg/sec, the strength of the motion artifact is almost the same at different positions. However, at 3.18 deg/sec side positions show a stronger artifact level than center near and center far. For an object that moves with 9.54 or 12.73 deg/sec, side positions show weaker artifact than center near and center far. Figure. 5.8a shows center near and center far have parallel diagrams while side position does not have a similar behavior. The comparison of interaction of speed and position in visibility and strength of motion artifact shows the center near and center far positions have parallel diagrams in both cases. However, in visibility of the motion artifact, the center near corresponds to more motion artifact than center far in all speeds. On the

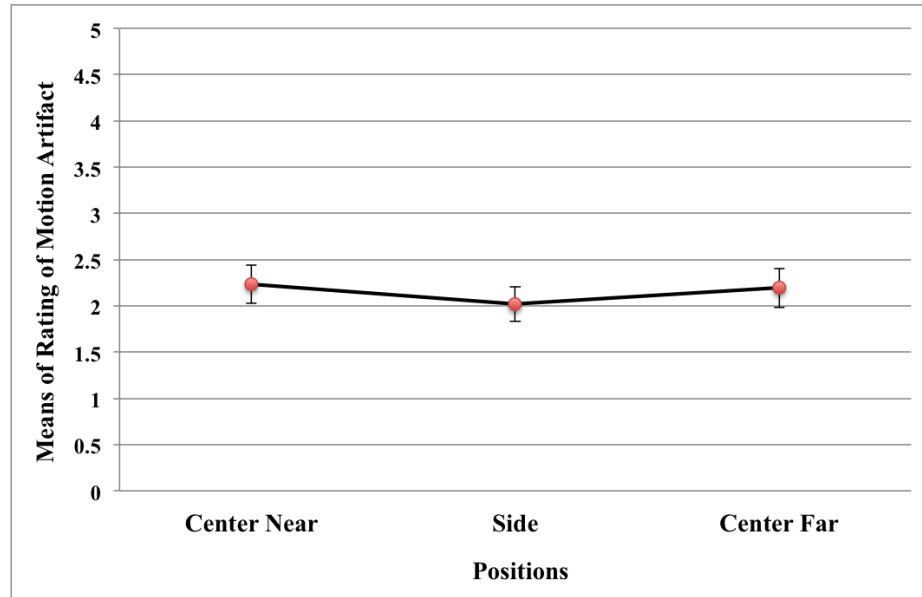
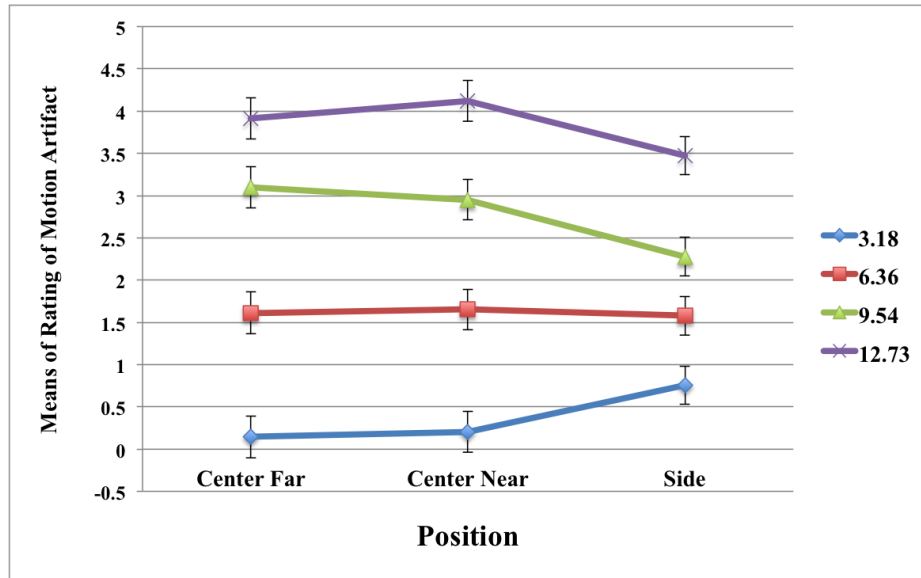


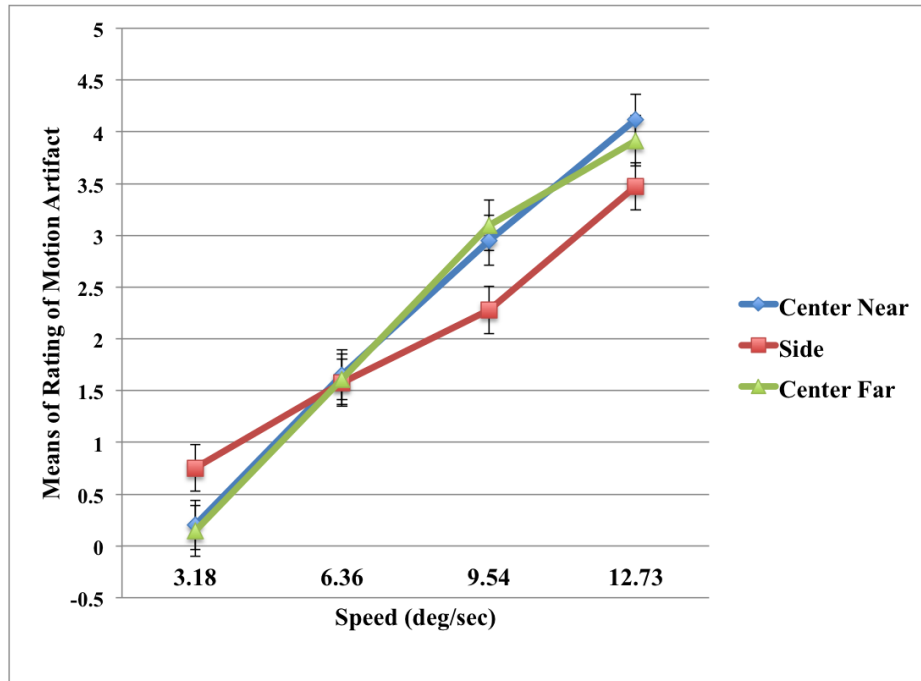
Figure 5.7: The effect of position on the strength of motion artifact

other hand in analysis of strength of motion artifact the center far and center near show very close means of motion artifact (Compare Figure 5.2 and 5.8). But in the analysis of visibility of motion artifacts, when the object moves at 6.36, 9.54 and 12.73 deg/sec, center near, center far and side positions result in close means for motion artifacts. For the analysis of strength of motion artifacts, when the object moves at these speeds the difference is larger. However, within each position at each speed there is not a significant difference (Compare Figure 5.2 and 5.8).

In addition to position, presentation protocol and disparity do not have a significant effect either. The double-flash and triple flash protocols with mean value of 2.18 and 2.12 do not result in a significant difference in strength of this phenomenon (Figure 5.9). Also, disparity does not have a significant effect on strength of the motion artifact. Three different levels of disparity with one, three and five camera parallax values lead to very close mean values of the motion artifact which are 2.14, 2.11 and 2.19 respectively (Figure 5.10).



(a)



(b)

Figure 5.8: The effect of interaction of speed and position on the strength of motion artifact

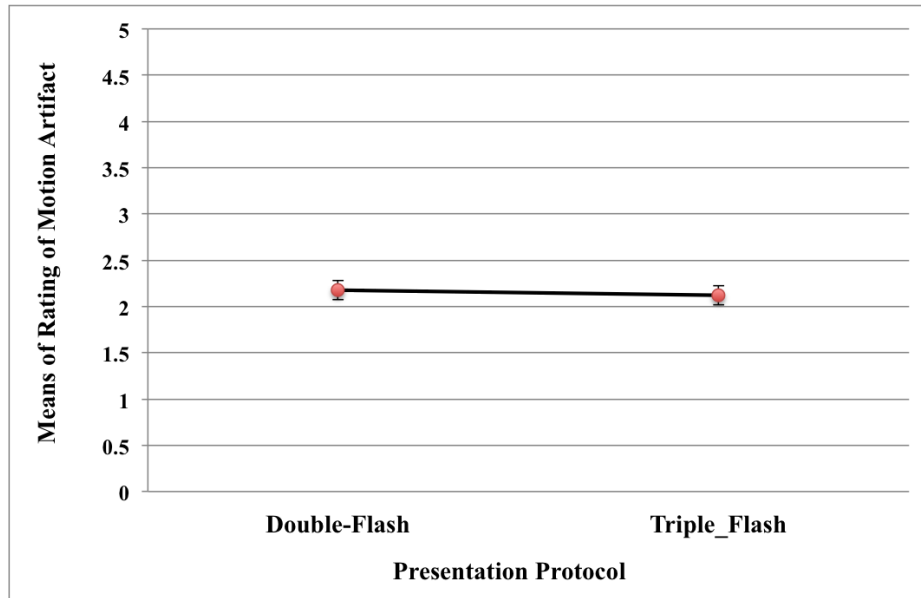


Figure 5.9: The effect of double-flash and triple-flash presentation protocols on the strength of motion artifact

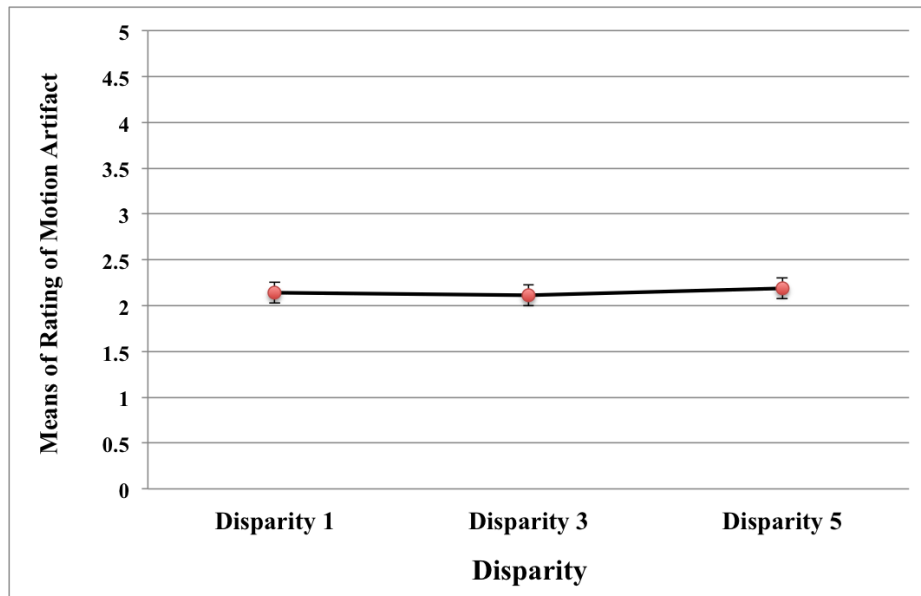


Figure 5.10: The effect of disparity on the strength of motion artifact

5.3 Speed Threshold for Visibility of Motion Artifact

The ANOVA analysis above, demonstrated that speed of the moving object appears to have had a significant effect on the visibility of the motion artifacts. In this section we would like to predict the speed threshold for a moving object – that is the level of speed above which a motion artifact will be perceived. Thus, a speed threshold for visibility of the motion artifact can help moviemakers to control this phenomenon. In this study, the motion artifact had been reported at four different speeds of the moving object in the real scene: 3.18, 6.36, 9.54 and 12.73 deg/sec (or 5, 10, 15 and 20 km/h). The frequency of reported motion artifact at lowest speed (3.18 deg/sec) is small (41 out of 180) and it substantially increases at higher speeds; the frequency is 173 out of 180 at the highest speed of 12.73 deg/sec. Therefore, we can determine a speed threshold for visibility of the motion artifact. The speed of the moving object in the real scene as seen from the camera was 3.18, 6.36, 9.54 and 12.73 deg/sec. However, this number would be different for different viewing positions in the theatre. As mentioned above, the speed of the target as seen from the shooting camera is the same as the speed of the object on the screen as seen from the projector. However, at the other positions the sweeping angle is different as shown in Figure 4.4. The speed at different positions can be approximated using the following equation:

$$V_c = V_o \frac{R_p}{R} \quad (5.1)$$

Where V_c is corrected angular velocity seen by viewer in the theatre, V_o is original angular velocity as seen from the camera position, R_p is the projector distance from the screen and R is the distance of a particular position in the theatre from screen. Here $\frac{R_p}{R}$ is the correction factor. Using this equation the corrected speeds for different positions in the theatre are calculated and shown in Table 5.5.

Table 5.5: The corrected speed at different viewing positions in the theatre

	3.18 deg/sec	6.36 deg/sec	9.54 deg/sec	12.73 deg/sec
Center Near	7.70	15.40	23.10	30.80
Center Far	3.44	6.87	10.31	13.74
Side	6.30	12.60	18.90	25.20

A Cumulative Gaussian function is fitted to the normalized frequency data and the 0.5 point is selected as a value for speed threshold [17]. Knowing the correction factor for each position, the speed threshold is calculated for 18 different cases in Table 5.6. Each case corresponds to a particular position of the viewer, a disparity value of the stereoscopic video and a presentation protocol.

Table 5.6 shows that at the center near position the speed threshold ranged from 11.55 to 11.92. At the side position the speed threshold is between 9.53 and 9.61 and at the center far position it is

between 6.87 and 7.85. Also, the average speed threshold at the center near, side and center far positions are 11.47, 9.58 and 7.10 respectively.

After applying the correction factor we realized that the corrected speed threshold for those sitting close to screen was higher than those sitting at further distance from the screen. On average, center far position has the minimum speed threshold and speed threshold for side position is between the threshold for center near and center far.

Table 5.6: Speed thresholds

	Position	Disparity	Presentation Protocol	Speed Threshold	Standard Deviation
1	Center Near	1	Double	11.76	1.08
2	Center Near	3	Double	11.76	1.08
3	Center Near	5	Double	11.55	1.12
4	Center Near	1	Triple	11.69	1.12
5	Center Near	3	Triple	11.92	1.14
6	Center Near	5	Triple	11.76	1.08
7	Side	1	Double	9.61	1.09
8	Side	3	Double	9.61	1.09
9	Side	5	Double	9.53	1.09
10	Side	1	Triple	9.53	1.09
11	Side	3	Triple	9.61	1.09
12	Side	5	Triple	9.61	1.09
13	Center Far	1	Double	7.24	1.94
14	Center Far	3	Double	6.87	1.96
15	Center Far	5	Double	7.85	1.07
16	Center Far	1	Triple	6.87	1.69
17	Center Far	3	Triple	6.87	1.68
18	Center Far	5	Triple	6.87	1.69

Chapter 6

Discussion of Results

The results of the ANOVA analysis show that for watching a real stereoscopic movie in a theatre, disparity does not have a significant effect on the motion artifact. Also, double and triple flash presentation protocols result in the same level of motion artifact. The speed of the moving object has a significant effect on the perception of motion artifacts and it is the dominant factor for this phenomenon. Although the position of the viewer does not have a significant effect on perceived motion artifacts, the interaction between position and speed has a significant effect. It means that, at low speed levels the position of the viewer determined visibility or absence of the motion artifact.

The speed threshold for visibility of the motion artifact was determined to predict that a motion artifact happens when speed exceeds a specific value. In other words, speed threshold is the speed at which motion artifacts begin to be perceived. Section 5.3 illustrates that speed thresholds at each viewing position are very close to each other. At the center near position the speed threshold ranged from 11.55 to 11.92. At the side position the speed threshold is between 9.53 and 9.61 and at the center far position it is between 6.87 and 7.85. Since the speed threshold depends on the human visual system it is reasonable to assume that it is the same (in degrees/second) no matter where the viewer is sitting. However, center near position results in higher speed threshold (average is 11.47 deg/sec) than center far position (7.10 deg/sec). This may be due to the fact that the correction factor results in over-estimating the speed threshold as described in section 5.3. The reason is that the above simple correction factor does not account for the fact that the participants sitting close to the screen follow the object on the screen, which results in having a smaller retinal speed than what the above equation predicts. Therefore, the actual correction factor is likely a non-linear function, which is bounded by this simple correction factor.

As mentioned in section 5.3 the speed threshold at different positions was calculated by considering the distance of a particular position in the theatre from the center of the screen. The ratio of the projector distance from the screen to the distance of a particular position in the theatre from

center of the screen is referred to as the correction factor in this work. However, the actual correction factor at the side position is likely to be more complicated than what is obtained from this equation. In more detail, when the observer's location is at the center of the theatre the distance from right and left sides of the screen is equal. Yet this distance is significantly different from left and right sides of the screen when the observer is at the side position. In this study, at the side position the shortest distance is 6.22m from the screen and the longest distance is 10.26 m. Also, the distance from side position to the center of the screen is 7.58m. At the center near position with 6.2m distances from the screen, the distance from left and right sides of the screen is 7.28m. At the center far position with 13.9m distance from the screen, the distance from left and right sides of the screen is 14.41m.

It is likely that some participants may have rated motion artifact in the videos based on what was perceived when the moving object was at the very left side, at the middle or at the very right side of the screen. At the side position the distance from left to right of the screen varies by a relatively large amount (from 6.22m to 10.26m). The speed threshold at the side position for disparities with 1, 3 and 5 parallax values and both double and triple flash protocols are calculated. The average of speed threshold at different situations from the side position to the centre of the screen (7.58m), from the side position with shortest distance from the screen (6.22m) and from the side position with the longest distance from the screen (10.26m) are respectively 9.58, 11.62 and 7.05.

Analysis of artifacts in a theatre depends on more parameters compared to 3DTVs. The analysis of Hoffman et al. [17] is similar to our work in that they also determined the speed threshold for simultaneous capture with double flash and triple flash presentation protocols for a wide range of capture rates. For a capture rate of 24 frames per second (similar to our work) they obtained a speed threshold of 1.8 deg/sec for double-flash presentation protocol and a threshold of 1.6 deg/sec for triple-flash presentation protocol. These data are extracted from their graphs using WebPlotDigitizer software. These thresholds are significantly lower than what we found. This can be due to the fact that Hoffman et al.'s video was presented on a special CRT device with 116.5cm viewing distance, while this study was presented on a large screen in a theatre. Moreover, in the case of their work, the moving object was a white 1° square on dark background which obviously has a high contrast. However, this work focuses on the footage of a real scene where the contrast between the moving object and the background is relatively low. Another important factor is the perceived resolution in the theatre. In this work, the screen width was 7.62m and the video resolution was 1920x1080 pixels. Therefore each pixel on the screen is 3.97mm wide. Using the distance of viewers at different positions in the theatre, the size of each perceived pixel was 0.037, 0.030 and 0.016 degrees for center near, side and center far positions. These values for the perceived pixels are likely too small to affect our results on motion artifacts.

6.1 Further Research on Viewing Position

In general, choice of viewing position is a challenging matter for stereoscopic cinema. Viewing position is determined by the distance and angle to screen and projector position. Definitely, everyone cannot have an ideal viewing position in a large theatre; therefore, the effect of each viewing position on perception of stereoscopic artifacts should be investigated in more details. This work is limited to the study of the motion artifact in a theatre. However, there are a series of common artifacts in stereoscopic movies that may be associated with viewing position. Moreover, we need to determine the effect of each factor on both visibility and strength of stereoscopic artifacts. A moviemaker or cinematic exhibitor may not be able to completely eliminate the occurrence of a particular artifact, but it is important that they at least understand the effect of these phenomena.

Chapter 7

Conclusion and Future Work

7.1 Conclusion

This study investigated the effects on stereoscopic motion related artifacts of the speed of the moving object, viewing position in the theatre, presentation protocol and disparity through changing the camera base line. Based on our experimental results, it is concluded that: first changing disparity does not have a significant effect on perception of the motion artifacts. In this study we changed the disparity in a range that the left and right views can be fused easily and without any visual discomfort.

Second, there is not a significant difference in visibility and strength of motion artifacts of a real video that is presented with double flash and triple flash protocols when the capture rate is 24hz. Third, speed of the moving object in the real scene is one of the primary determinants of the motion artifacts. Speed of the moving object has a significant effect on both visibility and strength of the motion artifacts. The results show that after increasing the speed of the moving object to some levels, the visibility of the motion artifact does not change very much. The analysis of the strength of the motion artifact shows that there is almost a linear relationship between the speed and the strength of the motion artifact. This means that with increasing speed, observers evaluated the motion artifact as stronger and stronger.

Fourth, although position of the viewer alone does not have a significant effect on the perceived motion artifact, the interaction of speed in the real scene and position has a significant effect on both visibility and strength of the motion artifacts. Center near and center far positions at all speeds show the same trend in visibility and strength of the motion artifacts where the side position does not have a similar trend. This can be due to the fact that side position provides a different angle of view to observers compared to the center positions. These results are valid for the case that observer is watching a stereoscopic video in a theatre.

Fifth, the situation regarding the speed threshold of the moving object is more complicated. The threshold is that angular velocity (degrees/second) below which the motion artifact is not visible and above which it is visible. Our experiment was structured so that the moving object in the S3D videos (a cyclist) travelled in a circular path so that the angular velocity, as seen by the camera, was constant. Our initial assumption was that the corrected speed threshold for human subjects in the theatre would be the same, no matter where they were sitting. Corrected means that the threshold was adjusted for the distance that each seating position was from the screen. Our results showed that the corrected threshold angular velocities were not constant – indeed the average value at the center near position (11.47 deg/sec) was almost twice that at the center far position (7.10 deg/sec). The side position was in between. This means that the threshold depends on more than the distance from the screen. The other obvious physical parameter that varies with position is the angle that the screen subtends at the viewers eyes. As discussed in the previous chapter, perhaps the eyes track the object when they are close to the screen, thus reducing the velocity on the retinas.

7.2 Future Work and Extension of This Study

The results regarding the effects of disparity and presentation protocol on visibility or strength of movement artifacts are straightforward and do not require further work. The situation regarding the effects of object velocity and seating position on visibility and strength are complicated and definitely require further investigation. There are additional questions regarding the situation where the viewer is seated at the side of the theatre - these also require investigation. According to Huffman et.al [17] motion artifact includes judder, edge banding and motion blur. In this work we ask the participants to rate motion artifact based on these three factors in one question. In this work we assumed that changing capture and presentation parameters have the same effect on all three types of motion artifact. However, it is possible that they show different behavior or non-linear behavior to all parameters; as a result, in future work it is suggested that the effect of judder, edge banding and motion blur be studied in three different experiments. Screen size is another parameter in evaluating motion artifacts and other artifacts as well. The TV screen is smaller than the theatre and therefore the parallax of images reduces on TV. In future work, it is recommended to compare the results of motion artifact on TV and theatre screen with various sizes. Also, it is suggested to perform a qualitative study of the artifact in addition to quantitative approach of this work. For this purpose, a series of interviews with the participants need to be conducted to find out about the effect of artifacts in reducing the feeling of realism and realistic experiences. An obvious direction for extension of this work is to evaluate other common artifacts such as flicker, crosstalk, puppet theatre effect and cardboard effect.

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Appendix A

Consent Form

The following consent form was given to the participants:



OFFICE OF RESEARCH ETHICS

Participant ID: ____

CONSENT FORM**Presentation techniques for minimization of artifacts in stereo 3D video****Who is conducting the study?**

Principal Investigator: Saeedeh Bayatpour, M.Sc. student, School of Interactive Art and Technology, Simon Fraser University.

This research is part of my M.Sc. thesis and the results will be shown in the final dissertation available to the general public.

Supervisor: Prof. Tom Calvert, Emeritus Professor, School of Interactive Art and Technology, Simon Fraser University.

Co-supervisor: Prof. Jim Bizzocchi, Associate Professor, School of Interactive Art and Technology, Simon Fraser University.

Who is funding this study?

The study is being funded by the GRAND research network. Grand is a federally-funded Network of Centers of Excellence.

Why are we doing this study?

Whether in a movie theatre or on a home TV set, stereo 3D video is subject to a number of imperfections (or artifacts). The goal of this research is to investigate how these artifacts are perceived by viewers and to look for ways to minimize them.

Your participation is voluntary

Your participation is voluntary. You have the right to refuse to participate in this study. If you decide to participate, you may still choose to withdraw from the study at any time without any negative consequences to the education, employment or other services to which you are entitled or are presently receiving.

How is the study done?

The experiment includes two steps and approximately takes one hour:



OFFICE OF RESEARCH ETHICS

Participant ID: ____

1. It will start with a very short (less than 5 minutes) pre-test to check the ability of the participants to watch 3D movies. In this test, you will be asked to wear red/green glasses and watch a few images to determine whether or not you can see them in 3D.
2. Next, a series of video clips with artifacts will be displayed in a 200 theatre. After watching each clip, you will be asked to answer a few questions. This part takes 45-60 minutes.

If you feel tired at any stage of the experiment, you can take a break. In this case, the experiment will be longer.

The data collected in this study will maintain the confidentiality of your name and the contributions you have made to the extent allowed by the law. Data will be stored on a USB thumb drive. Both this consent form and the USB thumb drive will be stored in a locked cabinet.

Is there any way being in this study could be bad for you?

This experiment may cause eye strain and a little headache. You can leave at any time during the experiment or take a break and continue again.

What are the benefits of participating?

We do not think taking part in this study will help you directly. However, in the future, others may benefit from what we learn in this study.

Will you be paid for taking part in this research study?

You will receive course credit for your participation in this research study even if you decide to withdraw from the study during the test.

How will your identity be protected?

Your confidentiality will be respected. Information that discloses your identity will not be released without your consent unless required by law. Data will be stored in a locked cabinet or on password-secured computer.

What if you decide to withdraw your consent to participate?

You may withdraw from this study at any time without giving reasons and with no effects on grades, employment etc... .



OFFICE OF RESEARCH ETHICS

Participant ID: ____

Study results

The results of this study will be reported in Saeedeh Bayatpour’s graduate thesis and may also be published in conference papers and journal articles under Saeedeh Bayatpour, Tom Calvert and Jim Bizzocchi’s names. You can contact Dr. Tom Calvert to obtain the study results.

Who can you contact if you have questions about the study?

If you need any further information about this study, feel free to either ask me or contact my supervisor, Dr. Tom Calvert.

Contact for Complaints

If you have any concerns or complaints with respect to your participation in this research study as a research participant, please direct them to Dr. Jeffrey Toward, Director, Office of Research Ethics.

PARTICIPANT CONSENT AND SIGNATURE PAGE

Taking part in this study is entirely up to you. You have the right to refuse to participate in this study. If you decide to take part, you may choose to pull out of the study at any time without giving a reason and without any negative impact on your status as a student or an employee. You will still receive course credit if you withdraw from the experiment.

- Your signature below indicates that you have received a copy of this consent form for your own records.
- Your signature indicates that you consent to participate in this study.

Participant Signature

Date (yyyy/mm/dd)

Printed Name of the Participant Signing above

Appendix B

Questionnaire

The following questionnaire was given to the participants:

The Stereoscopic 3D Movie Artifacts Questionnaire:	
1. Gender:	<input type="checkbox"/> Male <input type="checkbox"/> Female
2. Age	_____
3. Profession	_____
4. Have you ever watched 3DTV?	<input type="checkbox"/> Yes <input type="checkbox"/> No If yes, how often? <input type="checkbox"/> Regularly <input type="checkbox"/> Rarely
5. Have you ever watched 3D movie in the theatre?	<input type="checkbox"/> Yes <input type="checkbox"/> No If yes, how often? <input type="checkbox"/> Regularly <input type="checkbox"/> Rarely
6. Have you ever played 3D games?	<input type="checkbox"/> Yes <input type="checkbox"/> No If yes, how often? <input type="checkbox"/> Regularly <input type="checkbox"/> Rarely
If you have any experience of watching a 3D movie or 3D TV channels or playing a 3D games:	
7. Have you ever experienced eye strain or eye fatigue after or while watching a 3D movie?	<input type="checkbox"/> Yes <input type="checkbox"/> No
8. Have you ever experienced headache after or while watching a 3D movie?	<input type="checkbox"/> Yes <input type="checkbox"/> No

1. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
2. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
3. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
4. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect

5. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
6. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
7. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
8. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect

9. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
10. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
11. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
12. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect

13. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
14. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
15. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
16. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
-
17. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
18. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
19. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
20. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
-
21. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
22. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
23. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
24. In this clip, did you see any motion artifact? Yes No
Please rate the effect of this artifact in decreasing the feeling of realism?
Weak effect 1 2 3 4 5 Very strong effect
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