Psychophysics of Autostereogram Videos: Blur, Contrast and Repetition Period

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Master of Science
in Artificial Intelligence
School of Informatics
University of Edinburgh
2010

Abstract

Autostereograms are single image stereograms that take advantage of the binocular fusion and stereopsis of the human vision system. In this way, through autostereograms, we visualise in three dimensions objects or scenes that are embedded in two-dimensional images. In addition to (static) autostereograms there are autostereogram videos which are either videos that are created from animated depth masks of objects/scenes or videos that are composed of sequences (frames) of static autostereograms. In the work presented in this thesis, we investigated the psychophysical aspects of Random Dot Autostereogram (RDA) videos with respect to blur, contrast and repetition period of the random dots that constitute the repetitive patches inside a random dot autostereogram. The approach we followed focused on human performance data gathering by conducting experiments on human subjects that we tested for stereopsis achievement and how fast it (stereopsis) was achieved. The stimuli we used were autostereogram videos of basic objects (cubes, tubes, pyramids, disks and pentagons) in which we varied the setting of one of the aforementioned features (blur, contrast etc.) each time while keeping the rest fixed. With respect to blur, our findings showed that there is an upper threshold of uniform blur radius at 33-35 pixels above which subjects were unable to achieve stereopsis. In addition, we found a threshold at 0.02 contrast below which subjects were also unable to achieve stereopsis. Regarding repetition period, we found that there is an optimal range of settings (70-100 pixels) for repetition period within which subjects identified the objects inside the autostereogram videos faster and a range (30-100 pixels) outside which misidentification of objects and lack of 3-D perception are present. Our findings, in the vast majority of the feature settings tested, showed no statistically significant differences in performance between males and females and between people that wear glasses or contact lenses and people that do not. On the contrary, we found statistically significant differences in the performance of experienced (in watching autostereograms) subjects when compared to inexperienced ones, with experienced subjects performing better.

Acknowledgements

First of all, I would like to thank my supervisor, Robert Fisher, for his invaluable guidance and support throughout the project period. I would also like to thank Dr. Richard Shillcock for the help he provided in analysing the data. Many thanks to my family that supported me both financially and emotionally during this project and throughout the whole year that I spent in Edinburgh. I would also like to thank all my friends here in Edinburgh for all the great times we had together.

Last but not least, I would like to thank my girlfriend, Stella, for everything she has done for me the past year and especially during writing this thesis.

Declaration

I declare that this thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or professional qualification except as specified.

(*Georgios Papadimitriou*)

To my family.

" Vision is the Art of Seeing what is Invisible to Others "

(Jonathan Swift)

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Chapter 1

Introduction

The world around us, as we perceive it, is a three-dimensional (3-D) environment in which every object can be described by its three dimensional coordinates (x, y, z). In most cases the term 3-D is misused and it refers to the techniques that people use to represent 3-D objects on 2-D planes (e.g. papers, computer screens etc.) [21]. By varying for instance an object's relative size, the shade and the light that are used to represent the object, we can incorporate depth information in a 2-D image and perceive it as a 3-D one [21]. These are some of the techniques used in order to enable humans perceive the world in three dimensions with their vision system. In addition, human eyes can see two different but similar images which are later combined and perceived as one 3-D image [21]. This phenomenon is called binocular fusion and the sense of depth in the images as we perceive them with our eyes is called stereopsis [21]. According to [13] the sense of depth can arise from stereopsis without the use of any other technique. The difference between stereopsis and the techniques that are used lies in the fact that, when using techniques such as shading to represent a 3-D object in a 2-D plane, humans are able to see the 3-D object even with one eye, which of course is not the case in stereopsis where a combination of the two similar images provides the final image of what we see.

Autostereograms (see figures 2.4, 2.5) is a type of stereograms that allows us to represent 3-D objects and scenes using ordinary display devices and means (computer screens, paper etc.) by taking advantage of the ocular fusion and stereopsis of the human vision system. More specifically, autostereograms are single image stereograms through which we are able to visualize 3-D objects inside a 2-D image. So far, there is a lot of research on the space of perceptibility and psychophysics of static and dynamic stereograms as well as their applications in health sectors [11], [12], [8], [24],

[20], [22], [9]. What has not been considered yet much is the space of perceptibility of autostereogram videos. Regarding autostereogram videos, there are parameters that affect how effectively humans perceive them or even whether they can perceive them or not. Like in static types of stereograms, factors such as image blur, the disparity between the background and the foreground (3-D object) of the image, the 3-D object represented in it, the colours used to generate an autostereogram and the repetition period of pixels inside the autostereograms (applicable for random-dot autostereograms) should also affect the outcome of an autostereogram video. The question that arises at this point is simple: which factors, how and to what extent affect the perception of an autostereogram video by a human?

1.1 Motivation, Aims and Objectives

Despite the fact that stereoscopic vision was discovered almost two centuries ago, despite the various types of stereograms developed since, and despite the numerous studies on the psychophysics and the space of perceptibility of static stereograms, there is less work on dynamic random dot stereograms and no work known to us regarding the space of perceptibility and psychophysics of autostereogram videos (the different types of stereograms will be explained in section 2.1.1). This is what motivated us to conduct research on the specific topic and set the basis for further research on this field.

The goal of our research is to study the psychophysics of autostereogram videos by conducting experiments on human subjects, gathering human performance data and analysing them in order to better understand the human vision system and find the thresholds under or above which humans are not able to perceive autostereogram videos. To be more precise, we explored the space of perceptibility of autostereogram videos with respect to different amounts of blur, different repetition period of the pixels inside the videos and different contrast. In addition, we compared the performance between males and females, experienced and inexperienced observers, and between observers that wear glasses and observers that do not, with respect to stereopsis.

1.2 Summary

As was mentioned above this project is about the psychophysics of autostereogram videos. This thesis is organised according to the procedure followed from the creation of autostereogram videos, to the experiments on human subjects and the analysis of the human performance data gathered from the experimental procedure.

More specifically, in chapter 2 we present the background needed for someone to understand concepts used in our project with respect to stereograms and their different types. Furthermore in chapter 2 we present and analyse the reasons for choosing the platforms we used (3-D Studio Max, 3-D Monster and 3-D Miracle) over other available platforms and finally, we present a review of the studies on stereograms in general.

In chapter 3 we describe the procedure of creating and selecting autostereogram videos (videos of different: blur, contrasts and repetition periods in the random dot patches that synthesise autostereogram videos) that were used as a testing material for the experiments on human subjects. In addition, this chapter accounts for all the decisions made during the various steps of the creation phase until the final outcome (autostereogram videos) could be created.

Chapter 4 focuses on the procedure of selecting human subjects for our experiments and the general experimental procedure followed in all experiments. Furthermore, the stimuli used for our experiments and the rationale behind our decisions regarding the sequence in which videos were projected to each subject can be found in section 4.3 of this chapter.

Chapter 5 presents the experimental results of the experiments conducted on twenty six human subjects. The results are analysed so that thresholds in perception regarding each one of the three categories of videos (videos of different blur, contrast, and repetition period) can be identified. The most important finding with respect to blur (section 5.1) is that the threshold is approximately at 34-35 pixels of blur radius. Above this threshold, autostereogram videos are not perceived in 3-D. For videos of different Michelson contrasts (section 5.2) we found that for contrasts below 0.02, autostereogram videos are not perceived in 3-D by any of the subjects. Note that the aforementioned thresholds in autostereogram videos are the same as in static autostereograms of the same settings. This finding is based on an experiment conducted on Subject A (his performance in perceiving autosterepgram videos can be seen in appendix C) using static autostereograms instead of autostereogram videos. With respect to repetition period (section 5.3) the most interesting finding was that there is an optimal range (70-100 pixels repetition period) within which autostereogram videos are perceived optimally in terms of how much time the observer needs to identify the object inside the videos in question. Furthermore, for each category, comparisons between different groups are made (males versus females, experienced versus inexperienced observers and observers that wear glasses or contact lenses versus observers that do not). Our findings show no statistically significant differences between males and females and no statistically significant differences between observers with glasses and observers without glasses with respect to how fast they identified the objects inside the autostereogram videos. Regarding experienced and inexperienced observers we also found no significant differences with respect to blur but we found significant differences with respect to contrast and repetition period.

Finally, in chapter 6 we give an overview of our work and present the conclusions drawn from the experimental results. Moreover, suggestions for future work are made.

Chapter 2

Background and Related Work

2.1 Background

The discovery of stereoscopic vision and stereograms can be traced back to 1838 by Wheatstone in his work presented in [25]. Wheatstone was the one to find an explanation of the binocular human vision and construct a stereoscope that when used, allows a person to acquire stereopsis from two similar 2-D stereo images (stereogram) by isolating the sight of each eye and directing it to the two 2-d images (i.e. the left eye sees only one image and the right eye the other one). Note that stereograms can also be seen with naked eyes if the stereo images are placed side by side. Since Wheatstone's discovery, a variety of different types of stereograms has been developed (see section 2.1.1).

2.1.1 Types of Stereograms

Throughout the literature there in no unique classification of stereograms since people tend to use the same names for different types of stereograms or different (but similar) names for the same type of stereograms. An alternative classification with respect to autostereograms can be found in [23].

2.1.1.1 Random Dot Stereograms

Julesz was the first to introduce the Random Dot Stereograms (RDS) in [11], where he also investigated the factors that affect perceptibility of RDS. Julesz initially used two identical random black and white images which viewed through a stereoscope. What he found was that the images converged into one uniform plane. After this discovery he experimented by selecting a square region in the centre of one of the two images and shifting it slightly to the right. When he observed the images again (the shifted and the original) through a stereoscope he saw the square region emerge in 3-D with a uniform background. This is what he named a RDS. RD stereograms though, can represent more objects than a mere square since any region can be shifted. Depending on how much we shift a region, more or less depth is perceived. Figure 2.1 illustrates a RDS.

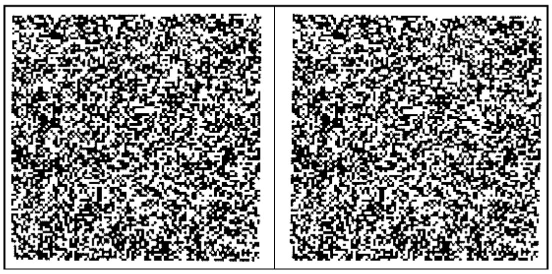

Figure 2.1: RDS demonstrating a 3-D square (Source: [11]).

Apart from (static) random dot stereograms that were described above, there are also dynamic random dot stereograms (DRDS). These DRDS are in fact random dot stereograms where the images that synthesize them are moving to the same or to opposite directions. Figure 2.2 illustrates three possible modes of movement in a DRDS.

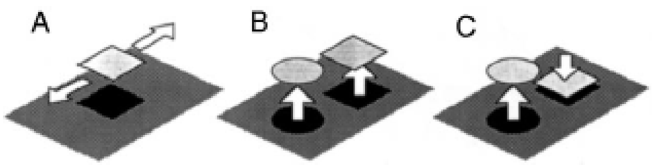

Figure 2.2: Three possible modes of DRDS movement. **(A)** illustrates a horizontal movement, **(B)** illustrates a front-rear synchronous movement and **(C)** illustrates a front-rear counter-phase movement (Source: [9]).

2.1.1.2 Textured Stereograms

This type of stereograms is consisted of two similar stereo images that are placed side by side and are captured by slightly different viewpoints. The scene or the object illustrated in these images will emerge in 3-D when the observer crosses his eyes in front of or behind the images. The 3-D scene actually emerges from a third image that will appear in the middle of the two initial stereo images. In textured stereograms, the texture is (at least visually) connected to what we are about to see in 3-D (i.e. the scene that is observed in the 2-D pair of images will emerge in 3-D) Figure 2.3 illustrates a textured stereogram.

Figure 2.3: Textured stereogram illustrating a church (Source: [1]).

2.1.1.3 Autostereograms

In chapter 1 we roughly defined what an autostereogram is. With this section we aim to give a more concrete definition of autostereograms. The essential difference between autostereograms and stereograms is that autostereograms are stereograms that consist of one single image (Single Image Stereograms or SIS) instead of an image pair. By observing them using either the diverging or the converging eye technique (depending on how they are created) we perceive the objects inside them emerging in 3-D in front or behind the background respectively. Both the diverging and the converging observation techniques will be explained in section 2.1.2. Autostereograms are divided into two major categories. Textured autostereograms (see figure 2.4) and random dot autostereograms (see figure 2.5). Both textured and random dot autostereograms consist of repeated, slightly different to each other, patterns. The texture used in textured autostereograms does not have to be visually connected to what the autostereogram is going to reveal when stereopsis will be acquired like in textured stereograms. Regarding random dot autostereograms, it is evident that the random dots are not visually connected to the embedded object (they would not be random if they were). This applies to the random dot stereograms described in section 2.1.1.1 as well. Another

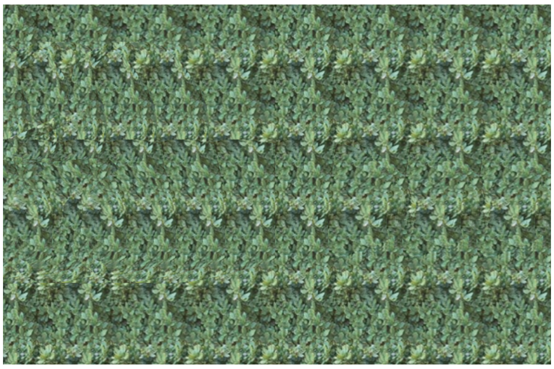

Figure 2.4: Textured autostereogram illustrating a duck.

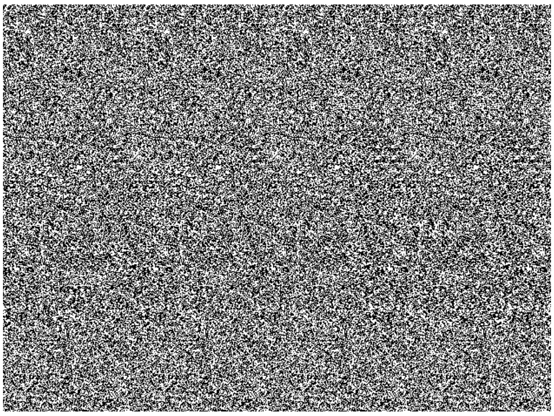

Figure 2.5: Random dot autostereogram illustrating a pyramid.

"property" of autostereograms in general is that they can be viewed without the use of any other equipment (i.e. a stereoscope). In addition, random dot autostereograms can consist of black and white or colourful random dots while textured autostereograms can consist of grey-scale or colourful textures.

Apart from (static) autostereograms there are also autostereogram videos (random dot or textured) which are either composed of sequences of static autostereograms or created by animated depth masks. More on their creation procedure will be explained in chapter 3. Before moving to the next section we need to emphasize that throughout this thesis wherever the term autostereogram video is used it will refer to random dot autostereogram videos unless explicitly stated otherwise.

2.1.1.4 Anaglyph Images

One of the most common types of stereograms is anaglyph images. Anaglyph images are mostly "magenta/cyan" or "red/green" anaglyph stereo images that consist of two similar images (captured from slightly different angles) combined into one. In order for the observer to perceive the scenes inside this images in 3-D, he needs "red/green" or "magenta/cyan" (depending on the colours used in the image) anaglyph glasses. The glasses are used to help the vision system perform binocular fusion. A "red/green" stereo anaglyph image is illustrated in figure 2.6.

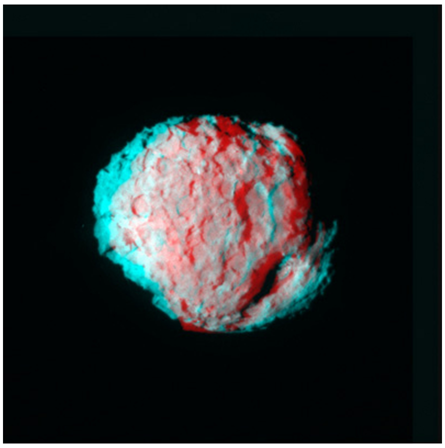

Figure 2.6: Red/green stereo anaglyph of Comet Wild 2 (Source: [2]).

2.1.2 Autostereoscopic Perception and Autostereogram Observation Techniques

So far, we have presented a classification of the various stereogram types but we have not explained how autostereoscopic perception works or how autostereograms are observed in order for stereopsis to be acquired. In this subsection we aim to cover these topics for better understanding of what is going to follow in later chapters.

With respect to autostereoscopic perception, it is considered to be a two step process. The first step relates to the achievement of stereopsis and the second with the maintenance of it. In the literature, this first step is referred to as the binocular fusion or as 3-D search phase [5], [17], [18] during which the observer performs binocular fusion of the appropriate dots (in random dot autostereograms) or points (in textured autostereograms) to acquire stereopsis. The second step is referred to as the 3-D phase

[5], [17], [18] during which the observer maintains or at least attempts to maintain the stereopsis acquired in the previous step.

Regarding the autostereogram observation techniques, according to [10], these are two, and their distinction is based on the level of ocular vergence and the fixation point of the observer's eyes while watching either static autostereograms or autostereogram videos. Specifically, the first technique is called the divergence technique since the eyes of the observer must diverge and fixate at a point behind the projection plane of the autostereogram. In the case of an autostereogram video the projection plane is the screen plane while in the case of a static autostereogram the projection plane is either a screen or a paper on which the autostereogram is drawn. Figure 2.7 illustrates the divergence technique schematically.

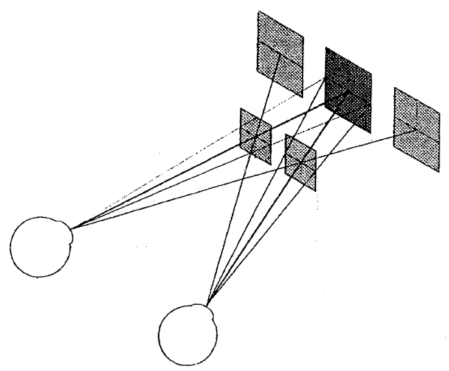

Figure 2.7: Autostereogram divergence observation technique. The autostereogram is represented as two frontal grey squares. Either one of these two squares forms two images on the retinas. The inner two of these images are superposed to create the sense of depth (dark square) in the autostereogram (Source: [10]).

Regarding the second technique (convergence technique), the observer of the autostereogram needs to converge his eyes and to fixate them in front of the projection plane [10]. This technique is considered more difficult to learn and since most beginner observers need to use a thin object like a pen or a pencil to help them fixate in front of the projection plane while this is not needed for the divergence technique [10]. Figure 2.8 illustrates the divergence technique schematically.

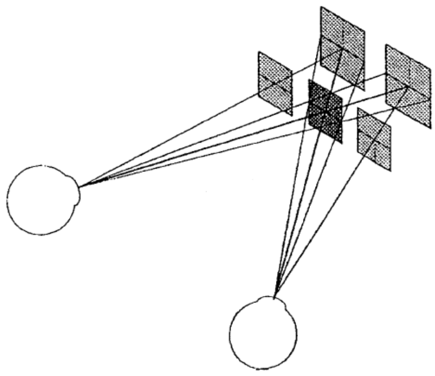

Figure 2.8: Autostereogram convergence observation technique. The autostereogram is represented as two posterior grey squares. Either one of these two squares forms two images on the retinas. The inner two of these images are superposed to create the sense of depth (dark square) in the autostereogram (Source: [10]).

At this point it is worth mentioning that most people prefer the divergence technique as it is easier to learn and consequently most autostereograms are created in order to be viewed with the divergence technique. In case an autostereogram is created to be viewed with the divergence technique and someone uses the convergence technique, stereopsis can be achieved but the object illustrated in the autostereogram will be perceived as inside-out and vice versa.

2.1.3 Platforms used

As part of the project we had to choose the most suitable software platforms in order to create the autostereogram videos. The evaluation procedure was prioritized based on each platform's published capabilities. Moreover it was almost entirely focused on the features that would be important for our research (i.e. ability to add color to the autostereogram videos, change the contrast of the outcome, vary the repetition period of the random dot patterns etc.) and not on the degree of usability. This is not due to the fact that usability is not important (because it is) but due to the fact that we wanted to conduct different experiments that would examine the effect of each feature on the perception of human subjects. Thus, we needed to be able to vary as many features as possible in order to maximize the efficiency of our experiments.

2.1.3.1 Platform for 3-D Object Creation

Regarding the platform for the creation of the 3-D objects, we decided to use 3-D Studio Max[1] without evaluating any other available platforms. Our choice was based on the fact that 3-D Studio Max is one of the most feature rich and commonly used platforms for 3-D modeling, rendering and animation. In addition, the creation of the 3-D objects does not require a software platform with a lot of capabilities since it is a simple task that is available in any 3-D editing software.

2.1.3.2 Platform for 3-D Depth Mask Creation

Regarding the software platform for the generation of depth masks we used 3-D Monster[2]. 3-D Monster was chosen over other platforms suitable for this task such as Easy Stereo[3] and Stereogram Explorer[4] because the feature of generating animated depth masks instead of static ones was not available to the latter two software platforms. Despite the fact that they outweigh 3-D Monster in the sense that they are complete suites for generating autostereogram videos, their lack of the aforementioned feature (animated depth mask generation) binds the user to generate autostereogram videos with these suites which animate the depth masks internally and the user has no control over them. This would normally not be a problem as long as the features available for exploration for the autostereogram video generation would be sufficient for the aims of our project. More on this and on the software platforms for generating autostereogram videos will be described and analysed in the next section. Figure 2.9 shows the environment of the 3-D Monster platform.

[1] http://usa.autodesk.com/ (Accessed on 23/8/2010)
[2] http://www.ixtlan.ru/ (Accessed on 23/8/2010)
[3] http://stereo.victorovich.com/show.php3 (Accessed on 23/8/2010)
[4] http://www.aolej.com/stereo (Accessed on 23/8/2010)

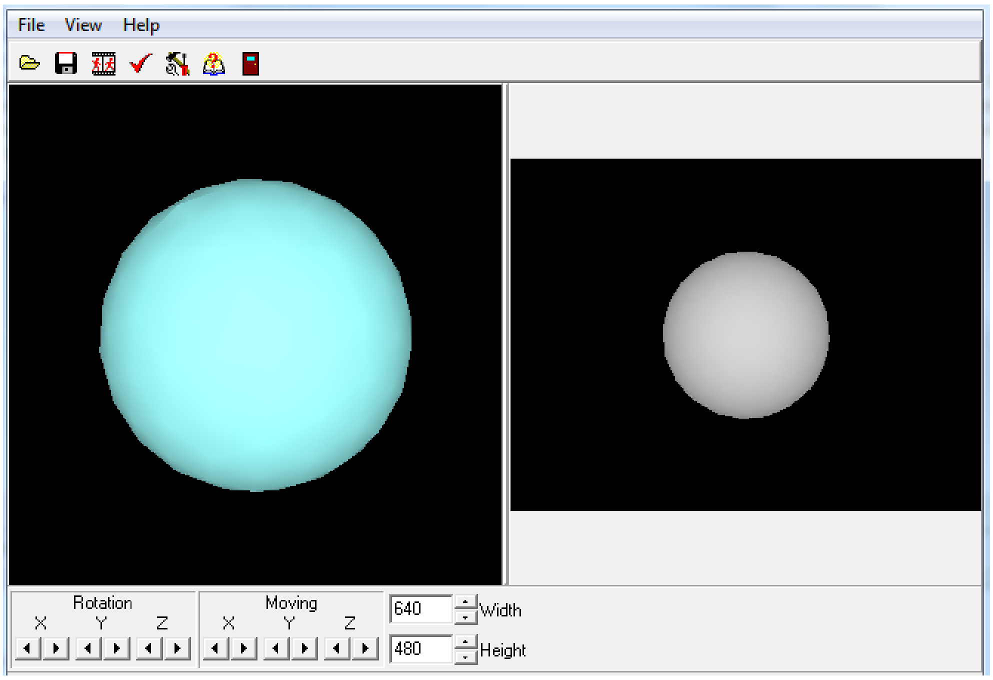

Figure 2.9: The 3-D Monster Environment illustrating a 3-D sphere that is loaded (left panel) and the corresponding depth mask of this sphere (right panel).

2.1.3.3 Platform for Autostereogram Videos Creation and Attributes of Autostereogram Videos

As was mentioned in the previous section both Easy Stereo and Stereogram Explorer were found to be insufficient for autostereogram video creation. On the other hand, 3-D Miracle[5] is a software platform dedicated to static/autostereogram video creation that was more feature rich than both Stereogram Explorer and Easy Stereo. The following table (Table 2.1) provides information about the capabilities of the evaluated platforms and consequently an explanation for the choices made.

[5]http://www.ixtlan.ru/ (Accessed on 23/8/2010)

Features examined	**3-d Miracle**	**Easy Stereo**	**Stereogram Explorer**
Repetition period of pixels	✓	**X**	**X**
% Filling the animation with depth mask	✓	**X**	**X**
3-D depth factor	✓	✓	✓
Oversampling	✓	✓	✓
Blur	✓	**X**	✓
Stereogram observation technique	✓	**X**	✓
Stereogram type	✓	Textured only	✓
Number of dots in image width	✓	Not applicable	**X**
Random dot color and contrast	✓	Not applicable	User can tick the RGB option but has no control over the colours or the contrast that will be used
Texture filling method	✓	**X**	**X**
Colour bitrate	✓	**X**	**X**
Stereogram Resolution	✓	✓	✓
Frame rate	✓	✓	✓
Compression	✓	**X**	**X**

Table 2.1: Software platforms capabilities (for autostereogram videos generation). The tick (✓) symbols denote that a feature is available while **X** symbols denote the absence of a feature. Not applicable denotes that a feature is not present because of other unavailable features that are connected to it (i.e. one cannot choose color for the random dots in the autostereogram if the platform does not support generation or random dot autostereograms.)

At this point it is imperative that we analyse the features shown in table 2.1 to provide the necessary background for the concepts that will appear later in this report. The "repetition period" feature refers to the repetition period of pixels in a random dot or a textured autostereogram. In this way the pixels that synthesize the autostereogram are organized into repeated patches. The repetition period is expressed in pixels and depends on the autostereogram width (i.e. if we want to create an autostereogram of 640 pixels width and define a repetition period of 64 pixels then the outcome would be an autostereogram that is consisted of 10 repeated patches of 64 pixels width each. The "% of filling the animation with depth mask" feature refers to how much space of the autostereogram image/video will the depth mask occupy (e.g. at 50%, the depth mask will be centered and will occupy half of the autostereogram while at 100% it will be centered and occupy the whole autostereogram image/video. The "3-D depth factor" refers to how close to the background or to the screen plane will the depth mask be placed. Values closer to zero place the depth mask closer to the background while values closer to 100 place the depth mask closer to the screen plane. Another feature in autostereogram videos is oversampling. By using oversampling we can correct (smooth) flaws on the object or the scene that is represented in the depth mask and consequently in the autostereogram video. The term flaw here is used for the sliced surface that objects may present as a result of a momentary rendering defect of the software platform or/and low resolution (i.e. 640X480 pixels) of the autostereogram that is to be generated. A value of one for oversampling means that the slightest smoothness for flaws will be used while values closer to 10 apply more smoothing. The "blur" feature, measured in pixels, refers to the radius of uniform blur that will be introduced into the autostereogram video or the static autostereogram. A value of zero pixels for the blur feature does not blur the image at all while a value of 200 pixels introduces a huge amount of blur. The "Stereogram observation technique" refers to the technique under which the autostereogram video will be viewed correctly (not inside-out and vice-versa). As was mentioned and explained in the background section the techniques are two, divergence eye movements and convergence eye movements. The "stereogram type" feature is used to define the type of the autostereogram video that will be created (texture or random dot stereograms). The "number of dots in image width" feature refers to the number of dots the autostereogram will contain in each strip of dots across its width. In addition, the "random dot color(s)" feature refers to the color of the random dots inside the autostereogram video and the contrast between these dots. Moreover, "the rendering algorithm" feature refers to the rendering algorithms that will be used for our videos (from left to right algorithm, from center algorithm and extra correction algorithm). Unfortunately, the program does not provide any documentation on these algorithms anywhere and there is no information that could be found in scientific articles or other sources such as the web. The only information that is provided is that the extra correction algorithm is the most advanced in terms of that it removes hidden surfaces and artificial echoes from the object/scene that will be represented inside the autostereogram (static or video). The choice we made for the rendering algorithm and the rational behind it will be explained in section 3.2. Furthermore, the "texture filling method" feature refers to the texture filling method that will be used in case textures (instead of random dots) are chosen for the video. For our videos, we will be using only random dots. So, for more information on the available filling techniques visit 3-D Miracle's help under the "textures" keyword. Finally, video compression was used in our autostereogram videos for size reduction.

2.2 Related Work

Since the discovery of stereoscopic vision is nearly two centuries old, there is a lot of research regarding the psychophysics of static stereograms and most of their subcategories such as random dot stereograms, texture autostereograms, random dot autostereograms. However, as was mentioned in the motivation section (section 1.1) there has been less research on dynamic random dot stereograms. In addition, there is no work known to us regarding the psychophysics and the space of perceptibility of autostereogram videos.

With respect to studies on static types of stereograms, Julesz and Chang in [12] investigated the effects of inserting dots that have a single binocular disparity value (unambiguous dots) into ambiguous random dot stereograms (stereograms that consist of dots with multiple disparity values) and discovered that this could pull the ambiguous percept. More specifically, they discovered that the closer the disparities are to each other the stronger the pulling effect [12]. Essig et al in [8] studied vergence eye-movements in autostereogram images and the effect of image gain size (granularity) on such movements. They found that human subjects could not achieve stable 3-D perception of autostereogram images with large granularities. In addition to this, they found that regardless of the level of granularity in the autostereogram images, the subjects performed divergence movements slower than convergence movements when they were trying to perceive 3-D objects inside the autostereogram images [8]. Van Ee and Erkelens in [24] used stereograms to study the "temporal aspects of binocular slant perception in the presence and absence of a visual reference" [24]. What they found was that when stereograms were observed for short time periods (less than few seconds) slant was poorly perceived in the case where no visual reference was present [24].

With respect to studies on dynamic random dot stereograms, Skrandies in [20] performed a study to assess depth perception of adults with stereovision deficiency by using dynamic random dot stereograms as stimuli. His study was performed at the neuron activity level where he recorded the neurons' responses to the dynamic stimuli. What he found is differences between the right and the left parafoveal areas of the brain with respect to information processing (i.e. "the processing of horizontally disparate stimuli information is more specific if it is processed in the right visual field than in the left visual field") [20]. Tanabe et al in [22] used dynamic random dot stereograms to test the neural responses in Macaque brain areas that are related to vision. Their experiments showed that stereoscopic depth representation in the V4 visual area is suited for "detecting fine structural features protruding from a background" [22]. Fujikado et al in [9] used dynamic random dot stereograms and coloured static stereograms to assess stereopsis capabilities in strabismic patients. Their study showed that dynamic random dot stereograms were more effective in detecting stereopsis in patients that failed (regarding stereopsis acquisition) in the animal Titmus stereo tests. Moreover, their results did not indicate any differences in the outcome between static coloured stereogram tests and the animal Titmus stereo tests, again regarding stereopsis acquisition and measurement.

Chapter 3

Creating the Autostereogram Videos

The main purpose of this chapter is to document the procedure of creating autostereogram videos that were used as a testing material for the experiments on human subjects. In addition, this chapter accounts for all the decisions made during the various steps of the creation phase until the final outcome (autostereogram videos) could be created. More specifically, this chapter is organized into sections as follows:

- Section 3.1 describes the creation of 3-D objects and the creation of animated depth masks.
- Section 3.2 describes the general procedure of creating autostereogram videos.
- Subsection 3.2.1 describes the creation of videos of different amounts of uniform blur and the rational behind the decisions made. Subsection 3.2.2 describes and analyses the creation of videos of different contrast while subsection 3.2.3 describes the creation of autostereogram videos of different repetition periods in the pixel patches that are used to form an autostereogram video.

Before proceeding to the various sections and sub-sections, for better understanding of what follows, it is important to mention that the creation of autostereogram videos is a three step procedure. First, we create the 3-D objects or scenes that are going to be used in the autostereogram videos (step 1). Then we take/create their animated depth masks (step 2) and finally, we use the depth masks as an input to create the autostereogram videos (step 3).

3.1 Autostereogram Video Creation (Steps 1 and 2)

In order to create the autostereogram videos that we used to conduct experiments on human subjects we applied a three-step process as was mentioned in the description of this chapter. This section describes the first two steps of this process as they were implemented for the purposes of our project. Moreover it gives the reasons about the choices made in the first two steps.

During the first step of the creation process we had to decide what kind of 3-D objects/scenes we should produce for our experiments. We decided to create simple 3-D objects/shapes since the creation of complex 3-D scenes would not add anything more than simple shapes would to our project. Bear in mind that this project is all about perception and one does not need the creation of complex scenes to test for it. On the other hand, one might argue that the creation of complex scenes could affect perception. This may be true but the aim of this project is not to test perception of complex autostereogram videos against perception of simple ones. Furthermore, the complex 3-D scene creation would be too time consuming considering the available time for the project and the low proportion of this task in the project. The simple 3-D objects that we created are: a pyramid, a cube, a pentagon, a tube, and a disk. The reason for choosing five shapes was to have diversity in our test videos and to have more options when determining the sequence in which the videos would be projected to the subjects (see section 4.3). Regarding our decision to create these specific objects, we aimed at simplicity and at creating "equivalent" (in terms of complexity) objects. Table 3.1 illustrates the creation parameters of these objects in 3-D Studio Max.

3-D Object	Position(x,y,z)	Dimensions(l,h,w,d,i-r,o-r,r)
Pyramid	(0,0,0)	(0,20,20,20,N/A,N/A,N/A)
Cube	(0,0,0)	(20,20,20,N/A,N/A,N/A,N/A)
Tube	(0,0,0)	(N/A,30,N/A,N/A,5,10,N/A)
Disk	(0,0,0)	(N/A,5,N/A,N/A,N/A,N/A,10)
Pentagon	(0,0,0)	(N/A,5,N/A,N/A,N/A,N/A,10)

Table 3.1: 3-D object creation parameters. **l** represents length, **h** represents height, **w** represents width, **d** represents depth, **i-r** represents inner radius, **o-r** represents outer radius, **r** represents radius and **N/A** is used to denote not applicable (i.e a cube cannot have a radius). Note also that the dimensions are expressed in the platform's (3-D Studio Max) default grid spacing units.

After creating the 3-D objects we proceeded to the second step (animated depth mask creation). The input for this procedure was the 3-D objects created in step one. Figure 2.9 shows the environment of the 3-D Monster platform.

Specifically, for the creation of the 3-D animated depth masks we loaded one 3-D object at a time. For each object we used the default setting of 3-D Monster. This means that the loaded objects were centered in the left panel shown in figure 2.9 and they were rendered with a resolution of 640X480 pixels. As a result the 3-D depth mask of each object was created (see figure 2.9 right panel). The next step was to animate the depth masks. Each animated depth mask we created for the purposes of our project consisted of ten clockwise rotation cycles around the y axis. The reason for choosing the same number or rotation cycles and the same rotation direction and axis was simply for the subjects not to able to infer the object illustrated in the autostereogram video later during the experiments. For instance, if one of the objects was rotating by the x axis and/or faster than the others the subject would be able to tell the difference just by observing the direction and the speed of the moving pixels even if he/she would not be able to perceive the object. Furthermore all the depth masks created consist of 2000 frames each and a frame rate of 50 fps. The frame rate at this point is of no significance since we can change it at the third step of the autostereogram video creation procedure which is described in detail in the next section. The important parameter is the number of frames per second since it defines the maximum duration of an autostereogram video in seconds. Initially, we created animated depth masks of 10000 frames with the aiming of creating autostereogram videos of high frame rates ($>$100 fps) and test the subjects' performance with these stereograms. In the end we abandoned this idea because our means of displaying the autostereogram videos could not achieve such high frame rates (more on the equipment used will be explained on the next section). So two thousand frames would produce autostereogram videos of considerable duration no matter what the frame rate would be as long as it would be below 100 fps. Regarding the export mode used, we decided to use the avi file so that we will not have to have 2000 bitmap images for each depth mask (one for each one of the 2000 frames). In addition, we used no compression so that the quality would me the highest possible. On the other hand, this resulted in creating depth masks of 600 MB each. Nevertheless, since we needed only five of them (one for each 3-D object), this was not a problem. Finally, regarding the scaling mode we scaled the animated depth mask by the x and z axes. In this way the optimal choice was made because the maximum depth is defined by the line that connects the x and z axes and encloses the object that is used (for each object the length of this line is different depending on the object's dimensions). You can see snapshots of the animated depth masks in figure 3.1.

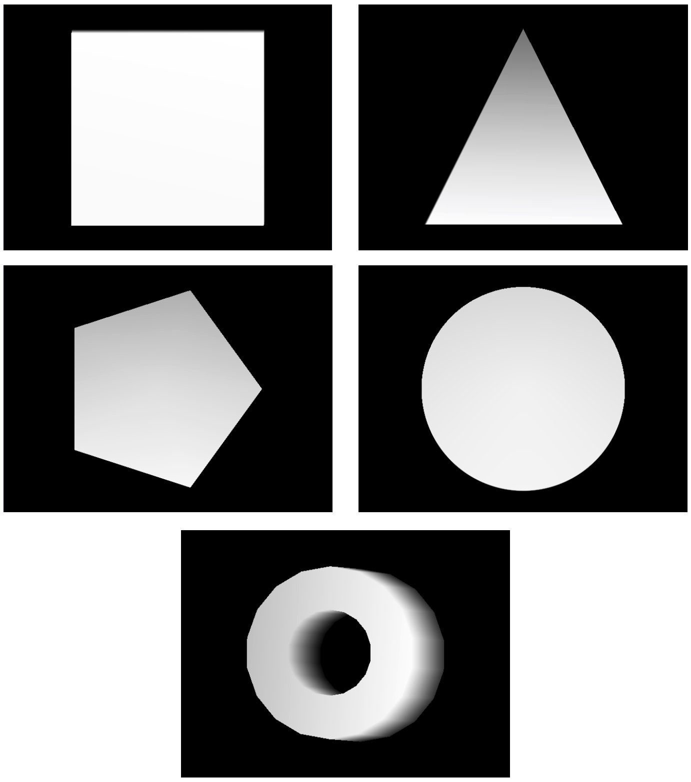

Figure 3.1: Snapshots of the animated depth masks. Upper left is the cube, upper right is the pyramid, middle left is the pentagon, middle right is the disk and on the bottom you can see the tube.

> **Important note 1:** *Note that one disadvantage of 3-D Monster is that it does not provide pixel rulers or any other means for determining where exactly the object is located inside the 3-D image or the 3-D depth mask. As a result we generated two depth masks of the same object. The second differed in position from the first by one click along the x axis. Then we used Gimp to measure the difference. We found that each click moves the object by three pixels.*

3.2 Autostereogram Video Creation (Step 3)

This section describes and analyses the third step of the three-step process of creating an autostereogram video as it was implemented for the purposes of our project. Moreover it reasons about the choices made.

Despite the plethora of features in the platforms used, we only varied a part of them to create the autostereogram videos for our experiments while keeping the others fixed.

This is due to the fact that it was impossible to test human subjects for all the features considering the available time for this project. The fact that even though we finally tested for three features (contrast, repetition period of pixels in the autostereogram videos, and blur) each experiment (including all three sub-experiments for the three features) lasted 55 to 65 minutes. In addition, before determining for which features we should test perception in order to make the most out of our research we created more than 1800 videos by varying all the available features throughout the range of each one. What we found is that the highest impact on perception was achieved by varying the three features mentioned above. This decision was made jointly by the author of this report and the supervisor of the project by examining sample videos of all the available features. Last but not least, there is no previous work known to us that involves investigation of autostereogram videos. As a result the chosen features and consequently the experiments (they will be described in the next chapter) were designed so that we could set the basis for further investigation. The three following sections (sections 3.2.1, 3.2.2, 3.2.3) describe the procedure of creating the different categories of videos that we used in our experiments and give the reasons for the parameter values we used.

3.2.1 Creating and Selecting Videos of Different Blur

Since the available blur radius feature in 3-D Miracle ranges from zero to two hundred (0-200) pixels we initially created autostereogram videos of a five-pixel incremental step each, up to 45 pixels blur radius for every one of the five animated masks. For blur radii greater than 45 pixels we used a step of 30 pixels up to 200 pixels blur radius in order to determine the range we should use in our autostereogram video creation. Again this was done for all the animated masks. We found that at 36 pixels blur radius we were not able to perceive the object inside the autostereogram no matter what the object was. As a result we decided to create autostereogram videos with a three-pixel blur radius incremental step each so that we could be able to conduct experiments with higher precision. Furthermore, at zero and at three pixels blur radius the objects inside the autostereograms were very easy to perceive so we decided to exclude these autostereogram videos from our experiments as well. Towards making these decisions, also helped the fact that we ran a trial experiment with Subject A (see appendix C for his performance) in which he was not able to perceive the objects (pyramid,tube) at 36 pixels blur radius while he was able to perceive all objects in the autostereograms with smaller radii of blur. The reference to the experiment with subject A at this point is just for the purpose of justifying our decisions for the range of blur values chosen for our experiments. The experiments, the experimental procedure as well as the results will be described and analysed in later chapters.

The result of the above procedure of creation and selection was to keep 55 videos of 40 seconds each (11 videos for each of the 5 animated depth masks) for a range of 6 to 36 pixels blur radius with an incremental step of 3 pixels each. A sample video of nine-pixel blur radius that illustrates a pyramid can be found in the personal website[1] of the University of Edinburgh professor, Robert Fisher, while snapshots of autostereogram videos of different blur radii can be seen in figure 3.2.

[1] http://homepages.inf.ed.ac.uk/rbf/SIRDVIDEOS/

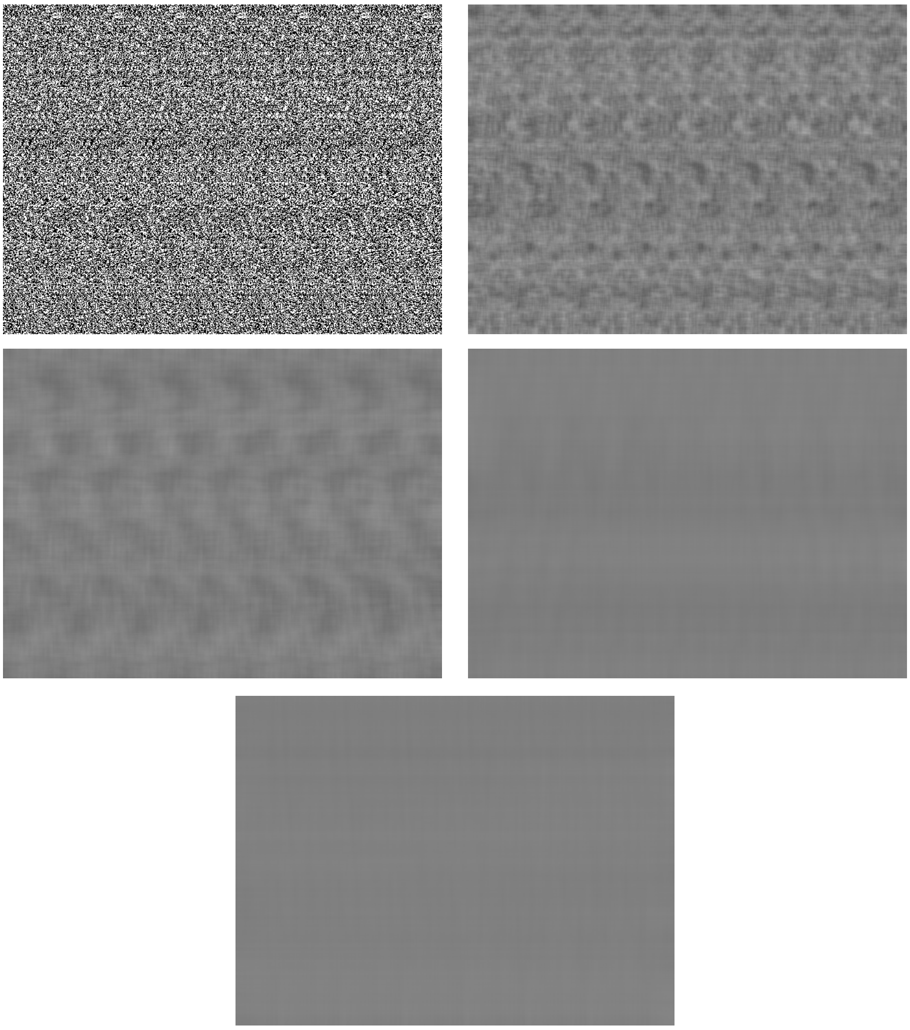

Figure 3.2: Snapshots of sample autostereogram videos of different blur. Upper left snapshot illustrates a pyramid without blur (video excluded from the experiments), upper right snapshot illustrates a pentagon of six pixels blur radius (video included in the experiments), middle left snapshot illustrates a pyramid of fifteen pixels blur radius (video included in the experiments), middle right snapshot illustrates a pentagon of thirty six pixels blur radius (included in the experiments) and the bottom snapshot "illustrates" a tube of forty pixels blur radius (excluded from the experiments). Again perception of these snapshots is affected by their size inside this document.

Table 3.2 illustrates the fixed generation parameters of these autostereogram videos for the five depth masks.

Fixed Parameter	Value
Repetition period of pixels	90 pixels
% Filling the animation with depth mask	100
3-D depth factor	90
Oversampling	1
Stereogram observation technique	divergence
Stereogram type	random-dot
Number of dots in image width	640
Random dots color	Black:(R,G,B)=(0,0,0) (Hue,Sat,Lum)=(160,0,0) White:(R,G,B)=(255,255,255) (Hue,Sat,Lum)=(160,0,240)
Contrast	1
Texture filling method	Not applicable
Color bitrate	24
Stereogram Resolution	640X480 pixels
Frame rate	50 fps
Compression	Cinepak by Radius

Table 3.2: Fixed features and their values (autostereograms of different blur). Not applicable denotes that a feature takes no value because of other unavailable features that are connected to it (i.e. we cannot choose a texture filling method since we do not use textured stereograms). (R,G,B) refers to (Red,Green,Blue) while (Hue,Sat,Lum) refers to (Hue,Saturation,Luminance).

The values shown in the above table were determined experimentally with the aim of finding parameters that give good quality videos. What needs more discussion at this point is why we used compression, how we measured contrast, how we determined the value for oversampling and why we chose the extra correction rendering algorithm.

With respect to the rendering algorithm used, it is worth mentioning that experiments on creating autostereogram videos with all three algorithms (the algorithms are mentioned in section 2.1.3.3) made no difference to the final outcome. The only explanation for this (if one accepts that the documentation of 3-D Miracle does not contain mistakes) might be the fact that in the experiments for determining the differences between the algorithms, basic simple objects (pentagons, pyramids, tubes, cubes, disks) without hidden surfaces or echoes were used.

Regarding oversampling, despite the fact that it is a very useful feature it has two drawbacks. The first is that it slows the rendering procedure significantly (the higher the value of oversampling the slower the rendering). The second drawback is that it affects the generated autostereogram in terms of color changes that introduces to the autostereogram in such a way that the observer can infer what object is hidden inside. The following figure (figure 3.3) illustrates this effect.

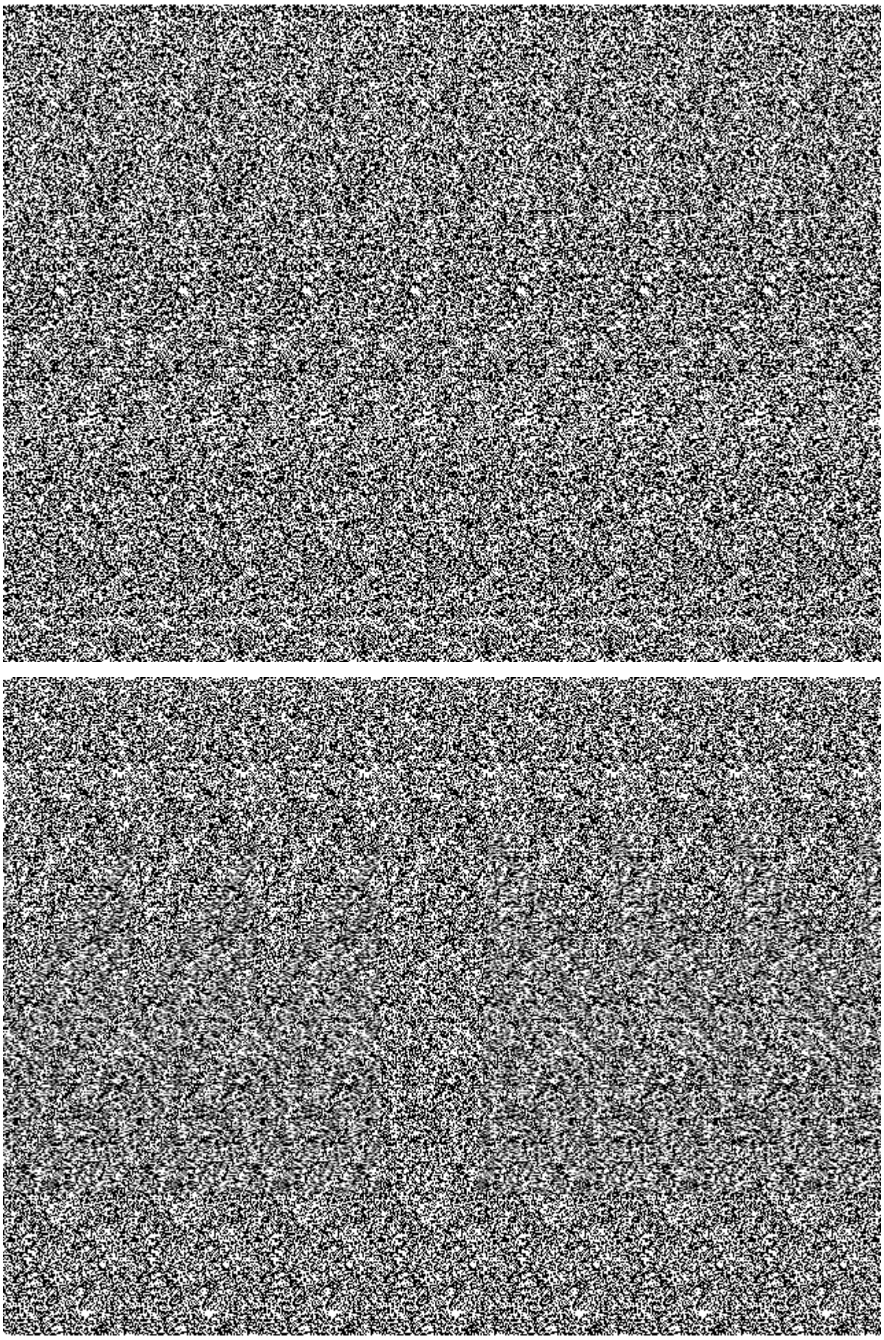

Figure 3.3: Autostereogram demonstrating a pyramid created with oversampling value of 1 (top), same autostereogram created with oversampling value of 7 (bottom). It is obvious that in the bottom image the viewer can infer that the autostereogram illustrates a triangle or a pyramid without having (the viewer) necessarily acquired 3-D perception of the object. Perception of the above snapshots is affected by their size inside this document.

In relation to compression, we used the Cinepak codec developed by Radius Inc with compression quality at 100%. Compression was necessary because without it each video's size was 1.8 GB (too big for a 40-second video). As a result every media player we tested (Vlc media player, Microsoft media player, Winamp media player, KM media player, Bs player) was inefficient at playing the videos without suspending them several times during their execution in order to complete buffering. With compression this problem was solved since each video's size was reduced to 155 MB. Regarding how we measured contrast, this will be explained in the next subsection of this chapter.

Before moving to the next subsection it is imperative to mention that apart from the videos of different blur radius that contained one of the five objects (disk, cube, pentagon, tube, pyramid) we also created a near blank video of 12 pixels blur radius. The near blank refers to the fact that we used as input to 3-D Miracle a depth mask of one pixel radius sphere. The value of the 3-D depth factor feature was one (really close to the background). The values of the rest of the features were kept the same as the ones shown in table 3.2. This video was created in order to use it in our experiments with videos of different radii of blur as a truth test video because it would be impossible for a subject to perceive anything in it. Consequently we would be able to understand that a subject would generally lie about what he/she observes if he/she would be able to perceive an object in this specific video.

3.2.2 Creating and Selecting Videos of Different Contrast

In order to create videos of different contrast we first needed to decide how to measure it since there are many ways.One of them is color contrast which is measured in terms of differences in color chromaticity of the colors involved. Another is concurrent contrast that measures contrast between areas of different chromaticity or luminance within some stimulus (image or video) that the observer watches concurrently. Among the different approaches to measuring contrast also lies luminance contrast. Luminance contrast is defined as the ratio of two components [3]. The first is the difference between the luminances that are examined (e.g. the background luminance of an image and the luminance of the foreground) and the second is a "measure of the luminance adaptation of the human eyes" [3]. The general form of the luminance contrast ratio is shown in formula 3.1 [3].

$$C_R = \frac{luminance\ change}{luminance\ eye\ adaptation} \quad (3.1)$$

For the creation of our videos, we used a variation of luminance contrast that is called Michelson contrast [3]. Michelson contrast is suitable in our case because autostereogram videos comprise of periodic patterns and "there is no large area of uniform luminance inside them that dominates the viewer's brightness adaptation" [3]. Michelson contrast is calculated by formula 3.2 [3].

$$C_M = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \quad (3.2)$$

where, L_{max} is the maximum luminance (in our case the luminance of white dots), L_{min} is the minimum luminance (in our case the luminance of black dots).
Initially in order to examine the range of Michelson contrast that would be appropriate for our experiments we created videos of incremental contrast of 0.1 starting from 0.01 Michelson contrast and reaching one for every one of the five animated depth masks. This resulted in the creation of 50 videos for contrast. Based on our observations and on a trial experiment performed on subject A (see appendix C) with these videos we found lack of perception for videos of 0.01 Michelson contrast and easy perception for the rest of the videos involving different Michelson contrast amounts. These findings pointed that we needed to change the step of Michelson contrast used for the videos creation in order to gain more accuracy on where the transition between perception and no perception occurs and what are its characteristics. The new Michelson contrast step we decided to use was 0.01 for videos up to 0.1 contrast starting from 0.01 again. Moreover we created videos of 0.12, 0.15 and 0.2 Michelson contrast. For videos of Michelson contrast greater than 0.2 we used a step of 0.1 until we reached 0.6 Michelson contrast which was our upper threshold for our creation process. There was no point in creating videos of greater contrast because as Michelson contrast increases, the object inside an autostereogram video becomes easier to perceive. Using this procedure we created seventeen videos for each one of the five depth masks. In total we created 85 videos for all the available depth masks. The rest of the parameters were kept fixed at the same values as in the subsection for videos of different blur (see table 3.2) for perception optimality reasons. Only this time we kept blur fixed at zero pixels and we varied Michelson contrast. A sample video of 0.2 Michelson contrast that

illustrates a tube can be found in the personal website[2] of the University of Edinburgh professor Robert Fisher. Snapshots of sample videos of different Michelson contrasts can be seen in figure 3.4.

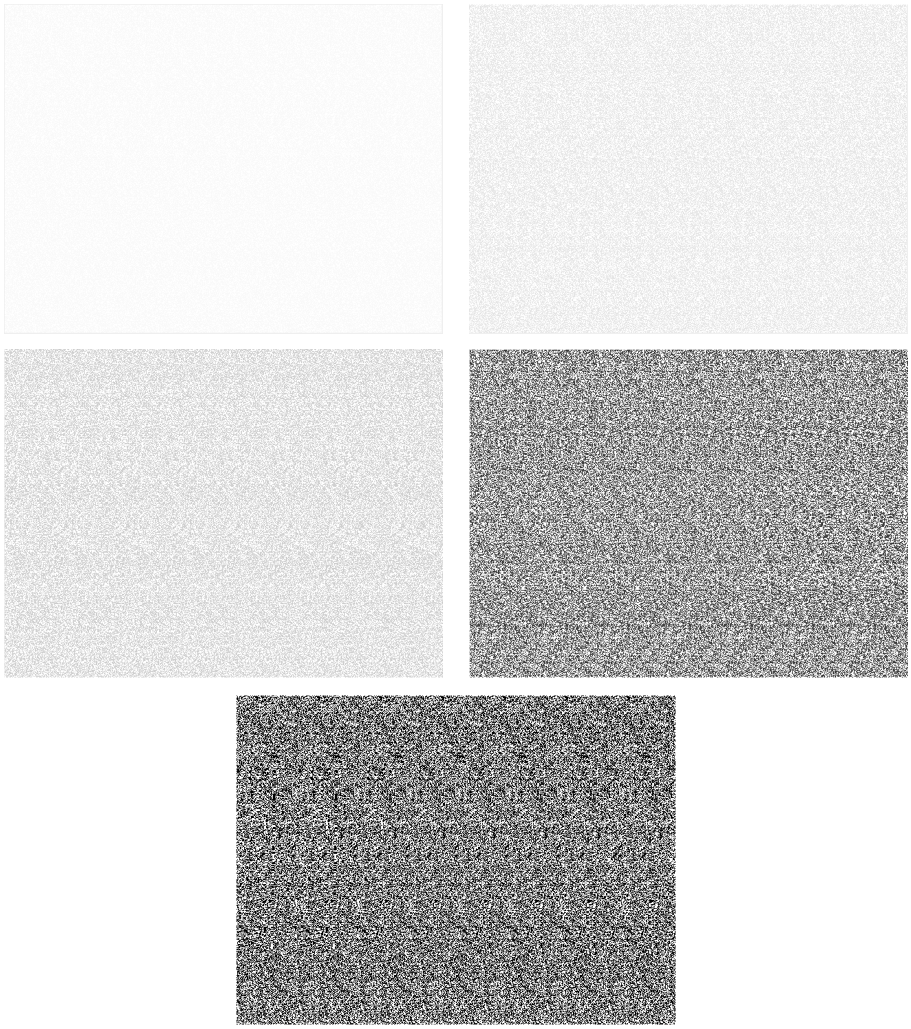

Figure 3.4: Snapshots of sample autostereogram videos of different Michelson contrast. Upper left snapshot "illustrates" a pyramid of 0.01 Michelson contrast (video included in the experiments), upper right snapshot illustrates a pentagon of 0.05 Michelson contrast (video included in the experiments), middle left snapshot illustrates a disk of 0.1 Michelson contrast (video included in the experiments), middle right snapshot illustrates a tube of 0.6 Michelson contrast (included in the experiments) and the bottom snapshot illustrates a cube of 1 Michelson contrast (excluded from the experiments). Again perception of these snapshots is affected by their size inside this document.

Table 3.3 illustrates the values for the random dot colors and illumination parameters for different amounts of Michelson contrast used for the generation of the final

[2]http://homepages.inf.ed.ac.uk/rbf/SIRDVIDEOS/

autostereogram videos.

Amount of Michelson Contrast	**Black Color** (R,G,B) (Hue,Sat,Lum)	**White Color** (R,G,B) (Hue,Sat,Lum)
0.01	(249,249,249) (160,0,235)	(255,255,255) (160,0,240)
0.02	(244,244,244) (160,0,230)	(255,255,255) (160,0,240)
0.03	(240,240,240) (160,0,226)	(255,255,255) (160,0,240)
0.04	(235,235,235) (160,0,221)	(255,255,255) (160,0,240)
0.05	(230,230,230) (160,0,217)	(255,255,255) (160,0,240)
0.06	(226,226,226) (160,0,213)	(255,255,255) (160,0,240)
0.07	(222,222,222) (160,0,209)	(255,255,255) (160,0,240)
0.08	(216,216,216) (160,0,203)	(255,255,255) (160,0,240)
0.09	(212,212,212) (160,0,200)	(255,255,255) (160,0,240)
0.1	(208,208,208) (160,0,196)	(255,255,255) (160,0,240)
0.12	(200,200,200) (160,0,189)	(255,255,255) (160,0,240)
0.15	(188,188,188) (160,0,177)	(255,255,255) (160,0,240)
0.2	(170,170,170) (160,0,160)	(255,255,255) (160,0,240)
0.3	(137,137,137) (160,0,129)	(255,255,255) (160,0,240)
0.4	(109,109,109) (160,0,103)	(255,255,255) (160,0,240)
0.5	(85,85,85) (160,0,80)	(255,255,255) (160,0,240)
0.6	(63,63,63) (160,0,60)	(255,255,255) (160,0,240)

Table 3.3: Values for the random dot color and illumination parameters for different amounts of Michelson contrast. (R,G,B) refers to (Red,Green,Blue) while (Hue,Sat,Lum) refers to (Hue,Saturation,Luminance).

Like in the previous section, we created a near blank video but this time we used a Michelson contrast of 0.2, a 3-D depth factor of one and zero pixels of blur radius. The values of the rest of the features were kept the same as the ones shown in table 3.2. This video was also used as a truth test in the experiments that involved videos of different Michelson contrast.

3.2.3 Creating and Selecting Videos of Different Repetition Period

The procedure of creating and selecting autostereogram videos of different repetition period is similar to the procedure followed in the previous two sections. In order to choose the most appropriate videos for our experiments we first created a series of different videos of a ten-pixel increasing repetition period rate starting at 10 pixels and reaching 160. Based on our observations and on the trial experiment conducted on subject A (see appendix C) we found that for a low repetition period (10 pixels) the perception of the objects inside the autostereograms was difficult to be achieved (subject A needed more time to perceive them than it needed for autostereograms of higher repetition periods). Consequently we decided to create more videos (smaller step) for repetition periods lower than 20 pixels to determine with higher accuracy where perception changes significantly. More specifically, we created one video with a repetition period of 10 pixels, one with a repetition period of 12 pixels, one of 16 pixels, one of 20 pixels and for repetition periods greater than 20 pixels we used the same step as during the initial creation procedure (10 pixels) until we reached 160 pixels of repetition period (this is the maximum repetition period that can be achieved using 3-D Miracle with 640X480 pixels autostereogram videos). In total we created 90 videos, 18 for every one of the five depth masks. The only thing that differs from table 3.2 is that we kept blur fixed at zero pixels and we varied repetition period of pixels in the autostereogram videos. A sample video of 90 pixels repetition period that illustrates a pyramid can be found in the personal website[3] of the University of Edinburgh professor, Robert Fisher, while snapshots of sample videos of different repetition periods can be seen in figure 3.5.

[3]http://homepages.inf.ed.ac.uk/rbf/SIRDVIDEOS/

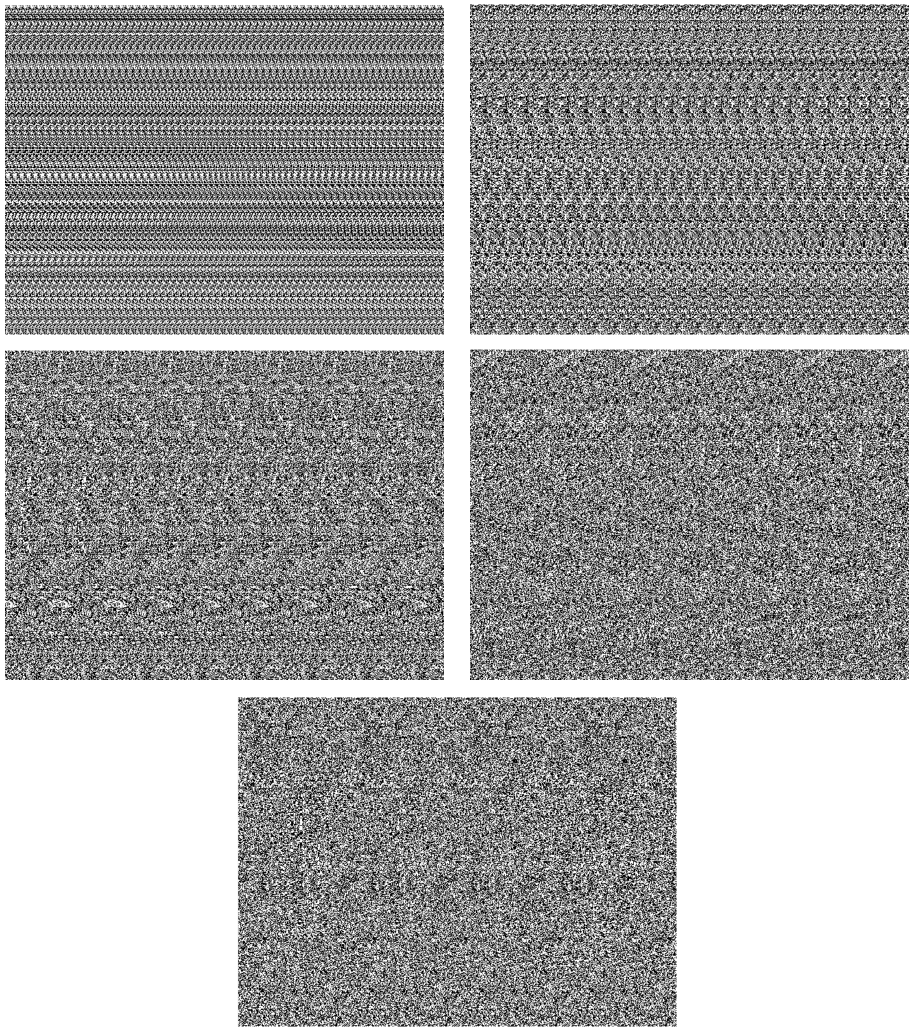

Figure 3.5: Snapshots of sample autostereogram videos of different repetition periods. Upper left snapshot illustrates a pyramid of a 10-pixels repetition period, upper right snapshot illustrates a cube of a 30-pixel repetition period, middle left snapshot illustrates a disk of a 80-pixel repetition period, middle right snapshot illustrates a pentagon of a 120-pixel repetition period and the bottom snapshot illustrates a tube of a 160-pixel repetition period. You can see that for repetition periods of 10 and 30 pixels the objects appear with lots of slices because the repetition period is low. Again perception of these snapshots is affected by their size inside this document.

Furthermore, we created a near blank video as in the two previous sections but this time of 90 pixels repetition period, a 3-D depth factor of one and a blur radius of zero pixels. The values of the rest of the features were kept the same as the ones shown in table 3.2. This video was also used as a truth test in the experiments that involved videos of different repetition periods.

Chapter 4

Gathering and Analysing Human Performance Data

This chapter mainly focuses on the procedure of selecting human subjects for our experiments (section 4.1) and the general experimental procedure followed (section 4.2) in all our experiments. Furthermore the stimuli used for each sub-experiment and the rationale behind our decisions regarding the sequence in which videos were projected to each subject can be found in section 4.3.

4.1 Human Subjects

With respect to the task of finding human subjects that would take part in our experiments we used student mailing lists of the University of Edinburgh. In the e-mail sent to the students we gave a short explanation of the aims and objectives of our project as they were set in chapter one of this thesis. We also informed the candidate subjects about the approximate duration of the experiments (one hour) and about the reward of eight pounds for the time they would spent watching the autostereogram videos. The funding for the experiments was provided by the Institute of Perception and Behavior (IPAB[1]) and the Informatics Teaching Organisation (ITO[2]) of the University of Edinburgh. The key point in the "advertising" e-mail was that the students were explicitly asked to reply to the e-mail only if they could achieve 3-D perception with autostereograms and in movies such as Avatar. For the purpose of testing themselves on achieving 3-D perception with autostereograms, we provided links to both static au-

[1]http://wcms.inf.ed.ac.uk/ipab/ (Accessed on 23/8/2010)
[2]http://www.inf.ed.ac.uk/admin/ITO/ (Accessed on 23/8/2010)

tostereograms[3] and autostereogram videos[4]. The purpose of the aforementioned key point in the e-mail was to discourage people for coming just for the eight pound reward and people that are stereoscopically blind. According to existing researches [19] five percent of the population are stereoscopically blind. The "advertisement" e-mail can be found in appendix A.

In total twenty eight (28) candidate subjects appeared in order to take part in the experiments. First, before the general experimental procedure, the candidate subjects were given a form with instructions and information about the nature of the experiment. This form was also used as a consent form since the candidate subjects had to sign it to prove that they agreed with the experimental procedure and they understood what the experiment was about. Only the candidate subjects that signed the form were allowed to take part in the experiment. Fortunately, every candidate subject agreed to participate by signing the form. The instructions/consent form can be seen in appendix B.

In addition, before the experimental procedure, subjects were presented with two static autostereograms illustrating a pyramid and a disk respectively for two minutes. This was done in order to practice their perception of depth information [8] and so that we could test whether they actually could perceive autostereograms or not. The candidate subjects that failed to recognize the objects inside the static autostereograms were also presented with an autostereogram video illustrating a cube so that we could make sure that they were not able to perceive autostereograms. Two of the candidate subjects failed the test with the static stereograms and as expected they also failed the test with the autostereogram video. These two subjects were allowed to take part in the experiments for a short period of time so that they would not get offended or would not have to confront the fact that they might be stereo blind. Their performance in the experiments though, was not used for analysis along with the other subjects' performance. As a result we ended up with 26 subjects. Their performance can be seen in appendix C.

4.2 General Experimental Procedure

In projects that involve extensive experiments it is very important for the outcome to be affected as little as possible from external factors which are difficult or impossible

[3] http://www.eyetricks.com/3dstereo33.htm (Accessed on 23/8/2010)

[4] http://www.youtube.com/watch?v=ArWY-Ck-CPc (Accessed on 23/8/2010)

to control and calculate (e.g. ambient lighting in our case). Furthermore, in order for the experiments to be reproducible in the future under the same conditions and using equivalent capabilities equipment and the outcomes to be comparable, it is imperative that everything that is involved in the experiments be documented and explained in detail.

Regarding the actual experimental procedure, after having the subjects practicing their perception of depth information and consequently testing their ability to perceive autostereograms the actual experimental procedure began for each subject. The stimuli for our experiments were the autostereogram videos of the different categories that were described in chapter 3. The experiment on each subject can be divided into three sub-experiments. One in which videos of different amounts (radii) of blur were used as stimuli, another in which videos of different contrasts were used and one last one in which videos of different repetition periods were projected to the subjects. These three sub-experiments were conducted in the sequence presented above and each one lasted approximately 20 minutes without intermissions in-between. For each selected value within the range (see chapter 3) of each of the three features tested (blur, contrast, repetition period) two videos of different objects where projected to each subject until the whole range was covered (e.g. for 0.01 Michelson contrast two videos were projected to each subject, one illustrating a disk and one illustrating a pentagon). The sequence of the videos with which each subject was presented was fixed but unsystematic. The sequence can be found in section 4.3 of this chapter. At this point it is only necessary to mention that this sequence was identical for each subject. More on the sequence will be explained in section 4.3. Another thing that is worth mentioning at this point is that the first approach to the experimental procedure that we thought would be appropriate was to conduct the three different sub-experiments in three different sessions for each subject to avoid having less people volunteering due to the duration of the experiments being high. This approach was finally abandoned because it would be more tiresome for the subjects to come to the lab where the experiments would be conducted three times instead of one in order to complete the experiment.

With respect to the equipment used for the projection of autostereogram videos, we used a laptop with an Nvidia 9600GT graphics card under the default settings. The settings of the graphics card can be seen in table 4.1

Attribute	Value
Brightness	50%
Contrast	50%
Hue	0%
Saturation	0%
Gamma (red)	1.00
Gamma (green)	1.00
Gamma (blue)	1.00
Color range	0-255
Edge enhancement	0%
Noise reduction	0%

Table 4.1: Graphics card settings that were used for the experiments.

The screen used for projecting the autostereogram videos was a 18-inch, 1800FP (model number) LCD Dell monitor. The settings used for the screen were the factory defaults. For information on the default settings have a look in Dell's documentation for the screen which you can find in [6]. The media player used for the videos was Vlc[5]. The videos were projected in full screen and before each video each subject was presented with an eight-second video of random black and white dot noise created in Matlab with 640X480 resolution and a two-second "get ready" message with a white font on a black background. The reasons for these projections before each autostereogram video was to help the subjects to lose focus from the previous autostereogram projection and prepare them for the next one respectively. Figure 4.1 shows a snapshot from each of these projections.

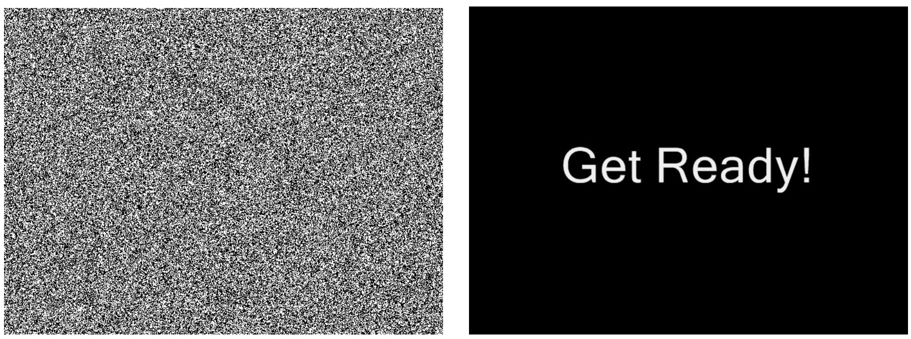

Figure 4.1: Snapshots of the random black and white dot noise video (left) and the get ready video (right).

[5]http://www.videolan.org/vlc/ (Accessed on 23/8/2010)

For each experiment each time, we recorded information about the subject and information about the perception of the autostereograms. With respect to each subject the information recorded was: age, gender, nationality, handedness, if the subject was wearing glasses or contact lenses, if he/she had any other known eye problems and the experience in watching autostereograms. Experience was defined in terms of how many times has the subject watched autostereograms (both static and videos) in the past. Subjects that had seen less than 60 autostereograms were classified as inexperienced and subjects that had seen more than 60 were classified as experienced. Regarding each autostereogram video the information recorded was: the object perceived by the subject, time to achieve perception and whether the perception was stable or not in terms of whether the subject lost perception of the object for some time (unstable) or not (stable). The time to achieve perception was measured by an electronic stopwatch which the subject stopped each time he/she perceived the object by clicking on the stop button. The electronic stopwatch was on the right of each subject in a different screen from the one the videos were projected and was controlled through mouse clicks from the subject. Note that the subject did not need to look at the stopwatch in order to stop it since the buttons of the stopwatch were big enough (in this way clicks outside the button area where avoided). Each time the subject stopped the stopwatch we stopped the projection of the video to record time and what he/she saw. The perception achieved was divided into three categories: "no perception" when the object had no perception of any kind of the five objects that were used for the experiments (cube, disk, pentagon, tube, pyramid), "something moving" when the subject stated that could see a 3-D object but could not resolve what the object was and "object name" when the subject was able to identify what the object was (i.e disk, cube etc.). To clarify things more, a subject was considered to be able to identify an object under a specific setting for one of the three features (blur, contrast, repetition period) if he was able to identify the object in one of the two videos of the same setting projected to him. Finally, the aforementioned information was recorded in a spreadsheet. Before proceeding to the next video the subject needed to look to the side screen and clear the stopwatch measurement by clicking the clear button. This was an additional way (the other was the random noise projection described above) for the subject to lose focus after 3-D perception was achieved and then look back to the screen in which videos where projected.

In order for the experiments to be consistent we tried to have a controlled and fixed environment and experimental setting respectively (at least as controlled and fixed as possible). The experiments were conducted in a dim room with the only light sources to be the projection screen and the screen we used for the electronic stopwatch. The distance of the projection screen from the observer was fixed at 44 cm. The distance was kept fixed by a chin support object that we constructed with Lego parts and a soft surface on top. Figure 4.2 illustrates a capture of the front view of the experimental setting while figure 4.3 illustrates a capture of the side view of the same setting.

Figure 4.2: Front view of the experimental setting. The Lego chin support object with soft surface on top can be seen in front of the projection screen.

Figure 4.3: Side view of the experimental setting. Apart from the chin support object and the projection screen you can see the screen which served as an electronic stopwatch on the right.

The height of the chin support object was 36 cm and its width 6.4 cm. The projection screen formed an angle of 90 degrees with the plane on which it was placed and the observer's eyes formed an angle of 38 degrees with a hypothetical plane that is perpendicular to the projection screen in the center of the screen.

4.3 Stimuli

The stimuli for each one of the sub-experiments were different in terms of the feature that we varied each time while keeping the rest fixed. The videos that we decided to use in our sub-experiments can be found in the corresponding subsections of chapter 3 (subsections 3.2.1, 3.2.2, 3.2.3). As was briefly mentioned in section 4.2 for each selected value within the range of the feature tested each time we used two videos of different objects and before each one of these videos was projected to the subject, a random black and white dot and a get ready video was used for the reasons explained in section 4.2.

The videos projected to each subject were projected in such a way that two consequent autostereogram videos were not of the same object. Moreover the sequence of the projections was pseudo-random. This means that the videos did not follow any ascending or descending pattern with respect to the value of the feature tested or the object projected each time but their sequence was the same for each subject. The reason for pseudo-randomness in both the sequence of the projected objects and the sequence of the selected values of the feature that was tested each time was to prevent subjects from recognising a pattern in the sequence of autostereogram projections and thus successfully predicting the object inside the autostereogram even without being able to perceive it. In addition, the reason for projecting the videos in the same sequence to each subject was to have consistent experiments and to avoid variations in the performance that might appear due to different conditions each time (e.g. projecting a video of 0.01 Michelson contrast prior to two videos of 0.5 Michelson contrast might have different effects than projecting it afterwards). As a result, the eye luminance adaptation [4] and the stimulus adaptation of ocular vergence [7] would be affected in a different way leading to inconsistencies between experiments conducted on different subjects.

On the grounds mentioned above we created three different play-lists of autostereogram videos (stimuli) one for each sub-experiment. Table 4.2 depicts the sequence in which videos of different blur radii were projected to subjects, table 4.3 depicts the sequence of videos of different contrast while table 4.4 depicts the sequence of videos of different repetition periods. Bear in mind that we also created near blank videos (subsections 3.2.2, 3.2.1, 3.2.3) which we used in the playlists for each sub-experiment for the reasons explained in the aforementioned sections.

Position in Playlist	Blur Radius Value (in pixels)	Projected Object
1	6	cube
2	9	tube
3	6	pentagon
4	9	pyramid
5	12	disk
6	15	cube
7	12	tube
8	18	disk
9	15	pentagon
10	18	cube
11	36	pyramid
12	21	tube
13	24	disk
14	21	cube
15	**12**	**blank**
16	30	pentagon
17	33	cube
18	33	disk
19	27	tube
20	24	pyramid
21	27	cube
22	30	disk
23	36	tube

Table 4.2: Projection sequence of autostereogram videos of different blur radius. The fifteenth video is a near blank "truth test" video (see section 3.2.1).

Position in Playlist	**Michelson Contrast Value**	**Projected Object**
1	0.01	disk
2	0.01	pentagon
3	0.02	pyramid
4	0.02	tube
5	0.15	pentagon
6	0.07	pyramid
7	0.05	pentagon
8	0.6	disk
9	0.05	pyramid
10	0.1	cube
11	0.1	disk
12	0.08	tube
13	0.04	pyramid
14	0.2	cube
15	0.07	tube
16	0.2	pyramid
17	0.3	pentagon
18	0.12	pyramid
19	0.4	disk
20	0.3	pyramid
21	0.4	pentagon
22	0.03	disk
23	0.15	cube
24	0.5	tube
25	0.03	cube
26	0.06	disk
27	0.09	cube
28	0.04	pentagon
29	0.08	disk
30	0.5	cube
31	0.06	pentagon
32	0.12	disk
33	0.09	pentagon
34	0.6	tube
35	**0.2**	**blank**

Table 4.3: Projection sequence of autostereogram videos of different Michelson contrast. The video with serial number thirty five is a near blank "truth test" video (see section 3.2.2).

Position in Playlist	Repetition period (in pixels)	Projected Object
1	10	pyramid
2	10	pentagon
3	80	tube
4	30	disk
5	50	cube
6	16	pyramid
7	20	disk
8	20	cube
9	12	disk
10	40	cube
11	140	tube
12	120	pentagon
13	100	pyramid
14	130	disk
15	**90**	**blank**
16	100	tube
17	12	cube
18	110	pyramid
19	60	tube
20	70	disk
21	90	cube
22	90	disk
23	80	pyramid
24	70	cube
25	60	pentagon
26	16	disk
27	110	tube
28	120	pyramid
29	30	tube
30	40	pentagon
31	130	pyramid
32	140	cube
33	150	disk
34	160	cube
35	50	pentagon
35	150	tube
35	160	pyramid

Table 4.4: Projection sequence of autostereogram videos of different repetition period. The fifteenth video is a near blank "truth test" video (see section 3.2.3).

Chapter 5

Experimental Results and Statistical Analysis

This chapter presents the experimental results of the experiments conducted on 26 human subjects. Each of the three sections focuses on the results of one of the three sub-experiments and the statistical analysis of these results. More specifically, section 5.1 presents and analyses the results of the experiments that involve different amounts of blur, section 5.2 presents the outcome of the experiments with videos of different contrasts while section 5.3 focuses on the outcome of the experiments with videos of different repetition periods.

5.1 Experiments with Autostereogram Videos of Different Blur Radius

The results of the experiments involving autostereogram videos of different blur radius are mainly presented and analysed in terms of comparisons between the two sexes, experienced and inexperienced subjects, subjects that wear glasses or contact lenses and subjects that do not. In this section there are also plots illustrating the percentage of videos in which objects were correctly identified and plots illustrating the percentage of subjects that were able to identify the objects in videos of different blur. Figure 5.1 illustrates a box plot with the main statistics of the twenty six subjects that took part in the sub-experiment with different blur radii.

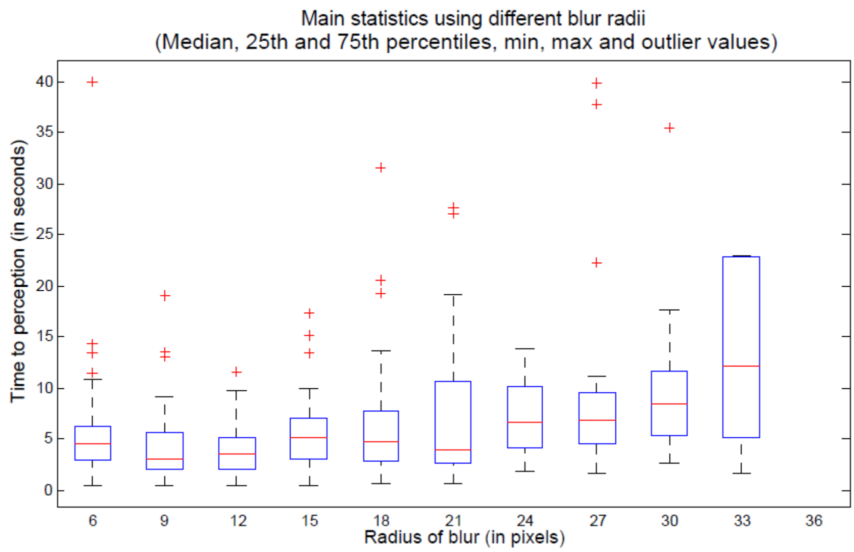

Figure 5.1: Main statistics of the subjects in the sub-experiment of autostereogram videos of different blur radii. Inside each blue box, the red segment represents the median value (in our case the median time to perception), the bottom and top edges of the boxes are the 25th and 75th percentiles respectively, the black whiskers extend to the most extreme data points that are not outliers and outlier values are represented as red crosses.

Before proceeding to the analysis of the box plot shown in figure 5.1 we need to explain how we defined outliers and whiskers in our case. Data points that are either larger than $q3+w(q3-q1)$ or smaller than $q1-w(q3-q1)$ are drawn as outliers [14]. q1 and q3 are the 25th and 75th percentiles respectively. Note that outlier values are included in the calculations of the rest of the statistics (maximum, minimum, median values etc.). With respect to w, it represents the maximum whisker length. In our case w equals 1.5 (default value in Matlab) which corresponds to approximately $+/2.7\sigma$ or in other words 99.3% coverage when the data are normally distributed [14]. The whiskers extend to the adjacent values (lower, upper), which are the most extreme data values that are not outliers [14]. Keep these in mind because more box plots will follow in this section and in later sections.

The most important observation we can make by examining the above box plot is that no subject was able to perceive the objects in the autostereogram videos of 36 pixels blur radius. This means that the human 3-D perception in autostereogram videos cannot be achieved for blur radii grater than approximately 33-35 pixels. As you can also observe, despite the fluctuations, there is a general trend of an increasing median time to perception as the radius (amount) of blur increases. This is as expected since the blurrier an object is the harder for someone to identify it, let alone when this object is part of an autostereogram video where the observer has to perform binocular fusion to acquire stereopsis. It is also worth observing that under most blur radii there are outlier values (apart from radii of 24 and 33 pixels) but every one of them is larger than the corresponding $q3+w(q3-q1)$ and no one is smaller than the corresponding $q1-w(q3-q1)$ value. This shows that there were some subjects that identified the objects noticeably slower than the majority of the subjects but none was able to identify them noticeably faster. By examining the source of the outliers we will attempt to draw some conclusions about them. The subjects that produced these values are subjects A, B, C, D, F, J, N, O, R, U, X (see appendix C). All of them except for subjects B, C, D, F are "responsible" for just one (1) outlier value while B, C, D, F for three (3) outlier values each. In our analysis we will be treating the generation of one or two outlier values by a subject as random while the generation of more as systematic. The possible explanation for subject B is that the particular subject was unable to diverge his eyes to achieve 3-D perception when he observed our autostereogram videos. The only way he could see stereograms was by converging his eyes. As a result he perceived all the videos inverted (inside-out) since our videos were created for viewing by using the divergence technique. This is a factor that can lead to worse performance since it takes more time for the subject to resolve what the object is. In regard of subjects C, D, and F, they all share one thing in common. They all wear glasses which leads us to hypothesize that people that wear glasses tend to acquire 3-D perception slower. Before examining this hypothesis any further (see section 5.1.1) we present the average time to object identification including all twenty six subjects (figure 5.2).

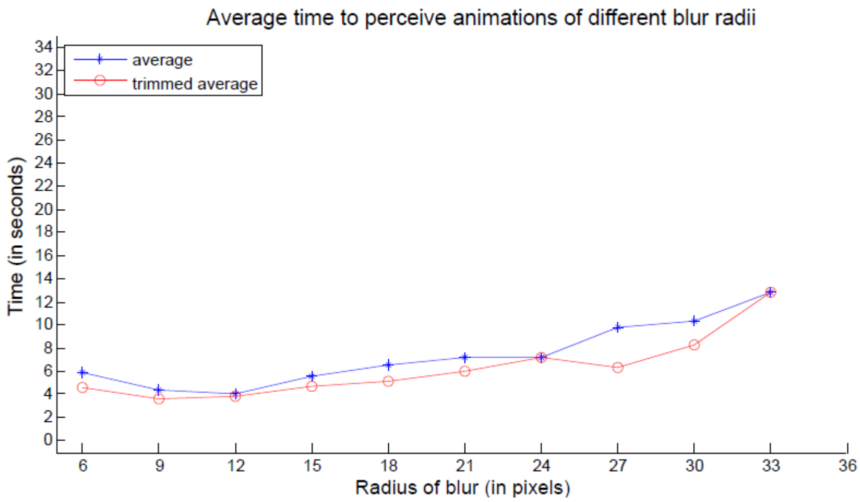

Figure 5.2: Average and trimmed average (outliers excluded) time to achieve stereopsis with videos of different blur radii.

Figure 5.2 verifies, despite the fluctuations, the existence of an increasing difficulty to object identification when blur is increased. The fact that the trend is disrupted at twenty seven (27) pixels of blur might be due to the existence of a disk object in one of the videos of 24 pixels blur radius. This might sound absurd but when this particular video of a disk of 24 pixels blur radius was projected to the subjects only nine out of twenty six (9/26 or 34.6%) of them was able to perceive a disk while six out of twenty six (6/26 or 23.07%) perceived a pentagon and 42.3% perceived either something that could not resolve or had no perception at all. This is as expected since when blur is involved it is difficult for someone to distinguish between a pentagon and a disk of similar size since the edges of the pentagon are blurred and the pentagon looks like a disk. Moreover, even the subjects that were able to identify a disk needed more time to resolve the object because of this. Consequently, it is the average time at twenty four (24) pixels of blur radius higher than it should be and thus at twenty seven pixels it seems that there is a decrease with respect to 24 pixels. One possible explanation for the initial high average time to identify the objects (at six pixels radius of blur) is the fact that the videos of this blur were projected first (see section 4.3) and as a result the stimulus adaptation of ocular vergence [7] was not still established. The analysis of the results shown in figure 5.2 is based on the trimmed average for safer conclusions. The non trimmed results though, present a similar behaviour with respect to perception. The increasing difficulty in identifying the objects as blur increases is also confirmed by the fact that as blur increases the number of people that are able to perceive autostereogram videos correctly as well as the number of videos in which people identified the object inside the video decreases (see figure 5.3).

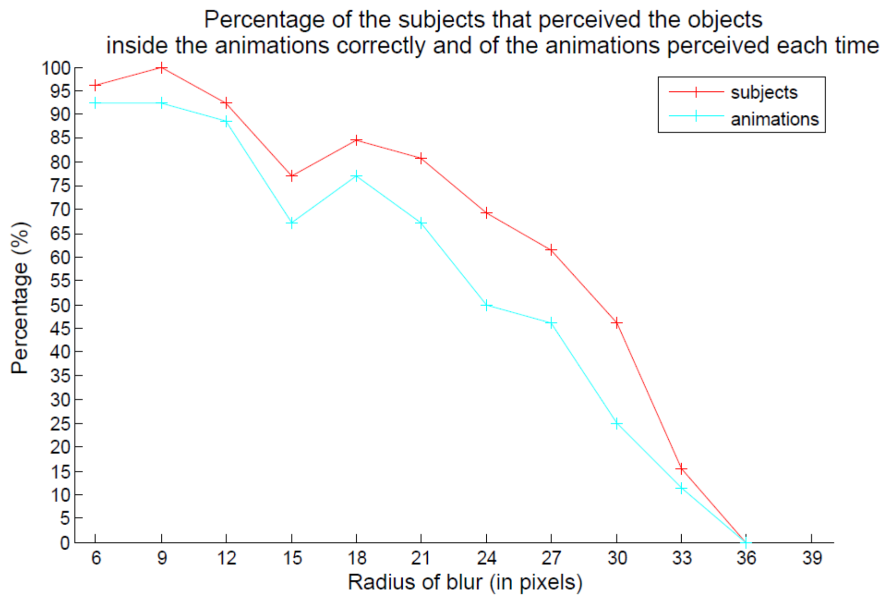

Figure 5.3: Percentage of the subjects that correctly perceived the objects inside the videos and percentage of the videos perceived under different amounts of blur.

A subject is considered to have identified videos of a specific amount of blur either when he/she identified the object correctly in one or both videos of the same blur setting. Thus the graph for the percentage of subjects is higher than the one for the videos. Moreover approximately half of the subjects (46.15%) were able to perceive the correct objects in videos of 30 pixels blur radius and at 24 pixels blur radius 50% of the projected videos were perceived.

5.1.1 Subjects Wearing Glasses Versus Subjects not Wearing Glasses (different amounts of blur)

This section compares the performance between subjects that wear glasses or contact lenses and subjects that do not, in identifying the objects in autostereogram videos of different blur. In our experiments 11 subjects wore glasses while 15 did not. Bear in mind that in section 5.1 we hypothesized that people that wear glasses need relatively more time to identify the objects in the autostereogram videos. Figure 5.4 helps us draw some safer conclusions regarding the aforementioned hypothesis since it shows the average time needed by both subjects that wear glasses and subjects that do not to identify the objects.

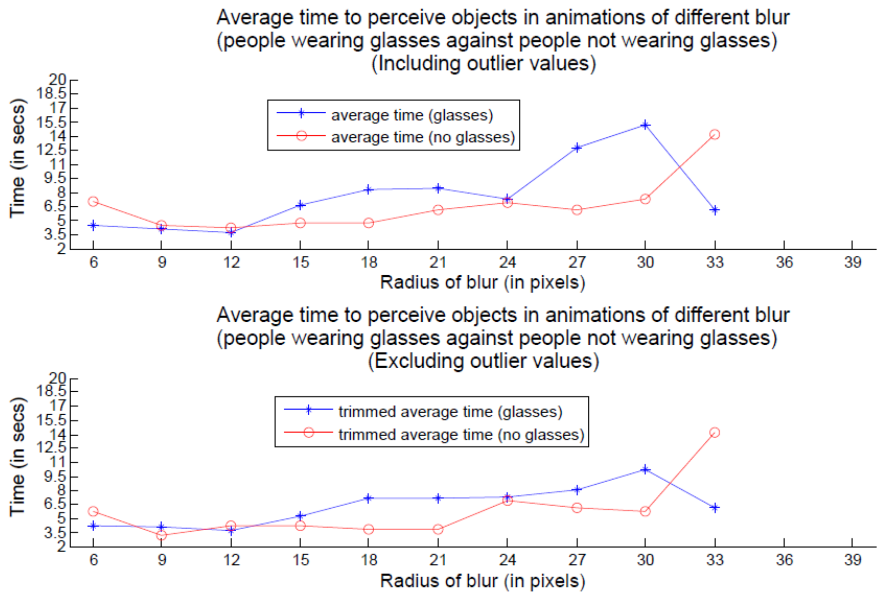

Figure 5.4: Average and trimmed average (outliers excluded) time to achieve stereopsis with videos of different blur radii between subjects that wear glasses and subjects that do not.

By either observing the averages or the trimmed averages in figure 5.4 and despite the fluctuations we can see that subjects that wear glasses (in our case every subject that wore glasses had myopia) are relatively slower in identifying the objects than subjects that do not wear glasses since in eight out of ten different blur radii settings (9-30 pixels blur radius) they perform about the same or worse than subjects that do not wear glasses. In order to assess if this difference is significant we performed two sample t-tests between the times recorded for each group (wearing glasses, not wearing glasses). The null hypothesis for each test was that for the corresponding radius (amount) of blur the recorded times of both groups were independent random samples from Gaussian distributions, with equal but unknown variances and equal means. The alternative hypothesis was that the means were not equal [16]. The test statistic used is shown in formula 5.1 [16].

$$t = \frac{\bar{x} - \bar{y}}{\sqrt{\frac{(s_x)^2}{n} + \frac{(s_y)^2}{m}}} \tag{5.1}$$

where, $\bar{x}$, $\bar{y}$ are the sample means, s_x and s_y are the sample standard deviations and n, m are the sample sizes.

The results of the t-tests confirmed the null hypothesis for each blur radius setting at 95% significance level which means that even if there are differences between the two groups of subjects in the time needed to achieve object identification they are not significant. In addition, we also used the default non-parametric two sample Kolmogorov-Smirnov tests that Matlab provides [15]. The null hypothesis for each test was that for the corresponding radii (amounts) of blur the recorded times of both groups are from the same continuous distribution. The alternative hypothesis was that they were from different continuous distributions. The results of the Kolmogorov-Smirnov tests confirmed the null hypothesis at 95% significance level which was expected judging from the results of the t-tests. Figure 5.5 shows the box plots for the two groups in question which also confirm our findings while figure 5.6 illustrates the percentage of the two groups that was able to identify the objects inside the autostereogram videos under different blur radii settings. With respect to subjects that wear glasses, somewhere between videos of 27 and 30 pixels blur radius, 50% of them can perceive the 3-D object shown in the autostereogram video. The same percentage (50%) of the subjects that do not wear glasses is also able to perceive the 3-D object somewhere between videos of 27 and 30 pixels of blur radius.

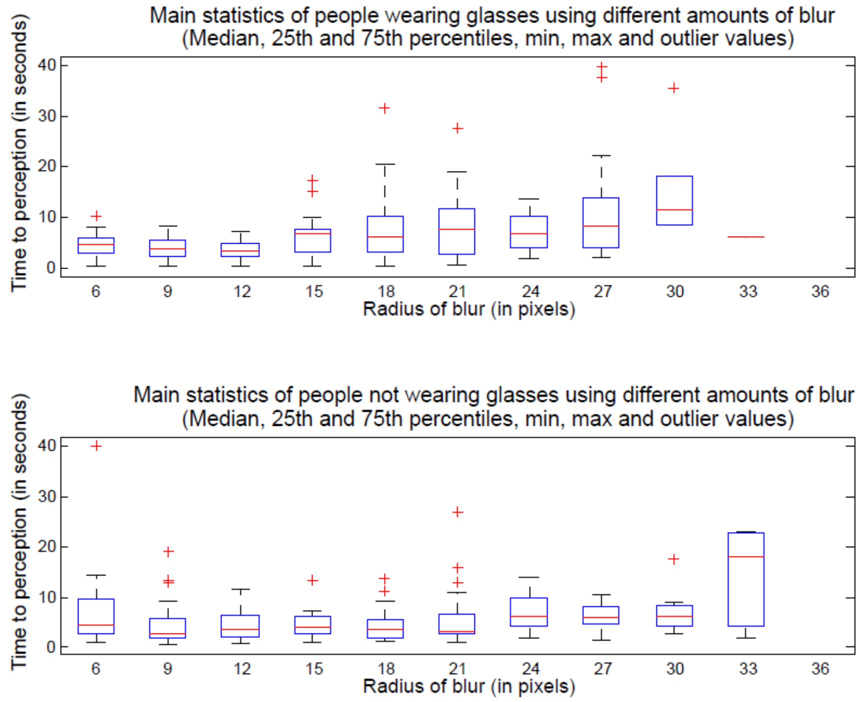

Figure 5.5: Main statistics of the two groups examined in this section.

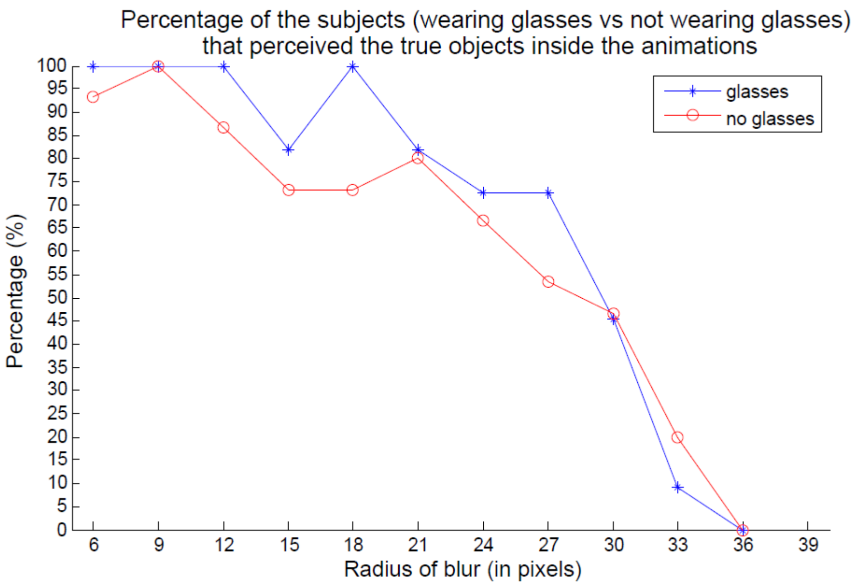

Figure 5.6: Percentage of the subjects (wearing versus not wearing glasses) that perceived the true objects inside the videos of different blur.

5.1.2 Female Versus Male Subjects (different amounts of blur)

In this section we perform a comparison between female and male subjects' ability in achieving 3-D perception of autostereogram videos of different blur. Ten (10) females and sixteen (16) males took part in our experiments. Figure 5.7 illustrates the main statistics of the two groups.

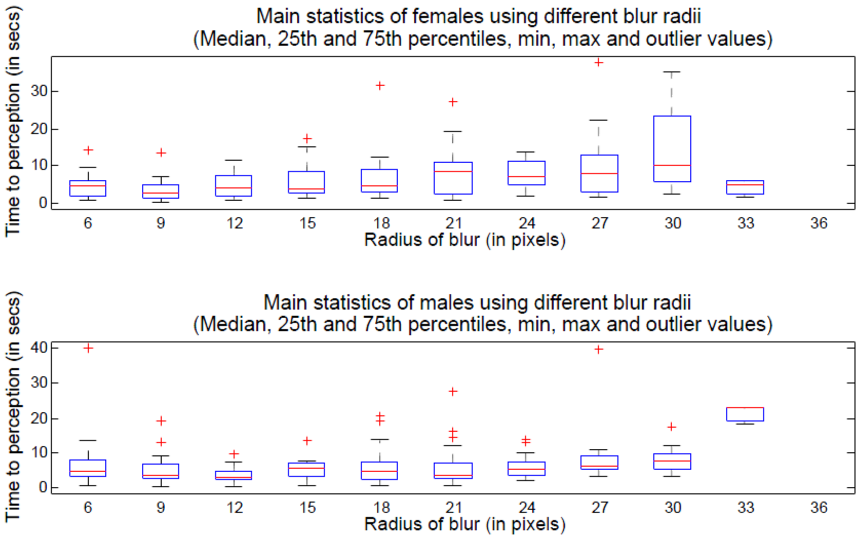

Figure 5.7: Main statistics of the two groups examined in this section.

By observing figure 5.7 carefully, we can see that males are generally faster at perceiving videos of different blur when compared to females. Another noticeable difference is that females seem to be more stable in their performance since they present less outlier values than males but no safe conclusion can be drawn since their numbers were not equal. The variations in their performance with respect to videos with high blur (greater than 21 pixels blur radius) might also be due to the decreasing number of videos perceived under these blur settings. Less samples means less safety in our conclusions. Again in figure 5.7 we can see than no subject was able to perceive videos at 36 pixels blur radius. The fact that males are relatively faster than females under most blur settings used in our experiments can also be seen in figure 5.8.

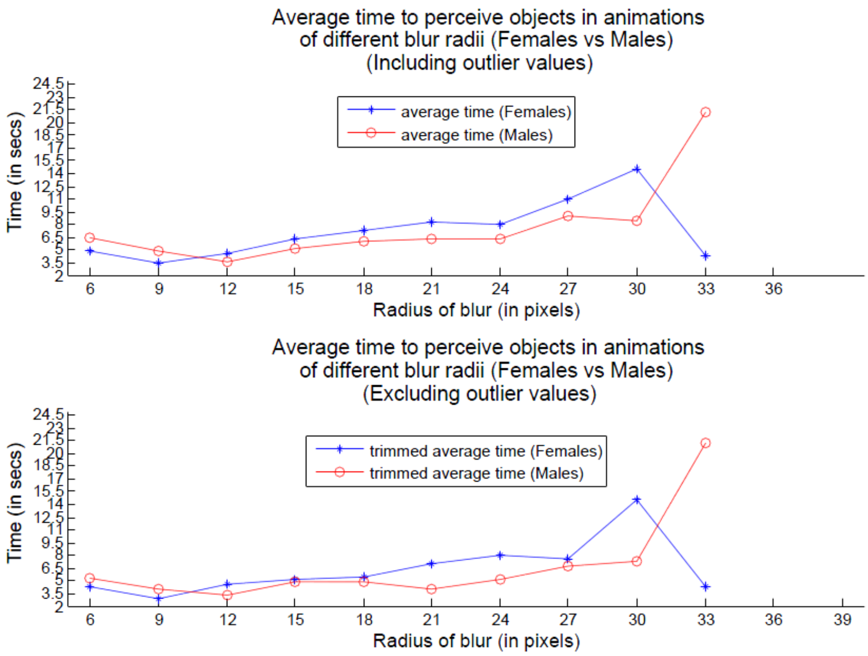

Figure 5.8: Average and trimmed average (outliers excluded) time to identify the objects in videos of different blur radii (males versus females).

Again, like in section 5.1.1 we performed t-tests and Kolmogorov-Smirnov tests with the appropriate (the same approach as in subsection 5.1.1) null and alternative hypotheses for the groups in question to test whether the difference (females being slower than males) was statistically significant. What we found was that it was not statistically significant (null hypothesis could not be rejected) apart from the difference at 33 pixels blur radius. At this blur the t-test under the null hypothesis returned a probability of 0.12% of observing a value as extreme or more extreme than the test statistic of the t-test (see section 5.1.1). Nonetheless, this does not have to add anything to the statistically insignificant differences since at such high blur the low number of samples can lead to false results (see figure 5.9). Figure 5.9 shows the percentage of males and females that were able to perceive the true objects inside the autostereogram videos of different blur. Regarding females, at 27 pixels blur radius 50% of them can perceive the 3-D object shown in the autostereogram videos while 50% of the male subjects is able to perceive the 3-D object at 30 pixels of blur radius (3 pixels of blur radius more).

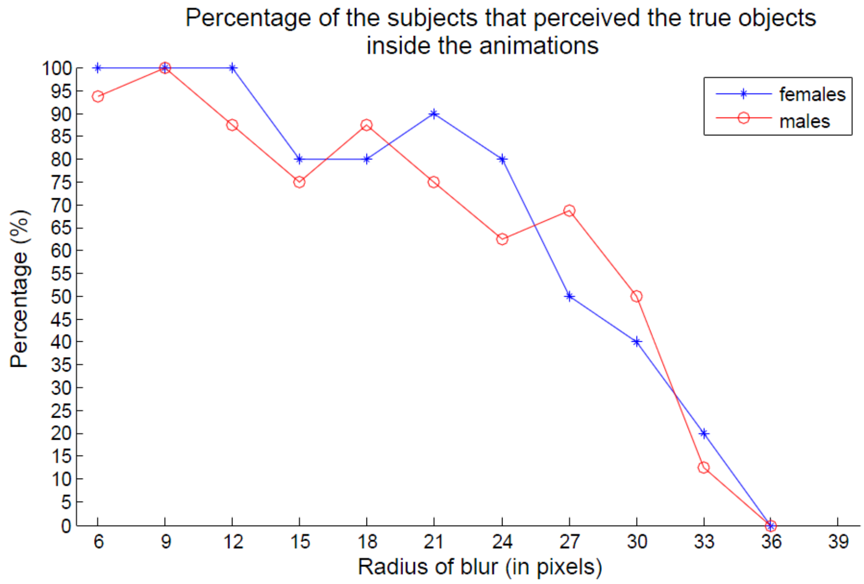

Figure 5.9: Percentage of the subjects (males versus females) that perceived the true objects inside the videos of different blur.

5.1.3 Experienced Versus Inexperienced Subjects (different amounts of blur)

This section compares the performance between experienced subjects and inexperienced subjects regarding object identification in autostereogram videos of different blur radii settings. Out of the 26 subjects that took part in our experiments 15 of them were experienced in watching static autostereograms or autostereogram videos while 11 of them were inexperienced. Experience was measured in terms of how many autostereograms had the subjects watched in the past (see section 4.2). Figure 5.10 illustrates the main statistics (minimum, maximum, median, percentiles etc.) of the two groups.

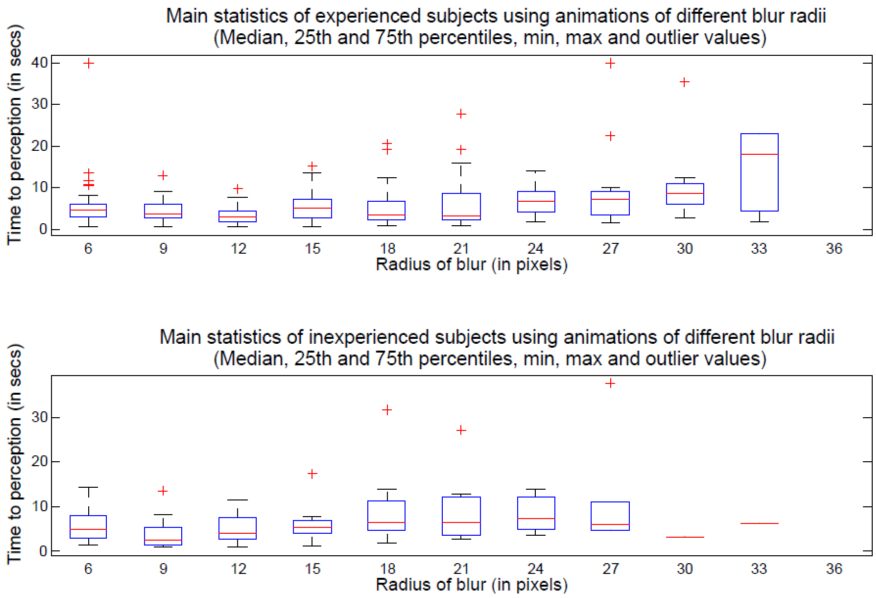

Figure 5.10: Main statistics of the experienced and inexperienced subjects using videos of different blur.

Judging from the performance of the two groups we can see that experienced subjects identify the objects relatively faster than inexperienced subjects in videos of 12-27 pixels blur radius. Furthermore, the dispersion of the recorded times under most blur settings is lower for experienced than for inexperienced subjects which means that experienced subjects are more stable in their performance than inexperienced subjects. The fact that inexperienced subjects seem to perform faster for blur radii greater than 27 pixels on its own does not give us a lot of information for the performance of the two groups since for blur radii greater than 27 pixels the number of people that were able to perceive the objects inside the autostereograms is dramatically reduced and safe conclusions can not be drawn. Figure 5.11 gives us a better understanding of the performance of the two groups.

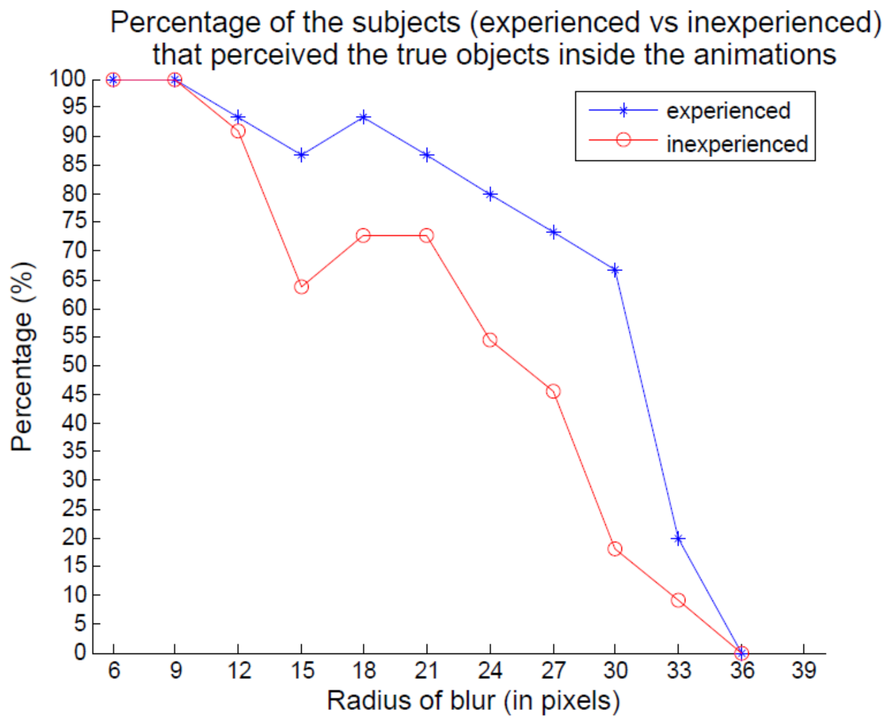

Figure 5.11: Percentage of the subjects (experienced versus inexperienced) that perceived the true objects inside the videos of different blur.

In figure 5.11 we can clearly observe that for blur radii greater than nine pixels, experienced subjects are able to perceive more videos than inexperienced ones. Consequently they are not only faster at perceiving videos of different blur radii, they are also less prone to mistakes in identifying the object inside the videos than inexperienced subjects. Regarding experienced subjects, somewhere between videos of 30 and 33 pixels blur radius, 50% of them can perceive the 3-D object shown in the autostereogram video. The same percentage (50%) of the inexperienced subjects is also able to perceive the 3-D object somewhere between videos of 24 and 27 pixels of blur radius. The better performance of experienced subjects is obvious. Note that if the two groups were balanced in numbers this difference in their percentages might not be that large since in our case (unbalanced samples) the performance of inexperienced subjects is affected more than the performance of experienced subjects when a subject that belongs to the relative group does not perceive the true objects. Finally, in figure 5.12 we present the average time to object identification regarding the two groups.

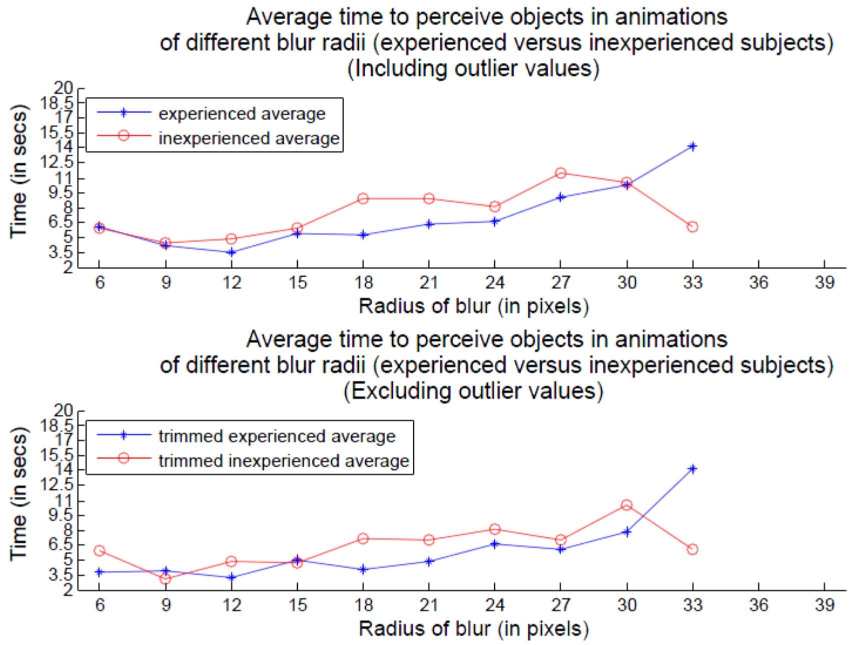

Figure 5.12: Average and trimmed average (outliers excluded) time to object identification in videos of different blur radii (experienced versus inexperienced subjects).

Again figure 5.12 proves that experienced subjects generally perceive videos faster than inexperienced users. The fluctuations of the graph for blur radii greater than 27 pixels is present due to the low number of subjects that were able to perceive the objects inside the videos especially in the inexperienced group (see figure 5.11).

For the analysis of the experiments with videos of different blur radii settings we performed t-tests and K-S tests on the times recorded for each group under the different blur settings following the same approach as in previous sections. Both tests showed that the differences in the times recorded among the two groups is not statistically significant at 95% significance level. Nonetheless, the difference is present especially when it comes to the percentages of the subjects than were able to perceive the true objects inside the videos of different blur.

5.2 Experiments with Autostereogram Videos of Different Michelson Contrast

This section presents the results of the sub-experiments that involved different Michelson contrast settings. Apart from the main statistics of the twenty six (26) subjects tested in these sub-experiments and their success rate in identifying the true object inside the videos we make comparisons between the performance of the two sexes, between subjects that wear glasses or contact lenses and subjects that do not and finally, between experienced and inexperienced subjects. First we present the main statistics of all the subjects that took part in our experiments (see figure 5.13).

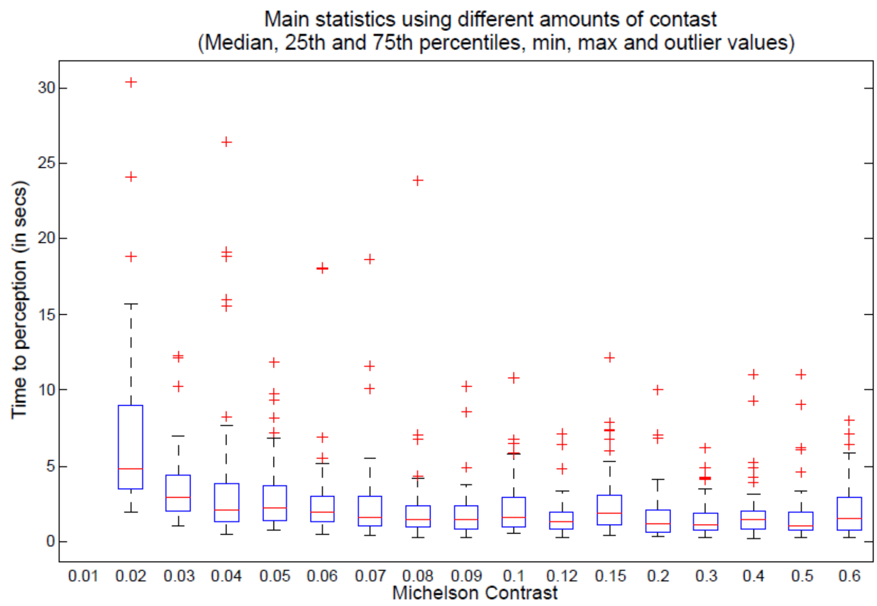

Figure 5.13: Main statistics of the subjects in the sub-experiments with autostereogram videos of different Michelson contrast.

The most important observation we can make by looking at figure 5.13 is than no subject was able to perceive the objects in videos of 0.01 Michelson contrast. As a result, this defines the threshold below which people are not able to perceive autostereogram videos (at least the autostereogram videos we created). Another important observation to be made is that as contrast increases the outlier values are closer to the median value of our observations which means that the performance of the subjects becomes more stable. In general, the rate of improvement in the performance of the subjects is higher for contrasts within the range of 0.02-0.09. For higher contrasts, outside the aforementioned range, the performance seems to be relatively stable with some fluctuations in contrasts of 0.1, 0.15 and 0.6. The average and the trimmed (outlier values excluded) average time to object identification will help us understand subjects' performance better (see figure 5.14).

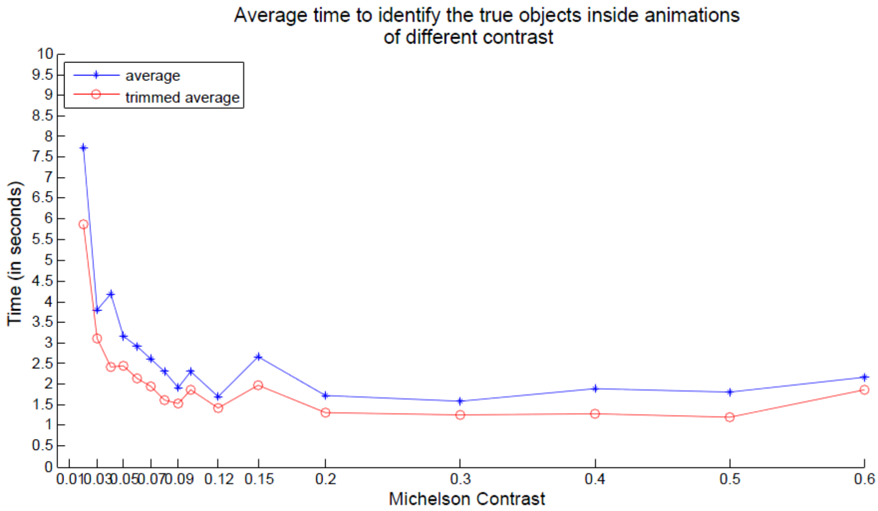

Figure 5.14: Average and trimmed average (outliers excluded) time to achieve stereopsis with videos of different blur radii.

Judging from figure 5.14 we can verify that there is a rapid improvement in the subjects' performance within the range of 0.02-0.09 of Michelson contrast. From this contrast and for greater ones the performance seems to stabilize again with fluctuations and a slightly increasing trend in the average times recorded. Furthermore, we expect to find lower percentages of subjects that identified the objects and consequently lower percentages of videos that were identified in contrast settings where performance is worse. Figure 5.15 verifies our expectations.

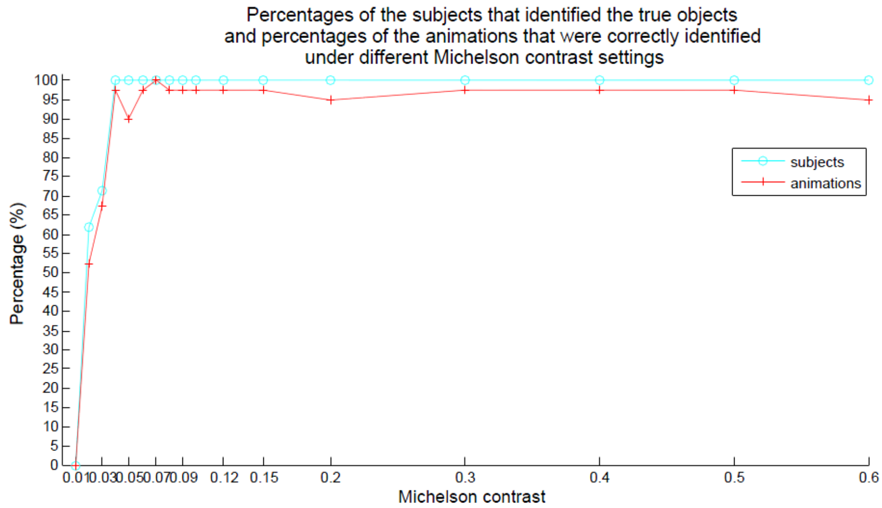

Figure 5.15: Percentage of the subjects that identified the objects and percentage of the videos perceived under different Michelson contrast settings.

As expected the percentages of subjects that were able to identify the objects inside the videos of different Michelson contrasts are reduced within the range of 0.01-0.03 (Michelson contrast). For videos of higher contrasts the percentage of subjects that identified the objects reaches 100%. In addition, the percentages of videos are also reduced within the aforementioned contrast range and increased outside this range (at least 90% of them are identified).

5.2.1 Subjects Wearing Glasses Versus Subjects not Wearing Glasses (different Michelson contrast settings)

This section presents and analyses the results of the two groups (subjects that wear glasses or contact lenses and subjects that do not) with respect to their performance in identifying the objects inside videos of different contrast settings.

In our experiments 11 subjects wore glasses or contact glasses while 15 did not. By observing figure 5.16 we can see that subjects that wear glasses or contact lenses perceived the true objects inside the videos of different Michelson contrasts settings relatively faster than subjects that do not wear glasses (average graph). By removing the outlier values from the recorded times of the two groups (trimmed average graph) we can see that subjects that do not wear glasses perform faster than subjects that wear glasses for Michelson contrasts up to 0.05. For Michelson contrasts greater than 0.05 there are alternations between the two groups with respect to which group identified the objects inside the videos faster. In general, the recorded differences do not seem to be significant. Again we can observe that there is a rapid improvement in performance for Michelson contrasts up to 0.09 and a stabilization for higher contrasts.

In order to have a more complete view of how the two groups performed under different Michelson contrast settings we present figure 5.17 which illustrates the percentages of the two groups that were able to perceive the true objects inside the videos. The most important observation we can make is that the two groups performed almost identically with respect to how many of the subjects were able to identify the objects inside the videos. The differences lie in Michelson contrasts of 0.02 and 0.03 where subjects that do not wear glasses achieve higher percentages (73.3% and 80% respectively) than subjects that wear glasses (54.55% and 72.73% respectively). Furthermore, the rapid improvement can also be observed in this figure (like in figure 5.16) but regarding the quantity (percentage of subjects that identified the true objects inside the videos) measured in figure 5.17 we can see that for a Michelson contrast of 0.04 and above everyone was able to identify the true objects.

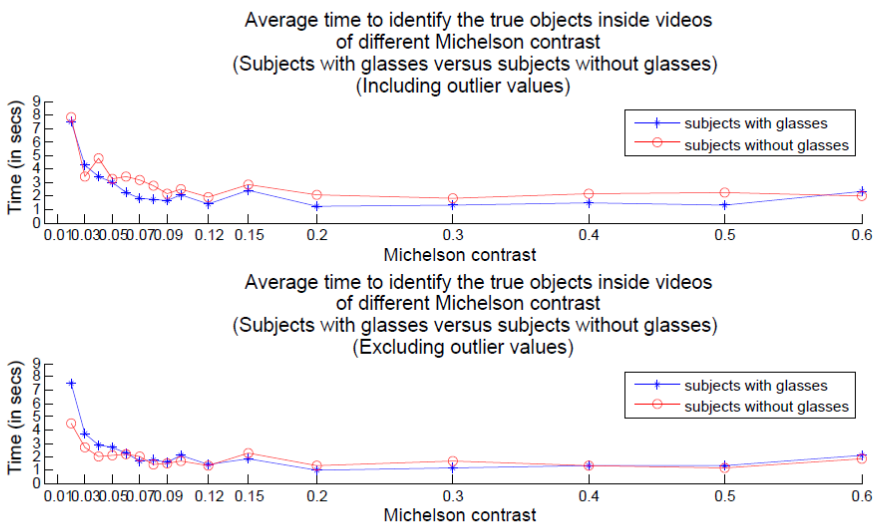

Figure 5.16: Average and trimmed average (outliers excluded) time to identify the objects inside videos of different Michelson contrast settings between subjects that wear glasses or contact lenses and subjects that do not.

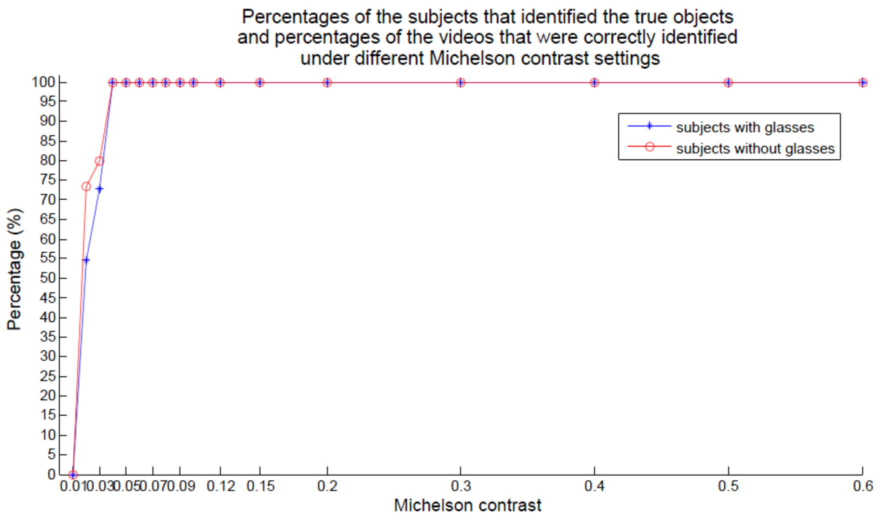

Figure 5.17: Percentage of the subjects (wearing versus not wearing glasses or contact lenses) that identified the objects inside the videos of different Michelson contrast settings.

Finally in order to check whether the differences were statistically significant we also performed t and Kolmogorov-Smirnov tests to the recorded times of the two groups using the appropriate null and alternative hypotheses similar to the ones used in section 5.1.1 but for different Michelson contrast settings. Both tests showed that the differences between the two groups with respect to how fast they were able to identify the objects inside the animations are not statistically significant at a 95% significance level.

5.2.2 Female Versus Male Subjects (different Michelson contrast settings)

This section compares the performance between males (16 subjects) and females (10 subjects) with respect to identifying the objects inside videos of different Michelson contrast settings. Figure 5.18 illustrates the average and the trimmed average (excluding outliers) times recorded for identification of the objects inside the videos while figure 5.19 illustrates the percentages of the subjects of the two groups that were able to identify the objects.

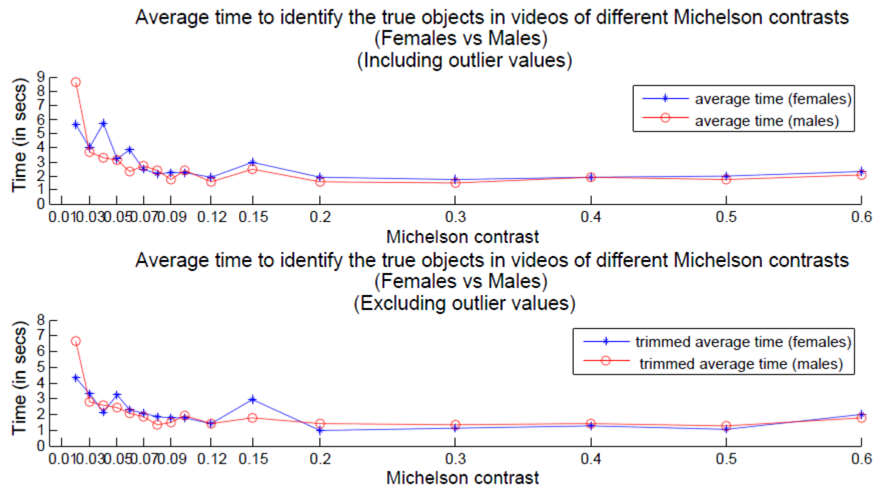

Figure 5.18: Average and trimmed average (outliers excluded) time to perceive the true objects inside videos of different Michelson contrasts (females versus males).

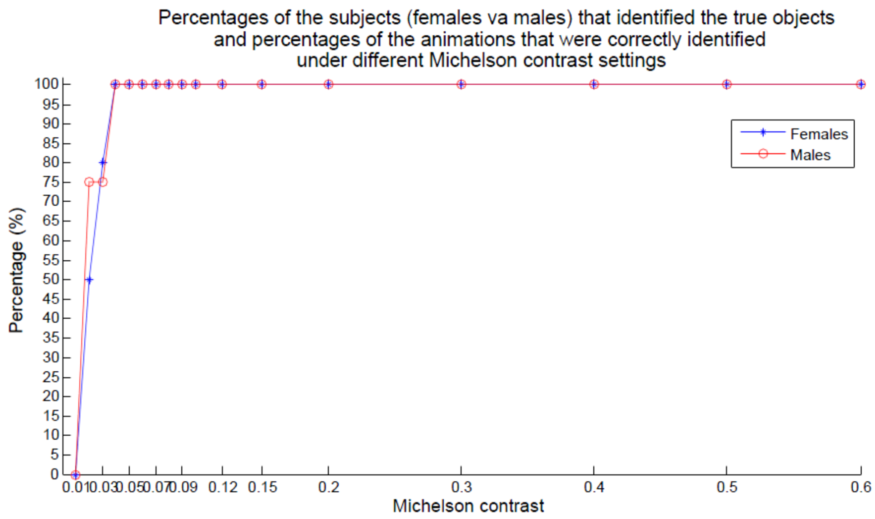

Figure 5.19: Percentage of the subjects (females versus males) that perceived the true objects inside the videos of different Michelson contrasts.

The most important observation we can make by looking at figure 5.18 is that both groups seem to perform the same for Michelson contrasts equal of greater than 0.07 regardless of whether the outlier values are included or not. It is also obvious, in both graphs of figure 5.18, that males start to identify the correct objects inside the videos at the same Michelson contrast setting as females (0.02) but at this setting the performance of females is better than the performance of males. When we look at the trimmed averages (outliers excluded) we can see that males have a smoother improvement in their performance than females as contrast increases.

By looking at figure 5.19 we can see that both males and females have identical performance with respect to the percentage of each group that was able to identify the objects under almost every Michelson contrast setting (from 0.04 Michelson contrast and above everyone (100%) was able to identify the correct objects inside the videos). The slight differences lie in contrasts below 0.04 where 50% and 80% of the females are able to perceive the true objects inside videos of 0.02 and 0.03 Michelson contrast respectively while 75% and 76% of the males are able to do the same for videos of 0.02 and 0.03 Michelson contrast respectively.

Again we performed t and Kolmogorov-Smirnov tests to the recorded times for both groups having null and alternative hypotheses similar to the ones used in section 5.1.1, only this time they (the hypotheses) referred to different contrast settings and to the groups we examine in this section. What we found is that there no statistically significant difference between males and females at 95% significance level.

5.2.3 Experienced Versus Inexperienced Subjects (different Michelson contrast settings)

This section compares the performance between experienced subjects and inexperienced subjects regarding identification of the objects in autostereogram videos of different Michelson contrasts. Out of the 26 subjects that took part in our experiments 15 were experienced in watching static autostereograms or autostereogram videos while 11 were inexperienced. Figure 5.20 shows the average and the trimmed average times for each Michelson contrast setting while figure 5.21 illustrates the percentages of both groups in terms of identifying the true objects inside the videos of different Michelson contrasts.

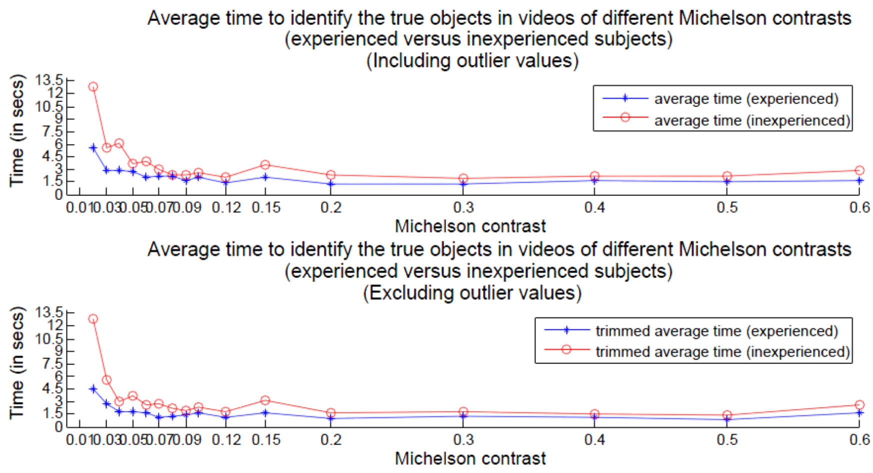

Figure 5.20: Average and trimmed average (outliers excluded) time to identify the objects in videos of different Michelson contrasts (experienced versus inexperienced subjects).

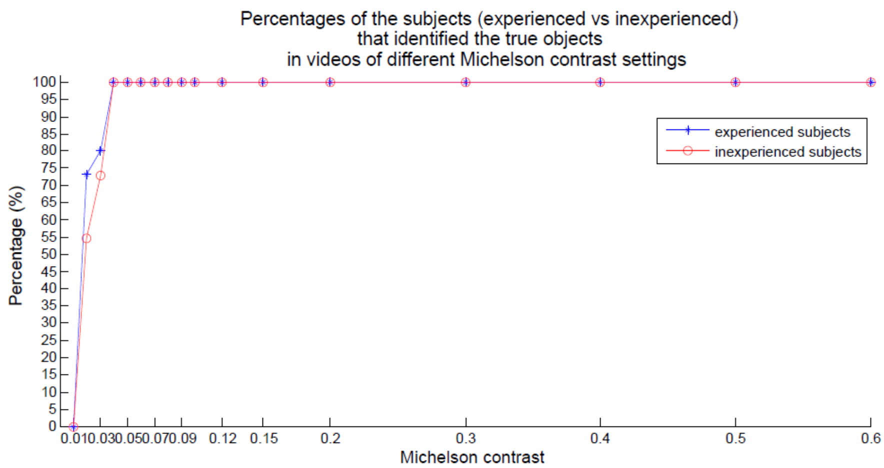

Figure 5.21: Percentage of the subjects (experienced versus inexperienced) that identified the objects inside the videos of different repetition periods.

The most important observation that one can make by looking at figure 5.20 is that experienced subjects are faster than inexperienced in identifying the objects inside videos of different Michelson contrasts. The maximum difference in their performance is observed for a Michelson contrast of 0.02. In addition, there is a rapid improvement in performance till 0.03 Michelson contrast (for trimmed average) is reached. Beyond this setting, performance seems to stabilize for both groups. Inexperienced subjects though, undergo the improvement in their performance with a higher rate than experienced users as Michelson contrast increases up to 0.03. Finally there seems to be a slightly increasing trend (worst performance) for the transition from 0.5 to 0.6 Michelson contrast for both groups (trimmed average time).

Regarding figure 5.21, one can observe that in relation to the percentage of subjects that were able to perceive the true objects inside the videos there is no difference for a Michelson contrast of 0.04 and above since everyone (100%), regardless of the group that belonged in, was able to identify the true objects. However, the supremacy of experienced over inexperienced subjects is obvious for Michelson contrasts of 0.02 and 0.03 where 73.3% and 80% of the experienced subjects respectively, were able to identify the objects, while the percentages for inexperienced subjects for the same settings are 54.55% and 72.73%.

Again, like we always did for any comparison between groups of subjects we performed t and Kolmogorov-Smirnov tests to the recorded times of the two groups (including outlier values) with the appropriate hypotheses (see section 5.1.1) adjusted to the two groups examined in this section. The results of the t-tests showed that the differences are statistically significant (the null hypothesis could not be rejected) for 0.02, 0.03, 0.04, 0.06, 0.15, 0.2 and 0.6 Michelson contrasts. For these Michelson contrast settings the t-tests under the null hypotheses returned probabilities of 0.5%, 0.41%, 3,53%, 4.51%, 2.13%, 4.14% and 1.18% of observing a value as extreme or more extreme than the test statistic of the t-tests. The Kolmogorov-Smirnov tests yielded similar results to the t-tests with statistically significant differences in performance for Michelson contrats of 0.02, 0.03, 0.04, 0.05, 0.07, 0.08 and 0.15. Both statistical tests were conducted at 95% significance level. At is point it is imperative to mention once more that Kolmogorov-Smirnov tests are non-parametric and consequently, not so accurate.

5.3 Experiments with Autostereogram Videos of Different Repetition Periods

Each experiment with videos of different repetition periods was conducted after each experiment with videos of different amounts of blur and different Michelson contrasts. Like in the previous sections (sections 5.1, 5.2) the results of these experiments will be presented and analysed in terms of comparisons between the two sexes, experienced and inexperienced subjects, subjects that wear glasses or contact lenses and subjects that do not. Figure 5.22 illustrates a box plot with the main statistics of the twenty six subjects that took part in the experiments of different repetition period videos.

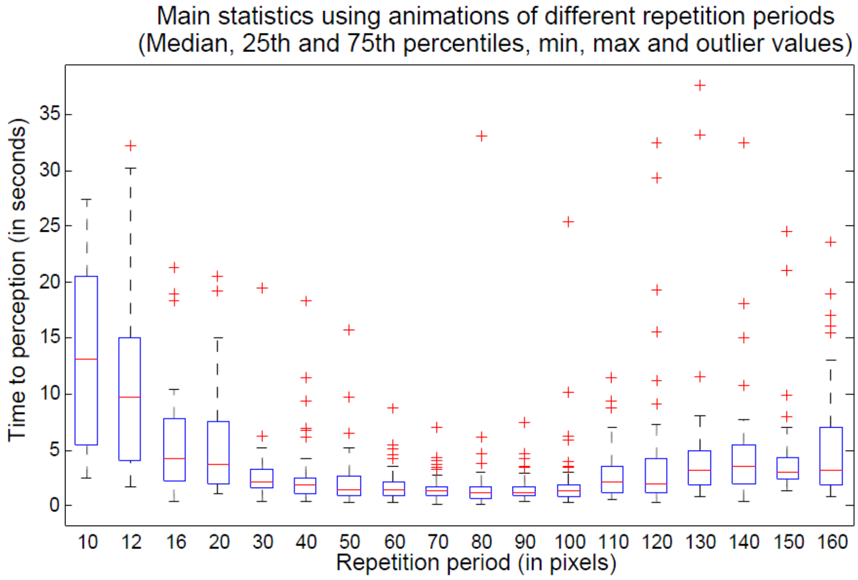

Figure 5.22: Main statistics of the subjects in the experiments with autostereogram videos of different repetition periods.

Judging from the box plot in figure 5.22, it seems that the time for a subject to identify the object inside the video is initially high but decreases as the repetition period of the pixels/dots inside the autostereogram increases until a repetition period of seventy (70) pixels is reached. For repetition periods greater than 70 pixels, the time for a subject to identify the objects stabilizes until a repetition period of 100 pixels is reached and then, for greater repetition periods, there is an increasing trend in time which is maintained until 160 pixels with a small fluctuation at 150 pixels. These findings show us that the optimal repetition period for the autostereogram videos tested is between 70 and 100 pixels. It is worth mentioning at this point that for repetition periods of 60 pixels and below the subjects stated that they observed the objects in a sliced form. In addition, judging from the outlier values, we can see that there were cases in which identification occurred noticeably slower than the majority of the cases but there was not any case in which identification was performed noticeably faster. Figure 5.23 illustrates the average time for object identification under different repetition period settings.

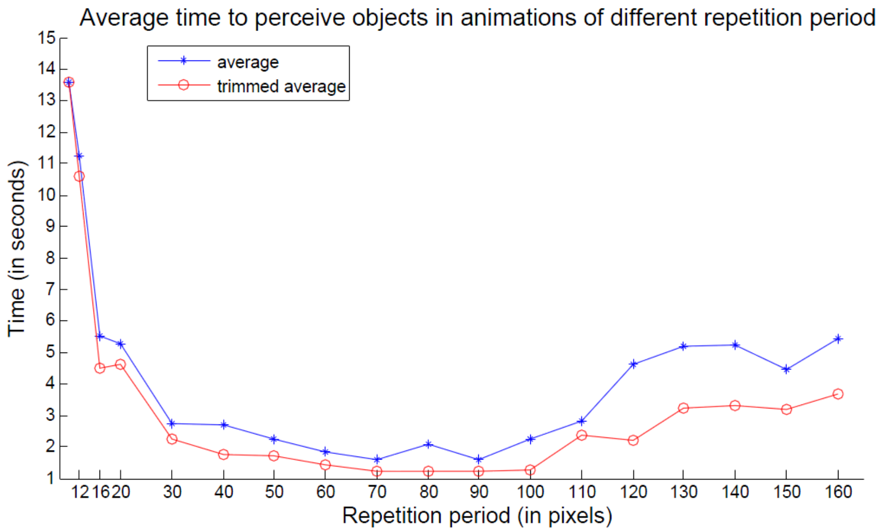

Figure 5.23: Average and trimmed average (outliers excluded) time to perception of the true objects inside videos of different repetition periods.

Again, we can see that the optimal setting for repetition period is between 70 and 100 pixels. Outside this range the time for a subject to achieve perception of the true object is increased. But this increase is greater for repetition periods below 20 pixels where time is increased dramatically. We can also see that the rate of decrease in time as we approach the optimal settings is high for repetition periods between 10 and 20 pixels (including 10 but excluding 20 pixels). Because of the increased time outside of the range of what seems to be the optimal parameters for repetition period one would expect to see a decreased number of subjects that perceived the true objects inside the videos and a decreased number of videos in which the true object was perceived. Figure 5.24 verifies, to some extent, this expectation.

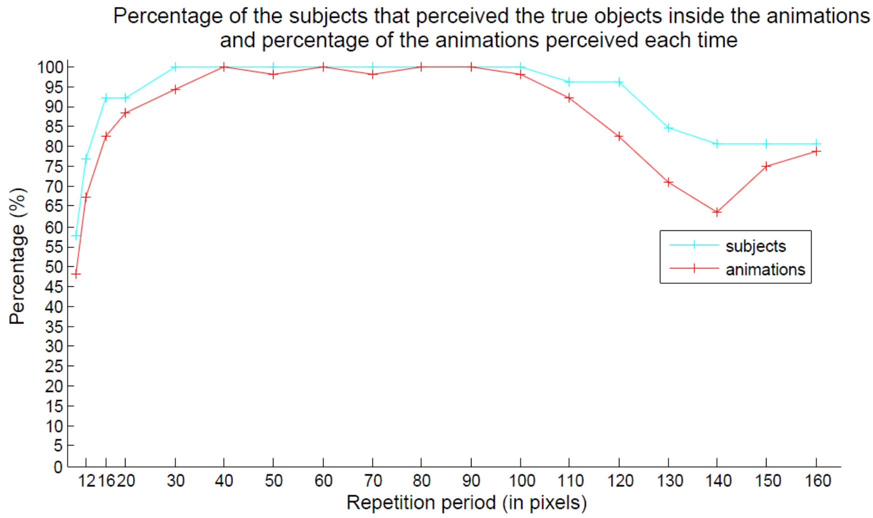

Figure 5.24: Percentages of the subjects that perceived the true objects inside the videos and percentages of the videos perceived correctly (true object) under different repetition period settings.

Regarding the graph illustrating the subjects that perceived the true objects inside the videos, we can see that it looks, to some extent, like an inverted graph of the average time shown in figure 5.23. The difference lies in the fact that the decrease in the number of people that perceived the true objects inside the videos is observed outside the range of 30-100 pixels with respect to repetition period. This means that the increase in time outside the range of 70-100 pixels is not fully reflected by the percentage of subjects that perceived the true objects inside the videos. The percentages of videos in which the true object was perceived follows the same trends as the percentage of subjects, something that is expected. Again to some extent the percentage of the videos perceived correctly reflects our findings of optimal settings regarding repetition period of random dots in autostereogram videos.

5.3.1 Subjects Wearing Glasses Versus Subjects not Wearing Glasses (different repetition periods)

In this section we perform a comparison between people that wear glasses or contact lenses (11 subjects) and people that do not (15 subjects). The main statistics of these two groups are shown in figure 5.25.

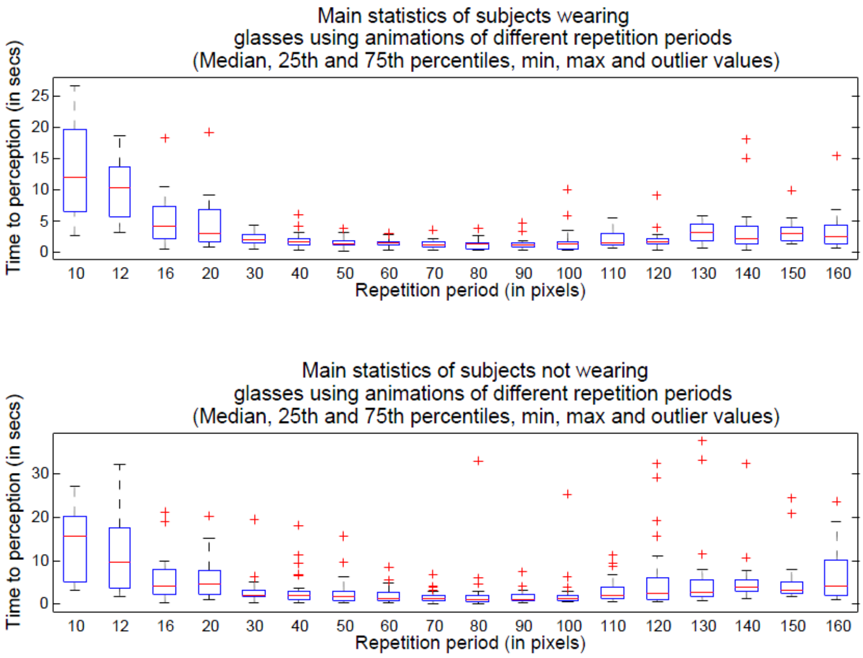

Figure 5.25: Main statistics of people that wear glasses or contact lenses and people that do not using animations of different repetition periods.

By observing the main statistics in both graphs in figure 5.25 it becomes clear that people that wear glasses or contact lenses perform faster with respect to object identification. Again we can see that within the range of 70-100 pixels both groups perform faster than with higher or lower repetition periods. Moreover, a great improvement in performance is apparent as repetition period increases from 10 to 16 pixels for both groups. In order to have a more complete understanding of the performance of the two groups we present the average times recorded (figure 5.26), the percentage of subjects of the two groups that perceived the true objects inside the videos and the percentage of videos in which the true objects where perceived (figure 5.27) under different repetition period settings.

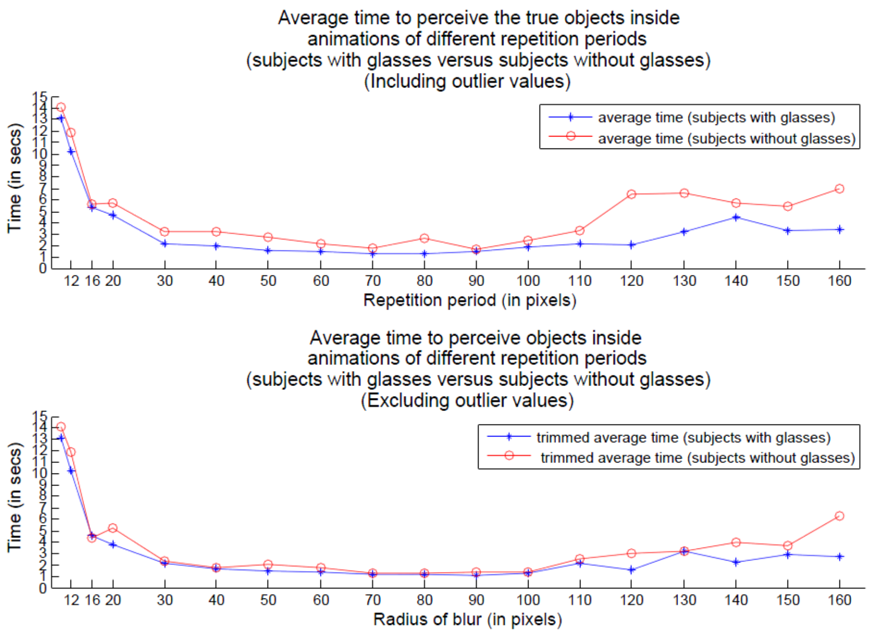

Figure 5.26: Average and trimmed average (outliers excluded) time to perceive the true objects in videos of different repetition periods (subjects that wear glasses or contact lenses versus subjects that do not).

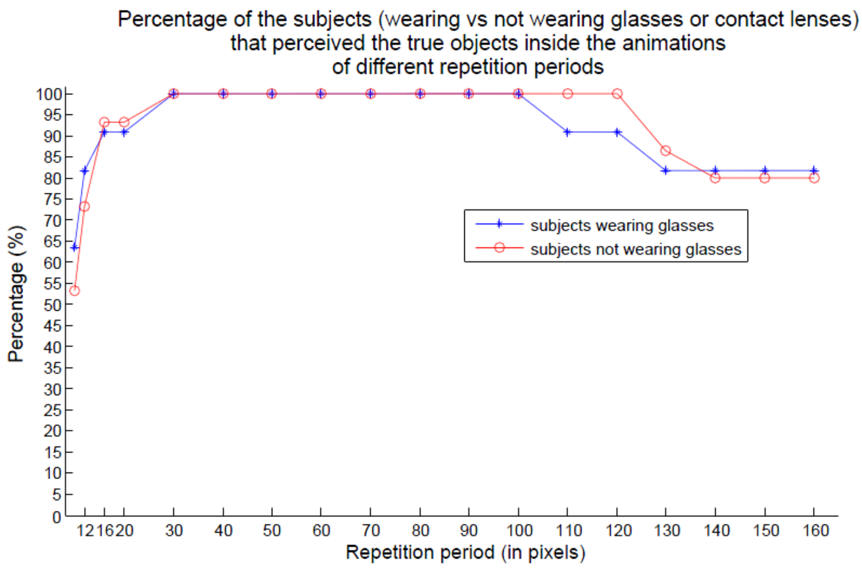

Figure 5.27: Percentage of the subjects (wearing versus not wearing glasses or contact lenses) that perceived the true objects inside the videos of different repetition periods.

By observing figure 5.26 we can see that people that wear glasses performed faster than people that do not. Furthermore, both groups achieve the same percentage (100%)

of subjects that identified the objects inside the videos of repetition periods within the range of 30-100 pixels. In addition, a higher percentage of people that do not wear glasses is observed for repetition periods of 16, 20, 110, 120 and 130 pixels and lower for the rest of the repetition period settings.

Again we performed two sample t and Kolmogorov-Smirnov tests, including outlier values as well, to check whether the differences in the performance of the groups regarding their recorded times was statistically significant. Both tests have not shown any statistically significant difference in the performance apart from a difference in 120,160 (t-test) and 140 (Kolmogorov-Smirnov test) pixels repetition period which means that the two groups performed significantly different in higher repetition periods. The significance level used in the tests was 95% and the hypotheses (both null and alternative) were adjusted to fit the groups in question but were similar to the hypotheses used in previous sections where statistical significance analysis was also performed.

5.3.2 Female Versus Male Subjects (different repetition periods)

This section compares the performance between female and male subjects in identifying objects inside videos of different repetition periods. Figure 5.28 shows the average times recorded for the two groups while figure 5.29 represents the performance of the two groups in terms of percentages of people that identified the objects inside the videos.

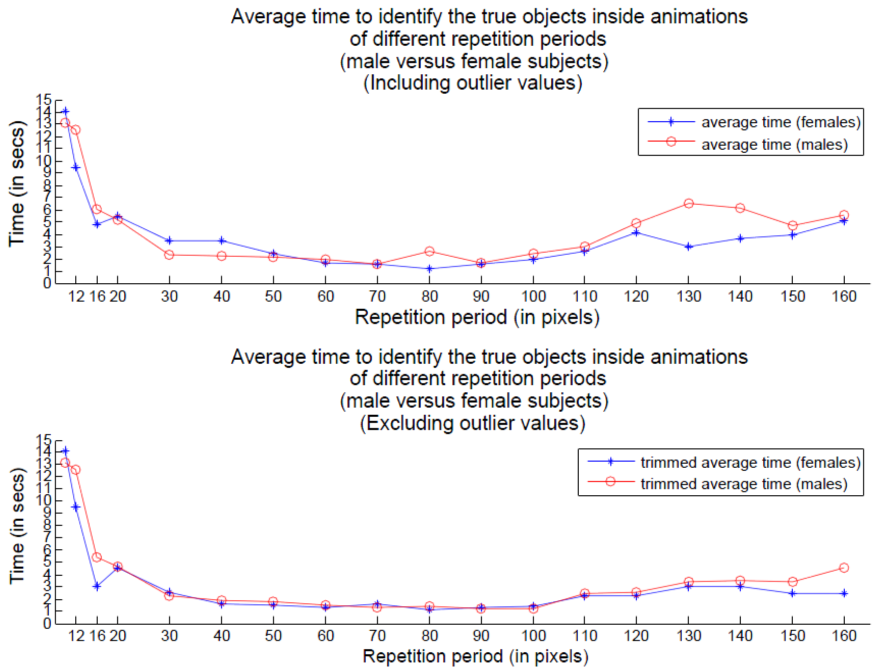

Figure 5.28: Average and trimmed average (outliers excluded) time to perceive the true objects in videos of different repetition periods (females versus males)

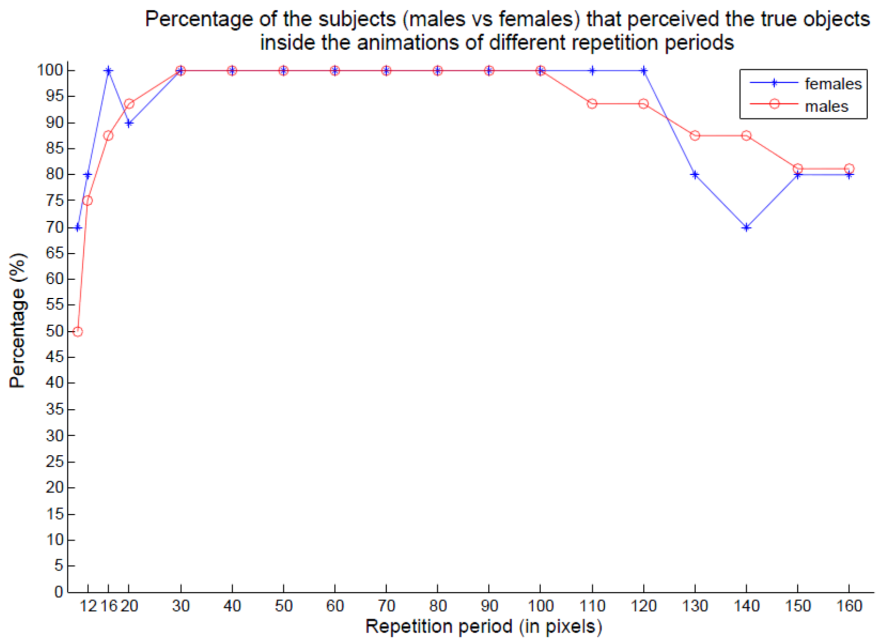

Figure 5.29: Percentage of the subjects (females versus males) that perceived the true objects inside the videos of different repetition periods.

Judging from figure 5.28 we can see that females perform either faster or the same as males under almost all the different repetition period settings. The differences are slight but are more obvious for repetition periods greater than 120 and lower than 20 pixels. In addition, both groups seem to have the same lower threshold (30 pixels) under which people stop identifying all the objects inside the videos and start making errors. Females though, seem to have a higher upper threshold (120 vs 100 pixels) than males above which misidentifications are observed. Again the number of males (16) and females (10) was not equal in our experiments and we cannot draw any safer conclusions. Nonetheless, we also performed t and KS tests like in previous cases of comparisons between groups. The t-tests showed no significant difference while the Kolmogorov-Smirnov tests showed a significant difference at 150 pixels. At this point it is necessary to mention once more that KS tests are not as accurate t-tests since they are non parametric.

5.3.3 Experienced Versus Inexperienced Subjects (different repetition periods)

The procedure followed for comparisons between experienced and inexperienced subjects in this section is the same as the one used in previous sections. Figure 5.30 shows the average and the trimmed average times to perform identification of the objects for each repetition period setting while figure 5.31 illustrates the percentages of both groups in terms of identifying the objects inside the videos of different repetition periods.

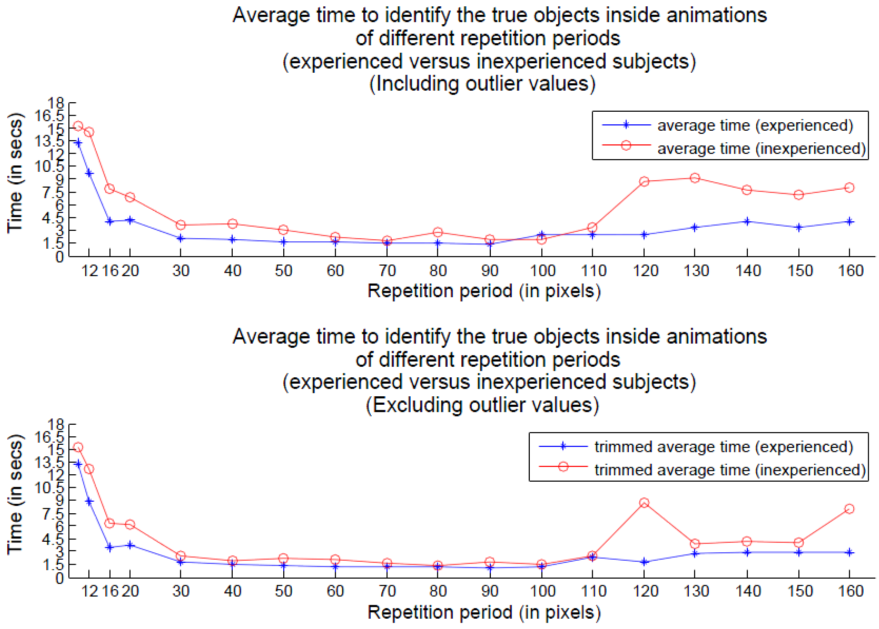

Figure 5.30: Average and trimmed average (outliers excluded) time to perceive the true objects in videos of different repetition periods (experienced versus inexperienced)

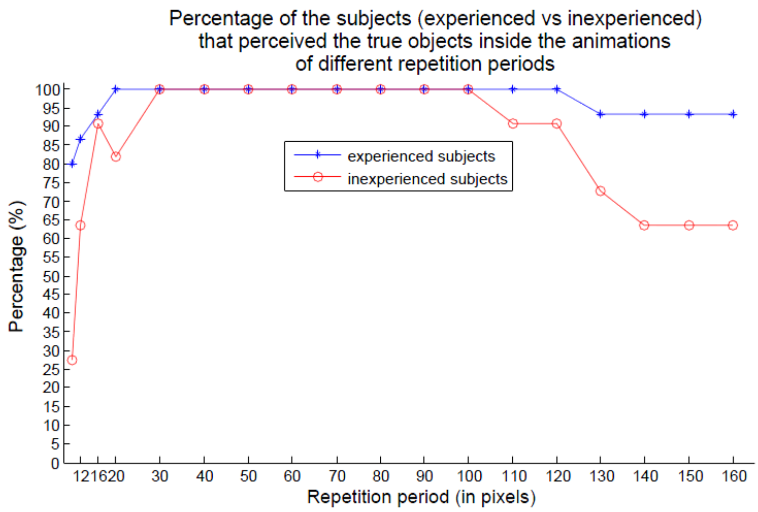

Figure 5.31: Percentage of the subjects (experienced versus inexperienced) that perceived the true objects inside the videos of different repetition periods.

What we see is that experienced subjects identify the objects inside the videos of different repetition periods faster than inexperienced ones, something that was expected based on our findings in the previous section. This difference is greater for videos that have a repetition period equal to or greater than 20 pixels and for videos with repetition period equal to or greater than 120 pixels. This also shows that with "difficult to perceive" videos experience is of key importance. The fact that by excluding the outlier values (trimmed average) the graph that represents the performance of inexperienced observes changes significantly for repetition periods between 120 and 150 means that the distribution of recorded times is wider for inexperienced observers than for experienced ones under these repetition period settings.

With respect to figure 5.31 we can see that experienced subjects not only identify the objects faster but achieve higher success rates as well (repetition periods 10-30 and 110-160 pixels). Experienced subjects also seem to have a larger range of repetition period settings in which their success rate is maximum compared to inexperienced subjects (30-120 and 30-100 pixels for experienced and inexperienced subjects respectively).

The t-tests that we performed to the recorded times of both groups showed statistically significant differences (95% significance level) in repetition periods of 16, 40, 120, 130, 140, and 160 pixels which lines, to some extent, with the analysis made above.

Chapter 6

Conclusions and Future Work

6.1 Overview

In this project we studied the psychophysical aspects of autostereogram videos with respect to blur, contrast and repetition period of the random dots that synthesise an autostereogram video. In order to do that, first, we had to choose the appropriate platforms to use for the autostereogram video creation. The platforms that were finally chosen were: 3-D Studio Max for 3-D object creation, 3-D Monster for animated depth mask creation and 3-D Miracle for autostereogram video creation. The objects used inside the videos were: pentagons, disks, pyramids, tubes and cubes. For the gathering of human performance data and analysis we conducted experiments on 26 human subjects with videos in which we varied the aforementioned features (blur, contrast, repetition period) while keeping the rest fixed. The videos were presented in a fixed but unsystematic sequence to the subjects so that the experiments would be consistent. We also enhanced consistency by using the same setting for our equipment each time and by having a controlled and fixed environment in which the experiments were conducted. The data gathered were analysed in terms of finding the thresholds under or above which the subjects were unable to perceive the objects inside the autostereogram videos and in terms of comparisons between different groups (males versus females, experienced versus inexperienced observers and observers that wear glasses or contact lenses versus observers that do not). The significance analysis of the results was conducted with t and Kolmogorov-Smirnov tests.

6.2 Conclusions

This section presents the conclusions drawn from the experiments that were conducted on human subjects using videos in which we varied three features (blur, Michelson contrast and repetition period). In this section the conclusions will be categorized according to the three features examined in our experiments and the groups (e.g males versus females) that were examined in each of them. What we can say in sort, before proceeding to the various conclusions presented in the following sections, is that our project achieved its goals and objectives as they were set in section 1.1 of the introductory chapter. Note that the thresholds with respect to feature settings under or above which subjects have no perception of the objects inside autostereogram videos are the same as in static autostereograms of the same settings. This finding is based on an experiment conducted on Subject A using static autostereograms.

6.2.1 Conclusions for Autostereogram Videos of Different Blur

The most important finding for autostereogram videos of different uniform blur is that humans are unable to perceive them for a blur radius greater than approximately 33-35 pixels. This consequently defines the upper threshold in human stereo vision with respect to blur. In addition, as blur increases, there is an increasing time for the subjects to identify the objects in the videos and a decreasing number of videos in which objects are identified. The number of subjects that identify the objects inside the videos also declines as blur increases which was generally expected.

6.2.1.1 Conclusions for Different Groups

Based on our findings, with respect to observers that wear glasses or contact lenses and observers that do not we conclude that the latter are relatively faster in identifying the objects inside the videos of different blur. Nevertheless, this difference is not statistically significant at 95% significance level. On the other hand, observers with glasses seem to perform better regarding how many of them identified the objects inside the videos of different blur. Our findings also show that males are faster than females in identifying the objects inside videos of different blur but this difference is not statistically significant. Finally, we found that experienced observers are relatively faster than inexperienced ones in identifying the objects but this difference is not statistically significant as well. What is significant is that experienced observers seem to be less prone to misidentifications of objects and lack of perception as blur increases.

6.2.2 Conclusions for Autostereogram Videos of Different Michelson Contrasts

The most important finding regarding the experiments conducted with videos of different Michelson contrasts is that people have a threshold at 0.02 Michelson contrast below which they are unable to perceive the objects inside the autostereogram videos. Moreover, there is a decrease at the time needed by the subjects to identify the objects for contrasts up to 0.09. For higher contrasts their performance (regarding time to correct perception again) stabilizes. The threshold below which misidentifications of objects and lack of perception occur is at 0.04 Michelson contrast.

6.2.2.1 Conclusions for Different Groups

In relation to the performance of observers that wear glasses or contact lenses and observers that do not we found that the latter are slightly faster than the first for contrasts below 0.05 but in any case the differences are not statistically significant. This is also verified by the fact that both groups have the same threshold (0.04 Michelson contrast) below which misidentifications of objects and lack of perception occur and the same threshold (0.02) below which none was able to perceive the objects inside the animations. Furthermore, males and females do not seem to behave significantly different with respect to different Michelson contrast settings both regarding time to identify the objects and the threshold (0.04 Michelson contrast) below which both groups begin misidentifying the objects or not achieving perception. On the other hand, experienced observers appear to be significantly faster in identifying the objects inside the videos of 0.02, 0.03, 0.04, 0.06, 0.15, 0.2 and 0.6 Michelson contrast but have the same threshold (0.04 Michelson contrast) as inexperienced observers below which they begin to misidentify objects or not perceive them at all. Last but not least, we found that neither experienced nor inexperienced observers are able to perceive the objects at 0.01 Michelson contrast.

6.2.3 Conclusions for Autostereogram Videos of Different Repetition Periods

The most important finding for this category of autostereogram videos is that there seems to be an optimal range of repetition period settings (70-100 pixels) outside which the performance of the observers becomes worse with respect to the time they need to identify the objects inside the videos. This leads us to conclude that the optimal parameters are the ones found in the middle of the parameter range (i.e. neither high nor low repetition periods are optimal for perception). Apart from this, we found a range of repetition period settings (30-100 pixels) outside which the observers either start misidentifying the objects in the videos or not perceiving them at all.

6.2.3.1 Conclusions for Different Groups

Based on our results, both observers that wear glasses or contact lenses and observers that do not wear either of them seem to perform about the same with respect to the time they need to identify the true objects inside the videos of different repetition periods apart from repetition periods of 120 and 160 pixels where observers that wear glasses perform significantly faster that observers that do not. Both groups have the same threshold (30 pixels) of repetition period below which they start misidentifying the objects or not perceiving them at all but observers that do not wear glasses or contact lenses present a higher threshold (120 against 100 pixels of repetition period for the other group) above which they start misidentifying or not perceiving the objects inside the videos. By examining males and females, we found that both groups performed almost identically with respect to how fast they identified the objects under every repetition period setting tested in our experiments. On the other hand, females have a higher upper threshold than males (120 instead of 100 pixels) above which they start to misidentify or not perceive the objects inside the videos but both groups have the same low threshold at 30 pixels of repetition period below which they start to misidentify or not perceive the objects. Regarding comparisons between experienced and inexperienced observers we found that experienced observers perform significantly faster in repetition periods of 16, 40, 120, 130, 140 and 160 pixels with respect to how much time they needed to identify the objects correctly. This leads us to conclude that experience is an important factor and this is evident especially in videos that are outside the optimal range presented in the previous section. Finally, experienced observers have a lower threshold than inexperienced (20 pixels repetition period instead of 30) below which they start misidentifying or not perceiving the objects in the videos and a higher threshold above which the same behaviour is present (120 pixels repetition period instead of 100). This is a finding that also verifies that the performance of experienced subjects is better than the performance of inexperienced ones.

6.2.4 Future Work

In every project, it is imperative that future work on the researched topic is suggested so that the work conducted so far can be extended in favour of further advancements and ideally, in favour of the society.

One interesting direction for future work would be to examine the psychophysical aspects of more features of autostereogram videos. These features include: depth in which objects are presented to the observer and insertion of additional colours inside the autostereogram videos. In this way we would be able to determine more thresholds under or above which humans are not able to perceive objects inside autostereogram videos and consequently we would hopefully obtain a better understanding of the human visual system. As supplementary future work we could also consider the case of making more comparisons and evaluations between different groups of observers. These may include groups created according to age, handedness and visual competency. This particular future work would be supplementary in the sense that we already have collected the relevant data for such comparisons and evaluations during the human performance data gathering of our project.

Another interesting direction for future work would be to examine the psychophysical aspects mentioned above and the ones already examined in this project using textured autostereogram videos instead of random dot ones. By comparing the performance of the observers in both types of autostereogram videos with respect to stereopsis we would be able to broaden our knowledge on how the human stereo system works. Furthermore we can expand our work in the future in order to use an eye tracking device and examine the ocular movements during the phase in which observers try to achieve stereopsis. All the aforementioned extensions and supplements in our work constitute suggestions that will lead us to a better understanding of the human stereo system as was mentioned above and will hopefully enable us to apply this knowledge to improve the life of people with visual incompetencies. Similar extensions (with respect to visual incompetencies) have already been given with the use of dynamic stereograms [9]. Apart from future work that is strongly connected to obtaining knowledge there are also improvements that could be made with respect to the experimental procedure.

One of the improvements that we would like to make in the future is to automate the procedure of recording human performance data. This is very important in the sense that we would achieve higher precision in the recorded times for each observer. Last but not least it would be really helpful to use a lab in which we would have the appropriate equipment for our needs. This equipment includes special chin support mechanisms, mechanisms through which we can change the viewing angle of the autostereogram videos real time and so on. As a result, we would be able to achieve consistency between experiments in a more efficient way.

Appendix A

E-mail for Human Subject Gathering

I am looking for paid volunteers to take part in a visual experiment as part of my MSc project in the School of Informatics.My dissertation is on the "Psychophysics of Autostereogram videos" and I am looking for people that are able to perceive autostereograms (magic eye images) and autostereogram animations. We are interested in the range of parameters for the videos that still allow humans to see the 3-D effect. You will be looking at a set of short videos. The experiment should not take more than an hour and you will receive 8 pounds for your time. The experiments will be in Appleton Tower 3.01. Please note: only volunteer if you can see the 3D effect in all of the following:

- in movies, such as Avatar
- in autostereogram images, such as the one at:
  - http://www.eyetricks.com/3dstereo33.htm
- in autostereogram videos, such as those at:
  - http://www.youtube.com/watch?v=ArWY-Ck-CPc

If you are interested and can perceive the above effects, please email me and we can arrange a time for the experiment. Thanks, Georgios Papadimitriou.

Appendix B

Instructions for the Experimental Procedure/Consent Form

I'm going to show you a series of videos. In each video, you will see one of the five different shapes available. In some of the videos the shapes may appear sliced up into vertical sections. All the shapes are going to be rotating. When you perceive the object of the video I want you to stop a timer that will be running as you watch the videos. After each video finishes you will be asked to tell me which of the five objects you observed and if your perception of the object was stable or not (i.e. the perception was lost at some point). You can also tell me to stop the video at any time when you are certain you can identify the shape. You can also ask me to stop the videos at any time if you feel uncomfortable.

The purpose of the experiment is to investigate the thresholds at which some stereo video effects can be seen and how fast is perception achieved. The experiment is divided into three sub-experiments, one in which we explore repetition period of the dots used to generate the stereogram, one in which we explore different amounts of blur and finally one in which we explore different contrast.

For the experiment that involves different amounts of blur I will show you twenty-two (22) videos up to forty (40) seconds each plus one ten-second (10) video of random noise of black and white dots before each stereogram animation so that you can lose your focus. A message will also appear informing you to get ready before each animation.

For the experiment that involves different repetition periods I will show you thirty-six (36) videos up to forty (40) seconds each plus one ten-second (10) video of random noise of black and white dots before each stereogram animation so that you can lose your focus. A message will also appear informing you to get ready before each animation.

For the experiment that involves different contrast I will show you thirty-four (34) videos up to forty (40) seconds each plus one ten-second (10) video of random noise of black and white dots before each stereogram animation so that you can lose your focus. A message will also appear informing you to get ready before each animation. Finally in each sub-experiment there is one forty-second (40) blank (no object is present) autostereogram video.

The experiment should not take more than forty (40) minutes. Do you have any questions? Are you ready to start? Please sign to indicate that you understand:

- what the experiment is about.
- that the results of the experiment are going to be used anonymously and agree to participate as an experimental subject.

Appendix C

Human Performance Data

This appendix contains all the data we collected from our experiments. It is divided in such a way so that data from the three sub-experiments (blur, Michelson contrast and repetition period) are presented in each section. More specifically, section C.1 illustrates the data collected from the experiments with autostereogram videos of different blur, section C.2 illustrates the data from the experiments with autostereogram videos of different Michelson contrasts and section C.3 illustrates the data from the experiments with videos of different repetition periods. In the beginning of each section there is a table that illustrates the sequence in with videos where projected in each sub-experiment. Finally, "NaN" values in the data denote "Not a Number", "something moving" values denote that the observer was able to see something but he/she could not resolve it while "no perception" values mean that the observer had no perception at all (in 3-D). Time was recorded in seconds.

C.1 Blur Data

Position in Playlist	Blur Radius Value (in pixels)	Projected Object
1	6	cube
2	9	tube
3	6	pentagon
4	9	pyramid
5	12	disk
6	15	cube
7	12	tube
8	18	disk
9	15	pentagon
10	18	cube
11	36	pyramid
12	21	tube
13	24	disk
14	21	cube
15	**12**	**blank**
16	30	pentagon
17	33	cube
18	33	disk
19	27	tube
20	24	pyramid
21	27	cube
22	30	disk
23	36	tube

Table C.1: Projection sequence of autostereogram videos of different blur radius. The fifteenth video is a near blank "truth test" video (see section 3.2.1).

Subject id:	Subject A			Subject B (sees videos inverted)		
Age:	25			22		
Gender:	Male			Male		
Nationality:	Greek			Slovakian		
Handedness:	Right-handed			Right-handed		
Glasses/Eye Contacts:	No			No		
Other known eye/seeing problems:	No			No		
Experience in watching SIRDS	Experienced			Experienced		
True Object:	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
6blur_cube	cube	13.452	Yes	cube	40	No
9blur_tube	tube	3.68	yes	tube	13.01	Yes
6blur_pentagon	pentagon	10.51	Yes	pentagon	11.41	Yes
9blur_pyramid	pyramid	2.523	yes	pyramid	9.188	Yes
12blur_disk	disk	4.989	yes	something moving	40	No
15blur_cube	cube	3.156	Yes	no perception	NaN	NaN
12blur_tube	tube	2.644	Yes	something moving	21.236	Yes
18blur_disk	disk	7.434	Yes	no perception	NaN	NaN
15blur_pentagon	pentagon	4.443	Yes	no perception	NaN	NaN
18blur_cube	cube	2.918	Yes	no perception	NaN	NaN
36blur_pyramid	no perception	NaN	NaN	no perception	NaN	NaN
21blur_tube	tube	4.476	Yes	no perception	NaN	NaN
24blur_disk	pentagon	6.07	Yes	no perception	NaN	NaN
21blur_cube	cube	6.754	Yes	no perception	NaN	NaN
placebo_blur	no perception	NaN	NaN	no perception	NaN	NaN
30blur_pentagon	pentagon	7.628	Yes	no perception	NaN	NaN
33blur_cube	cube	18.103	Yes	no perception	NaN	NaN
33blur_disk	disk	22.959	Yes	tube	22.022	No
27blur_tube	tube	7.201	Yes	no perception	NaN	NaN
24blur_pyramid	pyramid	3.7	Yes	no perception	NaN	NaN
27blur_cube	cube	20.894	Yes	no perception	NaN	NaN
30blur_disk	pentagon	7.234	Yes	no perception	NaN	NaN
36blur_tube	no perception	NaN	NaN	no perception	NaN	NaN

Subject C			Subject D			Subject E		
25			27			25		
Female			Female			Male		
Romanian			Greek			Greek		
Right-handed			Right-handed					
Yes (Myopia)			Yes (Myopia)			No		
No			No			No		
Inexperienced			Experienced			Experienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
cube	3.04	yes	cube	0.969	yes	cube	2.869	yes
tube	2.05	yes	tube	2.758	yes	tube	5.448	yes
pentagon	5.07	yes	pentagon	1.979	yes	pentagon	3.858	yes
pyramid	2.03	yes	pyramid	0.431	yes	pyramid	1.909	yes
disk	4.897	yes	disk	7.454	yes	disk	3.796	yes
cube	3.037	yes	cube	15.103	yes	cube	6.377	yes
tube	4.061	yes	tube	1.549	yes	tube	2.04	yes
disk	31.63	yes	disk	4.366	yes	disk	1.466	yes
pentagon	17.352	yes	disk	4.606	yes	pentagon	2.433	yes
cube	4.665	yes	cube	6.678	yes	cube	4.733	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
tube	11.123	yes	tube	8.589	yes	tube	2.734	yes
pentagon	18.914	yes	no perception	NaN	NaN	disk	4.584	yes
cube	3.977	yes	cube	19.121	yes	cube	15.978	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
cube	30.791	yes	no perception	NaN	NaN	pentagon	7.233	yes
cube	6.103	yes	no perception	NaN	NaN	no perception	NaN	NaN
pentagon	15.2	yes	tube	28.895	yes	disk	22.785	yes
tube	37.779	yes	no perception	NaN	NaN	tube	6.186	yes
disk	30.307	yes	pyramid	6.573	yes	pyramid	6.676	yes
cube	4.607	yes	cube	22.315	yes	no perception	NaN	NaN
pentagon	11.94	yes	disk	35.45	yes	disk	5.385	yes
no perception	NaN	NaN	no perception	NaN	NaN	cube	10.764	yes

Subject F			Subject G			Subject H		
57			31			27		
Male			Male			Male		
USA			British			Chinese		
Right-handed			Right-handed			Right-handed		
Yes (Myopia)			Yes (Myopia)			Yes (Myopia)		
No			No			No		
Experienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
cube	4.983	yes	cube	1.682	yes	cube	10.375	yes
tube	8.036	yes	tube	0.558	yes	tube	5.296	yes
pentagon	8.056	yes	pentagon	0.451	yes	pentagon	8.011	yes
pyramid	6.818	yes	pyramid	0.416	yes	pyramid	2.842	yes
disk	7.205	yes	disk	2.463	yes	disk	3.981	yes
cube	6.646	yes	cube	0.451	yes	cube	7.65	yes
tube	3.458	yes	tube	0.386	yes	tube	3.123	yes
disk	8.036	yes	disk	0.814	yes	disk	7.29	yes
pentagon	7.799	yes	pentagon	0.465	yes	disk	4.645	yes
cube	19.233	yes	cube	0.607	yes	cube	8.454	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
tube	5.032	yes	tube	0.714	yes	no perception	NaN	NaN
pentagon	6.486	yes	pentagon	9.727	yes	disk	7.474	yes
cube	27.684	yes	cube	0.702	yes	cube	12.207	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	disk	7.366	yes	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
tube	39.818	yes	tube	3.258	yes	something moving	13.123	yes
pyramid	13.848	yes	pyramid	2.03	yes	pyramid	13.106	yes
no perception	NaN	NaN	cube	6.452	yes	cube	11.123	yes
no perception	NaN	NaN	disk	12.219	yes	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN

Subject I			Subject J			Subject K		
25			25			23		
Male			Male			Male		
Greek			Scotish			British		
Left-handed			Right-handed			Right-handed		
Yes (Myopia)			No			No		
No			slight stigmatism			No		
Experienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
cube	4.51	yes	cube	10.825	yes	cube	1.296	yes
tube	7.414	yes	something moving	4.491	yes	tube	1.052	yes
pentagon	4.233	yes	pentagon	5.08	yes	pentagon	2.765	yes
pyramid	2.454	yes	pyramid	6.349	yes	pyramid	1.267	yes
disk	6.593	yes	disk	9.616	yes	disk	6.01	yes
something moving	5.458	yes	cube	13.36	yes	cube	3.901	yes
tube	2.814	yes	tube	2.174	yes	tube	2.899	yes
disk	4.756	yes	disk	1.976	yes	disk	3.042	yes
disk	9.853	yes	pentagon	1.946	yes	pentagon	3.981	yes
no perception	NaN	NaN	cube	1.784	yes	cube	13.665	No
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
something moving	6.896	yes	tube	2.521	yes	tube	3.35	yes
something moving	9.048	yes	disk	2.58	yes	disk	7.197	yes
something moving	5.188	yes	cube	2.927	yes	no perception	NaN	NaN
something moving	11.544	yes	no perception	NaN	NaN	no perception	NaN	NaN
something moving	11.806	yes	something moving	8.41	yes	no perception	NaN	NaN
no perception	NaN	NaN	something moving	12.456	yes	no perception	NaN	NaN
no perception	NaN	NaN	something moving	5.706	yes	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	tube	10.342	yes
disk	9.164	yes	pyramid	10.183	yes	pyramid	6.236	yes
no perception	NaN	NaN	cube	9.157	yes	no perception	NaN	NaN
no perception	NaN	NaN	disk	5.28	yes	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN

Subject L			Subject M			Subject N		
24			22			23		
Male			Female			Female		
Indian			English			British		
Right-handed			Right-handed			Right-handed		
Yes (Myopia)			No			No		
No			No			No		
Inexperienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
cube	3.455	yes	cube	4.362	yes	cube	7.915	yes
tube	8.288	yes	tube	2.674	yes	tube	7.259	yes
pentagon	6.099	yes	pentagon	2.786	yes	pentagon	14.303	yes
pyramid	3.159	yes	pyramid	2.979	yes	pyramid	0.968	yes
something moving	9.308	yes	disk	3.49	yes	disk	9.691	yes
no perception	7.418	yes	cube	2.475	yes	disk	3.355	yes
tube	5.107	yes	tube	1.174	yes	no perception	NaN	NaN
disk	13.455	yes	disk	1.525	yes	tube	5.835	yes
something moving	12.912	yes	pentagon	2.656	yes	no perception	NaN	NaN
no perception	NaN	NaN	cube	1.256	yes	something moving	17.378	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	tube	1.715	yes	no perception	NaN	NaN
something moving	8.393	yes	disk	1.843	yes	tube	9.535	yes
no perception	NaN	NaN	cube	1.042	yes	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	disk	3.816	yes	no perception	NaN	NaN
no perception	NaN	NaN	cube	1.654	yes	no perception	NaN	NaN
no perception	NaN	NaN	disk	5.168	yes	no perception	NaN	NaN
no perception	NaN	NaN	tube	3.275	yes	no perception	NaN	NaN
no perception	NaN	NaN	pyramid	13.638	yes	pyramid	13.838	yes
something moving	27.566	yes	cube	1.633	yes	no perception	NaN	NaN
no perception	NaN	NaN	disk	2.63	yes	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN

Subject O			Subject P			Subject Q		
22			27			20		
Female			Male			Male		
Slovakian			Polish			British		
Right-handed			Right-handed			Left-handed		
No			No			No		
No			No			color blind (red,green)		
Inexperienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
cube	9.636	yes	cube	3.531	yes	cube	3.662	yes
tube	13.501	yes	tube	3.657	yes	tube	2.478	yes
something moving	9.282	yes	pentagon	3.918	yes	pentagon	4.264	yes
pyramid	5.709	yes	pyramid	3.248	yes	pyramid	2.193	yes
disk	11.571	yes	disk	3.801	yes	disk	2.703	yes
something moving	20.179	yes	cube	7.098	yes	cube	5.112	yes
tube	8.724	yes	tube	4.1	yes	tube	1.301	yes
no perception	NaN	NaN	disk	3.279	yes	disk	5.112	yes
no perception	NaN	NaN	pentagon	5.516	yes	pentagon	3.931	yes
something moving	12.134	yes	cube	3.558	yes	cube	1.764	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
cube	15.697	yes	tube	1.516	yes	tube	2.632	yes
something moving	19.368	yes	pentagon	3.746	yes	something moving	5.642	yes
cube	12.856	yes	cube	2.892	yes	something moving	1.835	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
something moving	16.356	yes	something moving	18.712	yes	no perception	NaN	NaN
something moving	22.827	yes	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	tube	5.454	yes	tube	4.607	yes
pyramid	11.725	yes	pyramid	4.071	yes	something moving	3.796	yes
disk	21.528	yes	cube	8.414	yes	no perception	NaN	NaN
no perception	NaN	NaN	disk	9.042	yes	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN

Subject R			Subject S			Subject T		
24			50			19		
Male			Male			Male		
Chinese			Colombian			Chinese		
Right-handed			Left-handed			Right-handed		
No			Yes (Myopia)			No		
No			No			No		
Inexperienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
cube	11.705	yes	cube	4.866	yes	cube	4.834	yes
something moving	12.103	yes	tube	6.491	yes	tube	1.569	yes
something moving	8.051	yes	pentagon	4.577	yes	pentagon	2.468	yes
pyramid	19.088	yes	pyramid	4.195	yes	pyramid	2.524	yes
pentagon	9.934	yes	disk	1.513	yes	disk	0.871	yes
no perception	NaN	NaN	cube	5.851	yes	cube	6.381	yes
something moving	8.968	yes	tube	1.569	yes	tube	3.756	yes
no perception	NaN	NaN	disk	2.228	yes	disk	5.451	yes
no perception	NaN	NaN	pentagon	2.505	yes	pentagon	6.98	yes
something moving	14.63	yes	cube	7.209	yes	cube	5.726	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
something moving	20.338	yes	tube	7	yes	tube	3.956	yes
no perception	NaN	NaN	no perception	NaN	NaN	pentagon	5.707	yes
no perception	NaN	NaN	no perception	NaN	NaN	cube	6.412	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	Nan	Nan
no perception	NaN	NaN	no perception	NaN	NaN	disk	5.254	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	Nan	Nan
no perception	NaN	NaN	something moving	22.656	yes	no perception	Nan	Nan
something moving	23.614	yes	something moving	18.627	yes	tube	6.06	yes
pentagon	7.963	yes	pyramid	4.323	yes	pyramid	3.33	yes
no perception	NaN	NaN	something moving	11.367	yes	cube	5.365	yes
disk	17.631	yes	something moving	14.374	yes	disk	3.3	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN

Subject U			Subject V			Subject W		
27			29			28		
Male			Female			Female		
Spanish			Italian			German		
Right-handed			Right-handed			Left-handed		
Yes (Myopia)			Yes (Myopia)			Yes (Myopia)		
No			No			No		
Experienced			Experienced			Experienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
cube	3.133	yes	cube	5.957	yes	cube	4.74	yes
tube	3.932	yes	tube	5	yes	tube	4.445	yes
pentagon	5.231	yes	pentagon	5.916	yes	pentagon	1.948	yes
pyramid	2.858	yes	pyramid	4.855	yes	pyramid	1.419	yes
disk	6.332	yes	disk	4.416	yes	disk	2.42	yes
cube	7.368	yes	cube	9.959	yes	cube	3.521	yes
tube	2.907	yes	tube	3.984	yes	tube	2.702	yes
disk	3.211	yes	disk	5.755	yes	disk	3.186	yes
pentagon	7.531	yes	pentagon	6.877	yes	pentagon	4.171	yes
cube	20.484	yes	cube	12.366	yes	cube	2.715	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
tube	2.935	yes	tube	9.703	yes	tube	1.028	yes
pentagon	3.586	yes	disk	6.905	yes	disk	4.107	yes
cube	14.504	yes	cube	8.404	yes	cube	2.407	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
disk	5.471	yes	disk	5.783	yes	something moving	4.154	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
tube	3.357	yes	tube	7.773	yes	tube	9.817	yes
pyramid	3.728	yes	pyramid	11.031	yes	pyramid	7.785	yes
cube	8.333	yes	cube	9.158	yes	cube	2.213	yes
disk	8.606	yes	disk	11.566	yes	disk	8.471	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN

Subject X			Subject Y			Subject Z		
31			23			24		
Female			Female			Female		
USA			British			Greek		
Right-handed			Right-handed			Right-handed		
No			No			No		
No			No			No		
Inexperienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
cube	5.962	yes	cube	4.409	yes	cube	6.454	yes
cube	10.625	yes	tube	2.334	yes	tube	1.375	yes
no perception	NaN	NaN	pentagon	0.96	yes	pentagon	1.456	yes
pyramid	5.115	yes	pyramid	0.634	yes	pyramid	1.116	yes
disk	7.56	yes	disk	1.198	yes	disk	2.041	yes
cube	5.691	yes	cube	3.173	No	cube	1.121	yes
tube	8.179	yes	tube	1.752	yes	tube	1.058	yes
disk	11.251	yes	disk	4.975	yes	disk	3.67	yes
disk	6.166	yes	disk	3.132	yes	disk	3.161	yes
cube	9.221	yes	no perception	NaN	NaN	cube	9.544	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
tube	27.039	yes	tube	3.579	yes	disk	4.162	yes
no perception	NaN	NaN	disk	8.892	yes	disk	4.632	yes
cube	11.037	yes	no perception	NaN	NaN	cube	3.347	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
cube	7.309	yes	no perception	NaN	NaN	something moving	4.327	yes
no perception	NaN	NaN	no perception	NaN	NaN	pyramid	5.172	yes
no perception	NaN	NaN	no perception	NaN	NaN	pentagon	6.762	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN

C.2 Michelson Contrast Data

Position in Playlist	Michelson Contrast Value	Projected Object
1	0.01	disk
2	0.01	pentagon
3	0.02	pyramid
4	0.02	tube
5	0.15	pentagon
6	0.07	pyramid
7	0.05	pentagon
8	0.6	disk
9	0.05	pyramid
10	0.1	cube
11	0.1	disk
12	0.08	tube
13	0.04	pyramid
14	0.2	cube
15	0.07	tube
16	0.2	pyramid
17	0.3	pentagon
18	0.12	pyramid
19	0.4	disk
20	0.3	pyramid
21	0.4	pentagon
22	0.03	disk
23	0.15	cube
24	0.5	tube
25	0.03	cube
26	0.06	disk
27	0.09	cube
28	0.04	pentagon
29	0.08	disk
30	0.5	cube
31	0.06	pentagon
32	0.12	disk
33	0.09	pentagon
34	0.6	tube
35	**0.2**	**blank**

Table C.2: Projection sequence of autostereogram videos of different Michelson contrast. The video with serial number thirty five is a near blank "truth test" video (see section 3.2.2).

Subject id:	Subject A			Subject B (sees animations inverted)		
Age:	25			22		
Gender:	Male			Male		
Nationality:	Greek			Slovakian		
Handedness:	Right-handed			Right-handed		
Glasses/Eye Contacts:	No			No		
Other known eye/seeing problems:	No			No		
Experience in watching SIRDS:	Experienced			Experienced		
True Object:	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
0.01contrast_disk	no perception	NaN	NaN	no perception	NaN	NaN
0.01contrast_pentagon	no perception	NaN	NaN	no perception	NaN	NaN
0.02contrast_pyramid	pyramid	3.707	Yes	no perception	NaN	NaN
0.02contrast_tube	tube	4.629	Yes	something moving	32.325	Yes
0.15contrast_pentagon	pentagon	2.864	Yes	pentagon	7.835	Yes
0.07contrast_pyramid	pyramid	1.711	Yes	pyramid	11.645	yes
0.05contrast_pentagon	pentagon	3.561	Yes	no perception	NaN	NaN
0.6contrast_disk	disk	1.32	Yes	disk	5.701	Yes
0.05contrast_pyramid	pyramid	1.923	Yes	pyramid	11.835	Yes
0.1contrast_cube	cube	1.646	Yes	cube	6.488	yes
0.1contrast_disk	disk	1.996	Yes	disk	10.811	yes
0.08contrast_tube	tube	1.046	Yes	tube	23.872	yes
0.04contrast_pyramid	pyramid	1.271	Yes	pyramid	8.26	yes
0.2contrast_cube	cube	2.127	Yes	cube	6.838	yes
0.07contrast_tube	tube	1.1	Yes	tube	18.71	yes
0.2contrast_pyramid	pyramid	1.887	Yes	pyramid	2.33	yes
0.3contrast_pentagon	pentagon	3.213	Yes	pentagon	4.069	yes
0.12contrast_pyramid	pyramid	1.262	Yes	pyramid	2.7	yes
0.4contrast_disk	disk	1.746	Yes	disk	2.395	yes
0.3contrast_pyramid	pyramid	2.255	Yes	pyramid	3.234	yes
0.4contrast_pentagon	pentagon	9.272	Yes	pentagon	5.26	yes
0.03contrast_disk	disk	3.011	Yes	no perception	NaN	NaN
0.15contrast_cube	cube	0.663	Yes	cube	6.74	yes
0.5contrast_tube	tube	1.832	Yes	tube	6.127	yes
0.03contrast_cube	cube	2.767	Yes	no perception	NaN	NaN
0.06contrast_disk	disk	1.844	Yes	disk	6.923	yes
0.09contrast_cube	cube	0.74	Yes	cube	8.601	yes
0.04contrast_pentagon	pentagon	0.943	Yes	pentagon	18.87	no
0.08contrast_disk	disk	0.737	Yes	disk	6.733	yes
0.5contrast_cube	cube	2.669	Yes	cube	9.043	yes
0.06contrast_pentagon	pentagon	1.276	Yes	disk	7.446	yes
0.12contrast_disk	disk	0.958	Yes	disk	6.411	yes
0.09contrast_pentagon	pentagon	1.607	Yes	pentagon	3.62	yes
0.6contrast_tube	tube	4.819	Yes	tube	2.757	yes
placebo_contrast	no perception	NaN	NaN	no perception	NaN	NaN

Subject C			Subject D			Subject E		
25			27			25		
Female			Female			Male		
Romanian			Greek			Greek		
Right-handed			Right-handed					
Yes (Myopia)			Yes (Myopia)			No		
No			No			No		
Inexperienced			Experienced			Experienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
disk	18.607	yes	no perception	NaN	NaN	pyramid	5.499	yes
disk	34.351	yes	pyramid	30.116	yes	tube	4.168	yes
pentagon	4.969	yes	pentagon	3.302	yes	pentagon	2.663	yes
pyramid	2.161	yes	pyramid	0.646	yes	pyramid	2.195	yes
pentagon	1.161	yes	pentagon	0.981	yes	pentagon	2.376	yes
disk	5.877	yes	disk	0.756	yes	disk	2.727	yes
pyramid	2.454	yes	pyramid	0.956	yes	pyramid	2.127	yes
cube	1.823	yes	cube	0.851	yes	cube	1.796	yes
disk	2.47	yes	disk	0.651	yes	disk	1.851	yes
tube	2.746	yes	tube	0.678	yes	tube	1.643	yes
pyramid	15.511	yes	pyramid	0.899	yes	pyramid	2.186	yes
cube	1.206	yes	cube	0.506	yes	cube	2.17	yes
tube	1.949	yes	tube	0.758	yes	tube	1.642	yes
pyramid	1.328	yes	pyramid	0.389	yes	pyramid	1.351	yes
pentagon	1.945	yes	pentagon	0.612	yes	pentagon	1.159	yes
pyramid	0.948	yes	pyramid	0.511	yes	pyramid	1.26	yes
disk	1.388	yes	disk	0.643	yes	disk	1.543	yes
pyramid	0.957	yes	pyramid	0.723	yes	pyramid	1.502	yes
pentagon	1.863	yes	pentagon	0.428	yes	pentagon	1.84	yes
disk	5.207	yes	disk	1.306	yes	disk	2.529	yes
cube	1.847	yes	cube	0.728	yes	cube	1.84	yes
tube	1.904	yes	tube	0.34	yes	tube	1.57	yes
disk	12.997	yes	cube	1.404	yes	cube	2.693	yes
disk	2.659	yes	disk	0.948	yes	disk	2.05	yes
cube	1.839	yes	cube	0.773	yes	cube	1.829	yes
pentagon	2.556	yes	pentagon	1.397	yes	pentagon	2.862	yes
disk	1.959	yes	disk	1.133	yes	disk	1.709	yes
cube	0.862	yes	cube	0.594	yes	cube	1.242	yes
pentagon	1.918	yes	pentagon	0.639	yes	pentagon	2.559	yes
disk	2.248	yes	disk	0.668	yes	disk	1.45	yes
pentagon	1.713	yes	pentagon	0.633	yes	pentagon	1.672	yes
tube	1.945	yes	tube	0.455	yes	tube	1.143	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN

Subject F			Subject G			Subject H		
57			31			27		
Male			Male			Male		
USA			British			Chinese		
Right-handed			Right-handed			Right-handed		
Yes (Myopia)			Yes (Myopia)			Yes (Myopia)		
No			No			No		
Experienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	pyramid	7.264	yes	pyramid	9.704	yes
no perception	NaN	NaN	tube	12.648	yes	something moving	12.143	yes
pentagon	2.672	yes	pentagon	1.04	yes	pentagon	12.16	yes
pyramid	2.241	yes	pyramid	1.24	yes	pyramid	3.687	yes
pentagon	5.877	yes	pentagon	0.722	yes	pentagon	6.478	yes
disk	3	yes	disk	0.552	yes	disk	7.128	yes
pyramid	2.977	yes	pyramid	0.822	yes	pyramid	3.793	yes
cube	3.036	yes	cube	0.572	yes	cube	5.876	yes
disk	3.633	yes	disk	0.595	yes	disk	2.994	yes
tube	1.981	yes	tube	0.256	yes	tube	4.335	yes
pyramid	2.805	yes	pyramid	0.596	yes	pyramid	3.903	yes
cube	1.827	yes	cube	0.44	yes	cube	4.126	yes
tube	1.848	yes	tube	0.448	yes	tube	5.049	yes
pyramid	2.131	yes	pyramid	0.486	yes	pyramid	3.099	yes
pentagon	1.838	yes	pentagon	0.349	yes	pentagon	4.22	yes
pyramid	1.745	yes	pyramid	0.345	yes	pyramid	2.564	yes
disk	2.137	yes	disk	0.327	yes	disk	4.871	yes
pyramid	1.908	yes	pyramid	0.296	yes	pyramid	2.62	yes
pentagon	3.906	yes	pentagon	0.241	yes	pentagon	3.12	yes
disk	6.773	yes	disk	3.573	yes	disk	10.278	yes
cube	2.078	yes	cube	0.442	yes	cube	3.242	yes
tube	2.75	yes	tube	0.354	yes	tube	3.383	yes
cube	4.21	yes	cube	1.857	yes	cube	12.292	yes
disk	2.654	yes	disk	1.249	yes	disk	3.359	yes
cube	1.971	yes	cube	0.882	yes	cube	2.577	yes
pentagon	5.168	yes	pentagon	1.277	yes	pentagon	5.358	yes
disk	2.03	yes	disk	0.951	yes	disk	4.195	yes
cube	2.75	yes	cube	0.458	yes	cube	2.134	yes
pentagon	2.915	yes	pentagon	0.526	yes	pentagon	3.894	yes
disk	2.29	yes	disk	0.553	yes	disk	3.121	yes
pentagon	2.03	yes	pentagon	0.593	yes	pentagon	2.6	yes
tube	1.637	yes	tube	0.415	yes	tube	2.848	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN

Subject I			Subject J			Subject K		
25			25			23		
Male			Male			Male		
Greek			Scotish			British		
Left-handed			Right-handed			Right-handed		
Yes (Myopia)			No			No		
No			slight stigmatism			No		
Experienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	pyramid	2.728	yes	pyramid	24.14	yes
no perception	NaN	NaN	tube	3.477	yes	tube	14.78	yes
pentagon	4.732	yes	pentagon	0.831	yes	pentagon	3.16	yes
pyramid	3.475	yes	pyramid	0.828	yes	pyramid	2.23	yes
pentagon	9.363	yes	pentagon	0.926	yes	pentagon	2.379	yes
disk	3	yes	disk	0.551	yes	disk	2.129	yes
pyramid	8.173	yes	pyramid	0.782	yes	pyramid	3.405	yes
cube	4.617	yes	cube	0.762	yes	cube	1.639	yes
disk	5.176	yes	disk	0.544	yes	disk	1.545	yes
tube	2.337	yes	tube	0.736	yes	tube	1.119	yes
pyramid	4.198	yes	pyramid	1.183	yes	pyramid	1.324	yes
cube	1.158	yes	cube	0.966	yes	cube	1.092	yes
tube	3.159	yes	tube	0.846	yes	tube	0.73	yes
pyramid	1.081	yes	pyramid	0.642	yes	pyramid	0.713	yes
pentagon	1.198	yes	pentagon	0.92	yes	pentagon	3.421	yes
pyramid	1.097	yes	pyramid	0.798	yes	pyramid	1.417	yes
disk	1.459	yes	disk	0.807	yes	disk	1.434	yes
pyramid	0.765	yes	pyramid	0.466	yes	pyramid	0.879	yes
pentagon	2.017	yes	pentagon	0.663	yes	pentagon	1.341	yes
no perception	NaN	NaN	disk	1.183	yes	disk	4.585	yes
cube	1.691	yes	cube	0.695	yes	cube	0.938	yes
tube	2.518	yes	tube	0.648	yes	tube	0.884	yes
no perception	NaN	NaN	cube	1.042	yes	cube	2.653	yes
disk	4.668	yes	disk	1.232	yes	disk	1.098	yes
cube	3.09	yes	cube	0.737	yes	cube	0.986	yes
pentagon	7.708	yes	pentagon	2.081	yes	pentagon	1.642	yes
disk	2.567	yes	disk	0.53	yes	disk	0.873	yes
cube	1.172	yes	cube	0.563	yes	cube	0.553	yes
pentagon	5.126	yes	pentagon	1.818	yes	pentagon	1.345	yes
disk	3.333	yes	disk	1.715	yes	disk	0.73	yes
pentagon	2.458	yes	pentagon	1.013	yes	pentagon	0.908	yes
tube	1.812	yes	tube	0.808	yes	tube	0.514	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN

Subject L			Subject M			Subject N		
24			22			23		
Male			Female			Female		
Indian			English			British		
Right-handed			Right-handed			Right-handed		
Yes (Myopia)			No			No		
No			No			No		
Inexperienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	disk	13.145	yes	no perception	NaN	NaN
no perception	NaN	NaN	pyramid	3.53	yes	no perception	NaN	NaN
no perception	NaN	NaN	tube	3.065	yes	no perception	NaN	NaN
pentagon	2.492	yes	pentagon	1.539	yes	something moving	24.709	yes
pyramid	3.284	yes	pyramid	1.562	yes	pyramid	2.733	yes
pyramid	4.23	yes	pentagon	1.418	yes	something moving	15.822	yes
disk	6.438	yes	disk	2.887	yes	disk	2.453	yes
pyramid	2.298	yes	pyramid	1.324	yes	pyramid	9.768	yes
cube	1.362	yes	cube	1.271	yes	no perception	NaN	NaN
disk	1	yes	disk	1.262	yes	disk	3.694	yes
tube	1.169	yes	tube	1.39	yes	tube	3.842	yes
pyramid	1.937	yes	pyramid	1.332	yes	pyramid	6.102	yes
cube	0.904	yes	cube	0.829	yes	cube	3.823	yes
tube	0.896	yes	tube	1.159	yes	tube	5.544	yes
pyramid	0.645	yes	pyramid	1.029	yes	no perception	NaN	NaN
pentagon	0.612	yes	pentagon	0.968	yes	no perception	NaN	NaN
pyramid	0.549	yes	pyramid	1.109	yes	no perception	NaN	NaN
disk	0.438	yes	disk	0.991	yes	no perception	NaN	NaN
pyramid	0.497	yes	pyramid	0.812	yes	pyramid	1.056	yes
pentagon	0.202	yes	pentagon	0.716	yes	pentagon	1.462	yes
something moving	6.451	yes	disk	2.831	yes	no perception	NaN	NaN
cube	0.832	yes	cube	0.897	yes	cube	4.107	yes
tube	1.086	yes	tube	0.928	yes	tube	1.508	yes
no perception	NaN	NaN	cube	3.289	yes	no perception	NaN	NaN
disk	2.077	yes	disk	1.232	yes	disk	4.473	yes
cube	0.912	yes	cube	0.925	yes	cube	3.759	yes
pentagon	5.845	yes	pentagon	1.438	yes	something moving	18.555	yes
disk	2.449	yes	disk	1.492	yes	disk	2.656	yes
cube	1	yes	cube	0.687	yes	cube	2.703	yes
pentagon	4.204	yes	pentagon	1.776	yes	pentagon	5.573	yes
disk	2.556	yes	disk	0.982	yes	disk	1.524	yes
pentagon	3.317	yes	pentagon	1.484	yes	no perception	NaN	NaN
tube	2.593	yes	tube	0.758	yes	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN

Subject O			Subject P			Subject Q		
22			27			20		
Female			Male			Male		
Slovakian			Polish			British		
Right-handed			Right-handed			Left-handed		
No			No			No		
No			No			color blind (red,green)		
Inexperienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	pyramid	7.58	yes	pyramid	6.777	yes
no perception	NaN	NaN	tube	3.437	yes	tube	2.781	yes
pentagon	7.383	yes	pentagon	1.675	yes	pentagon	2.307	yes
pyramid	5.349	yes	pyramid	0.942	yes	pyramid	2.055	yes
something moving	16.418	yes	pentagon	1.712	yes	pentagon	4.244	yes
disk	8.041	yes	disk	2.212	yes	disk	1.276	yes
pyramid	7.252	yes	pyramid	0.962	yes	pyramid	1.952	yes
cube	6.708	yes	cube	0.594	yes	cube	1.657	yes
disk	5.814	yes	disk	1.076	yes	disk	1.571	yes
something moving	10.075	yes	tube	0.923	yes	tube	1.311	yes
pyramid	16.048	yes	pyramid	0.774	yes	pyramid	2.13	yes
cube	10.013	yes	cube	0.455	yes	cube	2.186	yes
tube	10.079	yes	tube	0.76	yes	tube	1.549	yes
pyramid	7.085	yes	pyramid	0.371	yes	pyramid	1.46	yes
pentagon	6.182	yes	pentagon	0.863	yes	pentagon	1.225	yes
pyramid	7.167	yes	pyramid	0.814	yes	pyramid	1.241	yes
disk	11.066	yes	disk	0.831	yes	disk	1.442	yes
pyramid	4.909	yes	pyramid	0.384	yes	pyramid	1.659	yes
pentagon	4.26	yes	pentagon	0.785	yes	pentagon	1.356	yes
no perception	NaN	NaN	disk	3.623	yes	disk	1.656	yes
cube	7.293	yes	cube	0.802	yes	cube	1.312	yes
tube	11.102	yes	tube	0.823	yes	tube	1.917	yes
something moving	11.367	yes	cube	2.937	yes	cube	1.747	yes
disk	18.058	yes	disk	1.807	yes	disk	1.344	yes
cube	10.241	yes	cube	0.58	yes	cube	1.245	yes
pentagon	26.429	yes	pentagon	1.338	yes	pentagon	3.08	yes
disk	7.086	yes	disk	1.188	yes	disk	1.235	yes
cube	6.208	yes	cube	0.363	yes	cube	1.518	yes
pentagon	18.126	yes	pentagon	1.252	yes	pentagon	2.219	yes
disk	4.824	yes	disk	0.706	yes	disk	1.601	yes
pentagon	4.914	yes	pentagon	0.742	yes	pentagon	1.745	yes
tube	4.266	yes	tube	0.491	yes	tube	1.355	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN

Subject R			Subject S			Subject T		
24			50			19		
Male			Male			Male		
Chinese			Colombian			Chinese		
Right-handed			Left-handed			Right-handed		
No			Yes (Myopia)			No		
No			No			No		
Inexperienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
pyramid	30.336	yes	pyramid	18.863	yes	pyramid	8.161	yes
no perception	NaN	NaN	no perception	NaN	NaN	tube	3.205	yes
pentagon	2.183	yes	pentagon	1.618	yes	pentagon	2.787	yes
pyramid	1.866	yes	pyramid	1.106	yes	pyramid	2.606	yes
pentagon	3.395	yes	pentagon	1.619	yes	pentagon	2.67	yes
disk	2.607	yes	disk	0.685	yes	disk	2.569	yes
pyramid	0.996	yes	pyramid	1.016	yes	pyramid	2.016	yes
cube	1.833	yes	cube	0.685	yes	cube	3.496	yes
disk	1.13	yes	disk	0.599	yes	disk	2.168	yes
tube	1.328	yes	tube	0.678	yes	tube	1.915	yes
pyramid	1.1	yes	pyramid	1.32	yes	pyramid	3.87	yes
cube	1.3	yes	cube	0.369	yes	cube	2.574	yes
tube	1.1	yes	tube	0.6	yes	tube	3.379	yes
pyramid	1.14	yes	pyramid	0.642	yes	pyramid	2.153	yes
pentagon	1.479	yes	pentagon	0.261	yes	pentagon	0.779	yes
pyramid	1.312	yes	pyramid	0.622	yes	pyramid	1.444	yes
disk	1.038	yes	disk	0.608	yes	disk	2.345	yes
pyramid	0.803	yes	pyramid	0.314	yes	pyramid	1.703	yes
pentagon	1.08	yes	pentagon	0.287	yes	pentagon	1.771	yes
disk	5.371	yes	no perception	NaN	NaN	disk	3.25	yes
cube	1.15	yes	cube	0.589	yes	cube	2.155	yes
tube	0.976	yes	tube	0.385	yes	tube	1.517	yes
cube	2.031	yes	no perception	NaN	NaN	cube	3.616	yes
disk	1.638	yes	disk	2.056	yes	disk	2.86	yes
cube	0.36	yes	cube	0.344	yes	cube	2.103	yes
pentagon	2.134	yes	pentagon	1.843	yes	pentagon	3.672	yes
disk	1.207	yes	disk	0.375	yes	disk	2.147	yes
cube	0.631	yes	cube	0.442	yes	cube	2.044	yes
pentagon	1.74	yes	pentagon	0.54	yes	pentagon	1.7	yes
disk	0.716	yes	disk	0.264	yes	disk	1.624	yes
pentagon	0.927	yes	pentagon	0.402	yes	pentagon	1.474	yes
tube	0.641	yes	tube	0.396	yes	tube	0.505	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	Nan	Nan

Subject U			Subject V			Subject W		
27			29			28		
Male			Female			Female		
Spanish			Italian			German		
Right-handed			Right-handed			Left-handed		
Yes (Myopia)			Yes (Myopia)			Yes (Myopia)		
No			No			No		
Experienced			Experienced			Experienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
pyramid	3.358	yes	pyramid	3.288	yes	pyramid	8.951	yes
tube	3.934	yes	tube	4.998	yes	tube	1.947	yes
pentagon	1.86	yes	pentagon	2.03	yes	pentagon	1.255	yes
pyramid	1.653	yes	pyramid	1.561	yes	pyramid	1.33	yes
pentagon	2.258	yes	pentagon	4.886	yes	pentagon	2.573	yes
disk	3.937	yes	disk	3.876	yes	disk	1.112	yes
pyramid	1.527	yes	pyramid	2.499	yes	pyramid	0.955	yes
cube	1.55	yes	cube	2.533	yes	cube	0.843	yes
disk	1.395	yes	disk	2.627	yes	disk	0.955	yes
tube	1.8	yes	tube	1.567	yes	tube	0.833	yes
pyramid	1.45	yes	pyramid	3.386	yes	pyramid	1.491	yes
cube	1.234	yes	cube	2.185	yes	cube	1.022	yes
tube	1.487	yes	tube	1.313	yes	tube	0.803	yes
pyramid	1.375	yes	pyramid	1.221	yes	pyramid	0.953	yes
pentagon	1.772	yes	pentagon	2.976	yes	pentagon	0.688	yes
pyramid	1.847	yes	pyramid	1.325	yes	pyramid	1.207	yes
disk	1.872	yes	disk	1.941	yes	disk	0.741	yes
pyramid	1.375	yes	pyramid	1.506	yes	pyramid	0.865	yes
pentagon	1.767	yes	pentagon	2.228	yes	pentagon	0.925	yes
disk	2.936	yes	disk	5.646	yes	disk	1.148	yes
cube	1.271	yes	cube	1.492	yes	cube	1.151	yes
tube	1.321	yes	tube	0.746	yes	tube	1.151	yes
cube	2.185	yes	cube	4.352	yes	cube	1.602	yes
disk	1.927	yes	disk	2.146	yes	disk	1.088	yes
cube	1.221	yes	cube	2.54	yes	cube	0.882	yes
pentagon	1.772	yes	pentagon	3.08	yes	pentagon	1.574	yes
disk	1.09	yes	disk	2.642	yes	disk	0.894	yes
cube	1.09	yes	cube	1.025	yes	cube	1.37	yes
pentagon	1.451	yes	pentagon	2.372	yes	pentagon	1.445	yes
disk	1.436	yes	disk	1.458	yes	disk	0.946	yes
pentagon	1.507	yes	pentagon	1.924	yes	pentagon	1.392	yes
tube	1.407	yes	tube	0.854	yes	tube	0.975	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN

Subject X			Subject Y			Subject Z		
31			23			24		
Female			Female			Female		
USA			British			Greek		
Right-handed			Right-handed			Right-handed		
No			No			No		
No			No			No		
Inexperienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	cube	6.393	No
pyramid	15.713	yes	pyramid	3.63	yes	cube	5.569	yes
something moving	20.102	yes	tube	5.327	yes	disk	12.533	yes
pentagon	6	yes	pentagon	2.625	yes	pentagon	5.282	yes
pyramid	3.152	yes	pyramid	0.475	yes	pyramid	2.042	yes
pentagon	6.841	yes	pentagon	2.601	yes	pentagon	2.1	yes
disk	3.777	yes	disk	0.761	yes	disk	1.103	yes
pyramid	6.349	yes	pyramid	1.743	yes	pyramid	1.916	yes
cube	4.247	yes	cube	0.958	yes	cube	0.899	yes
disk	2.234	yes	disk	1.639	yes	disk	0.746	yes
tube	3.998	yes	tube	0.981	yes	tube	1.542	yes
pyramid	2.978	yes	pyramid	0.469	yes	pyramid	1.165	yes
cube	1.686	yes	cube	0.411	yes	cube	0.724	yes
tube	4.34	yes	tube	1.056	yes	tube	1.312	yes
pyramid	1.49	yes	pyramid	0.343	yes	pyramid	0.308	yes
pentagon	4.18	yes	pentagon	1.711	yes	pentagon	0.938	yes
pyramid	2.757	yes	pyramid	0.985	yes	pyramid	1.051	yes
disk	1.489	yes	disk	1	yes	disk	0.796	yes
pyramid	1.13	yes	pyramid	0.609	yes	pyramid	0.552	yes
pentagon	2.815	yes	pentagon	1.333	yes	pentagon	0.746	yes
disk	12.196	yes	disk	3.434	yes	pentagon	3.217	yes
cube	2.31	yes	cube	1.557	yes	cube	0.661	yes
tube	4.612	yes	tube	1.011	yes	tube	1.069	yes
no perception	NaN	NaN	cube	2.722	yes	cube	6.963	yes
disk	4.411	yes	disk	2.984	yes	disk	0.789	yes
cube	2.712	yes	cube	0.804	yes	cube	0.512	yes
pentagon	19.122	yes	pentagon	2.486	yes	pentagon	1.707	yes
disk	2.307	yes	disk	2.123	yes	disk	1.23	yes
cube	1.047	yes	cube	0.744	yes	cube	0.244	yes
pentagon	3.63	yes	pentagon	2.295	yes	pentagon	1	yes
disk	3.405	yes	disk	1.965	yes	disk	0.691	yes
pentagon	3.295	yes	pentagon	1.997	yes	pentagon	0.282	yes
tube	3.314	yes	tube	0.755	yes	tube	0.248	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN

C.3 Repetition Period Data

Position in Playlist	Repetition period (in pixels)	Projected Object
1	10	pyramid
2	10	pentagon
3	80	tube
4	30	disk
5	50	cube
6	16	pyramid
7	20	disk
8	20	cube
9	12	disk
10	40	cube
11	140	tube
12	120	pentagon
13	100	pyramid
14	130	disk
15	**90**	**blank**
16	100	tube
17	12	cube
18	110	pyramid
19	60	tube
20	70	disk
21	90	cube
22	90	disk
23	80	pyramid
24	70	cube
25	60	pentagon
26	16	disk
27	110	tube
28	120	pyramid
29	30	tube
30	40	pentagon
31	130	pyramid
32	140	cube
33	150	disk
34	160	cube
35	50	pentagon
35	150	tube
35	160	pyramid

Table C.3: Projection sequence of autostereogram videos of different repetition period. The fifteenth video is a near blank "truth test" video (see section 3.2.3).

Subject id:	Subject A			Subject B (sees animations inverted)		
Age:	25			22		
Gender:	Male			Male		
Nationality:	Greek			Slovakian		
Handedness:	Right-handed			Right-handed		
Glasses/Eye Contacts:	No			No		
Other known eye/seeing problems:	No			No		
Experience in watching SIRDS:	Experienced			Experienced		
True Object:	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
10pixels_pyramid	pyramid	21.453	Yes	no perception	NaN	NaN
10pixels_pentagon	pentagon	15.716	Yes	no perception	NaN	NaN
80pixels_tube	tube	4.676	Yes	tube	6.117	yes
30pixels_disk	disk	1.498	Yes	disk	4.854	yes
50pixels_cube	cube	0.658	Yes	cube	9.692	yes
16pixels_pyramid	pyramid	8.728	Yes	no perception	NaN	NaN
20pixels_disk	disk	3.769	Yes	no perception	NaN	NaN
20pixels_cube	cube	3.568	Yes	cube	6.511	yes
12pixels_disk	disk	25.726	Yes	no perception	NaN	NaN
40pixels_cube	cube	1.191	Yes	cube	9.42	yes
140pixels_tube	tube	7.71	Yes	tube	5.339	yes
120pixels_pentagon	pentagon	5.801	Yes	pentagon	2.403	yes
100pixels_pyramid	pyramid	6.277	Yes	pyramid	2.521	yes
130pixels_disk	disk	11.564	Yes	disk	3.196	yes
placebo_repetition	no perception	NaN	NaN	no perception	NaN	NaN
100pixels_tube	tube	25.357	Yes	tube	2.244	yes
12pixels_cube	cube	9.746	Yes	no perception	NaN	NaN
110pixels_pyramid	pyramid	3.809	Yes	pyramid	2.04	yes
60pixels_tube	tube	0.761	Yes	tube	8.678	yes
70pixels_disk	disk	4.05	Yes	disk	2.759	yes
90pixels_cube	cube	1.557	Yes	cube	3.438	yes
90pixels_disk	disk	7.426	Yes	disk	2.906	yes
80pixels_pyramid	pyramid	1.011	Yes	pyramid	2.581	yes
70pixels_cube	cube	0.656	Yes	cube	7.024	yes
60pixels_pentagon	pentagon	2.289	Yes	pentagon	2.71	yes
16pixels_disk	disk	2.712	Yes	no perception	NaN	NaN
110pixels_tube	tube	3.538	Yes	tube	4.201	yes
120pixels_pyramid	pyramid	4.107	Yes	pyramid	0.972	yes
30pixels_tube	tube	2.28	Yes	no perception	NaN	NaN
40pixels_pentagon	pentagon	0.758	Yes	pentagon	3.737	yes
130pixels_pyramid	pyramid	8.046	Yes	pyramid	2.493	yes
140pixels_cube	cube	4.517	Yes	cube	3.169	yes
150pixels_disk	disk	7.974	Yes	disk	3.889	yes
160pixels_cube	no perception	NaN	NaN	cube	4.77	yes
50pixels_pentagon	pentagon	0.558	Yes	pentagon	3.563	yes
150pixels_tube	tube	6.295	Yes	tube	4.061	yes
160pixels_pyramid	pyramid	8.23	Yes	pyramid	1.29	yes

Subject C			Subject D			Subject E		
25			27			25		
Female			Female			Male		
Romanian			Greek			Greek		
Right-handed			Right-handed					
Yes (Myopia)			Yes (Myopia)			No		
No			No			No		
Inexperienced			Experienced			Experienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
pyramid	8.055	yes	pyramid	2.563	yes	pyramid	9.464	yes
pentagon	22.421	yes	pentagon	4.769	yes	pentagon	3.786	yes
tube	1.57	yes	tube	0.442	yes	tube	1.549	yes
disk	2.099	yes	disk	1.702	yes	disk	2.025	yes
cube	1.215	yes	cube	1.036	yes	cube	1.848	yes
pyramid	1.172	yes	pyramid	0.828	yes	pyramid	1.985	yes
disk	3.029	yes	disk	1.418	yes	disk	1.938	yes
cube	1.673	yes	cube	1.753	yes	cube	2.153	yes
pyramid	11.746	yes	disk	7.173	yes	disk	1.763	yes
cube	1.303	yes	cube	4.232	yes	cube	1.468	yes
tube	5.795	yes	no perception	NaN	NaN	tube	3.966	yes
pentagon	1.92	yes	pentagon	1.981	yes	pentagon	1.691	yes
pyramid	1.276	yes	pyramid	0.389	yes	pyramid	1.23	yes
disk	1.707	yes	disk	1.767	yes	disk	1.541	yes
no perception	NaN	NaN	no perception	NaN	Nan	no perception	NaN	NaN
tube	1.783	yes	tube	0.414	yes	tube	1.121	yes
cube	12.932	yes	cube	5.678	yes	cube	2.814	yes
pyramid	1.264	yes	pyramid	0.959	yes	pyramid	1.889	yes
tube	1.628	yes	tube	0.373	yes	tube	1.438	yes
disk	3.614	yes	disk	0.41	yes	disk	1.074	yes
cube	1.181	yes	cube	0.922	yes	cube	1.145	yes
disk	4.708	yes	disk	0.964	yes	disk	1.148	yes
pyramid	1.44	yes	pyramid	0.31	yes	pyramid	1.125	yes
cube	1.098	yes	cube	0.302	yes	cube	1.391	yes
pentagon	1.588	yes	pentagon	0.356	yes	pentagon	1.511	yes
disk	18.301	yes	disk	2.402	yes	disk	2.517	yes
tube	1.333	yes	tube	1.53	yes	tube	2.076	yes
pyramid	1.05	yes	pyramid	1.476	yes	pyramid	1.608	yes
tube	1.866	yes	tube	0.649	yes	tube	2.055	yes
pentagon	1.578	yes	pentagon	0.603	yes	pentagon	1.292	yes
pyramid	1.143	yes	pentagon	30.492	yes	pyramid	2.654	yes
cube	0.81	yes	cube	1.333	yes	cube	2.053	yes
disk	1.805	yes	disk	2.733	yes	disk	1.613	yes
cube	1.246	yes	cube	1.627	yes	cube	2.076	yes
pentagon	1.401	yes	pentagon	0.492	yes	pentagon	1.365	yes
tube	1.423	yes	tube	1.418	yes	tube	2.233	yes
pyramid	0.795	yes	pyramid	2.372	yes	pyramid	2.564	yes

Subject F			Subject G			Subject H		
57			31			27		
Male			Male			Male		
USA			British			Chinese		
Right-handed			Right-handed			Right-handed		
Yes (Myopia)			Yes (Myopia)			Yes (Myopia)		
No			No			No		
Experienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
pyramid	13.13	yes	pyramid	15.127	yes	no perception	NaN	NaN
no perception	NaN	NaN	pentagon	16.954	yes	something moving	15.658	yes
tube	3.858	yes	tube	1.583	yes	tube	2.072	yes
disk	2.061	yes	disk	0.566	yes	disk	3.754	yes
cube	1.327	yes	cube	0.636	yes	cube	3.141	yes
pyramid	6.287	yes	something moving	2.888	yes	pyramid	10	yes
disk	3.091	yes	disk	1.771	yes	disk	3.392	yes
cube	19.223	yes	cube	1.974	yes	cube	8.681	yes
disk	15.295	yes	disk	6.063	yes	something moving	9.027	yes
cube	1.76	yes	cube	2.022	yes	cube	3.221	yes
no perception	NaN	NaN	tube	18.043	yes	no perception	NaN	NaN
pentagon	3.921	yes	pentagon	0.386	yes	no perception	NaN	NaN
pyramid	3.528	yes	pyramid	0.503	yes	pyramid	5.823	yes
disk	5.298	yes	disk	3.336	yes	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
tube	1.179	yes	tube	0.539	yes	tube	3.378	yes
no perception	NaN	NaN	cube	11.434	yes	cube	13.679	yes
pyramid	1.231	yes	pyramid	0.715	yes	no perception	NaN	NaN
tube	2.163	yes	tube	1.619	yes	tube	1.965	yes
disk	1.753	yes	disk	0.796	yes	disk	2.271	yes
cube	1.123	yes	cube	0.525	yes	cube	3.462	yes
disk	1.049	yes	disk	0.67	yes	disk	3.482	yes
pyramid	0.987	yes	pyramid	0.339	yes	pyramid	2.717	yes
cube	1.163	yes	cube	1.603	yes	cube	2.213	yes
pentagon	1.405	yes	pentagon	1.498	yes	pentagon	2.773	yes
disk	4.877	yes	disk	3.352	yes	disk	8.038	yes
tube	1.945	yes	tube	1.141	yes	no perception	NaN	NaN
pyramid	1.352	yes	pyramid	1.341	yes	no perception	NaN	NaN
tube	3.59	yes	tube	0.93	yes	tube	2.076	yes
pentagon	1.748	yes	pentagon	0.907	yes	pentagon	2.663	yes
no perception	NaN	NaN	pyramid	3.166	yes	no perception	NaN	NaN
cube	1.235	yes	cube	2.626	yes	no perception	NaN	NaN
disk	3.899	yes	disk	2.991	yes	no perception	NaN	NaN
cube	2.905	yes	cube	1.24	yes	no perception	NaN	NaN
pentagon	1.231	yes	pentagon	1.06	yes	pentagon	3.236	yes
tube	4.378	yes	tube	3.05	yes	no perception	NaN	NaN
pyramid	3.19	yes	pyramid	2.186	yes	no perception	NaN	NaN

Subject I			Subject J			Subject K		
25			25			23		
Male			Male			Male		
Greek			Scotish			British		
Left-handed			Right-handed			Right-handed		
Yes (Myopia)			No			No		
No			slight stigmatism			No		
Experienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
no perception	NaN	NaN	something moving	5.287	yes	something moving	25.468	yes
no perception	NaN	NaN	pentagon	5.777	yes	something moving	13.472	yes
tube	1.199	yes	tube	0.63	yes	tube	33.07	yes
disk	4.286	yes	disk	1.617	yes	disk	1.886	yes
cube	2.289	yes	cube	3.082	yes	cube	2.375	yes
pyramid	7.502	yes	pyramid	3.522	yes	pyramid	1.951	yes
disk	8.468	yes	disk	2.42	yes	disk	1.892	yes
something moving	15.015	yes	cube	4.767	yes	cube	10.237	yes
no perception	NaN	NaN	disk	3.63	yes	disk	3.896	yes
cube	2.018	yes	cube	2.233	yes	cube	2.394	yes
tube	3.555	yes	tube	3.503	yes	no perception	NaN	NaN
pentagon	2.161	yes	pentagon	0.743	yes	pentagon	32.351	yes
pyramid	1.183	yes	pyramid	0.8	yes	pyramid	1.406	yes
disk	3.116	yes	disk	1.244	yes	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
tube	1.093	yes	tube	1.079	yes	tube	1.341	yes
no perception	NaN	NaN	cube	3.439	yes	cube	10.41	yes
pyramid	2.402	yes	pyramid	1.411	yes	pyramid	2.183	yes
tube	3.088	yes	tube	0.911	yes	tube	1.103	yes
disk	1.13	yes	disk	1.01	yes	disk	1.111	yes
cube	1.256	yes	cube	1.358	yes	cube	0.792	yes
disk	1.506	yes	disk	0.801	yes	disk	1.085	yes
pyramid	0.869	yes	pyramid	2.656	yes	pyramid	0.648	yes
cube	0.953	yes	cube	1.511	yes	cube	1.317	yes
pentagon	1.085	yes	pentagon	1.084	yes	pentagon	1.264	yes
something moving	13.32	yes	disk	2.704	yes	disk	4.861	yes
tube	2.557	yes	tube	1.192	yes	tube	5.767	yes
pyramid	2.647	yes	pyramid	1.037	yes	pyramid	11.121	yes
tube	1.213	yes	tube	1.901	yes	tube	1.82	yes
pentagon	2.184	yes	pentagon	3.04	yes	pentagon	1.546	yes
pyramid	3.367	yes	pyramid	2.191	yes	no perception	NaN	NaN
cube	1.906	yes	cube	1.323	yes	something moving	19.442	yes
disk	2.994	yes	disk	1.717	yes	something moving	32.789	yes
cube	3.226	yes	cube	1.463	yes	something moving	36.519	yes
pentagon	1.456	yes	pentagon	1.054	yes	pentagon	1.46	yes
tube	3.057	yes	tube	3.127	yes	something moving	23.996	yes
pyramid	4.29	yes	pyramid	1.954	yes	something moving	16.871	yes

Subject L			Subject M			Subject N		
24			22			23		
Male			Female			Female		
Indian			English			British		
Right-handed			Right-handed			Right-handed		
Yes (Myopia)			No			No		
No			No			No		
Inexperienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
no perception	NaN	NaN	pyramid	9.928	yes	no perception	NaN	NaN
no perception	NaN	NaN	pentagon	3.439	yes	something moving	4.958	yes
tube	0.495	yes	tube	0.951	yes	tube	1.269	yes
disk	2.791	yes	disk	1.794	yes	no perception	NaN	NaN
cube	2.288	yes	cube	0.732	yes	cube	15.7	yes
no perception	NaN	NaN	pyramid	4.424	yes	pyramid	18.963	yes
something moving	7.193	yes	disk	1.3	yes	no perception	NaN	NaN
no perception	NaN	NaN	cube	1.436	yes	no perception	NaN	NaN
no perception	NaN	NaN	disk	3.678	yes	something moving	8.825	yes
cube	6.141	yes	cube	2.415	yes	cube	18.313	yes
tube	2.271	yes	tube	10.741	yes	no perception	NaN	NaN
pentagon	1.305	yes	pentagon	4.29	yes	no perception	NaN	NaN
pyramid	1.175	yes	pyramid	0.974	yes	pyramid	0.783	yes
disk	4.496	yes	disk	1.58	yes	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
tube	1.41	yes	tube	1.836	yes	tube	1.136	yes
no perception	NaN	NaN	cube	12.26	yes	no perception	NaN	NaN
pyramid	2.795	yes	pyramid	8.76	yes	no perception	NaN	NaN
tube	2.05	yes	tube	0.551	yes	tube	1.098	yes
disk	1.698	yes	disk	1.033	yes	disk	0.95	yes
cube	1.071	yes	cube	1.334	yes	cube	2.177	yes
disk	1.807	yes	disk	0.968	yes	disk	0.894	yes
pyramid	1.307	yes	pyramid	0.808	yes	pyramid	0.715	yes
cube	1.125	yes	cube	0.745	yes	no perception	NaN	NaN
pentagon	1.435	yes	pentagon	0.976	yes	pentagon	3.526	yes
no perception	NaN	NaN	disk	2.035	yes	no perception	NaN	NaN
tube	1.176	yes	tube	2.864	yes	tube	2.093	yes
pyramid	1.743	yes	pyramid	1.725	yes	pyramid	19.364	yes
tube	2.867	yes	tube	0.806	yes	tube	19.523	yes
pentagon	2.944	yes	pentagon	1.088	yes	pentagon	1.86	yes
something moving	16.851	yes	pyramid	1.863	yes	no perception	NaN	NaN
cube	15.103	yes	cube	1.762	yes	no perception	NaN	NaN
disk	4.368	yes	disk	1.927	yes	no perception	NaN	NaN
cube	6.806	yes	cube	1.886	yes	no perception	NaN	NaN
pentagon	3.865	yes	pentagon	0.837	yes	pentagon	0.921	yes
tube	9.84	yes	tube	2.987	yes	no perception	NaN	NaN
pyramid	15.424	yes	pyramid	16.138	yes	no perception	NaN	NaN

Subject O			Subject P			Subject Q		
22			27			20		
Female			Male			Male		
Slovakian			Polish			British		
Right-handed			Right-handed			Left-handed		
No			No			No		
No			No			color blind (red,green)		
Inexperienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
no perception	NaN	NaN	pyramid	18.87	yes	no perception	10.055	yes
pentagon	26.775	yes	pentagon	27.302	yes	no perception	10.444	yes
tube	3.031	yes	tube	0.441	yes	tube	1.874	yes
disk	6.305	yes	disk	1.511	yes	something moving	4.306	yes
cube	5.233	yes	cube	1.423	yes	cube	2.708	yes
pyramid	6.811	yes	pyramid	2.288	yes	pyramid	6.373	yes
disk	7.421	yes	disk	2.162	yes	disk	9.663	yes
cube	15.079	yes	cube	6.882	yes	cube	3.65	yes
disk	13.27	yes	disk	14.511	yes	no perception	10.598	yes
cube	11.376	yes	cube	0.669	yes	cube	3.177	yes
tube	5.14	yes	pyramid	12.04	yes	no perception	NaN	NaN
pentagon	5.749	yes	pentagon	1.227	yes	no perception	NaN	NaN
pyramid	3.06	yes	pyramid	0.551	yes	no perception	NaN	NaN
disk	4.998	yes	disk	1.774	yes	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
tube	3.945	yes	tube	0.52	yes	tube	1.591	yes
cube	16.964	yes	cube	30.196	yes	cube	24.284	yes
pyramid	4.288	yes	pyramid	1.154	yes	pyramid	6.973	yes
tube	5.471	yes	tube	0.592	yes	tube	1.868	yes
disk	3.455	yes	disk	1.158	yes	disk	1.403	yes
cube	4.239	yes	cube	0.566	yes	cube	1.748	yes
disk	2.252	yes	disk	0.437	yes	disk	2.835	yes
pyramid	2.403	yes	pyramid	0.273	yes	pyramid	1.379	yes
cube	4.323	yes	cube	0.951	yes	cube	1.571	yes
pentagon	4.623	yes	pentagon	0.816	yes	pentagon	4.182	yes
pentagon	13.649	yes	disk	9.86	yes	disk	21.247	yes
tube	2.609	yes	tube	1.801	yes	tube	3.581	yes
pyramid	3.038	yes	pyramid	7.301	yes	pyramid	4.652	yes
tube	6.294	yes	tube	0.477	yes	tube	2.451	yes
pentagon	6.857	yes	pentagon	0.773	yes	pentagon	1.431	yes
pyramid	4.055	yes	no perception	NaN	NaN	pyramid	4.376	yes
cube	3.875	yes	cube	5.183	yes	cube	5.929	yes
disk	6.994	yes	no perception	NaN	NaN	disk	3.042	yes
cube	3.141	yes	cube	16.996	yes	cube	7.511	yes
pentagon	3.796	yes	pentagon	0.69	yes	pentagon	2.72	yes
tube	2.75	yes	tube	4.35	yes	tube	5.063	yes
pyramid	4.3	yes	pyramid	8.751	yes	pyramid	4.683	yes

Subject R			Subject S			Subject T		
24			50			19		
Male			Male			Male		
Chinese			Colombian			Chinese		
Right-handed			Left-handed			Right-handed		
No			Yes (Myopia)			No		
No			No			No		
Inexperienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
no perception	NaN	NaN	pyramid	4.521	yes	no perception	Nan	Nan
no perception	NaN	NaN	pentagon	10.95	yes	no perception	Nan	Nan
tube	1.185	yes	tube	0.406	yes	tube	2.073	yes
disk	3.514	yes	disk	3.486	yes	disk	2.64	yes
cube	6.528	yes	cube	0.258	yes	cube	2.556	yes
pyramid	4.938	yes	pyramid	0.515	yes	pyramid	7.925	yes
disk	5.864	yes	disk	1.029	yes	disk	5.255	yes
cube	4.834	yes	cube	2.925	yes	cube	12.454	yes
disk	19.364	yes	disk	5.543	yes	no perception	Nan	Nan
cube	0.86	yes	cube	0.948	yes	cube	2.376	yes
pyramid	26.427	yes	no perception	NaN	NaN	no perception	Nan	Nan
no perception	NaN	NaN	pentagon	0.819	yes	pentagon	29.245	yes
pyramid	0.866	yes	pyramid	0.327	yes	pyramid	1.744	yes
disk	37.589	yes	disk	0.764	yes	no perception	Nan	Nan
no perception	NaN	NaN	no perception	NaN	NaN	no perception	Nan	Nan
tube	0.815	yes	tube	0.316	yes	tube	1.362	yes
cube	32.188	yes	cube	13.445	yes	no perception	Nan	Nan
pyramid	0.996	yes	pyramid	0.694	yes	pyramid	9.363	yes
tube	1.817	yes	tube	0.343	yes	tube	5.058	yes
disk	1.698	yes	disk	0.679	yes	disk	1.431	yes
cube	1.212	yes	cube	0.411	yes	cube	2.339	yes
disk	0.442	yes	disk	0.375	yes	disk	1.661	yes
pyramid	0.211	yes	pyramid	0.512	yes	pyramid	1.605	yes
cube	0.448	yes	cube	0.479	yes	cube	1.754	yes
pentagon	0.707	yes	pentagon	0.706	yes	pentagon	2.076	yes
disk	9.407	yes	disk	10.031	yes	no perception	Nan	Nan
tube	11.396	yes	tube	1.385	yes	tube	2.987	yes
pyramid	1	yes	pyramid	0.334	yes	no perception	Nan	Nan
tube	3.274	yes	tube	1.573	yes	tube	2.412	yes
pentagon	2.233	yes	pentagon	0.401	yes	pentagon	2.169	yes
pyramid	7.091	yes	pyramid	2.331	yes	pyramid	33.24	yes
cube	6.1	yes	cube	0.412	yes	cube	32.405	yes
no perception	NaN	NaN	disk	1.289	yes	no perception	Nan	Nan
no perception	NaN	NaN	cube	1.133	yes	cube	19	yes
pentagon	0.487	yes	pentagon	0.791	yes	pentagon	1.074	yes
no perception	NaN	NaN	tube	1.809	yes	tube	24.569	yes
no perception	NaN	NaN	pyramid	1.336	yes	pyramid	12.965	yes

Subject U			Subject V			Subject W		
27			29			28		
Male			Female			Female		
Spanish			Italian			German		
Right-handed			Right-handed			Left-handed		
Yes (Myopia)			Yes (Myopia)			Yes (Myopia)		
No			No			No		
Experienced			Experienced			Experienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
no perception	NaN	NaN	pyramid	23.985	yes	something moving	12.825	yes
pentagon	8.066	yes	pentagon	26.582	yes	something moving	12.166	yes
tube	2.346	yes	tube	1.42	yes	tube	1.302	yes
disk	2.453	yes	disk	2.902	yes	disk	0.958	yes
cube	1.198	yes	cube	1.949	yes	cube	1.119	yes
pyramid	6.039	yes	pyramid	4.063	yes	pyramid	2.312	yes
disk	2.454	yes	disk	4.229	yes	disk	1.586	yes
cube	4.546	yes	cube	9.219	yes	cube	7.602	yes
disk	3.213	yes	disk	9.077	yes	disk	3.924	yes
cube	1.905	yes	cube	2.252	yes	cube	0.866	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
pentagon	9.063	yes	pyramid	18.086	yes	no perception	NaN	NaN
pyramid	1.544	yes	pyramid	0.779	yes	pyramid	10.122	yes
disk	2.772	yes	no perception	NaN	NaN	disk	5.802	yes
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
tube	1.569	yes	tube	1.828	yes	tube	1.639	yes
no perception	NaN	NaN	cube	16.843	yes	cube	18.753	yes
pyramid	3.22	yes	no perception	NaN	NaN	pyramid	3.54	yes
tube	1.179	yes	tube	1.79	yes	tube	1.117	yes
disk	1.65	yes	disk	1.903	yes	disk	0.999	yes
cube	1.158	yes	cube	1.556	yes	cube	1.567	yes
disk	1.487	yes	disk	1.148	yes	disk	1.778	yes
pyramid	1.206	yes	pyramid	1.688	yes	pyramid	1.244	yes
cube	1.283	yes	cube	1.283	yes	cube	0.955	yes
pentagon	1.161	yes	pentagon	1.718	yes	pentagon	0.829	yes
disk	3.531	yes	disk	4.2	yes	disk	2.292	yes
tube	3.963	yes	tube	5.479	yes	tube	4.122	yes
pyramid	2.911	yes	pyramid	1.333	yes	pyramid	2.287	yes
tube	1.815	yes	tube	1.991	yes	tube	1.769	yes
pentagon	1.213	yes	pentagon	1.492	yes	pentagon	1.038	yes
pyramid	4.994	yes	no perception	NaN	NaN	pyramid	4.418	yes
cube	2.247	yes	no perception	NaN	NaN	cube	2.341	yes
disk	5.529	yes	no perception	NaN	NaN	disk	2.875	yes
cube	2.03	yes	no perception	NaN	NaN	cube	2.72	yes
pentagon	1.466	yes	pentagon	1.802	yes	pentagon	1.1	yes
tube	3.369	yes	no perception	NaN	NaN	tube	2.722	yes
pyramid	4.9	yes	no perception	NaN	NaN	pyramid	4.672	yes

Subject X			Subject Y			Subject Z		
31			23			24		
Female			Female			Female		
USA			British			Greek		
Right-handed			Right-handed			Right-handed		
No			No			No		
No			No			No		
Inexperienced			Experienced			Inexperienced		
Object perceived:	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**	**Object perceived:**	**Time to perceive it:**	**Stable perception:**
something moving	30.384	yes	pyramid	20.143	yes	pyramid	3.938	yes
no perception	NaN	NaN	pentagon	16.367	yes	no perception	NaN	NaN
tube	1.029	yes	tube	1.378	yes	tube	0.478	yes
disk	4.46	yes	disk	3.444	yes	disk	0.48	yes
cube	1.778	yes	cube	3.363	yes	cube	0.463	yes
pyramid	8.133	yes	pyramid	0.752	yes	pyramid	0.493	yes
disk	8.269	yes	disk	2.816	yes	disk	1.194	yes
cube	20.51	yes	cube	8.013	yes	cube	1.511	yes
something moving	28.471	yes	disk	4.514	yes	disk	2.612	yes
cube	6.766	yes	cube	1.894	yes	cube	1	yes
tube	3.363	yes	tube	1.838	yes	no perception	NaN	NaN
pentagon	2.524	yes	pentagon	2.021	yes	disk	23.942	yes
pyramid	1.877	yes	pyramid	0.746	yes	pyramid	2.448	yes
disk	4.179	yes	disk	2.02	yes	no perception	NaN	NaN
no perception	NaN	NaN	no perception	NaN	NaN	no perception	NaN	NaN
tube	1.688	yes	tube	1.718	yes	tube	1.049	yes
something moving	19.659	yes	cube	5.127	yes	cube	9.819	yes
pyramid	1.412	yes	pyramid	1.527	yes	pyramid	2.083	yes
tube	1.988	yes	tube	0.901	yes	tube	0.472	yes
disk	3.228	yes	disk	1.413	yes	disk	0.548	yes
cube	1.121	yes	cube	0.945	yes	cube	0.38	yes
disk	1.945	yes	disk	0.824	yes	disk	0.449	yes
pyramid	1.09	yes	pyramid	1.614	yes	pyramid	0.181	yes
cube	0.994	yes	cube	2.38	yes	cube	0.172	yes
pentagon	1.199	yes	pentagon	3.47	yes	pentagon	0.356	yes
disk	4.288	yes	disk	3.809	yes	disk	0.846	yes
tube	1.07	yes	tube	1.254	yes	tube	0.526	yes
pyramid	0.601	yes	pyramid	0.946	yes	pyramid	15.588	yes
tube	1.7	yes	tube	5.238	yes	tube	1.376	yes
pentagon	2.366	yes	pentagon	1.563	yes	pentagon	0.416	yes
pyramid	0.92	yes	pyramid	2.143	yes	pyramid	5.59	yes
cube	3.827	yes	cube	2.853	yes	no perception	NaN	NaN
disk	1.825	yes	disk	2.633	yes	disk	20.963	yes
cube	1.363	yes	cube	2.95	yes	cube	23.627	yes
pentagon	1.985	yes	pentagon	2.639	yes	pentagon	0.848	yes
tube	3.472	yes	tube	3.584	yes	no perception	NaN	NaN
pyramid	1.1	yes	pyramid	3.754	yes	pyramid	10.741	yes

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