Eye Tracking with Stereoscopic Images

Punit Seth
Clemson University

Dhaval Shah
Clemson University

Eamon Moore
Clemson University

Abstract

Stereograms have been around for hundreds of years. They have evolved from two images being superimposed, to a single image with the same effect. With the emerging eye tracking technology, an understanding of how participants view stereograms can be formed. Furthermore, analysis can be done to see if a specific pattern of vergence is evident when viewing stereograms. The researchers hypothesize that divergence is the key strategy used regardless of conditions when viewing stereograms. The experiment consists of a placebo group, which views a nonstereo image, and an experimental group, which views a stereogram. Contrary to our hypothesis, the results indicated that convergence is actually the pattern that is used; however, there was not a significant difference between conditions which partially supports our hypothesis. These results can be used in areas of marketing, where exploring the third dimension for advertising is becoming a hot topic. In the future various areas such as three-dimensional coordinates, gender variations, and other characteristics of the eyes can be examined.

Keywords: convergence, divergence, baseline, placebo group, experimental group, ANOVA, stereogram

1. Introduction

A stereoscopic image or stereogram [7] is an optical illusion of depth brought into appearance by focusing ones eyes in front of or behind the image one is looking at. Human eyes are set about two-and-a-half inches apart, so each eye is able to view an image slightly differently which gives us our perception of depth. Stereograms are usually seen by a parallel viewing method known as divergence [4]. However, some are still not able to see the hidden images within the stereogram.

With the use of eye trackers, one is able to follow the eye movements and record the gaze coordinates. This functionality proves to be helpful in determining what general method a person uses to view a stereogram. Also, data analysis from participants that are not able to view the stereogram could be compared to those who are able to view the image and find a possible cause for the problem.

The best way to examine what method the participant uses to view the images is to measure the divergence or convergence distance between the eyes. This distance can then be compared and analyzed to the normal eye distance previously acquired. After obtaining this information from experiments ran with multiple participants, the researchers expect to corroborate divergence with the results. Different conditions can be evaluated, such as a placebo group versus an experimental group, where a random dot image and a stereogram could be used as stimuli respectively. This would show whether the stimulus has a significant effect on the viewing strategy adopted by the user (convergence or divergence).

Why is it necessary to understand how participants view stereograms? One study [1] mentioned that marketers and researches were constantly trying to discover new ways of displaying visual information. Attempts were being made to utilize one's ability to see three-dimensional effects in advertisements or other visual displays. Three-dimensional effects helped to enrich data interpretation and add a strategic element to marketing campaigns.

The study concluded that marketers will be able to enhance vividness, clarity, realism, and depth of visual representations with the use of stereograms. Therefore, as we learn more about how participants view stereograms, research that studies useful applications of stereograms will become more practical.

The null hypothesis for our particular experiment was that there will not be a statistically significant change in the distance of the eyes when viewing stereograms. The alternate hypothesis was that there will be a significant change that will yield a divergence of the eyes, regardless of whether the participant is in the experimental or placebo condition.

1.2 Background

Since each eye acquires its own scene representation, two different pictures are sent to the brain for processing. When the two images arrive concurrently in the back of the brain, they are merged to create a single image. The mind combines the two images by matching up the similarities and adding in the small distinctions. The small variation between the two pictures creates a significant difference in the final picture. Therefore, the combined picture is not simply a merging of the two pictures, but an actual three dimensional image that is called stereo [6].

The word "stereo" comes from the Greek word "stereos" which means firm or solid. Stereo vision allows you to see objects as solids in the dimensions of width, height, and depth. These dimensions can be represented with x, y, and z coordinate axes respectively. What distinguishes stereo images from two-dimensional images is the added element of depth which allows stereo images to be highly detailed [6].

Stereoscopic vision may have evolved as a means of survival. Stereo vision allows us to be able to locate our bodies relative to those objects that are moving in the depth dimension. Stereo vision also enables us to see around objects without moving the head. It also permits empty space to be measured through image processing in the brain.

The idea of stereoscopy preceded photography, which was invented in 1827 [10]. While most people are familiar with popular stereograms created by the *Magic Eye*®, drawings were made much earlier by Giovanni Battista della Porta in the late 1500s. During the same period Empoli produced drawings side by side which clearly indicated his understanding of binocular vision. He found that if one took two separate photographs that were the same distance apart, it would be possible to recreate the illusion of depth which resembles a present day stereogram. The down side of recreating depth in this manner is that two pictures are needed. In a speech given by Jesuit d'Aguillion in 1613, d'Aguillion coined the word "stéréoscopique" [14]. This referred to the earlier images that used s*tereopsis,* the vision of the third dimension known as depth, by comparing the differences of the images that each eye produced.

After these photos were created, the use of three-dimensional glasses (red filter for the left eye blue filter for the right eye) to view images with depth were adopted. This was demonstrated in 1838 by Wheatstone [13]. *Figure 1.1* (below) illustrates a floating box image which can be viewed by three dimensional glasses.

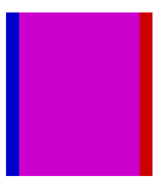


Figure 1.1. Example of stereo image viewed by three dimensional glasses

Julesz created the first modern stereogram in 1959 by producing an image for the left eye and transforming it to create another image for the right eye. The left eye saw the original image, while the right eye saw the transformed image. These images were then fused together by the brain to create an image that appeared to be multidimensional. This example can be seen in *Figure 1.2* (next column), where one image is transformed into another by taking a square sample from the image and moving it to another part of the same image (overlapping where needed) and then filling in the rest of the image with random dots [11].

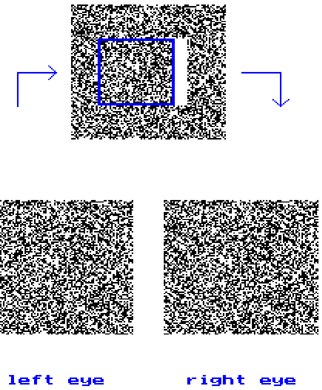


Figure 1.2. Example of Julesz's method for creating the first modern stereogram

Julesz designed an experiment [11] to test one's ability to perceive three dimensional images. Since Julesz used randomly distributed dots, he eliminated depth necessities in the picture that are in nonstereo images.

In 1979, a student of Julesz, Tyler discovered that the offset idea could be applied to a single image. Tyler then created the first black and white, single image, random dot stereogram shown in Figure 1.3 (below) [11].

Figure 1.3. Random Dot Stereogram

In 1991, Baccei and Smith wanted to improve on the research of Julesz. With the help of Salitsky, they developed the first colored stereogram program. This eliminated the need for dots. The new program in conjunction with three-dimensional modeling software, led to the development of *Magic Eye®* [11] which was first released in 1996.

In order for an individual to have depth perception, one must have the ability to use both eyes. Most people that have depth perception are able to see stereograms. On the other hand, individuals with impaired depth perception or a single dominant eye have more difficulty seeing stereograms. In some cases, they are not able to see them at all.

1.3. Previous Research

There is not much research available that specifically deals with stereograms and eye tracking. However, one such study, *Tracking of Eye Movements and Visual Attention*, was conducted by the Neuroinformatics Group at Bielefeld University [8]. The group concentrated on vergence eye movements using stereograms in a manner similar to the analysis that will be presented in this paper. The purpose of the experiment was to examine the influence of granularity of stereogram images on vergence movements.

The Neuroinformatics Group decided to use eight students that were experienced in viewing stereograms. Ten stereograms were used showing two horizontally divided half planes at different distances. These images varied in their granularities (1, 2, 4, 8 and 12) and were presented in random order. When the participant realized the three-dimensional impression, he/she had to change his/her views from one plane to the other every couple of seconds. The factor in this stereoscopic experiment was the granularity of the stereograms as shown in *Figure 1.4* (below) [8].

a)

b)

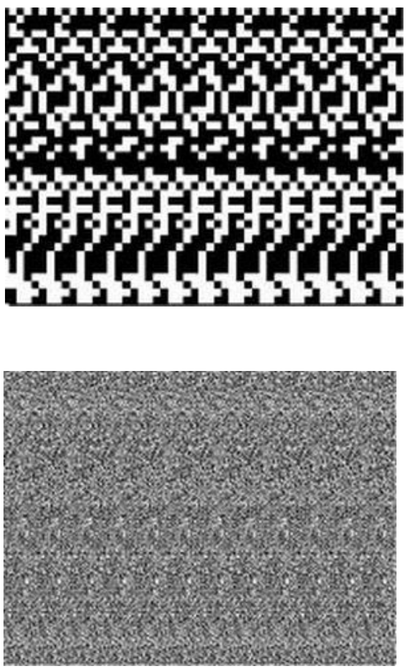


Figure 1.4. a) coarse granularity image b) stereogram image.

The Neuroimformatics Group concluded that participants have problems achieving a stable three-dimensional perception for large grain sizes, while stereogram images with granularities two and four brought out the most stable three dimensional perceptions. They also concluded that convergence movements are faster than divergence movements, and that vergence mechanisms can clearly be driven by relatively high frequencies (fine granularities). In addition, they found that divergence movements were completed more quickly for coarse granularities than for fine ones [8].

Another study was the Varrier^{TM} Auto-Stereographic Display [15]. The Electronic Visualization Laboratory at the University of Illinois at Chicago concentrates on many different areas of eye tracking including stereographic display.

The Electronic Visualization Laboratory performed their experiment by providing a means for modern computer graphics hardware to perform real-time image generation given any viewpoint. This was done by showing the image through a line screen placed over an LCD display. The user wore a three-dimensional head tracking system to update the computer on his/her current viewpoint, thus allowing the computer to generate the new interleaved image to provide the expected view [15].

Some advantages to this experiment included: the method, which had automatic correction for the instantaneous position of the viewer, a non-uniform line screen, no cumbersome glasses were needed, and the compatibility with LCD panels. Neither the virtual nor the physical barrier strips need to be binary or uniform. They can be fuzzy or randomly positioned. The disadvantages were that this method created a lower resolution and high sensitivity to tracker latencies and errors. In addition, a non-tracked viewer of the display will see images that change from stereo to pseudostereo as the tracked viewer moves.

One study conducted by the physiology department at the Neuroscience Institute [2] offered some insight about vergence eye movements. The study discussed the dynamics of horizontal and vertical vergence eye movements by using random dot patterns and tracing the vergence eye patterns. The purpose of the study was to understand the relationship between horizontal and vertical vergence given different behavioral conditions. The study showed that horizontal eye movements were of more importance than vertical eye movements. While there was an interaction between both horizontal and vertical eye movements, the study indicated that vertical vergence dynamics are inferior to horizontal vergence. For this reason, it was decided to only focus on horizontal vergence in this experiment.

Another experiment conducted at the School of Electrical and Electronic Engineering at the University of Nottingham [3], designed a program to create stereograms and examined how they were actually viewed. While research is still being conducted, it has sparked interest from advertising and news agencies as well as educational institutions. For this reason along with past research that has already been discussed, the researchers were able to conclude that the proposed stereogram experiment given in this paper is important since there is an interest in areas of business and academia. Tracking each eye separately while calculating vergence distance will provide new insight that will prove useful for further research.

2 Apparatus

The Tobii system is a video-based combined pupil and corneal reflection eye tracker. It runs on a 2.4GHz central processing unit with 256 MB RAM on a Windows XP platform in conjunction with Red Hat Linux Release 9, Version 2.4.20. Each operating system is run on a separate Dell machine. For usability purposes, there is a dual monitor setup which allows for an extended desktop as shown in *Figure 2.1* (next page). The Tobii eye tracker has a sampling rate of 50 hertz and an accuracy of one degree visual angle. In addition to the chipset, a firewire card which is also required for the eye-tracking system along with either an USB port or a nine-pin serial port is included. The Tobii system is also complete with two monitors; although, this is not required for the system to work. The Tobii eye-tracking system implements all of the eye tracking and gaze positioning automatically using the hardware and complex algorithms that are provided. The setup of the eye tracking hardware is summarized below in *Figure 2.1* and *Figure 2.2* (below).

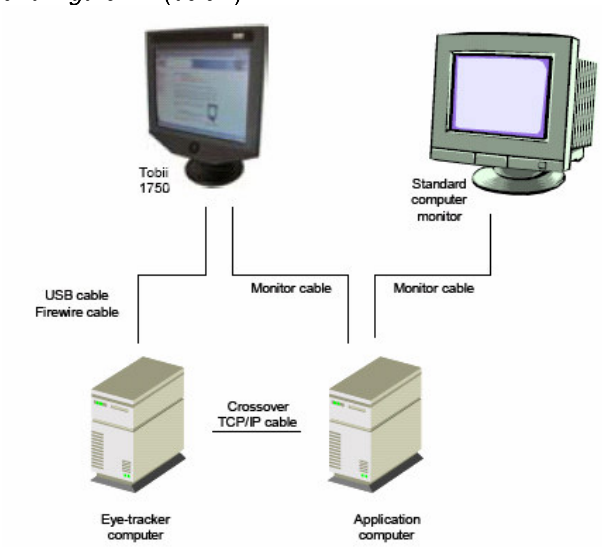


Figure 2.1 Double computer, double screen configuration for Tobii system [16]

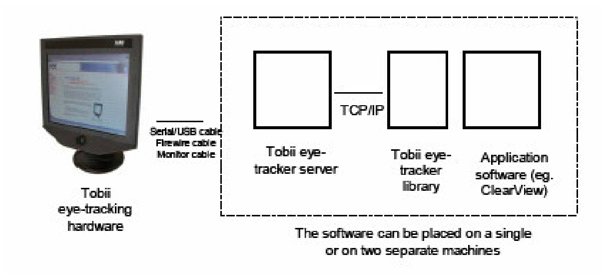


Figure 2.2 Overview of Tobii system [16]

3 Experimental Design

A between-subjects manipulation of the experimental analysis was implemented. Two conditions were created, where one consisted of an experimental group that was shown a stereogram, and the other was a placebo group that was shown a nonstereo image. The two conditions serve as the independent variable, while the resulting vergence is the dependent variable. Ten participants were used, which is a minimum rule of thumb for conducting statistical analysis. All participants were shown the control image to serve as a baseline to determine the normal distance between their eyes. Five students were then shown a stereogram, while the other five were shown a nonstereo, random dot image to serve as a placebo study. The baseline results were then compared to the experimental and placebo group results in order to discover whether a true pattern of vergence existed.

3.1 Participants

Ten college students, eight men and two women, ranging from the ages of nineteen to twenty (M= 19.7, S= 0.483) participated in this experiment. They were randomly chosen by a volunteer basis.

3.2 Stimulus

The control image that was used was a plain checkerboard image which is shown in *Figure 3.1a (next column)*. This was chosen as the control image because it does not contain any cues within the image that would cause a subject to converge or diverge his/her eyes. *Figure 3.1b* (below) shows the stereogram image that was shown to the real group. The stereogram contains a three-dimensional impression of a snowman. Finally, *Figure 3.1c* (below) shows the nonstereo image that was shown to the placebo group. It consists of a colored random dot sequence that appears similar to the snowman stereogram.

a)

b)

c)

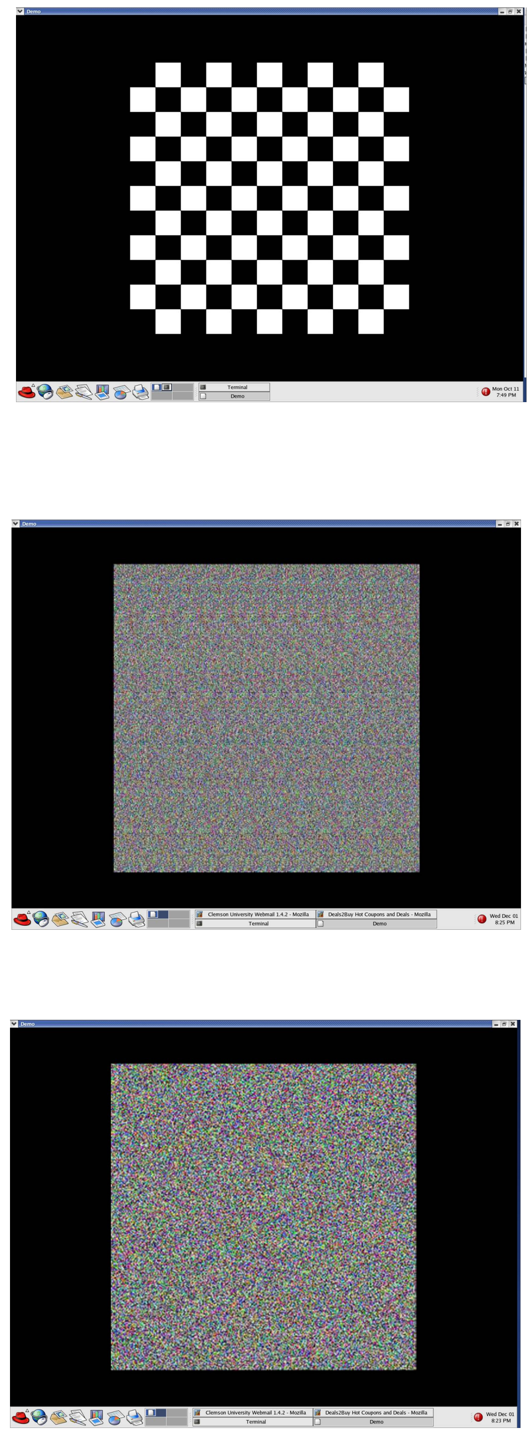


Figure 3.1. a) control checkerboard image b) stereogram snowman image c) nonstereo random dot image

3.3 Procedure

Participants were first asked to sign an informed consent, agreeing to participate in the experiment. Then, all participants were centered in relation to the screen. This allowed the Tobii eye tracker to accurately record gaze point data. The participants' eyes are then calibrated by choosing "Calibrate" from the menu options. The eyes were calibrated by having the subject focus on five yellow circles that appeared clockwise in each corner of the screen with the final circle in the center. Once the eyes were calibrated, the baseline image was shown. Eye data was recorded for two minutes and stored to the appropriate file automatically. Then depending on the participants group, experimental or placebo, the participant was shown the stereogram or a nonstereo image respectively. The participant was told to place his/her finger on the "S" key to stop the recording process when he/she was able to see and accurately identify the three-dimensional impression. If the participant was unable to see the hidden impression, the program would automatically stop after two minutes. Once both data files were recorded, the participant may choose "Analysis" from the menu options in order to see a preliminary report of whether his/her eyes converged or diverged by a certain distance.

In order to implement the experiment, additions were made to the source code that was provided. The first change to be made was reducing the number of calibration points. The original program used sixteen calibration points which was cumbersome and time consuming. The researchers reduced the number of points to five which allowed for precision of calibration in a time effective manner.

Next, a file structure was implemented to store the coordinates of participants' eye movements. The files contained x and y coordinates for both the left and right eye, which also included the duration for each coordinate, and total time elapsed from the start hitherto. The validity of the data collected by the eye tracker was taken into account. Coordinates with a validity level of 0 were the only ones accepted. A validity level of 0 means: "The system is certain that it has recorded all relevant data for the particular eye, and that the data recorded belongs to the particular eye (no risk of confusing left eye with right eye by the system) [16]." The other levels of validity only assured data collection of one eye and were deemed insufficient since coordinates from both eyes are needed for this experiment.

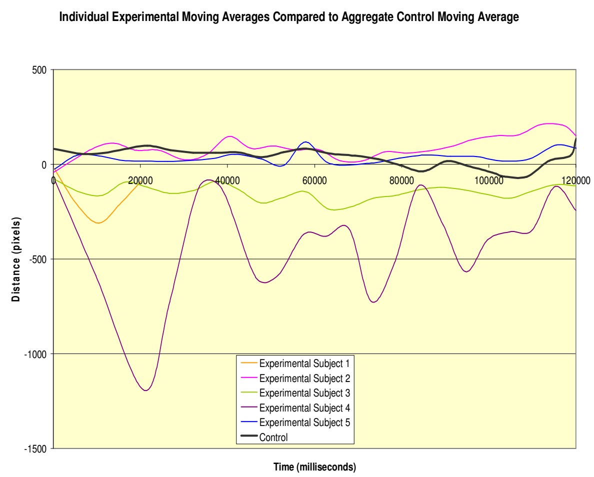
In order to be able to interpret the data, an additional analysis option was added to the menu which calculated the convergence or divergence for each subject. This calculation was performed by comparing the average distance between the eyes in the baseline file and vergence files. The analysis option only offered preliminary results of individual participants. The time columns within the files were used to depict the results graphically.

Additional features included a timer which stopped recording coordinates after two minutes had elapsed, and shortcut keyboard keys which made choosing options off the menu easier for the participant. The participants were fully debriefed at the end of the experiment.

4. Data Analysis

This experiment was a between-subjects design, as each subject was randomly assigned to either the placebo or experimental conditions. The dependent variable was distance, which was the average distance of each subject over time taken to view the stereogram. *Figures 4.1a* and *4.1b* (below) depict the individual data compared to an average baseline for both placebo and experimental conditions. *Figures 4.2a* and 4.*2b* (next page) depict the average data compared to an average baseline for both placebo and experimental conditions. Microsoft Excel 2002 was used to plot the graphs.

a)



b)

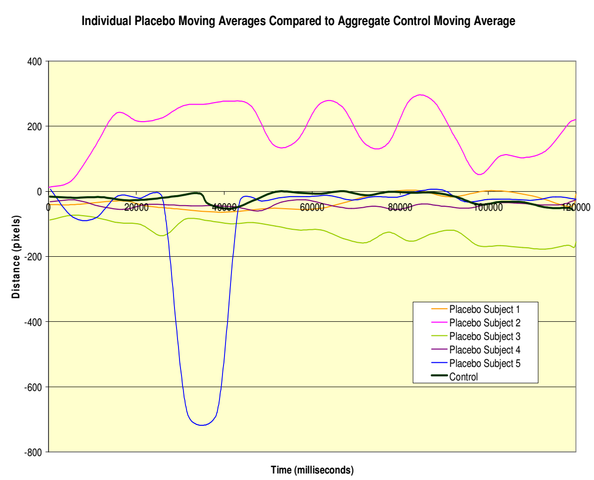
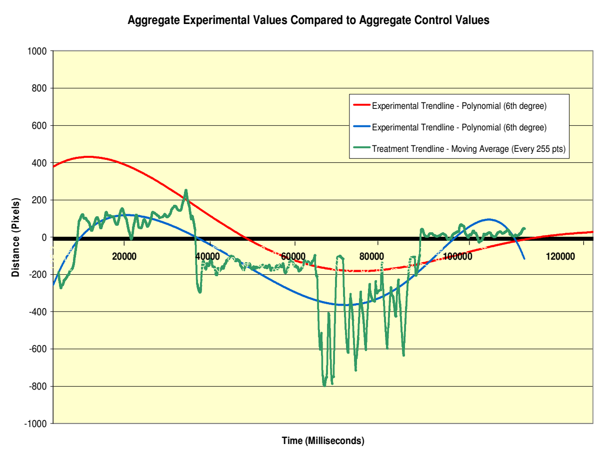


Figure 4.1 a) Individual experimental group values versus average baseline b) Individual placebo group values versus average baseline

Figure 4.1a and 4.*1b* (above) depict the individual distances over time of each subject in the experimental and placebo group respectively. The graphs show the distance in pixels along the y-axis against the time in milliseconds on the x-axis. Negative distance values represented a convergence in relation to the baseline average that was obtained; whereas, a positive value represented a divergence. Moving average trend lines of 255 points were used for the individual participants. This trend line was computed by taking the average of every 255 points in the raw data and then plotting the point. The number 255 was chosen as the value because it was the highest value the program would allow. The higher the value, the more noise was eliminated. This trend line was chosen to filter out the noise of the raw data, while still keeping the general shape of the curve. All participants, with the exception of participant one in the experimental group, showed a two minute pattern. Participant one's pattern, as shown in *Figure 4.1a* (previous page), showed a much shorter curve than the other participants because participant one was the only one able to accurately identify the hidden image in the given two minute time limit. The program stopped recording data when the participant was able to recognize the hidden image. This explained participant one's smaller curve compared to the rest. *A sixth degree* polynomial trend line was used to show the average base line in both graphs. A sixth degree was chosen because it was the highest degree allowed in this program. The higher the degree, the more accurately it reflected the raw data. Since it was more important to see the general pattern than the raw data for the baseline, a polynomial trend line was deemed sufficient. The smooth curve made it easy to compare to other curves.

a)



b)

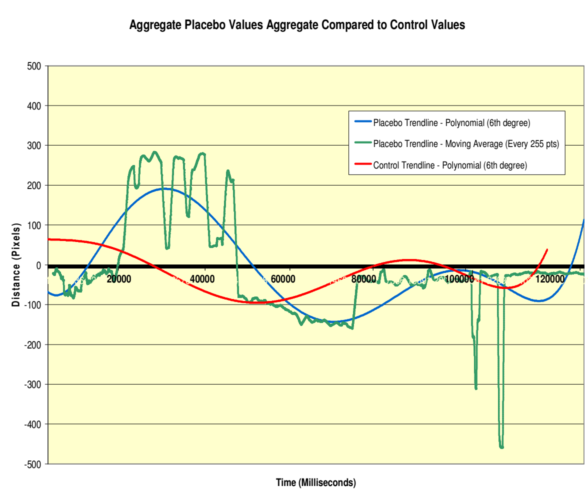


Figure 4.2 Average experimental values versus baseline

Figure 4.2a and 4.*2b* (above) depict the average distance over time for the experimental and placebo group respectively. The axes follow the same criteria as mentioned for *Figure 4.1* (previous page). A moving average of 255 points and a sixth degree polynomial trend line were used to represent the groups. These were used together in order to illustrate both the pattern of the raw data with the moving average, along with the smoother general curve that results with the polynomial curve. As in *Figure 4.1* (previous page), a sixth degree polynomial trend line was deemed sufficient to represent the baseline.

Since the independent variable was a categorical variable and the dependent variable was a continuous variable, a one way analysis of variance (ANOVA) was conducted for this experiment. In order to conduct an ANOVA, several assumptions must be met. The first assumption and one of the most important ones is independence, which is met when participants are randomly assigned and when each participant is represented in only one of the independent variable conditions (each participant only contributes to each cell once). The next assumption of homogeneity of variance, which means that the variance should be equally distributed across all groups, is met as shown in *Table 4.1* (below).

Levene Statistic	df1	df2	Sig.
3.335	1	8	.105

Table 4.1 Test of Homogeneity of Variances

Since the significance value was greater than .05, this indicates that the variance was equally distributed across all groups. However, the third assumption of normality was not completely met because the data shows a polymodal distribution, which is shown in *Figure 4.3 (below)*.

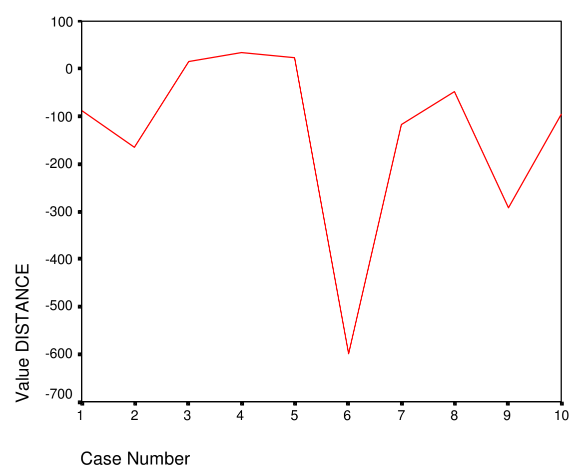


Figure 4.3. Distribution of average distance across all participants

Even though one could transform the data, it becomes difficult to transform with a polymodal distribution. Although this is an assumption of ANOVA, it is not a serious violation of one does not meet normality. Therefore, the researchers decided to conduct the ANOVA. SPSS for Windows 10.0.5, Standard Version was used to analyze the data.

4.2. Descriptive Statistics

Ten participants were randomly assigned to either the placebo or experimental condition. Five men were in the placebo condition and three men and two women were in the experimental condition. The results indicated that the average distance across all participants was -133.498, with a standard deviation of 191.149. The negative value indicates that there was an overall trend towards convergence across all participants regardless of the condition in which they were assigned. The data is summarized below in *Table 4.2*.

	N	Min	Max.	Mean Statistic	Mean Std. Error	Std. Dev.	Variance
Distance	10	-599.35	33.28	-133.4980	60.4466	191.1490	36537.957

Table 4.2. Descriptive Statistics Overall Summary

4.3. One-Way Analysis of Variance

A one-way ANOVA indicated that there was not a significant difference between the placebo (M= -36.048, S= 86.891) and experimental (M= -230.949, S= 225.652) conditions, F(1, 8)= 3.248, p=.109 (see *Table 4.3* and *4.4* below). *Figure 4.4* (below) depicts box plots indicating the range of average distances per group along with the standard error. The graph shows that the mean of each group is not in the center of each block. As discussed previously, this represents a nonnormal distribution.

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Placebo	5	-36.0475	86.8910	38.8589	-143.9370	71.8419	-163.99	33.28
Experimental	5	-230.9485	225.6521	100.9147	-511.1326	49.2355	-599.35	-48.72
Total	10	-133.4980	191.1490	60.4466	-270.2378	3.2418	-599.35	33.28

Table 4.3 Descriptive Statistics by Group Summary

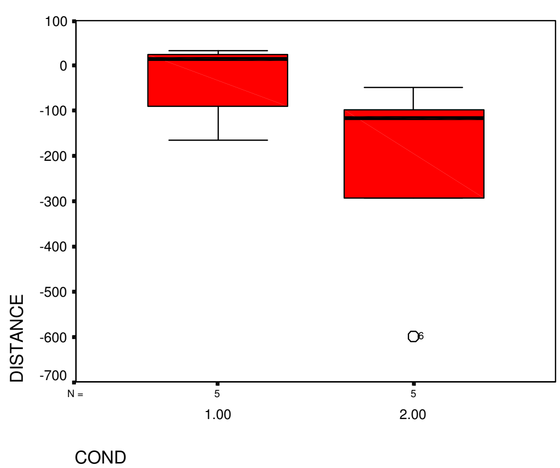


Figure 4.4. Range of average distances and standard error by group

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	94965.981	1	94965.981	3.248	.109
Within Groups	233875.629	8	29234.454		
Total	328841.610	9			

Table 4.4. Analysis of Variance

The G-power, Version 2.0 [9] was used to conduct a post-hoc power analysis. Power is defined as the probability of correctly rejecting the null hypothesis, which states that there are no significant differences between the two groups. With ten participants, the study had a power of .1077. These results indicated that there was approximately only an eleven percent chance the null hypothesis could have been rejected.

5. Discussion

The primary focus of this study was to determine whether eyes converge or diverge when viewing stereograms. The results could help researchers better understand how people view stereograms, which could then be used in areas such as marketing. The different experimental conditions show that stereograms are viewed using the same general pattern of convergence regardless of the actual stimuli.

Overall, this experiment found that there was no significant difference between the placebo and experimental conditions. The researcher's hypothesis, which stated that regardless of condition, participants would diverge, was partially supported. The results indicated that in both conditions, participants were more likely to converge than diverge. However, there were no differences across groups. Therefore, the researchers were correct in hypothesizing that participants would respond similarly regardless of condition.

It seems that the nonsignficant results could be attributed to several things. Foremost, there were only five participants in each condition, which gave the study low power. It is also quite possible that if the experiment had a larger number of participants, then the results would indicate that they were more likely to diverge. When examining the means for the placebo group, it seems that many of the participants were diverging. Although the overall mean (-36.0475) indicates convergence, there appears to be a trend towards divergence, which was not seen as explicitly in the experimental condition.

Further analysis of *Figure 4.1a and 4.1b* (page 5) show the high level of variance in patterns used by each participant. Although participant one in the experimental group was the only participant to be able to see and identify the stereogram, participants three and four also stated they were able to see crude shapes but were unable to identify the image. All three of these participants show a pattern of convergence, while the others that did not see anything are close to the base line or showing a general pattern of divergence. With the exception of participant 2, *Figure 4.1b* (page 5) also shows a general pattern of convergence among the participants. However, as the relatively smaller standard deviation in the placebo condition suggests, the convergence is not as great as seen in the experimental group. This graphical analysis supports the statistics which show convergence is the key strategy in viewing stereograms.

When analyzing *Figure 4.2a* and 4*.2b* (previous page), the statistics are further supported. The end of *Figure 4.2a* (previous page) shows a trend towards divergence before time expires. This can possibly be attributed to the fact that although participants were able to see images while not being able to identify them, they were possibly trying a divergence strategy at the end in order to obtain a clearer picture. Nevertheless, *Figure 4.2a* (page 6) shows an average pattern of convergence for the experimental group, which supports all of the other previously drawn conclusions. Alternatively, *Figure 4.2b* (page 6) offers the first explanation of the possible reason for the relatively smaller standard deviation in the placebo group. The moving average and polynomial trend lines both show a fluctuating pattern of convergence and divergence in relation to the baseline. This pattern can be attributed to the fact that since the image is nonstereo, participants were possibly trying both divergence and convergence strategies when attempting to view the hidden image. However, as the results indicate, convergence was used more frequently, but not to the extent at which it was used in the experimental group.

5.2. Limitations

One of the major limitations of this study was the small number of participants in each group, which resulted in low power for the study. If the study had a larger number of participants in each condition, then the researchers may have obtained significant results and support for their hypothesis, especially since there seemed to be a trend towards divergence in the placebo condition. If one were to conduct an a priori power analysis, then the results would indicate that 210 participants would have been needed for the study to have a power of .95 or 95% chance of rejecting the null. The study would have also yielded an effect size (i.e., magnitude of the significant effect) of .25, which is a medium. However, due to lack of time and resources, the researchers were not able to recruit the number of participants needed to obtain the results. Additionally, a larger number of participants could have given the researchers a normal distribution, which is one of the assumptions of an ANOVA that was not met in this experiment, specifically due to the polymodal distribution, which becomes difficult to correctly transform. There here was also a large standard deviation and standard error, specifically in the experimental group. This was pictorially depicted within the box plots in *Figure 4.4* (previous page). It is possible that a larger number of participants could have resulted in a lower variation within each group and made each group more homogeneous.

Another limitation of this study can be attributed to the Tobii Eye Tracker itself. On the feedback forms, all participants stated that it would have been easier to view the image if they had been allowed to view the screen at a much closer distance. Unfortunately, the cameras of the eye tracker are not able to record data at such a close distance. All five participants of the experimental group were able to accurately identify the image when allowed to move closer to the screen. Another possible limitation is that the stereograms are said to be harder to view on a computer screen than on paper [11]. The distance from the screen along with the use of the LCD monitor creates a major limitation in this experiment.

5.3. Future Work

There are many options available for extending this research in the future. Obviously, one of the main changes that could be made is to have a larger sample size. With a larger sample size other variables such as gender or age could be taken into account. Representative sample for both sexes and age groups corresponding to young adults, middle aged adults, and the elderly could provide data that would allow the broad conclusion in this experiment to be narrowed down by various criteria.

Another option is not only to explore horizontal vergence, but also three dimensional space by introducing the z coordinate by using the flock of bird virtual reality helmet. This would allow a participant's distance from the screen and head movements to be recorded. This data could be combined with the vergence results which would provide more detailed, meaningful results.

Finally, another option is to take advantage of all of the data collected by the eye tracker. Measuring more characteristics of the eyes such as diameter of pupil, may show a correlation to pupil diameter and viewing stereograms. A noticeable change in the size of pupil was observed during general observation of participants as they took part in the experiment.

5.4. Conclusion

Following the long history of the creation of stereograms, and the research that is now underway with state-of-the-art eye tracking technology, this research offers a step in the right direction towards finding out more about how individuals view stereograms. It also raises questions as to what sort of practical applications are available for stereograms. The goal of this experiment is to trigger more research in stereograms for the purpose of expanding interests in areas such as marketing, business, and general academic interest. With a growing interest in the areas of eye tracking and stereograms, the future work outlined in this paper shall expand on the general findings of this paper and explore other avenues that were not able to be investigated here.

6. Acknowledgements

Special thanks go to Dr. Andrew Duchowski representing the Clemson University Computer Science Department for supplying the equipment, technical expertise, and the research opportunity. Other special thanks go to Ms. Puja Seth, a doctoral student at the University of Georgia, for assisting the researchers in implementing SPSS for statistical analysis and offering her insight on various types of analyses that would be appropriate for this experiment. Finally, special thanks go to Mr. Jacob Hicks for creating the stereogram image used in this experiment.

7. References

[1] Academy of Marketing Science Review. Three-Dimensional Stereographic Visual displays in Marketing and Consumer Research. Available at: http://www.vancouver.wsu.edu/amsrev/theory/holbrook11-97t.htm. Last Accessed: 10 October, 2004.

[2] Annals of the New York Academy of Sciences 2002.. Binocular Eye Movement Responses to Dichoptically Presented Horizontal and/or Vertical Stimulus Steps http://www.annalsnyas.org/cgi/content/full/956/1/487 Last Accessed: December 2, 2004.

[3] BBC, Nottingham. SIRDS: An optical illusion. http://www.bbc.co.uk/nottingham/features/2003/08/sirds.shtml#what Last Accessed: December 2, 2004.

[4] CIT,Cornell University. How To See A Magic Eye Poster. Available At: http://instruct1.cit.cornell.edu/courses/psych470/To_Be_Edited/How%20To%20See%20A%20Magic%20Eye%20Poster%20(MVW).doc. Last Accessed: December 2, 2004.

[5] C. Rashbass & G. Westheimer J. Physiol. Disjunctive Eye Movements. 159, 339-360, 1961

[6] Cooper, Rachel. What is Stereo Vision?. 2004. Available At: http://www.vision3d.com/stereo.html. Last Accessed: 16 September 2004.

[7] Dictionary.com. http://dictionary.reference.com/search?q=stereogram Last Accessed: December 2, 2004.

[8] Essig, Kai and Ritter, Helg. Tracking of Eye Movements and Visual Attention. Available at: http://www.techfak.uni-bielefeld.de/ags/ni/projects/eyetrack/eye_autostereo.html. he Neuroinformatics Group. Bielefeld University. Last Accessed: 10 October, 2004.

[9] Faul, F., & Erdfelder, E. (1992). G-Power: A priori, post-hoc, and compromise power analyses for MS-DOS (computer program). Bonn, FRG:Bonn University, Department of Psychology.

[10] History of Photography and the Camera. Available At: http://inventors.about.com/library/inventors/blphotography.htm Last Accessed: December 2, 2004.

[11] Magic Eye Inc®. Frequently Asked Questions. 2004. Available at: http://magiceye.com/faq.htm. Last Accessed: 16 September 2004.

[12] Mowforth, P. et al. Vergence Eye Movements Made in Response to Spatial-Frequency-Filtered Random-Dot-Stereograms. Perception, 10, 299-304, 1981

[13] Patrick Hahn. The History of Stereograms 1996. Available At: http://www2.vo.lu/homepages/phahn/rds/history.htm. Last Accessed: December 2, 2004.

[14] Robert Leggat. Stereoscopic photography 2003. Available At: http://www.rleggat.com/photohistory/history/stereosc.htm. Last Accessed: December 2, 2004.

[15] Sandin, Daniel et al. The Varrier™ Auto-Stereographic Display. Available at http://www.evl.uic.edu/todd/varrier/VarrierSPIE.html. Electronic Visualization Laboratory. University of Illinois at Chicago. Last Accessed: 10 October, 2004.

[16] Tobii Technology. User Manual. http://andrewd.ces.clemson.edu/courses/cpsc412/docs/UsersManual_TobiiClearView_2_1_0.pdf Last Accessed: December 2, 2004.