The Effect of Interpupillary Distance on Binocular Field of Vision

IB Higher Level Biology Internal Assessment

Akshat Shah

IBIS Personal Code: jfd304

The Relationship between Interpupillary Distance and Binocular Field of Vision in Human Adolescents aged 17/18

Introduction

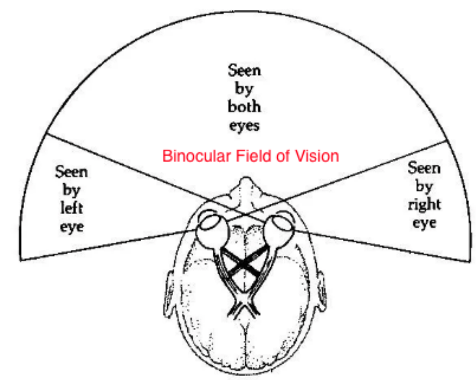
Aim and Objective

This Internal Assessment aims to investigate the relationship between interpupillary distance and binocular field of vision in human adolescents aged 17/18, by summing the angle between the central focused line of sight and the visual limit of each eye as measured by the Visual Limit Meter.

Background Information

Binocular field of vision is simply the area on the tangential (horizontal) plane which an organism (with two eyes) can see with both eyes (Opto, 2022). This area is specifically the overlap between the field of vision of the left and right eyes. *(Summing the visual limit of each eye on its respective side will give the total degrees of binocular vision)*. Since the right and left eyes are horizontally separated by an interpupillary distance (the distance between the centres of the pupils), they both see two slightly different versions of the world around us. The difference in the images between the right and left eyes is interpreted by the brain and converted into a three-dimensional view of the world (Salmon, 2020). There are a few key biological advantages of binocular vision to organisms. Mainly, it provides a larger field of view, and is critical for having precise depth perception. Depth perception is a vital part of survival for many organisms as it allows them to break the camouflage of other organisms, which is important for both prey and predators (Nityananda et. al, 2017). Moreover, Binocular vision is also crucial to our daily activities, since depth perception is responsible for our locomotion, grasping and catching abilities, alongside many others (Otto et. al, 2010). My initial interest in this topic stemmed from my extensive background playing cricket and table tennis, two sports that rely heavily on hand-eye coordination and depth perception, hence being impacted by binocular vision. Through this experiment, I would be able to determine how my physical biological characteristics either advantage or disadvantage me in the sports I enjoy.

Figure 1 - Diagram representation of Binocular Field of Vision



Studying this relationship between interpupillary distance and binocular field of vision also has a global significance in many interdisciplinary areas. For example, coaches for sports teams can use this relationship to determine how to form hand-eye coordination training plans. Athletes with a smaller binocular field of vision would be trained extensively in their peripheral vision to help them make better use of their eyes, despite having a limited binocular range. Moreover, it has applications to Virtual Reality headsets, the study of optometric diseases, and is even essential to the performance of fighter pilots and surgeons (Vivid, 2022). Due to the immense applicability of understanding binocular vision, and its significance to my passion for sports, the following research question was developed: **What is the relationship between interpupillary distance (mm) and the field of binocular vision of teenagers aged 17-18 (°), determined by summing the angle between the central focused line of sight and the visual limit of each eye?**

Before discussing binocular vision in further detail, it is crucial to first understand the concept of vision in the biological perspective. Vision is a type of sensory perception, dependent on a group of receptors known as photoreceptors. These photoreceptors detect changes in the environment as stimuli, and relay nerve impulses to the brain which are converted into an image. The pathway light takes to our brain is as follows (AAO, 2017). First it passes through the cornea, which is curved in a way such that the light is refracted towards the retina. The amount of light that makes it to the retina is controlled by the pupil, which either dilates or constricts to increase or reduce the passing light. In the retina, there are rod cells, which are responsible for vision in low light, and cone cells, which provide colour vision (Bianco, 2023). Moreover, the retina has a region called the Macula, in which the Fovea Centralis is responsible for our ability to see fine detail. The retina also contains crucial pigments known as Rhodopsin (or visual purple), which is the chemical that converts light into the electrical impulses our brains can interpret as vision. Rhodopsin is a mixture of a protein called scotopsin and a Vitamin A derivative known as 11-cis-retinal (Birge, 2005). When exposed to light, Rhodopsin undergoes a physical change, and through several intermediate steps, decomposes into metarhodopsin II (Bianco 2023). This is the final chemical, and it directly converts the light into an electrical impulse. The nerve impulse eventually reaches a ganglion cell and then the optic nerve. Finally, the optic nerve fibres pass through the optic chiasm to the occipital lobe (where the primary visual cortex is located). It is in this part of the brain that light is interpreted into our vision (Albert et. al, 2015).

Having a basic understanding of visual perception, we can finally briefly discuss the finer details of depth perception and binocular vision. Firstly, without binocular vision, there would be no depth perception. There are various components of depth perception (such as Accommodation and Stereopsis) (Banerjee et. al, 2018). Stereopsis is the component of depth perception that results from binocular vision, making it applicable to this exploration. It is important to note that depth perception is multifaceted with many other visual cues such as convergence, texture, motion parallax and perspective (Brinkmann, 2008). Hence, all results on binocular vision from this investigation are applicable exclusively to the stereopsis component of depth perception. Finally, various studies have supported the idea that there is a relationship between gender and binocular field of vision, and this will be considered as a future extension.

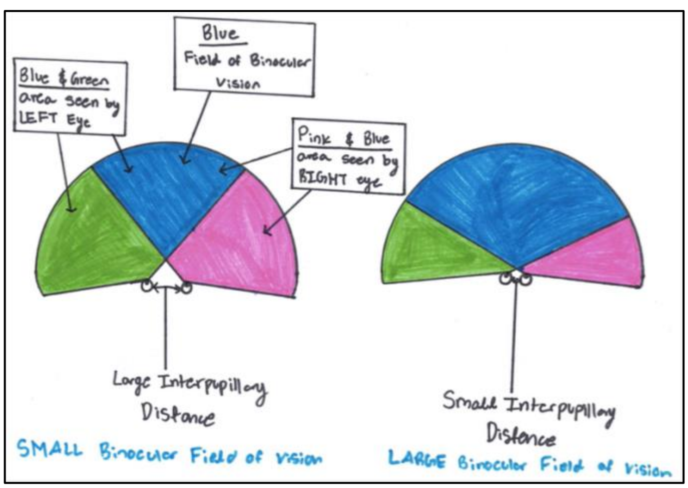
Experimental Hypothesis

Null Hypothesis (H_O): There is no correlation between interpupillary distance and binocular field of vision in human adolescents ages 17/18

Alternative Hypothesis (H_A): There is a negative correlation between interpupillary distance and binocular field of vision; as interpupillary distance increase, binocular field of vision decreases.

(All images are self-made unless stated otherwise)

Figure 2 *– Diagram to show expected impact of interpupillary distance on binocular field of vision*



While such an experiment has not been conducted, this hypothesis can be supported by looking at other organisms with binocular vision. One such study compared the binocular fields of vision of owls and pigeons and found that owls had a significantly larger binocular field of vision, while having a smaller overall peripheral vision (John, 2011). Knowing that owls have a smaller interpupillary distance than pigeons (they're eyes are towards the front, whereas pigeons are on either side), the same correlation can be extended to this experiment. Therefore, it was hypothesized that an increasing interpupillary distance is correlated with a decrease in binocular field of vision.

Materials and Method

Materials

1. Ruler (+/- 0.5 mm)
2. Visual Limit Meter (VLM)
    a. Foamboard (50.0 cm x 76.0 cm)
    b. Craft Knife (1)
    c. Protractor (1)
    d. Pencils or markers
    e. Green construction paper (20.0 cm x 20.0 cm)
    f. Red construction paper (20.0 cm x 20.0cm)

Safety

The main safety concern in this experiment was the use of a craft knife for building the VLM. It was important to ensure that the knife was used safely, and minors should have an adult supervising the use of the knife. Additionally, the VLM was made on a stable, solid surface, which reduced the likelihood of any accidents. For general knife safety, refrain from waving the knife around carelessly, ensure your eyes are always on the knife, carry the knife pointed downwards when moving, and only work in a clean working space.

Apart from personal safety, it was also crucial to ensure the safety of all participants in the experiment. To avoid any injuries to the participants, the participants were allowed to set up the VLM themselves in the position they find most comfortable. Moreover, the production of the VLM itself should be precise and there were no imperfections on it that could pose a risk to the participants eyes. While the VLM was quite a safe apparatus, vision tests do have rare cases of dizziness, so it was ensured that that the participant was seated when performing the test. Finally, the VLM was sanitized between each participant to avoid pathogen spread. Following all the personal and participant safety steps was crucial to a well-designed experiment.

Variables

Table 1 *– Table of all controlled variables, the independent variable and dependent variable, alongside how they will be measured/controlled*

Variable	Description	How it will be controlled, measured, or manipulated
<u>Independent</u>	Interpupillary Distance (mm)	The interpupillary distance was measured with a simple ruler, with an uncertainty of +/- 0.5 mm. Interpupillary distance was measured as the distance between the centres of each pupil. For accurate measurements, all participants were asked to focus directly on the forwards direction. The experiment was conducted on fifty participants to ensure a large enough sample size to reach more accurate and reliable conclusions.
<u>Dependent</u>	Binocular Field of Vision (°)	The binocular field of vision was measured using the VLM. Specifically, the visual limit for each eye was determined, and then these degrees were summed together to form the binocular field of vision.
<u>Controlled</u>	Age of Participants	The age of participants was strictly individuals between 17 and 18 years old. This was important as facial structure continues to grow until 20 years of age (Sharma, 2014). Additionally, this age range made the experiment more personally significant and allowed for an assessment how much of an impact it has on my abilities as a cricket batsman.

Variable	Description	How it will be controlled, measured, or manipulated
Controlled	Angle at which the measuring apparatus is kept	The VLM was kept tangential to the ground, meaning that it was 180° to the ground. This was very important as any upwards or downwards angle impacts the binocular field of vision. Keeping it tangential to the ground for every trial made the results as reliable as possible.
Controlled	Lighting of the surrounding	While lightning has no effect on binocular field of vision itself, it does impact the ability of the eye to pick up colour and focus (Optical, 2023). This was important when the participant had to identify whether they could still see the red indicator. To keep the surrounding lighting controlled, all trials were conducted in the same area in the same room.
Controlled	Measuring Apparatus	Unfortunately, with the resources available for this experiment, no two VLMs could be constructed in the exact same way. To ensure that this did not pose a problem, the same VLM was used for all 50 samples (150 trials).

Things that were monitored in the experiment

Participants with visual impairments were not included in the experiment as that would be its own investigation. Visual impairments were difficult to control for and could lead to outliers or biased data which would reduce the accuracy of the results. For example, individuals with Amblyopia (Lazy Eye) struggle with focusing correctly and therefore have compromised binocular vision (Birch, 2013). Individuals with glasses were accounted for and were able to easily use the VLM as it was placed on the lower portion of the nose bridge. However, in these cases, the angle at which the VLM was kept was carefully monitored to ensure results were not skewed. Finally, scientific literature supports the idea that there is a difference in interpupillary distance between males and females due to inherent differences in skull structure, specifically in the location of the orbit cavity and cranium size. Therefore, the biological sex of the participant was collected, and to avoid sampling bias, an equal amount of male and female participants were chosen.

Preliminary Work

The preliminary work was essential to this investigation, as it was used fine-tune the VLM and experimental method prior to collecting the actual data for analysis. The VLM started off with a 10.0 cm radius circle, but when asking the participants for feedback, they all noted that the smaller size made it uncomfortable on their face. After doing a few more trials, 38.0 cm was determined to be the ideal radius for the VLM. Then, it was crucial to perfect the methodology prior to data collection. It was discovered that for measuring the visual limit for each eye, having a bright red moving marker, approximately the same size as the area of focus allowed for a more accurate measure. Finally, for measuring interpupillary distance, it was determined that the ideal positioning for the ruler was on the participants nose bridge, as it allowed for the most precise measure and was comfortable for the participant.

Method

Part A - Making the Visual Limit Meter (VLM)

1. A 220° sector of a circle with a radius of 38.0 cm was drawn on a 42.0 cm x 76.0 cm piece of foamboard
2. The 220° sector was cut out using a ruler and craft knife
3. Whole number degree increments were marked around the VLM using a protractor and pencil
4. A line was drawn from the centre to the 90° mark, and to the 30° and 60° marks from both sides of the middle
5. A small divot was cut out at the centre of the shape so that the VLM could be placed on the participants nose bridge
6. The green indicator was attached to the VLM
    a. A 2.0 cm base by 6.0 cm height triangle was cut out from green construction paper
    b. A small 0.5 cm cut was created at the 90° mark and the triangle was placed into the cut invertedly
7. The red marker was made by cutting a 2.0 cm base by 6.0 cm height square from red construction paper

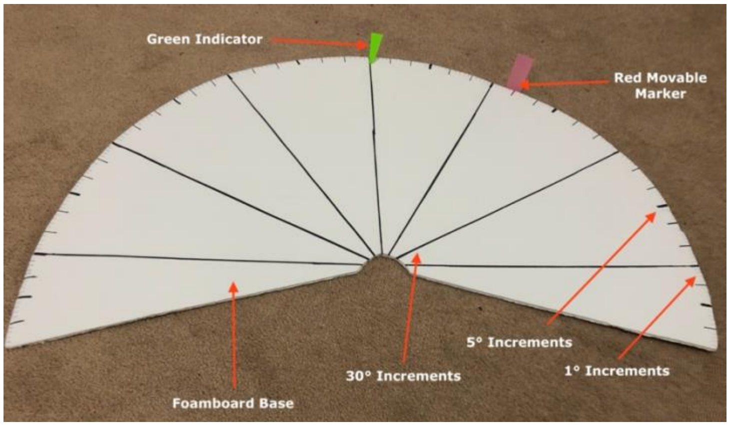


Figure 3 *– Annotated Diagram of VLM*

Part B - Visual Limit – Data Collection

1. The participant was asked for their consent; it was ensured that they sign the consent form.
2. The participant was asked to place the VLM on their nose bridge, parallel to the ground. The experiment was conducted in a well-lit room, with the same VLM from each trial and participant. All participants were aged 17/18
3. The participant was instructed to focus directly on the green indicator at 90° forward.
4. The participant was asked to close their left eye.
5. The participant was instructed to remain focused on the green indicator, while the red marker was slowly moved away from the green indicator to the side opposite of the open eye.
6. The participant was asked to state when they cannot see the red indicator anymore.
7. Qualitative observations, specifically regarding the participants focus on the green indicator were noted.
8. The degree value at which the red indicator was stopped was recorded. This was the visual limit for the right eye and was measured. Steps 1-7 were repeated three times for three trials.
9. Steps 1-8 were repeated to determine the visual limit for the left eye. For the visual limit of the left eye, the participant was asked to close the right eye instead in step 4.

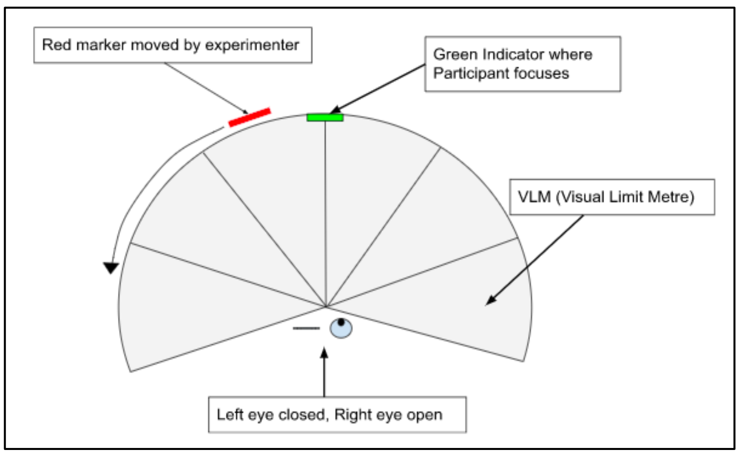


Figure 4 *– Exemplar Image of how the experiment was carried out (for visual limit of right eye)*

Part C - Measuring Interpupillary Distance

1. The participant was asked to remove their glasses if they were wearing any.
2. The participant was asked to look directly forwards.
3. The distance between the centres of their pupils was recorded with a ruler; ruler was rested on the participants nose bridge.

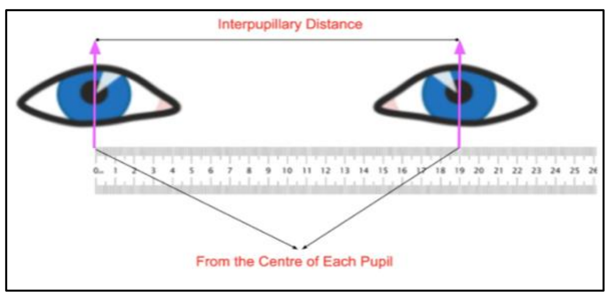


Figure 5 *– Diagram of how to measure Interpupillary distance*

Consent Form
The consent form below was signed by all participants prior to partaking in the experiment.

Biology IA Participant Consent Form

OVERVIEW OF INVESTIGATION: The purpose of this investigation is to determine how interpupillary distance affects one's binocular field of vision. To do so, a quick visual test will be conducted to determine the visual limit of each eye using an apparatus. This will be done using the Visual Limit Metre (VLM), which is essentially a large protractor. Then the interpupillary distance (distance between the centres of each pupil) will be measured using a ruler.

The participant will be asked to hold the VLM at eye level, tangential to the ground, by resting it on their nose bridge. They will then be asked to close one of their eyes and will be asked to state when they cannot see a red marker anymore.

By signing you agree to the following:
- I understand that my identity will remain anonymous
- I understand that my gender will be recorded
- I understand that there could be potential risks, although highly unlikely
- I understand my role as a part of this investigation

Please state any existing health/vision condition _________________

By signing this form, I ____________, consent to participating in this investigation

Signature: _____________ Date: _________________

Figure 6 *– Consent form signed by every participant*

Results and Discussion

Raw Data

Table 2 *– Table of Visual Limits of the left eye for each of the 50 participants with 3 trials per individual, alongside their interpupillary distance. The sex of each individual was recorded M = Male, F = Female*

Visual Limit – Left Eye (± 0.5°)					
Participant	Sex	Trial 1	Trial 2	Trial 3	Interpupillary Distance (± 0.5 mm)
1	M	39.9	40.4	39.4	73.5
2	M	54.0	54.7	54.0	72.4
Full Data Set in Appendix A.1					
49	F	57.3	58.6	56.7	69.9
50	F	72.8	72.5	76.0	55.1

Table 3 *– Table of Visual Limits of the right eye for each of the 50 participants with 3 trials per individual, alongside their interpupillary distance. The sex of each individual was recorded M = Male, F = Female*

Visual Limit – Right Eye (± 0.5°)					
Participant	Sex	Trial 1	Trial 2	Trial 3	Interpupillary Distance (± 0.5 mm)
1	M	40.2	40.1	42.1	73.5
2	M	54.1	53.9	55.4	72.4
Full Data Set in Appendix A.2					
49	F	58.8	57.6	59.6	69.9
50	F	72.7	73.7	71.1	55.1

Qualitative Observations

A few key qualitative observations were made during this experiment. Firstly, it was noticed that the participants eye occasionally lost focus from the green marker. In these scenarios, the red marker was held still, and the participant was reminded to focus on the green marker. This ensured that the participants visual limit was not increased or decreased. Furthermore, it was found that the closed eye of the participant often opened to a slight degree, which increased their binocular vision by a significant amount. Some participants also intentionally lost focus from the green marker or opened their closed eye to increase their binocular field of vision. While participants were clearly told about the confidentiality of information, this is a common form of response bias, and these inaccurate trials were removed. Since this experiment relied heavily on the participants honesty, their eyes were monitored carefully to ensure that the raw data was not skewed in any way. In terms of the correlation, it was generally noticed that those with a smaller interpupillary distance could see the red marker for a larger distance, however, this correlation can only be supported through the processed data.

Processed Data

Table 4 *– Table of Binocular field of vision for each trial, their average, the standard deviation of the trials, and the interpupillary distance, for each of the 50 participants. Sex was also recorded – M = Male, F = Female.*

Binocular Field of Vision (±1.0°)							
Participant	Sex	Trial 1	Trial 2	Trial 3	Average	Standard Deviation	Interpupillary Distance (± 0.5 mm)
1	M	80.1	80.5	81.5	80.7	0.7211	73.5
2	M	108.1	108.6	109.4	108.7	0.6557	72.4
Full Data Set in Appendix A.3							
49	F	116.1	116.2	116.3	116.2	0.1000	69.9
50	F	145.5	146.2	147.1	146.3	0.8021	55.1

Sample Calculations

Table 5 *– Sample calculations for binocular field of vision, average binocular field of vision, and standard deviation*

Sample Calculations

Binocular Field of Vision for Participant 1 Trial 1

Binocular Field of Vision = Visual limit of right eye + Visual limit of left eye
= 39.9 ± 0.5° + 40.2 ± 0.5°
= 80.1 ± 1.0°

Average Binocular Field of Vision for Participant 1

Average = (Trial 1 + Trial 2 + Trial 3)/3
= (80.1 ± 1.0° + 80.5 ± 1.0° + 81.5 ± 1.0°)/3
= 80.7 ± 1.0°

Standard Deviation Calculation for Participant 1

Standard Deviation was calculated using the STDEV Function, and then rounded to 4 degrees of significance using the ROUND function. D4, E4 and F4 represent the value for Trial 1, Trial 2, and Trial 3 respectively.

```
=ROUND(STDEV(D4,E4,F4), 4)
```

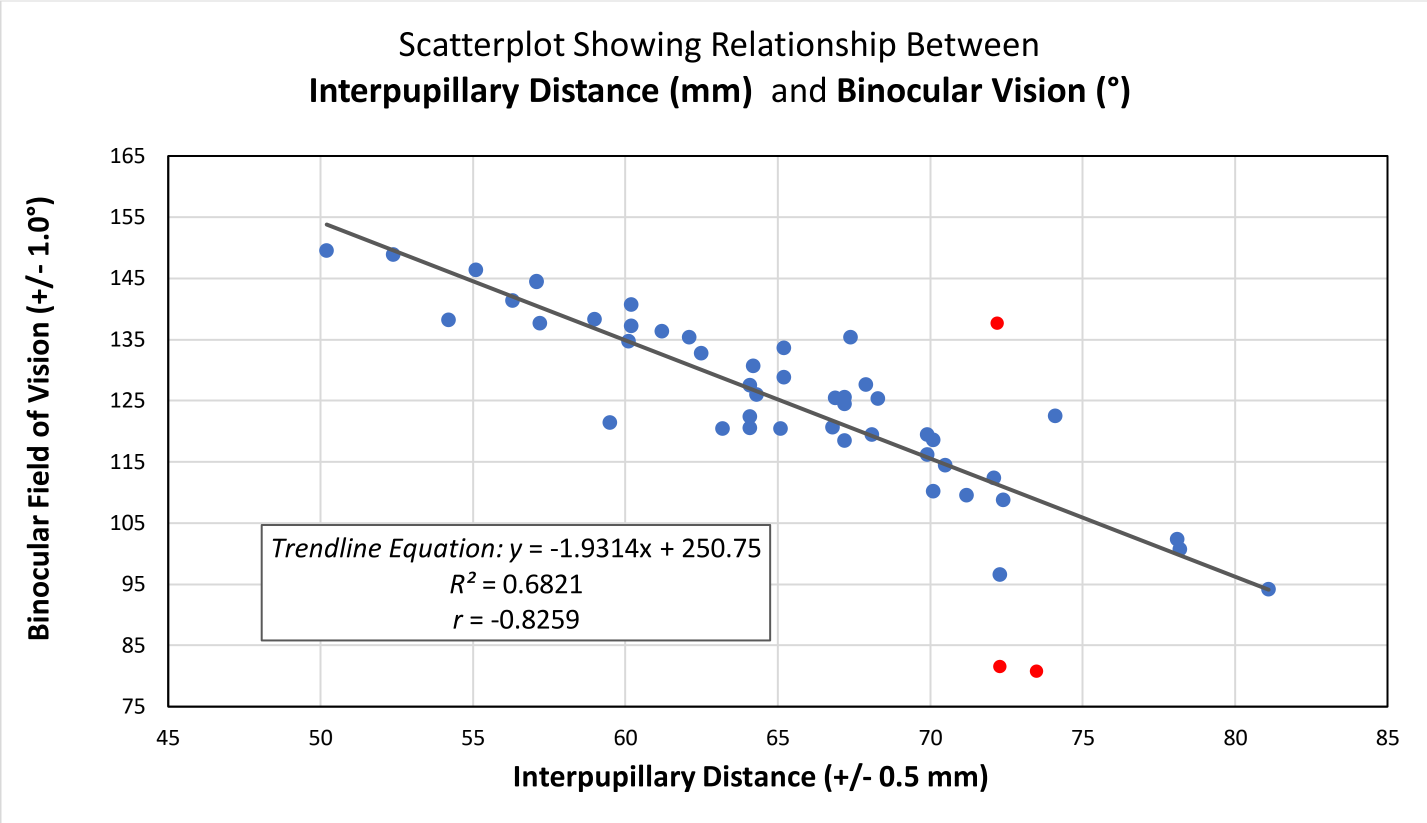


Figure 7 *– Scatterplot of the relationship between Interpupillary Distance and Binocular Vision, alongside a trendline, trendline equation,* ***R^2*** *(Coefficient of Determination),* ***r*** *(Pearson's Correlation Coefficient), and* ***outliers*** *(red dots)*

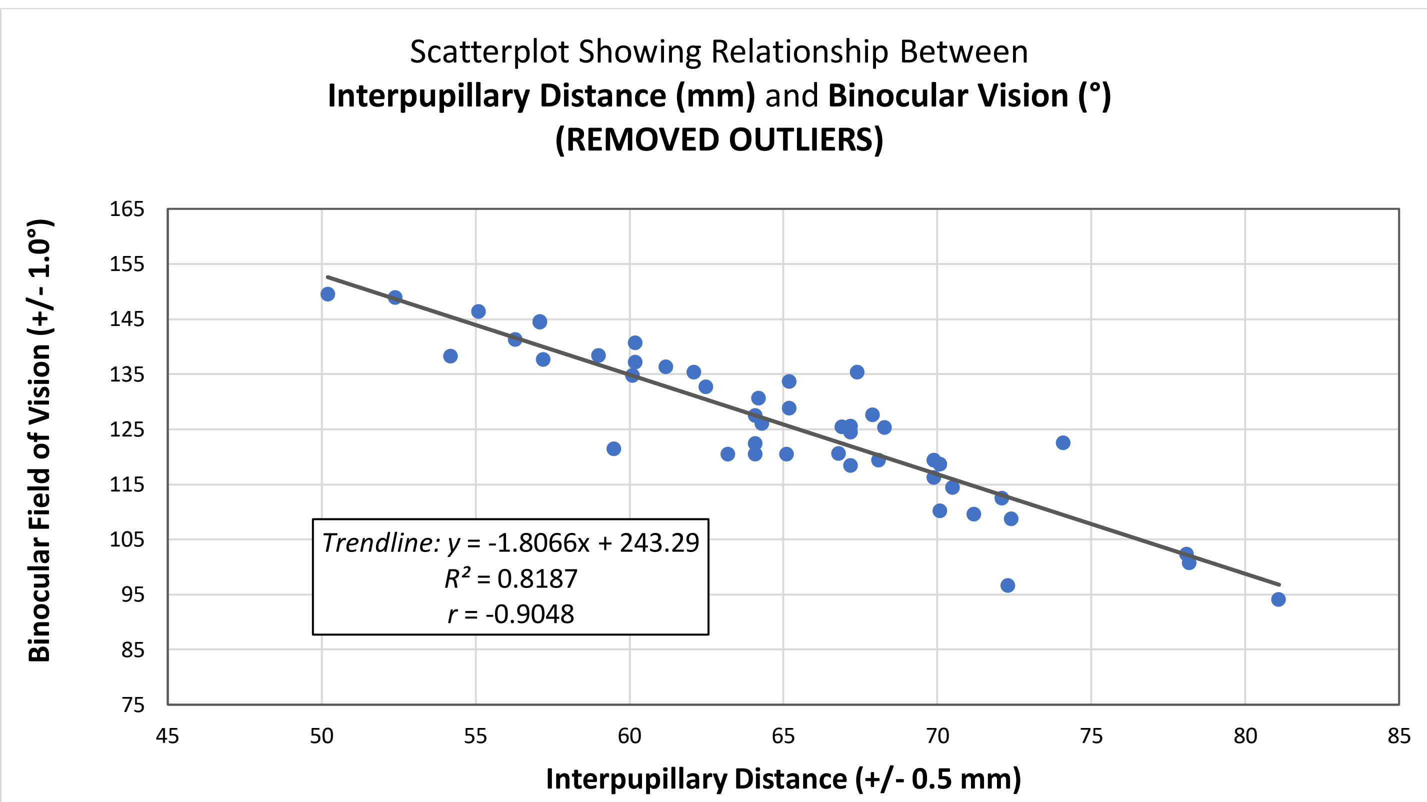


Figure 8 *– Re-evaluated version of Figure 7 Scatterplot by* ***removing the three red outliers***

Discussion – Interpretation of Processed Data

In *Figures 7 and 8*, the relationship between interpupillary distance and the binocular field of vision measured can be seen. The overall trend that this data demonstrated was that as the interpupillary distance increases, the binocular field of vision decreases, according to a linear trend. Firstly, this relationship was noticed through the trendlines of both scatterplots, showing the negative linear trend. This was further mathematically supported by the Pearson's Correlation Coefficient (r) and the Coefficient of determination (R^2) in *Figure 7*, which are -0.8259 and -0.6821 respectively. What the "r – value" signifies is the strength of correlation between interpupillary distance and binocular field of vision; a value of -0.8259 suggested a strong negative correlation ($-0.85 < r < -0.70$) between these two variables. The "R^2 – value" signifies how well the data on interpupillary distance can predict the binocular field of vision. Based on *Figure 7*, it can be said that the correlation was strong enough to explain 68.21% of the variance that may be present in the overall dataset. These r and R^2 values were calculated with the following formulas on Microsoft Excel:

***Table 6** – Formulas for Pearson's Correlation Coefficient (r) and Coefficient of Determination (R^2)*

Pearson's Correlation Coefficient (r) Formula:
r = CORREL (Interpupillary Distance Dataset, Binocular Field of Vision Dataset)
Coefficient of Determination (R^2) Formula:
R^2 = RSQ (Interpupillary Distance Dataset, Binocular Field of Vision Dataset)

Another thing considered when analyzing this biological data was the presence of outliers. Three outliers were found in the *Figure 7* scatterplot (shown as red dots), which were removed as they represented a significant variation from the dataset, suggesting that they were likely from experimental errors for that participant. Removing the outliers made the results more accurate as it took away data points that likely resulted from a measurement error, rather than natural biological variance. After removing the outliers, and readjusting the scatterplot, *Figure 8* was produced. In *Figure 8*, the "r - value" changed to -0.9048, and the "R^2 – value" changed to 0.8187, suggesting an even stronger negative correlation between interpupillary distance and binocular field of vision. The r-value specifically demonstrates that this strong negative correlation ($r < -0.85$) is almost perfectly linear due to how close the value is to -1. While the overall trend is similar between both *Figure 7* and *Figure 8*, the removal of the outliers has clearly increased the strength of the correlation between interpupillary distance and binocular field of vision.

The t-test or ANOVA are commonly used analysis when it comes to biological experiments, however, they were unapplicable to this one as the aim was not to determine if there is a statistical difference between two sets. Therefore, to further analyze the correlation between these two variables, another correlation test was considered, the Spearman's Correlation Coefficient (r_s). This test was more specifically suited for this specific exploration, as it measures how two variables covary (as the independent increases, how does the dependent behave). The Spearman's correlation coefficient can account for any *potential* lack of linearity in data and suggests how the data is correlated. It was thus chosen for further analysis. This correlation test works by ranking every value in each dataset in ascending order (Gupta, 2023). Then the variation between the ranks is calculated to see how directly correlated two variables are. For this exploration, the Spearman's correlation coefficient was calculated using an online calculator (Socsciatics, 2023) that can take the datasets as inputs, and output the coefficient value. This coefficient was calculated for the data before the outliers were removed *(Figure 7)*, and after the outliers were removed *(Figure 8)*.

For *Figure 7*, $r_s = -0.7830$, and for *Figure 8*, $r_s = -0.8760$. These are strong, and very strong negative correlations respectively, supporting the qualitative observations from the trendline, r, and R^2. Based on these three statistical tests, it can be said that there is a strong negative correlation between interpupillary distance and binocular field of vision. To bring together all these statistical results, the accuracy of the experiment was measured. This expanded upon the correlation and suggested how effectively the experiment was carried out. To do so, the trendline shown on *Figure 8*, found using Microsoft Excel, was considered. Only the trendline from *Figure 8* was used as it was determined to better represent the relationship between interpupillary distance and binocular vision (based on r, R^2, r_s), hence being more likely to produce an accurate trendline equation.

For *Figure 8*, the trendline was ***y* = -1.8066x + 243.29**. Apart from the correlation tests, a great way to determine the correlation between the two variables was to compare theoretical binocular vision values based on interpupillary distance and compare them to the experimental measure of binocular vision. To do so, 10 extra participants aged 17-18 were chosen at random. Their interpupillary distance and Binocular Field of Vision were measured, and the theoretical Binocular Field of Vision was calculated according to the *Figure 8* trendline equation. Then the percent error between these two values was measured and averaged across the 10 participants.

Table 7 *– Table of experimental and theoretically predicted binocular vision, alongside percent error and average percent error*

Interpupillary Distance (± 0.5 mm)	Experimental Binocular Field of vision (±1.0°)	Theoretical Binocular Field of Vision	Percent Error
74.3	110.2	109.1	2.84%
57.2	140.1	140	1.36%
55.1	139.1	143.7	3.20%
57.1	146.9	140.1	4.85%
69.2	119.8	118.3	1.27%
87.3	84.5	85.6	2.45%
66.2	124.2	123.7	1.21%
61.2	132.3	132.7	3.32%
79.9	87.1	98.9	5.86%
54.6	146.1	144.6	3.11%

All Values Calculated using Microsoft Excel Functions

Percent Error = $\left|\frac{\textit{Experimental} - \textit{Theoretical}}{\textit{Theoretical}}\right| \times \mathbf{100}\%$

Average Percent Error = 2.95%

The results from *Table 7* demonstrate that the actual measurements for binocular field of vision, and the theoretical measurement based on the *Figure 8* trendline, are on average different by a margin of 2.95%. That only amounts to a few degrees of inaccuracy, which suggests that this investigation was carried out very accurately, and that the procedure was well made. Through all the correlation tests, qualitative observations, and comparison between theoretical and experimental values, it can not only be stated that there is a strong negative correlation between interpupillary distance and binocular field of vision, but also that this experiment was well made and highly accurate. Finally, bringing together all this rich analysis, a conclusion can be reached as to whether the null hypothesis should be accepted, or whether it should be rejected.

Conclusion and Evaluation

Conclusion and Biological Explanation

This investigation aimed to determine the correlation between interpupillary distance and binocular field of vision; a negative correlation was hypothesized where an increasing interpupillary distance leads to a decreasing binocular field of vision. *Figure 7* supports the Alternative Hypothesis (H_A), as the overall trend seems to be that there is a linear decrease in binocular field of vision as interpupillary distance increases. After removing outliers in the data and producing *Figure 8*, an even stronger correlation was seen between these two variables. Therefore, all subsequent conclusions were reached based on *Figure 8*. Through further analysis, this negative linear correlation was supported by three separate tests: Pearson's Correlation Coefficient (r), Coefficient of Determination (R^2), and Spearman's Correlation Coefficient (r_s). For *Figure 8*, these values were -0.9048, 0.8187, and -0.8760 respectively. This suggests three things. Firstly, the data has a strong, negative linear correlation. Secondly, 81.87% of the variation in the dataset can be explained by the trendline. Finally, the relationship between these variables is highly monotonic and negative, meaning that as the independent variable increases, the dependent variable decreases 87.60% of the time. These statistical tests clearly work in favour of the Alternative Hypothesis.

Further supporting the Alternative Hypothesis and statistical tests, this experiment and methodology was found to be highly accurate, seen through the comparison of experimental values and theoretical values in *Table 7*, which only had on average a 2.95% percent error. Moreover, while there was uncertainty, they were miniscule. The Binocular Field of Vision had an uncertainty two times that of the VLM, leading to an uncertainty of ±1.0°. The interpupillary distance measurement had a small uncertainty of ±0.5 mm. There was also on average a standard deviation of less than 1° between the trials for each participant as seen in *Table 4*, suggesting low variability in data collection. In addition, there was a vast amount of data collected (50 participants), with three trials taken for each participant. Through this, the effect of random errors was reduced, which further added to the accuracy of this investigation. Therefore, the statistical tests and negligeable percent error between theoretical and experimental data, supported by the large dataset, small uncertainties, and small standard deviation, all work in favour of the Alternative Hypothesis.

Before finally rejecting the Null Hypothesis (H_o), and accepting the Alternative Hypothesis, comparisons to scientific content can be made to reinforce the raw and processed quantitative data, and qualitative data. In a biological context, the reasoning for such a relationship is that a higher interpupillary distance meant a a further separation of the eyes. Therefore, while both eyes still receive the same amount of light, the overlap area between the light received by each eye is lowered due to a larger distance between them. When the brain, specifically occipital lobe, subsequently combines the two images received by the right and left eye, a smaller field of binocular vision is generated. This explanation was supported by a paper in the journal of investigative ophthalmology and visual science that an increase in interpupillary distance leads to both a decreased depth perception and binocular field of vision (Jafari, 2014).

The correlation found by this investigation is also supported by explorations on other organisms. It was found that predatory animals had their eyes facing forwards, as the reduced interpupillary distance led to a larger range of binocular vision and therefore depth perception (OBDK, 2021). This of course was beneficial in more effectively catching prey. On the other hand, it was found that prey had eyes further apart on either side of the head, as the increased interpupillary distance led to a larger range of peripheral vision, allowing for better identification danger in the surroundings (OBDK, 2021). Based on the interpretation of processed and raw data, accuracy of data, and alignment with scientific content, ***the Alternative Hypothesis has been accepted***.

Strengths

There were a few key strengths of this exploration, apart from the low percent error, uncertainties and standard deviation. Firstly, the very large dataset and three trials for each participant heavily reduced the impact of inaccuracies in the data. Furthermore, it was noted and realized that there were differences between males and females based on scientific content, so an equal number of each sex were selected for the experiment. Another strength of this experiment was that the VLM was made with lots of care, and since the same VLM was used for each experiment, any flaws in the VLM remained equal throughout. Therefore, while the data could have been skewed due to mistakes in the production of the VLM, using the same apparatus each time reduced the impact of this.

Moreover, a large strength was the ease of data collection. Due to effort put into preliminary work, the VLM was perfected in a way that made the experiment process very convenient for participants. This made it very easy to obtain the large dataset required. Also, both the interpupillary distance and Binocular Field of Vision had very low uncertainties (± 0.5 mm and ±1.0° respectively), and on average, data collection for each participant had a standard deviation of less than 1°. These uncertainties virtually have no impact on the results, and the standard deviation suggests minimal variability in data collection, both of which were huge additional strengths for this experiment.

Weaknesses

***Table 8** – Table of errors in the experiment, their effect, and how they could be improved*

Sources of Error	Severity and Effect	Possible Improvement
Systematic Errors		
Production errors in the VLM	**Medium Severity**: While errors are possible since the VLM was hand made, each degree increment was precisely measured to be the same distance away from each other, with the help of a large protractor. This margin of error is covered within the uncertainty of the VLM itself, so while it is acknowledged as an error, the impact is not too large.	A very simple improvement would be to go to a store like Walmart and print out a VLM which was designed online. Through this, no human error in the production would be possible, and there would essentially be no margin of error.
Random Errors		
Inconsistencies in the Degree at which VLM was kept	**Medium Severity**: If the VLM was not kept at a perfectly horizontal plane, then there would be increases or decreases in Binocular Field of Vision. It was difficult to keep the VLM at the perfect angle throughout the experiment, and this likely impacted the data.	As an improvement, the VLM can be set on a flat chair that can be height-adjusted while the participant is using it. This would allow for VLM to remain perfectly horizontal throughout the process.
Size of Dataset	**Medium Severity**: Considering that the sampling was not perfectly random (students only within the school were chosen), and the experiment was only conducted on 50 people, some sampling bias could have affected the results.	A larger range (100+) of individuals aged 17-18 could be considered. These individuals would be selected from various areas rather than from just one place.
Honesty and Judgement of Participants	**Medium Severity**: As mentioned in the qualitative observations, some issues with honesty and judgement were found. Specifically, participants often overstated their field of vision. To help reduce the impact, the participants' eyes were carefully monitored.	It is quite difficult to improve this error, at least within the scope of the school. Given more equipment, a sensor that tracks the participants eye can be used to ensure fair trials.
Uncontrolled Background Influence	**Low Severity:** Participants were faced away from any background influence, however, changes in light, colour and movement in the peripheral vision could have affected data collection.	Ideally, this could be improved by collecting data in a separate room with minimal colour and no visual or auditory distractions.

Future Work and Extensions

A simple basic extension of this investigation is to simply explore other factors that have an impact on binocular field of vision. An example could be identifying how the binocular field of vision changes between different age groups, as there are changes in facial structure until the 20s. Therefore, a research question for such a topic would be: What is the relationship between age (7, 8, 9, 10, 11 years old) and Binocular Field of Vision (°). This extension could provide very useful results in the understanding of facial development of children, and how it connects to their overall growth. Something else that was found to be interesting was that in general, based on qualitative analysis of the data, females aged 17-18 had a higher Binocular Field of Vision than males. This relationship could be further explored with the question: what is the relationship between sex (adult male or female), and Binocular Field of Vision (°). Understanding this relationship could have connections to the evolutionary differences between male and female facial anatomy. Finally, the impact of interpupillary distance on another measure of vision, like peripheral vision can be measured. This could help provide further insight on the evolutionary advantages of eye placement in predators and preys. Overall, there are many possible extensions to this experiment which have various useful biological applications.

References

- *Binocular vision*. Binocular Vision - an overview | ScienceDirect Topics. (n.d.). Retrieved February 19, 2023, from https://www.sciencedirect.com/topics/neuroscience/binocular-vision

- *Binocular vision*. Binocular Vision | The Canadian Association of Optometrists. (n.d.). Retrieved February 19, 2023, from https://opto.ca/eye-health-library/binocular-vision

- *Binocular vision*. Vivid Vision. (n.d.). Retrieved February 19, 2023, from https://www.seevividly.com/info/Binocular_Vision

- Birch, E. E. (2013, March). *Amblyopia and Binocular Vision*. Progress in retinal and eye research. Retrieved February 19, 2023, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3577063/

- Carl Bianco, M. D. (2000, April 1). *How vision works*. HowStuffWorks. Retrieved February 19, 2023, from https://health.howstuffworks.com/mental-health/human-nature/perception/eye.htm

- *Correlation between interpupillary distance and stereo acuity*. (n.d.). Retrieved February 19, 2023, from https://www.researchgate.net/publication/295549633_Correlation_between_Interpupillary_Distance_and_stereo_acuity

- Encyclopædia Britannica, inc. (n.d.). *Optic nerve*. Encyclopædia Britannica. Retrieved February 19, 2023, from https://www.britannica.com/science/optic-nerve

- Gupta, A. (2023, February 2). *Spearman's rank correlation: The Definitive Guide to understand: Simplilearn*. Simplilearn.com. Retrieved February 19, 2023, from https://www.simplilearn.com/tutorials/statistics-tutorial/spearmans-rank-correlation#:~:text=Spearman's%20rank%20correlation%20measures%20the,represented%20using%20a%20monotonic%20function.

- *How different light affects your eyes*. How Different Light Affects Your Eyes | Denver Optometrists. (n.d.). Retrieved February 19, 2023, from https://www.opticalmasters.com/blog/different-light-affects-eyes.html

- John, K. S., & says:, A. M. (2011, March 18). Outside my window. Retrieved February 19, 2023, from https://www.birdsoutsidemywindow.org/2011/03/18/anatomy-field-of-view/

- *Metarhodopsin*. Metarhodopsin - an overview | ScienceDirect Topics. (n.d.). Retrieved February 19, 2023, from https://www.sciencedirect.com/topics/chemistry/metarhodopsin

- *Motion parallax*. Motion Parallax - an overview | ScienceDirect Topics. (n.d.). Retrieved February 19, 2023, from https://www.sciencedirect.com/topics/computer-science/motion-parallax

- Nityananda, V., & Read, J. C. A. (2017, July 15). *Stereopsis in animals: Evolution, function and Mechanisms*. The Company of Biologists. Retrieved February 19, 2023, from https://journals.biologists.com/jeb/article/220/14/2502/18621/Stereopsis-in-animals-evolution-function-and

- P-Themes. (n.d.). *What's the difference between a predator's eyes and their prey's?* Owl Brand Discovery Kits. Retrieved February 19, 2023, from https://obdk.com/blogs/obdk-blog/sept-3-predator-prey-eyes

- *Photoreceptors*. American Academy of Ophthalmology. (2017, November 18). Retrieved February 19, 2023, from https://www.aao.org/eye-health/anatomy/photoreceptors

- Sharma, P., Arora, A., & Valiathan, A. (2014, November 20). *Age changes of jaws and soft tissue profile*. The Scientific World Journal. Retrieved February 19, 2023, from https://www.hindawi.com/journals/tswj/2014/301501/

- *Spearman's Rho Calculator*. Social Science Statistics. (n.d.). Retrieved February 19, 2023, from https://www.socscistatistics.com/tests/spearman/

- *Stereopsis and tests for stereopsis*. EyeWiki. (2018, April 1). Retrieved February 19, 2023, from https://eyewiki.org/Stereopsis_and_tests_for_stereopsis

Appendix A.1 – Visual Limits for Left Eye

Visual Limit – Left Eye (± 0.5°)					
Participant	Sex	Trial 1	Trial 2	Trial 3	Interpupillary Distance (± 0.5 mm)
1	M	39.9	40.4	39.4	73.5
2	M	54.0	54.7	54.0	72.4
3	M	56.0	55.2	56.7	72.1
4	M	56.2	56.9	57.5	70.5
5	M	57.8	58.6	59.1	70.1
6	M	63.4	64.9	65.0	64.2
7	M	65.4	66.2	67.2	62.5
8	M	46.1	47.5	48.0	72.3
9	M	49.6	48.9	50.1	78.2
10	M	45.4	47.0	47.5	81.1
11	M	62.9	63.0	62.8	67.9
12	M	66.3	66.6	67.6	60.1
13	M	58.6	58.9	59.3	68.1
14	M	66.2	67.2	66.9	61.2
15	M	61.6	61.8	61.7	66.9
16	M	60.1	58.4	61.0	66.8
17	M	57.4	58.7	59.7	63.2
18	M	59.5	58.9	59.8	65.1
19	M	68.7	68.1	70.9	60.2
20	M	59.0	60.3	60.1	59.5
21	M	50.0	50.7	49.8	78.1
22	M	71.1	70.9	71.3	57.1
23	M	61.1	61.8	62.7	68.3
24	M	59.7	60.0.	60.5	74.1
25	M	61.5	62.9	62.9	65.2
26	F	60.0	60.5	61.3	64.1
27	F	60.6	61.6	61.2	67.2
28	F	62.1	63.8	64.7	64.1
29	F	66.2	66.0	65.9	65.2
30	F	67.1	66.7	67.7	60.2
31	F	65.7	67.8	67.1	67.4
32	F	53.9	52.6	54.1	71.2
33	F	73.7	74.1	73.3	50.2
34	F	67.2	68.3	69.4	72.2
35	F	69.3	68.5	70.2	59.0
36	F	60.4	60.1	58.5	64.1
37	F	39.5	40.9	41.0	72.3
38	F	67.0	68.0	66.9	62.1
39	F	54.6	54.4	55.4	70.1

Visual Limit – Left Eye (± 0.5°)					
Participant	Sex	Trial 1	Trial 2	Trial 3	Interpupillary Distance (± 0.5 mm)
40	F	62.2	62.0	61.9	67.2
41	F	68.5	66.6	69.4	57.2
42	F	70.8	69.7	70.7	56.3
43	F	57.2	59.0	60.0	69.9
44	F	62.0	63.3	62.0	64.3
45	F	68.2	66.6	69.3	54.2
46	F	58.4	57.5	59.6	67.2
47	F	70.9	71.6	71.8	57.1
48	F	72.3	74.4	73.9	52.4
49	F	57.3	58.6	56.7	69.9
50	F	72.8	72.5	76.0	55.1

Appendix A.2 – Visual Limits for Right Eye

Visual Limit – Right Eye (± 0.5°)					
Participant	Sex	Trial 1	Trial 2	Trial 3	Interpupillary Distance (± 0.5 mm)
1	M	40.2	40.1	42.1	73.5
2	M	54.1	53.9	55.4	72.4
3	M	56.3	57.2	55.9	72.1
4	M	57.3	57.5	57.9	70.5
5	M	60.3	60.2	59.9	70.1
6	M	66.8	65.6	66.1	64.2
7	M	67.1	66.3	65.9	62.5
8	M	49.5	49.4	49.4	72.3
9	M	50.6	51.7	51.1	78.2
10	M	48.6	47.1	46.8	81.1
11	M	64.4	64.7	65.1	67.9
12	M	67.8	67.9	67.9	60.1
13	M	60.6	60.5	60.2	68.1
14	M	69.9	69.1	69.5	61.2
15	M	63.5	63.3	64.3	66.9
16	M	60.3	61.6	60.5	66.8
17	M	62.6	62.2	60.7	63.2
18	M	60.5	61.1	61.4	65.1
19	M	71.3	72.8	70.3	60.2
20	M	62.3	61.2	61.2	59.5
21	M	52.1	52.1	52.3	78.1
22	M	73.4	73.6	73.3	57.1
23	M	64.1	63.5	62.8	68.3
24	M	62.2	62.6	62.6	74.1
25	M	66.9	65.9	66.3	65.2
26	F	62.1	62.2	61.1	64.1
27	F	63.6	63.3	62.9	67.2
28	F	64.6	63.7	63.7	64.1
29	F	67.1	67.8	67.9	65.2
30	F	69.5	70.4	70.1	60.2
31	F	69.5	67.4	68.5	67.4
32	F	55.3	56.4	56.1	71.2
33	F	75.5	75.4	76.4	50.2
34	F	69.9	69.4	68.6	72.2
35	F	68.7	69.6	68.6	59
36	F	60.1	60.2	62.1	64.1
37	F	41.6	40.4	41.1	72.3
38	F	68.3	67.5	68.3	62.1
39	F	55.6	55.7	54.8	70.1

Visual Limit – Right Eye (± 0.5°)					
Participant	Sex	Trial 1	Trial 2	Trial 3	Interpupillary Distance (± 0.5 mm)
40	F	62.9	63.2	64.3	67.2
41	F	68.9	70.5	68.8	57.2
42	F	70.2	71.3	71.3	56.3
43	F	61.6	60.7	59.7	69.9
44	F	63.6	62.8	64.4	64.3
45	F	69.8	71.8	68.8	54.2
46	F	59.1	60.9	59.8	67.2
47	F	72.9	72.6	73.3	57.1
48	F	76.2	74.5	75.4	52.4
49	F	58.8	57.6	59.6	69.9
50	F	72.7	73.7	71.1	55.1

Appendix A.3 – Binocular Field of Vision

Binocular Field of Vision (±1.0°)							
Participant	Sex	Trial 1	Trial 2	Trial 3	Average	Standard Deviation	Interpupillary Distance (± 0.5 mm)
1	M	80.1	80.5	81.5	80.7	0.7211	73.5
2	M	108.1	108.6	109.4	108.7	0.6557	72.4
3	M	112.3	112.4	112.6	112.4	0.1528	72.1
4	M	113.5	114.4	115.4	114.4	0.9504	70.5
5	M	118.1	118.8	119	118.6	0.4726	70.1
6	M	130.2	130.5	131.1	130.6	0.4583	64.2
7	M	132.5	132.5	133.1	132.7	0.3464	62.5
8	M	95.6	96.9	97.4	96.6	0.9292	72.3
9	M	100.2	100.6	101.2	100.7	0.5033	78.2
10	M	94.0	94.1	94.3	94.1	0.1528	81.1
11	M	127.3	127.7	127.9	127.6	0.3055	67.9
12	M	134.1	134.5	135.5	134.7	0.7211	60.1
13	M	119.2	119.4	119.5	119.4	0.1528	68.1
14	M	136.1	136.3	136.4	136.3	0.1528	61.2
15	M	125.1	125.1	126.0	125.4	0.5196	66.9
16	M	120.4	120.0	121.5	120.6	0.7767	66.8
17	M	120.0	120.9	120.4	120.4	0.4509	63.2
18	M	120.0	120	121.2	120.4	0.6928	65.1
19	M	140.0	140.9	141.2	140.7	0.6245	60.2
20	M	121.3	121.5	121.3	121.4	0.1155	59.5
21	M	102.1	102.8	102.1	102.3	0.4041	78.1
22	M	144.5	144.5	144.6	144.5	0.0577	57.1
23	M	125.2	125.3	125.5	125.3	0.1528	68.3
24	M	121.9	122.6	123.1	122.5	0.6028	74.1
25	M	128.4	128.8	129.2	128.8	0.4000	65.2
26	F	122.1	122.7	122.4	122.4	0.3000	64.1
27	F	124.2	124.9	124.1	124.4	0.4359	67.2
28	F	126.7	127.5	128.4	127.5	0.8505	64.1
29	F	133.3	133.8	133.8	133.6	0.2887	65.2
30	F	136.6	137.1	137.8	137.2	0.6028	60.2
31	F	135.2	135.2	135.6	135.3	0.2309	67.4
32	F	109.2	109	110.2	109.5	0.6429	71.2
33	F	149.2	149.5	149.7	149.5	0.2517	50.2
34	F	137.1	137.7	138.0	137.6	0.4583	72.2
35	F	138	138.1	138.8	138.3	0.4359	59.0
36	F	120.5	120.3	120.6	120.5	0.1528	64.1
37	F	81.1	81.3	82.1	81.5	0.5292	72.3
38	F	135.3	135.5	135.2	135.3	0.1528	62.1
39	F	110.2	110.1	110.2	110.2	0.0577	70.1

Binocular Field of Vision (±1.0°)							
Participant	Sex	Trial 1	Trial 2	Trial 3	Average	Standard Deviation	Interpupillary Distance (± 0.5 mm)
40	F	125.1	125.2	126.2	125.5	0.6083	67.2
41	F	137.4	137.1	138.2	137.6	0.5686	57.2
42	F	141.0	141.0	142.0	141.3	0.5774	56.3
43	F	118.8	119.7	119.7	119.4	0.5196	69.9
44	F	125.6	126.1	126.4	126.0	0.4041	64.3
45	F	138.0	138.4	138.1	138.2	0.2082	54.2
46	F	117.5	118.4	119.4	118.4	0.9504	67.2
47	F	143.8	144.2	145.1	144.4	0.6658	57.1
48	F	148.5	148.9	149.3	148.9	0.4000	52.4
49	F	116.1	116.2	116.3	116.2	0.1000	69.9
50	F	145.5	146.2	147.1	146.3	0.8021	55.1