A Thesis Presented to

The Faculty of Alfred University

Color Perception in Central and Peripheral Vision

by

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Under the Supervision of:

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Abstract

It is well accepted that color sensitivity is greater in the fovea than the periphery. Further support for this has been found through research investigating thresholds in which hues have higher thresholds in the periphery. Of the psychologically pure hues, blue has been found to have the lowest threshold, with green and red showing higher thresholds. The goal of the current studies were to investigate difference thresholds for the psychologically pure hues in central and peripheral vision with children and adults. Participants ages 5 – 23 completed the difference threshold task where red, green, yellow, and blue were compared with small differences in hue to determine thresholds in the fovea, and 50° to the left and right. Overall, adults showed a main effect of location, in which the right periphery had higher thresholds than left and center. A main effect of color suggested that blue had lower thresholds than red, green, and yellow. In children, the lowest thresholds appeared to be for the fovea compared to either periphery. They also showed the lowest mean thresholds for blue, and highest for green. These results supported previous research suggesting that color sensitivity is greater in the fovea than the periphery, as well as showing lower thresholds for blue than green or red.

Color Perception in Central and Peripheral Vision

Color perception is a very important part of our world because colors make objects much more vibrant and exciting, as well as making tasks such as object discrimination easier. It is well known that visual acuity is higher in the fovea (center of vision) than the periphery, and the same is true for color detection, discrimination, and identification (Hansen, Pracejus, & Gegenfurtner, 2009). Sensitivity for hue declines in the periphery the further stimuli are from the center of the visual field (Hansen et al., 2009). There are four principle colors, or *psychologically pure hues*: red, yellow, green, and blue (Dimmick, 1965), that are most often studied in research. The current study involves these four colors to investigate difference thresholds in central and peripheral vision in both children and adults.

The layout of cones and rods in the retina is what likely leads to color sensitivity differences. Cones are focused in the center of the retina and are useful for visual acuity and color vision. Rods, which are more populous around the outside of the retina, are used for vision in low light situations. Light from the rods suppresses the colors mediated by the cones, and light signals from rods and cones converge into the same pathways (Stabell & Stabell, 1996). Even though cones are the primary source of sensing color, the rods and cones work together to allow people to perceive colors. Acuity and contrast sensitivity are high in the fovea and they both deteriorate towards the periphery (Hansen et al., 2009). Hansen and colleagues (2009) also state that the fovea is more largely represented in the visual cortex than the periphery, which is another possibility as to why acuity and sensitivity are higher in the fovea.

Another common method for testing the ability to notice small changes is a just noticeable difference. Dimmick conducted a study in 1965 to determine just noticeable differences for hues in the visible spectrum. Hue is the color of light that we see in the visible spectrum and labeled in wavelengths with a unit of nanometers (nm). Dimmick (1965) listed three basic assumptions that need to be made about color specification. He listed four principle hues: red, yellow, green, and blue. Children, including babies who are not yet able to talk, also categorize colors in these same four categories that adults use (Bornstein & Lamb, 1999). Dimmick (1965) also said that all colors can be put into a spectrum with two unique hues as the end points. Finally, he wrote that this series needs to be labeled in terms of a unit determined based on a psychological scale and a judgmental procedure. He decided that an appropriate unit for this would be a *just noticeable difference*, meaning the smallest value something has to be changed in order to notice a difference. Later in his paper, Dimmick (1965) presented a chart that listed each wavelength in the visible spectrum from 400 – 700 nm and its corresponding just noticeable difference. Even though just noticeable difference is different than an absolute threshold, the measurement and concept behind the threshold are the same as the current study.

Specifically, the method of constant stimuli was used in this study in order to determine threshold. This method is typically used for measuring an absolute threshold, as it was in this study, however, Xu and Yaguchi (2005) used the method of constant stimuli to find a suprathreshold. Suprathreshold refers to a stimulus being large enough to generate a response, while absolute threshold is being able to detect a stimulus 50% of the time. There are two other methods commonly used for detecting thresholds: the method of limits and the method of adjustment. While the method of constant stimuli is the longest and most laborious of the three methods, it has the highest reliability, least variable results, and is the most accurate (Schiffman, 2001; Siegel, 1962). In a study where Siegel (1962) directly compared these three methods, it was found that the method of constant stimuli has the least possibility of anticipation errors and habituation because the random order does not allow the participants to guess what is coming next, and it has the lowest standard deviation, accounting for greater sensory determinacy. Xu and Yaguchi (2005) also stated that this method is more accurate and repeatable than the staircase method, another common method for measuring thresholds. McMahon and MacLeod (1998) reference work by Helmholtz (1896) and also Weber's law (1834) that states that a "just detectable change in excitation requires a constant proportion of initial stimulus value" (p. 973). McMahon and MacLeod (1998) state that these assumptions must be made in order to understand color characterization and discrimination, which is necessary in order to use these methods to find thresholds for color.

A newer method to measure thresholds, similar to and developed based on the method of limits, is the staircase method, which was used by Hansen and colleagues in 2009. They had their participants do three tasks: detection, where participants detected the location of stimuli in the periphery while looking at the center; identification, where participants pressed a button to identify the color of the stimuli; and discrimination, where participants saw three disks, two of which were the same and one of which was different, and they had to determine the location of the different colored disk. They found that all three of these tasks were possible in the periphery at 50 degrees off center. The threshold measured in each of the tasks increased from the fovea to 50 degrees in the periphery.

Three of the pure hues, blue, green, and red, are each processed by their own individual cones: short (S), medium (M), and long (L), respectively. Hering's Opponent Process Theory proposes that it is possible to see green-blues and yellow-reds, but not red-greens or yellow-blues because there are two opponent processes in the visual system; the red-green system is controlled by a different mechanism than the yellow-blue system (Hurvich & Jameson, 1957). In a previous study of difference thresholds with the psychologically pure hues, it was found that the highest threshold, meaning the largest difference between the colors needed to discriminate between them, was for green, followed by red, then yellow, and the lowest threshold for blue (Xu & Yaguchi, 2005). It is interesting that the order of difference progressed in this way with green and red on one end and yellow and blue on the other because this is how the color vision system is split between the two cone-opponent processes. The “red-green” system is operated by L and M cones, while the “blue-yellow” system uses S cones. The difference in thresholds for these colors may come from the difference in how the visual system is organized.

In terms of color thresholds from foveal to peripheral vision, it has been well established that declining sensitivity towards the periphery is greater for red-green colors than for yellow-blue colors (Goulart et al., 2008; Hansen et al., 2009; Mullen & Kingdom, 2002). Mullen and Kingdom (2002) suggest that red and green steeply decline towards the periphery while yellow and blue decline more gradually; this gradual decline is similar to that of achromatic vision. Goulart et al. (2008), also suggest that pigment density decreases with greater eccentricity (further in periphery), where there is greater sensitivity to shorter wavelengths. This finding corresponds with Mullen and Kingdom’s (2002) work as well as Hansen and colleagues’ (2009) work, since blue-yellow sensitivity, using the S cones for shorter wavelengths, declines less rapidly in the periphery. These findings have been well established for adults, but there is a vast amount of literature suggesting that children’s color perception may not be equal to that of adults.

The color vision system is not very mature in infancy. Color vision has said to be established by 2 months (Peeles & Teller, 1975), but color discrimination is not yet possible (Teller et al., 1978) until a later age. While Ling and Dain (2008) suggest that color vision does change between the ages of 5 and 12, as measured with a color vision test, Boon, Suttle, and

Dain (2007) suggest that there is only very slight maturation of the color vision system happening during these ages compared to adults as measured through visual evoked potentials. In children, it has been suggested that L-M chromatic thresholds decrease with age during childhood (Boon, Suttle, & Dain, 2007; Knoblauch et al., 2001), although this pathway does not show much change between 5 and 12 years of age (Boon et al., 2007). Boon et al. (2007) suggest that the color vision system matures through childhood and early adolescence, but there is just a very slight maturation between ages 5 and 12. They propose that the neurons responsible for the color system are not mature before age 12, but that there is significant maturation of the system from age 12 until adulthood. Goulart et al. (2008) grouped the children in their study into three age groups, 2-4, 5-7, and 7-11 years. They found that color discrimination thresholds decreased with age, as would be expected since this system matures with age. This group's findings, as well as Knoblauch et al. (2001), suggest that there is a consistent and gradual increase in discrimination from ages 2-7, which seems to slightly disagree with Boon and colleagues' (2007) findings; the latter suggested there is no change in discrimination between ages 5 and 12. However, all aforementioned researchers do suggest that color discrimination performance increases from childhood to adulthood.

In two studies, color difference thresholds were measured in central and peripheral vision. The second study included the addition of children participants as well as adults. It was predicted that adults would have lower thresholds in foveal vision than peripheral, and that red-green colors would have higher thresholds than blue. In the second study, children were predicted to show a similar pattern difference thresholds compared to adults, but would have higher thresholds overall.

Part I

Method

Design

This study was a two-way within-groups experiment. The first independent variable was the type of vision in which participants were viewing the stimuli; the two levels of this were central and peripheral vision. The second independent variable was the difference in wavelengths that the comparison color was away from the target color. There were eight levels of this variable: 0nm, 2nm, 4nm, 6nm, 8nm, 10nm, 12nm, and 14nm. The dependent variables were the threshold in central vision and the threshold in peripheral vision.

Participants

Participants were recruited through sign-up sheets from the Introduction to Psychology courses at Alfred University. There were nine participants involved in the study, four men, four women, and one identified as other. Participants were between the ages of 18 and 22 and were part of the Inamori School of Engineering, College of Liberal Arts and Sciences, and College of Professional Studies. All psychology students who participated received credit towards their class as compensation. The only restriction for this study was that people with a color deficiency were not allowed to participate.

Materials

Participants signed an informed consent form (see Appendix A) before beginning the study, and were given a debriefing statement after the study was completed (see Appendix B). They were also given a demographic questionnaire (see Appendix C) that asked their gender, age, and school that they belong to at Alfred University. Before completing the main part of the study, participants' color vision was tested with the Farnsworth-Munsell 100 Hue Color Vision Test (see Appendix D). The main part of the study was programmed with Python and displayed on a TV that was hooked up to a computer with the program. Python is an object-oriented high-level computer programming language that can be used for programming a large variety of things, including video games, scientific computations, psychological research experiments, etc. Its syntax allows for programming in simpler terms than other computer languages. The Panasonic TV has a resolution of 1920 x 1080 and is 50 inches. Because this part of the study is self-designed, no reliability or validity data exists for this task.

Procedure

The study took place in a classroom with a TV in front and no windows so that extra light would not affect viewing of the stimuli. The study lasted approximately 60 minutes and the Introduction to Psychology students were compensated with experiential credits for their class for their time and participation. After consenting to participate in this study, participants began by completing the Farnsworth-Munsell 100 Hue Color Vision Test online to ensure that no color deficiencies were present. In the main part of the study, the order in which participants do the central and peripheral tasks was counterbalanced. Participants were individually tested in this study to determine their thresholds by using the method of constant stimuli. On the screen, they saw two squares (one above the other) of given wavelengths of color and they were asked to say out loud whether the two colors were the same or different, and the researcher recorded their response before moving on to the next trial. There were 448 trials in each of the central and peripheral parts; each trial lasted no more than a few seconds. Seven wavelengths were selected as target colors, there were eight possible options for the comparison color, and each of those eight possibilities was tested eight times. For the peripheral task, participants were asked to keep their head on a chin rest to ensure that the stimuli were truly in their peripheral vision and they could not move their head to look at the colors. The stimuli were presented at 50 degrees in their peripheral. Once both the central and peripheral tasks were complete, participants filled out the demographic questionnaire. Finally, participants were debriefed with information about the study and their involvement was complete.

Results

The goal of this study was to determine if there is a significant difference between thresholds in fovea and periphery for being able to notice small differences in color. It was expected that the threshold in the fovea would be smaller than the threshold in the periphery. The absolute thresholds were determined by the difference between target and comparison colors detected 50% of the time. To determine if there is a significant difference between these thresholds, a one-way repeated measures ANOVA was used with the threshold in fovea and threshold in periphery as the two levels of the threshold variable.

The results of the ANOVA revealed that there is a significant difference between the thresholds, $F(1,9) = 12.962$, $p < 0.01$, *partial* $\eta^2 = 0.618$. This is a large effect size, meaning that the threshold in the fovea ($M = 6.89$, $SD = 1.764$) is significantly smaller than the threshold in periphery ($M = 10.44$, $SD = 2.963$). However, in the fovea, neither red nor green reached the 50% threshold, and in the periphery, red, yellow, and green did not reach the threshold criteria. Separate ANOVAs were run with red and green removed in fovea and red, yellow, and green removed in periphery to determine if there is still significance without the colors that did not reach threshold. This analysis revealed a non-significant difference between thresholds in fovea and periphery, $F(1,9) = 0.587$, $p = 0.466$. These results somewhat support and somewhat do not support the hypothesis. The first analysis suggests that color sensitivity is lower in the periphery since the threshold in periphery was higher, but when the colors that did not reach threshold were removed, the data was no longer significant. This may be evidence that color sensitivity for the remaining colors that did reach threshold could be more similar or even equal in these locations.

To determine if there are significant differences between the seven target colors, ANOVAs were used. Rather than using the “different” responses to determine thresholds, the “same” responses were used to determine the average comparison that participants could not detect as different. In the fovea, there were significantly different averages for the colors, $F(4.693,180) = 69.026$, $p < 0.001$, *partial* $\eta^2 = 0.278$. This is a moderate effect size in which red (*M* = 6.856, *SD* = 4.564) and green (*M* = 6.800, *SD* = 4.552) have significantly higher averages than orange (*M* = 2.856, *SD* = 2.691), yellow (*M* = 3.156, *SD* = 2.997), light blue (*M* = 2.722, *SD* = 2.889), dark blue (*M* = 1.833, *SD* = 1.878), and purple (*M* = 3.144, *SD* = 2.683). In the periphery, there were also significant differences for the colors, $F(6,223) = 6.691$, $p < 0.001$, *partial* $\eta^2 = 0.029$. This is a fairly small effect size; however, red (*M* = 7.067, *SD* = 4.703), yellow (*M* = 7.022, *SD* = 4.649), and green (*M* = 7.094, *SD* = 4.602) have significantly higher averages than orange (*M* = 5.292, *SD* = 3.984), light blue (*M* = 6.547, *SD* = 4.453), dark blue (*M* = 5.453, *SD* = 4.292), and purple (*M* = 6.081, *SD* = 4.521). These results suggest that some of the colors have to be much farther apart in wavelength between the target and comparison for people to be able to tell the difference between the two, while some hues can be more similar and people are able tell that they are different.

Finally, the colors were split into two groups of whether or not they reached the threshold. A one-way repeated measures ANOVA was used again in both the fovea and periphery. In the fovea, there were significantly different averages between the threshold and no threshold groups, $F(1,1084) = 575.972$, $p < 0.001$, *partial* $\eta^2 = 0.347$. This is a moderate effect size; the threshold group (*M* = 3.000, *SD* = 2.973) had a significantly lower average comparison than the no threshold group (*M* = 6.956, *SD* = 4.565). In the periphery, the ANOVA also revealed significantly different averages between the threshold and no threshold groups, $F(1,1181) = 34.745$, $p < 0.001$, $partial\ \eta^2 = 0.029$. This is a small effect size, which means that the threshold group (*M* = 5.893, *SD* = 4.360) has a slightly smaller average than the no threshold group (*M* = 7.001, *SD* = 4.597). These results may help shed some light on determining why the original thresholds are no longer significant when the no threshold colors are removed. The colors that did not reach threshold have significantly higher averages for not being able to tell changes than the colors that did reach threshold.

Discussion

The primary analysis in this study was done to determine if there is a significant difference between color thresholds in fovea versus periphery. The results revealed that there is a significant difference, with the threshold in fovea being smaller than the threshold in periphery. Since there were several colors in both types of vision that did not reach a threshold of being able to tell a difference between the colors 50% of the time, a sensitivity analysis was used to see if there is still a significant difference between the thresholds with these colors removed. When the colors not reaching threshold were not included, the results were no longer significant. This suggests that the colors that did not reach threshold were possibly causing some kind of variability that was taken away when they were removed. It seems as though there must be something different about these hues, as some were far from reaching threshold. These three colors, red, yellow, and green, are considered *psychologically unique hues*, meaning they are pure variants and all other colors are simply mixtures of any of the given four (Wright, 2013). It is interesting that these are the ones that people had the most trouble detecting differences in. These were the colors that were predicted to be the easiest for people to complete the task.

Another sensitivity analysis was done to see if the colors not reaching threshold are significantly different than the ones that did. Red and green in fovea were put in one group and orange, yellow, light blue, dark blue, and purple in another group. The same thing was done in the periphery, but red, yellow, and green were grouped together while the others were in a separate group. Analyses were then done to compare the threshold and no threshold groups in both fovea and periphery. They turned out to be significantly different in both visual locations. This suggests that there truly is something different about these colors that never reached a threshold up to a 14 nm difference in hue. The colors that did reach a threshold had smaller averages for their thresholds, meaning that it was easier to detect small differences in these colors.

These results were surprising in that some colors did not reach a threshold, and that these colors are our psychologically unique hues. Since the original results are contradictory in that there was a significant difference between threshold and fovea, but not when certain colors were removed, it was tricky to figure out exactly what seems to be the trend between thresholds. However, since there was originally significance, the hypothesis can be cautiously accepted. It seems that there is a difference between thresholds for noticing small differences in color in the fovea versus the periphery.

The task in periphery was tested at 50 degrees from center, similar to what Hansen et al. (2009) suggested about color processing still being possible up to this amount. All participants in this study were able to see the stimuli and do the task at 50 degrees from the center of their vision, which is further evidence that color vision may be possible more into the periphery than was suggested by earlier researchers. Hansen and colleagues (2009) also suggested that color sensitivity is greater in the fovea than the periphery, which was also supported by the current study. Since the original analysis showed that the threshold in fovea was smaller than that in the periphery, this suggests that people have an easier time noticing small differences in color when looking directly at it. This is likely because color sensitivity is greater for central vision.

This does get a bit confusing, however, because when the colors that did not reach threshold were removed, there was no longer a significant difference between the thresholds. This could be evidence opposing previous research and possibly indicating that color processing is the same in the fovea and periphery; since there is previous research along with theories suggesting this, it is not likely that this data is leading to another conclusion. Removing some of the data could have caused problems with variability that may have skewed the data. Future research will need to be done to determine exactly what the data is with the missing thresholds.

There is a theory called the Opponent Process Theory, also known as the Hering Theory, which explains that colors are combined into three main pairs: blue and yellow, red and green, and black and white. This theory states that these colors are mutually opponent, meaning that we can see red-blues or green-blues, but not yellow-blues because they are opposites (Hurvich & Jameson, 1957). It is interesting that one of these pairs were the exact colors that people had the most problems with in this task: the red-green pair. Hurvich and Jameson (1957) write that the red-green pair has a lower threshold than yellow-blue, which is not what was found in this study. However, this threshold likely refers to the point at which the color can be seen and detected as either red or green, as opposed to the threshold measured in this study, with the point at which a difference can be discriminated between two colors of the same category. Again, since this seems to be a new finding that does not support previous research, more research will need to be done to determine what is different about these colors.

The overall results of this study suggest that it is easier for people to notice small differences in color when they are looking directly at the stimuli, as opposed to viewing it in peripheral vision. This goes along with some things that have been found in previous studies, stating that color sensitivity and acuity are greater in the fovea. This is likely because of the layout of cones and rods in the retina. Cones, which are used for color vision, are more densely packed in the fovea, while rods are more spread out into the peripheral edges of the retina. Since the data was contradictory with a few colors, more analyses were run. These results suggest that there is a difference between red, green, and possibly yellow, compared to the other colors that were tested. These are typically considered psychologically unique hues, but it is interesting that red and green were so different from the others. Blue is also a psychologically unique hue, and this color seemed to be much easier for people to detect differences in. Yellow, which is also a unique hue, reached threshold in the fovea, but in periphery the data was too consistent around 40% for each comparison difference for a threshold to be determined. There must also be something different about yellow, but potentially only when it is being viewed in periphery.

Due to the participant pool only from Introduction to Psychology classes, the time in which participants could be tested was limited. Participants were tested for an hour each, but more time would have allowed for more testing. It would have been better to test the comparison color up to more than 14 nm away from the target color because the missing thresholds could have been determined with more data. Also, the peripheral test was only done on the right side. It may have been interesting to see if there is any difference between left and right periphery, or test both and counterbalance the order to ensure that one side is not stronger than the other in certain participants.

Future studies should focus on trying to find the missing thresholds and see what may be different about red, green, and yellow. This could be done by extending the range of comparison differences that are tested. However, even up 14 nm was not close to where red and green needed to be tested; these colors were only said to be different approximately 10% of the time up to this comparison difference. However, collecting more data about these colors with a greater variability may allow for the thresholds for red, green, and yellow to be determined. Overall, the results of this study seem to support previous research, but some of the data may lead to a different conclusion. Future studies with a closer examination of the psychologically unique hues could fill in the blanks to understand more about these colors and small color difference thresholds in central and peripheral vision

References

Bornstein, M. H., & Lamb, M. E. (1999). *Developmental psychology: An advanced textbook*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc., Publishers.

Dimmick, F. L. (1965). Color specification based on just noticeable difference of hue. *Vision Research, 5*, 679-694. doi: 10.1016/0042-6989(65)90040-4

Hansen, T., Pracejus, L., & Gegenfurtner, K. R. (2009). Color perception in the intermediate periphery of the visual field. *Journal of Vision, 9*, 1-12. doi: 10.1167/9.4.26

Hurvich, L. M., & Jameson, D. (1957). An opponent-process theory of color vision. *Psychological Review, 64*, 384-404. doi: 10.1037/h0041403

McMahon, M. J., & MacLeod, D. I. A. (1998). Dichromatic color vision at high light levels: Red/green discrimination using the blue-sensitive mechanism. *Vision Research, 38*, 973-983. doi: 10.1016/S0042-6989(97)00280-0

Schiffman, H. R. (2001). *Sensation and perception: An integrated approach*. New York, NY: John Wiley & Sons, Inc.

Siegel, M. H. (1962). Discrimination of color. I. Comparison of three psychophysical methods. *Journal of the Optical Society of America, 52*, 1067-1070. doi: 10.1364/JOSA.52.001067

Stabell, B., & Stabell, U. (1996). Peripheral color vision: Effects of rod intrusion at different eccentricities. *Vision Research, 36*, 3407-3414. doi: 10.1016/0042-6989(96)00079-X

Wright, W. (2013). Psychologically pure colors. *Encyclopedia of Color Science and Technology*. doi: 10.1007/978-3-642-27851-8_78-8

Xu, H., & Yaguchi, H. (2005). Visual evaluation at scale of threshold to suprathreshold color difference. *Color Research and Application, 30*, 198-208. doi: 10.1002/col.20106

Appendix A

Informed Consent Form

You are invited to participate in a research study of color perception. You have been selected as a participant because you are currently enrolled in an Introduction to Psychology class at Alfred University. Please read this form before agreeing to participate in the study.

This study is being conducted by Elizabeth Eberts, Alfred University, Alfred, NY 14802.

Background Information

The goal of this study is to investigate color perception and the ability to notice small color differences.

Procedures

If you agree to participate in this study, you will be seated in front of a computer screen where colors of different wavelengths will be presented and you will be asked if the two colors shown at once are the same or different. This procedure will be done with you looking directly at the color and also where the colors are in your periphery, where you will keep your head on a chin rest. Your color vision will be tested to ensure that you are not color blind. The study will take approximately 60 minutes.

Risks and Benefits of Being in the Study

There are no foreseen risks for your participation in this research. You are free to discontinue your participation in the study at any time without penalty. In the unlikely event that this study causes you any distress, you may contact the Alfred University Wellness Center (607) 871-2300 for assistance. Your participation in this study may provide you with additional knowledge about research in psychology and your participation will add to this general knowledge. You will also receive 3 experiential credits for your Introduction to Psychology class.

Confidentiality

All of the data collected in this study will be kept confidential by not having any connection to your name and the number that will be used to keep track of your data. Any report or poster that will be made will not include any information that will make it possible to identify you.

Voluntary Nature of the Study

Your decision whether or not to participate will not affect your current or future education and academic career at Alfred University. If you decide to participate you are free to withdraw at any time without penalty.

Contacts and Questions

If you have any questions about your participation in this study, please feel free to ask the researcher at any time. If you have questions after you leave the study, you may contact Elizabeth Eberts at eae9@alfred.edu or Professor Button at button@alfred.edu. If you have any questions about the integrity of this research, please contact Dr. Steve Byrne, Chair of the Alfred University Human Subjects Research Committee, at (607) 871-2212 or at HSRC@alfred.edu.

Statement of Consent

I have read the above information and I consent to participate in the study.

____ __________________

Signature Date

____

Printed Name

Appendix B

College of Liberal Arts and Sciences
Division of Psychology
1 Saxon Drive
Alfred, NY 14802-1205
607-871-2213
Fax 607-871-2342

Alfred University

Debriefing Statement

This study was conducted to determine the threshold of detecting differences in colors in a variety of wavelengths throughout the visible spectrum. You earned 3 research credits by participating in this study.

This research was conducted to look at a small color difference threshold in the periphery compared to central vision. Research has been done on thresholds in central vision, and it is known that color sensitivity is much lower in the periphery. The research question for this study is “Is the relationship between color thresholds significantly different between central vision and peripheral vision?” The hypothesis is that the threshold for detecting small color differences will be smaller in central vision than in the periphery. The project will be completed in the Spring 2017 semester. All data will be coded with a number so that participants cannot be connected to their data with their name.

There are no known risks associated with your agreement to participate in this research; you only experienced situations and completed tasks that carry the same level of risk you can expect in daily life. If, however, you experience any emotional distress as the result of participating in this study, psychological treatment is available through Alfred University Counseling Services (607) 871-2300, which is part of the free health services in the Wellness Center.

The primary researcher for this study is Elizabeth Eberts, and you may contact the researcher at eae9@alfred.edu for answers to questions about the study. Professor Amy Button is the faculty supervisor of Elizabeth Eberts. You may also contact Professor Button via email at button@alfred.edu or by phone (607) 871-2860 with questions or concerns about the study. If you have questions about research participants’ rights, you may contact the Human Subjects Research Committee chair, Dr. Steve Byrne, at (607) 871-2212 or hsrc@alfred.edu.

Please do not discuss the details of this study with any of your classmates or friends.

Appendix C

Participant Number: _________

What is your age? ________

What is your eye color? _______________

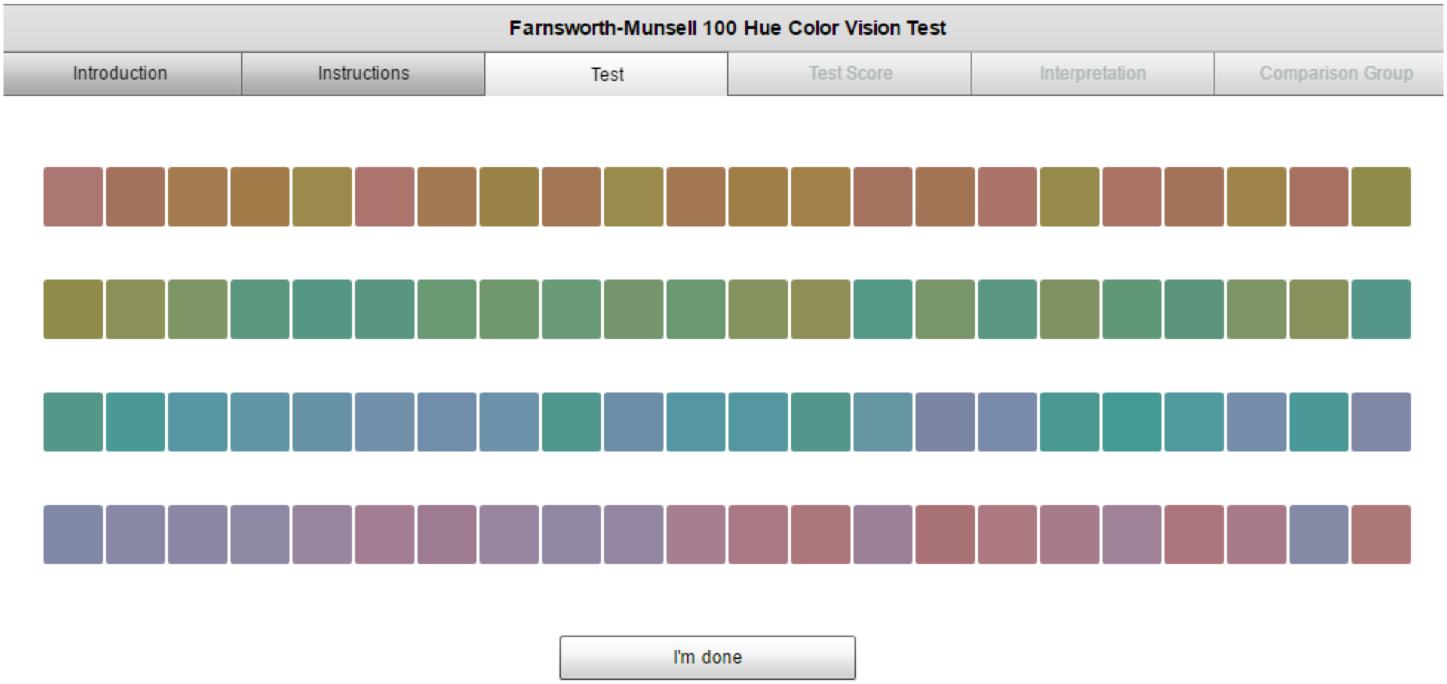
What is your gender? (Please circle)

Man	Woman	Other	Prefer not to say

What school do you belong to at Alfred University? (Please circle)

College of Liberal Arts and Sciences	College of Professional Studies
School of Art & Design	Inamori School of Engineering

Appendix D



Note: The instructions for this task ask participants to put the colors in the correct order based on the fixed end points. The number of errors made is used to calculate their color vision and degree of impairment.

Part II

Method

Design

This study was a three-way mixed groups experiment. The independent variables were age (children and adults), color (blue, green, yellow, and red), and location of presentation (left periphery, right periphery, and center). The dependent variable was the difference threshold.

Participants

Twenty-three adults ages 18 – 23 (13 males and 10 females) and 11 children ages 5 – 17 (4 boys and 7 girls) participated in this study. All adults were recruited through Introduction to Psychology classes at Alfred University and received credit towards their class as compensation. Children were recruited through faculty members and were compensated with a small toy. The only restrictions on participation were the presence of any color deficiencies, and children had to be five years of age or older.

Materials

The color difference threshold task was programmed with Python (Python Software Foundation, https://www.python.org/) and displayed on an ASUS laptop. Python is an object-oriented high-level computer programming language that is used for a variety of things such as creating video games, scientific computations, and psychological research experiments. On the full computer screen, participants saw a gray background with two color-filled squares of the same or different hues, one above the other; the target was the top color and the comparison the bottom (see Appendix A). The method of constant stimuli was used in this task for presentation of the stimuli. This method has been shown to be very accurate and have high reliability (Schiffman, 2001; Siegel, 1962).

Procedure

The study lasted approximately 30 minutes on average per person, but participants took anywhere from 20 – 45 minutes to complete it depending on their response time and length of breaks. Written consent was received from all adult participants, oral assent from children, and written consent from the children's parents. Before starting the main task, a brief demographic questionnaire was given to all adults and parents of the children (see Appendix B). Once this was complete, parents were allowed to leave the room while their child finished the study. At this time, the main task was explained verbally to the children and adults read the instructions on the screen. All participants started with 15 practice trials to familiarize themselves with the task. The order in which the three locations were completed was counterbalanced. The periphery locations were marked by a dot 50° left or right of center respectively. A chin rest was used for adult participants to ensure that stimuli were viewed at the proper angle and to encourage fixation on the dot in the peripheral tasks. Four target colors were presented along with the 9 comparison differences (0, 7, 14, 21, 28, 35, 42, 49, and 56 nm steps from the target color), 5 times each, resulting in 180 trials in each of the three locations. The presentation order of target and comparison color pairs was random. The participants were prompted to take a break between each of the five blocks and between the three locations for as long as they needed. Not all children were able to complete all three locations and terminated their participation in the study early. The data from the locations that they did complete were still used in the analyses. Once participants had finished all three locations, or had asked to be finished, their participation in the study was complete. They were debriefed about the purposes of the study and did not need to return for any further tests.

Results

The goal of this study was to determine if adults showed a significant difference between the thresholds for the four colors and the thresholds in the fovea versus periphery. It was expected that green and red would have the highest threshold, and blue would have the smallest, as well as the highest thresholds seen in the periphery. Thresholds were determined based on the participants being able to discriminate that the two colors were different. The comparison differences were used (0, 7, 14 nm, etc.) for each color and the lowest difference in which the majority of trials were said to be different by each participant were recorded for each color in each location. Since there were 5 trials for each color with each comparison difference, the threshold was determined based on the lowest difference in which a participant said the two colors were different 3 times. A two-way repeated measures ANOVA was used for the adults. Although 23 adults completed the study, when missing thresholds were excluded, 13 adults were included in the ANOVA. Thresholds were considered missing when three of the five (the majority) were not said to be different up to 56 nm for any color in any location. For the children, only 3 of the 10 had completed all three locations and met a threshold for each color in each location. For this reason, an ANOVA was not used for the children's data, and instead descriptive statistics will be reported to see if they show a similar pattern of thresholds to the adults.

Adults

The results of the ANOVA revealed that there was a significant main effect of color, $F(3, 36) = 6.801$, $p < 0.01$, *partial* $\eta^2 = 0.362$. Blue showed the lowest threshold ($M = 11.308$, $SE = 0.691$), followed by yellow ($M = 19.385$, $SE = 2.470$), green ($M = 21.179$, $SE = 2.687$), and the highest for red (*M* = 21.359, *SE* = 2.434). Blue was significantly different than all three colors, but yellow, green, and red were not different from each other. There was also a significant main effect for location, $F(2, 24) = 4.157$, $p < 0.05$, *partial* $\eta^2 = 0.257$. The foveal location (*M* = 16.827, *SE* = 1.322) and left periphery had the lowest thresholds (*M* = 16.154, *SE* = 2.312); they were not significantly different from each other, but the fovea was significantly different than the right periphery (*M* = 21.942, *SE* = 2.247). The interaction between colors and locations was also significant, $F(6, 72) = 3.257$, $p < 0.01$, *partial* $\eta^2 = 0.213$. In the center location, blue was significantly different than the other three colors, but the green, yellow, and red were not different. In the left periphery, there was no difference in thresholds between any of the four colors. In the right periphery, blue and green were significantly different from each other but not any of the other colors; yellow and red were not different from each other or any of the other colors. For blue, the center (*M* = 7.00, *SE* = 0.000) was different than the left (*M* = 15.077, *SE* = 1.745) and right (*M* = 11.846, *SE* = 1.458) locations, but left and right were not different from each other. For green, the only difference in locations was between left (*M* = 13.462, *SE* = 4.153) and right (*M* = 27.462, *SE* = 5.042). There was no significant difference between center (*M* = 22.615, *SE* = 2.875) and either of the two peripheral locations. For yellow, center (*M* = 16.154, *SE* = 2.154) and left (*M* = 15.077, *SE* = 3.348) were not significantly different from each other, but were both significantly different than right (*M* = 26.923, *SE* = 3.951). Finally, for red, there was no significant difference between center (*M* = 21.538, *SE* = 3.014), left (*M* = 21.000, *SE* = 3.545), or right (*M* = 21.538, *SE* = 3.497).

When all 23 adults were included in the descriptive statistics analysis, the same pattern seemed to hold true. The means and standard deviations for the adults can be found in Figure 1.

	Children	**Adults**

	Mean	Std. Deviation	Mean	Std. Deviation
Blue Center	9.33	3.500	9.43	5.426
Blue Left	18.38	15.847	14.91	5.704
Blue Right	13.13	5.842	13.39	5.549
Green Center	20.22	10.756	25.87	10.644
Green Left	32.00	20.551	15.56	16.382
Green Right	22.75	17.450	24.15	17.951
Yellow Center	17.11	9.333	17.96	8.396
Yellow Left	21.00	11.832	19.17	12.525
Yellow Right	21.88	11.495	25.57	12.052
Red Center	14.00	6.481	24.18	12.546
Red Left	19.00	16.523	22.47	12.254
Red Right	28.00	17.146	23.47	16.218

Fig 1. Mean thresholds and standard deviations for children compared to adults.

Children

The mean thresholds for all colors can be found in Figure 1. The children were split into two groups based on age (5 – 10) with six members and (11 – 17) with four members. These means can be found in Figure 2. Overall, the older age group showed lower thresholds for blue and green but not yellow and red, although the difference may or may not be significant. The only obvious difference between children and adults was that while adults showed the highest means for red, children did not have this overwhelming difference in red, but rather for green.

	Ages 5 - 10	Ages 11 - 17

	Mean	Std. Deviation	Mean	Std. Deviation
Blue Center	9.80	3.834	8.75	3.500
Blue Left	21.00	20.408	14.00	0.000
Blue Right	15.75	6.702	10.50	4.041
Green Center	16.80	13.646	24.50	4.041
Green Left	35.00	23.216	24.50	14.849
Green Right	10.50	4.041	35.00	17.146
Yellow Center	14.00	4.950	21.00	12.780
Yellow Left	22.40	11.502	18.67	14.572
Yellow Right	14.00	5.715	29.75	10.500
Red Center	10.50	7.000	17.50	4.041
Red Left	15.75	13.251	23.33	22.502
Red Right	23.33	10.693	31.50	21.764

Fig 2. Mean thresholds and standard deviations for younger children (ages 5 – 10) compared to older children (ages 11 – 17).

Discussion

The goal of the current study was to investigate difference thresholds for the psychologically pure hues in central and peripheral vision in children and adults. It was predicted that there would be lower thresholds in foveal vision than peripheral, that red-green colors would have higher thresholds than blue, and children would show a pattern of higher thresholds than adults. The analyses showed partial support for the first hypothesis. For adults, the thresholds in the center were lower than thresholds in the right periphery, but there was no difference between the center and left locations, or right and left locations. The difference between fovea and right periphery supports previous research that suggests that sensitivity to color is higher in the fovea than the periphery. While it was expected that there would be no difference between left and right periphery, it was surprising that there was also no difference between center and left periphery. It was expected that left and right would not be different, but it is possible that the left periphery is more similar to the fovea in terms of hue sensitivity than the right periphery. Further research would need to be conducted to make this conclusion.

The Opponent Process Theory has been widely accepted in cognitive psychology, and suggests that the red-green system operates through a different process than the yellow-blue system (Hurvich & Jameson, 1957). Along with this theory and previous research that has shown that red and green have the highest thresholds of the four colors (Xu & Yaguchi, 2005), it was expected that red and green would have the highest thresholds with blue showing the lowest. This hypothesis mostly held true in the current study because the main effect of color showed that blue did in fact have the lowest threshold of the four colors. However, although blue was significantly different than all three colors, there was no difference between the other three colors. It was expected that yellow would have a lower threshold than green and red because it operates through the same mechanism as blue. There was, however, no difference between red and green, and they both had higher thresholds than blue, so this does support the hypothesis. Because there is such strong support for the Opponent Process Theory and the idea that red and green have higher thresholds than blue and yellow, it is not likely that the current findings suggest that these propositions are false. Again, future studies would need to be done to further investigate this finding to conclude if red and green are truly the same as yellow for their difference thresholds, or if yellow is more similar to blue as has been suggested many times in past research.

For the children, these conclusions in terms of sensitivity based on location and differences in color could not be drawn because of the lack of power and small sample size, but descriptive statistics were reported to determine if their pattern of thresholds appeared similar to that of adults. The children did seem to show lower mean thresholds for blue compared to the other colors, similar to the adults. The children's data also seemed to show higher means for green, but not for red compared to other colors. Adults overall showed higher thresholds for yellow, red, and green compared to blue, but based simply on the means, children showed higher means only for green while yellow and red were more similar. While it cannot be determined from these results whether or not these were significant differences, it is possible that the lower sensitivity for red may develop with age. When the children were grouped by age with 5-10 year-olds in one group and 11-17 in the other, it appears as though the older group had similar means for red, green, and yellow, with blue still much lower. The younger children, in comparison, still only seemed to show higher means for green. Again, significance is not being suggested here, but this pattern suggests that the lower sensitivity to red and possibly yellow occur throughout development into adulthood.

The descriptive statistics needed to be used for children because not enough of them had completed all three locations and therefore had missing data. Another problem that was noticed in testing children was that many of them, especially the younger children, had trouble with response inhibition in that they could not keep their eyes on the peripheral dot and kept quickly moving their eyes back to the screen on trials where they were unsure about the answer. Although they were reminded several times throughout the task to keep their eyes on the dot when this behavior was noticed, they could not inhibit this response. This did cause problems in the data in that it cannot be guaranteed that the stimuli were being viewed at 50° consistently because of the frequent eye movements. It has been suggested that response inhibition develops with age and young children, therefore, have problems inhibiting responses. There have been many studies done that propose different ages in which this behavior matures. Bartgis, Thomas, Lefler, and Hartung (2008) suggest that while attention abilities improve between 5 and 7 years of age, response inhibition does not improve during this period, but Lo and colleagues (2013) reported that 6-year-olds showed better response inhibition than that of 5-year-olds. Piaget's conservation of numbers task requires inhibitory control, and is often difficult for children under the age of 7 (Poirel et al., 2012). This suggests that response inhibition may not be developed fully enough until age 7. Response inhibition can also be seen in the "marshmallow test" where young children cannot resist eating the marshmallow immediately in the delay-of-gratification paradigm (Mischel, Ebbesen, & Zeiss, 1972; Mischel, Shoda, & Rodriguez, 1989). Overall, while no specific age has been proposed at which response inhibition is fully developed, it is said to increase with age, especially between ages 8 and 20 (Tamm, Menon, & Reiss, 2002). In order to fix this problem in a future study, eye tracking would need to be used for children of this age range to ensure that the stimuli are viewed at the proper angle. If a participant were to break fixation at any point during a trial, the trial would either have to be deleted or repeated at the end to make sure the data is accurate and complete.

As mentioned, the inability for many of the children to maintain fixation on the dot was a big limitation in this study. If the study had used more children, more analyses could have been used to determine if the significance in their data had looked similar or different to that of the adults. Also in the adult data, as well as the children's, some thresholds were missing for several participants, resulting in missing data and reducing the total number of participants analyzed in the ANOVA. In order to have more power, larger differences between the target and comparison would need to be used so that all thresholds would be reached for each color for every person. Future studies could look at this same topic of difference thresholds across the visual field and throughout development, but would need to account for higher differences in color, as well as using eyetracking to ensure that fixation is always maintained. Some children were also not able to complete all three locations due to shorter attention spans, so the task duration could be adjusted for children to get a full data set while not causing too much fatigue. Overall, the results did support the hypothesis that thresholds would be lower in the fovea than the periphery, and the lowest thresholds would for blue and highest for green and red. These findings can be useful in understanding more about color perception and color sensitivity across the visual field, as well as how these properties of color perception develop with age.

References

Bartgis, J., Thomas, D. G., Lefler, E. K., & Hartung, C. M. (2008). The development of attention and response inhibition in early childhood. *Infant and Child Development, 17*, 491-502. doi: 10.1002/icd.563

Boon, M. Y., Suttle, C. M., & Dain, S. J. (2007). Transient VEP and psychophysical chromatic contrast thresholds in children and adults. *Vision Research, 47*, 2124-2133. doi: 10.1016/j.visres.2007.04.019

Dimmick, F. L. (1965). Color specification based on just noticeable difference of hue. *Vision Research, 5*, 679-694. doi: 10.1016/0042-6989(65)90040-4

Goulart, P. R. K., Bandeira, M. L., Tsubota, D., Oiwa, N. N., Costa, M. F., & Ventura, D. F. (2008). A computer-controlled color vision test for children based on the Cambridge Colour Test. *Visual Neuroscience, 25*, 1-6. doi: 10.10170S0952523808080589

Hansen, T., Pracejus, L., & Gegenfurtner, K. R. (2009). Color perception in the intermediate periphery of the visual field. *Journal of Vision, 9*, 1-12. doi: 10.1167/9.4.26

Hurvich, L. M., & Jameson, D. (1957). An opponent-process theory of color vision. *Psychological Review, 64*, 384-404. doi: 10.1037/h0041403

Knoblauch, K., Vital-Durand, F., & Barbur, J. L. (2001). Variation of chromatic sensitivity across the life span. *Vision Research, 41*, 23-36. doi: 10.1016/S0042-6989(00)00205-4

Ling, B. Y., & Dain, S. J. (2008). Color vision in children and the Lanthony New Color Test. *Visual Neuroscience, 25*, 441-444. doi: 10.10170S0952523808080206

Lo, Y-H., Liang, W-K., Lee, H-W., Wang, C-H, Tzeng, O. J. L., Hung, D. L., … Juan, C-H. (2013). The neural development of response inhibition in 5- and 6-year-old preschoolers: An ERP and EEG study. *Developmental Neuropsychology, 38*, 301-316. doi: 10.1080/87565641.2013.801980

Mischel, W., Ebbesen, E. B., & Zeiss, A. R. (1972). Cognitive and attentional mechanisms in delay of gratification. *Journal of Personality and Social Psychology*, *21*, 204-218. doi: 10.1037/h0032198

Mischel, W., Shoda, Y., & Rodriguez, M. I. (1989). Delay of gratification in children. *Science, 244*, 933-938. doi: 10.1126/science.2658056

Mullen, K. T., & Kingdom, F. A. A. (2002). Differential distributions of red-green and blue-yellow cone opponency across the visual field. *Visual Neuroscience*, *19*, 109-118. doi: 10.1017.S0952523802191103

Peeles, D. R., & Teller, D. Y. (1975). Color vision and brightness discrimination in two-month-old human infants. *Science, 189*, 1102-1103. doi: 10.1126/science.1162362

Poirel, N., Borst, G., Simon, G., Rossi, S., Cassotti, M., Pineau, A., & Houde, O. (2012). Number conservation is related to children's prefrontal inhibitory control: An fMRI study of a Piagetian Task. *PLoS ONE, 7*, 1-7. doi: 10.1371/journal.pone.0040802

Tamm, L., Menon, V., & Reiss, A. L. (2002). Maturation of brain function associated with response inhibition. *Journal of the American Academy of Child & Adolescent Psychiatry*, *41*,1231-1238. doi: 10.1097/00004583-200210000-00013

Teller, D. Y., Peeles, D., & Sekel, M. (1978). Discrimination of chromatic from white light by two-month old human infants. *Vision Research, 18*, 41–48.

Xu, H., & Yaguchi, H. (2005). Visual evaluation at scale of threshold to suprathreshold color difference. *COLOR Research and Application, 30*, 198-208. doi: 10.1002/col.20106

Appendix A

Appendix B

Adult Questionnaire

Participant Number: ________

What is your age? ________

What is your gender? (Please circle)

Man Woman Other Prefer not to say

Are you aware of any color deficiencies that you have? (Please circle)

Yes No

If yes, do you know of any details about it? If so, please explain.

Child Questionnaire

Participant Number: ________

What is your child's age? ________

What is your child's gender? (Please circle)

Boy Girl Other Prefer not to say

Are you aware of any color deficiencies that your child has? (Please circle)

Yes No

If yes, do you know of any details about it? If so, please explain.