Journal of
Emerging Investigators

What Can You See in the Dark? The Effects of Contrast, Light, and Age on Contrast Sensitivity in Low Light

Kathryn Virostek and Brittany Franckowiak
Wilde Lake High School, Maryland

Summary

Contrast sensitivity is the ability to read words which have low contrast with the background. How much light is needed to identify letters of different contrast levels at low levels of light? How does age affect contrast sensitivity? A testing card was created with 25 letters, five at each of five different levels of contrast ranging from 20% to 3% saturation. We hypothesized that subjects would be able to read the five letters at 20% saturation with 50 lux of light, and the younger subjects would be able to read more of the letters than the older subjects. Fifty subjects, ages 10 to 75, participated. Participants were asked to identify any letters they could read at each of six levels of low light, ranging from 0 lux to 50 lux. With more light, there was improvement in the ability to see the letters. There was no linear relationship between age and contrast sensitivity; however, there was a noticeable decrease in some of the adults' abilities to identify the letters. This research can be applied to improving safe driving at night or in situations, such as restaurant settings, where print must be read in low light, and it is important for accommodating people with certain vision impairments.

Received: Sept 22, 2013; **Accepted:** Dec 18, 2013; **Published:** April 25, 2014

Introduction

Light is a radiant energy that is capable of exciting the retina and producing a visual sensation. The human eye needs between five and fifteen photons to enter the eye before light is registered (1). A photon is the smallest detectable increment of light. Light energy is measured in units called lumens or lux. Brightness is a descriptive word used to describe the light's intensity rather than a quantitative word.

The human eye has two kinds of cells in the retina: rod cells and cone cells. There are about 120 million rod cells and about 7 million cone cells (2). The rod cells are effective in dim light and can detect movement but are not used to see color or detail (3). Instead, they see black and white and shades of gray. Rods take a long time to adapt to changing light conditions, which is why it is hard to see immediately after all the lights are turned off. The pupils must dilate for rod vision to be ideal (2). As opposed to rod cells that function in the dark, cone cells function in bright light and process color (4). Cone cells are mainly sensitive to blue, red, and green wavelengths, which are called the primary colors of light (5). Cone cells adapt much faster than rods, but are not as sensitive. Light enters the eye through the cornea. The pupil controls how much light enters the eye. The pupils automatically adjust their size to accommodate the amount of light present (6). The pupils of both eyes respond identically to light stimulation. In bright light, the pupils will become constricted because the circular muscle fibers in the eye contract. In dim light, the pupils will become dilated because the radial muscle fibers in the eye contract (7). The level of light greatly affects rod cells' ability to function. With too much light, rod cells will not function at all. At some levels of light, both rods and cones will function together.

Contrast sensitivity is the measure of the ability to see words that do not stand out from their backgrounds. The contrast of an object is described by its print saturation: how densely the ink dots are printed on a page (8). On a white background, black ink in high-resolution print would have a high contrast, whereas print that has fewer dots per inch and appears gray would have lower

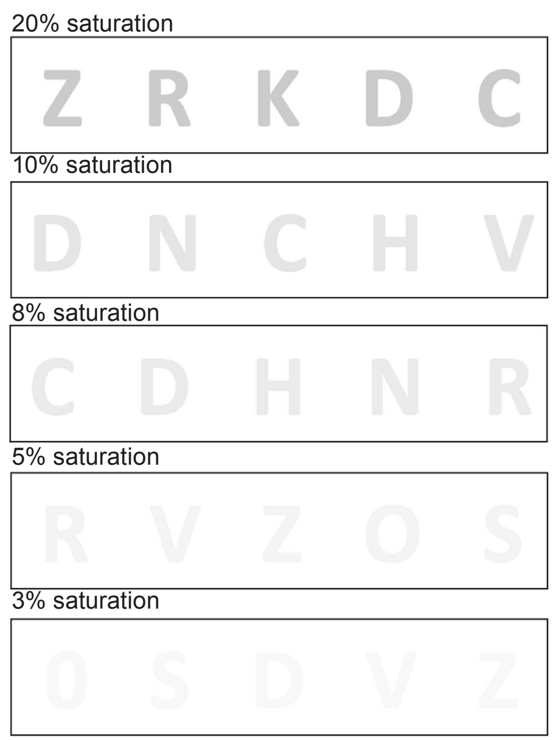

Figure 1: The chart given to subjects with letters of varying percentages of saturation (ranging from 20% to 3% saturation).

Number of Participants by Age Group

Age Group	Number of Participants
< 20 years	21
Ages 20-39	6
Ages 30-59	19
60+ years	4

Figure 2: The number of participants in each group.

contrast with the paper. Contrast sensitivity is important in many situations. It is used to drive safely at night, to read road signs, and to read a menu in a dark restaurant. Contrast is particularly relevant to people who have vision impairments. The student author has a genetic visual disorder called achromatopsia, which affects 1 in about every 30,000 people. It prevents the cone cells from functioning, thus rendering a person completely color-blind, sensitive to bright lights, and severely near-sighted (9). The student author sees much better in dim light than in bright light. This condition led the authors to question, in the general population, how much light is necessary to identify letters of low contrast at low levels of light and how does age affect the ability to read letters of low contrast at low light?

The authors used 5 differing levels of contrast that were quantified by a print saturation percentage. It was predicted that all 50 subjects would be able to identify the first five letters (20% saturation, **Figure 1**) on the testing card with 50 lux of light on. It was also hypothesized that the younger people would be able to see more letters on average because data from regular lighting contrast sensitivity tests tends to show that a person's contrast sensitivity decreases as they get older (10, 11). As people age, so do their eyes, and thus, their eyesight declines. The declining eyesight results in reduced contrast sensitivity (10, 11). The number of letters identified increased with increasing amounts of light. However, there was no direct linear relationship between age and the number of letters identified at each level of light.

Results

To test how age affected contrast sensitivity in low light, 50 subjects between the ages of 10 and 75 were asked to identify letters with low saturation levels in very dim levels of light (**Figure 2**). A contrast sensitivity test with five letters, each of a different level of saturation (20%, 10%, 8%, 5%, and 3%) (**Figure 1**), was used in six different levels of low light (0 lux, 10 lux, 20 lux, 30 lux, 40 lux, and 50 lux). The participants started in complete darkness, and the amount of light was increased gradually, by lighting an electric candle for each increment of 10 lux. None of the subjects could see any of the letters at zero lux.

Figure 3 shows that 10 lux of light was required for people under 40 to identify the highest contrast letters - those with 20% saturation. For the 40 to 59 age group, 20 lux was required, while 30 lux was required for the 60-and-older age group to identify the highest contrast letters. The number of letters identified increased with increasing amounts of light. However, there was no direct linear relationship between age and the number of letters identified at each level of light.

Figure 4 shows that, on average with 50 lux, subjects younger than 20 years identified 18 letters, subjects whose ages were 20 to 39 years identified 19 letters, subjects whose ages were 40 to 59 years identified 13 letters, and subjects between ages 60 to 75 years identified 11 letters. With 50 lux, only three subjects identified any of the lowest contrast letters at 3% saturation. In addition, 98% of the subjects identified at least five letters with 50 lux of light.

Discussion

The authors demonstrated that the more contrast there was between a letter and its background, the more commonly the letters were identified at lower levels of light. The authors also determined how much effect age has on contrast sensitivity.

The authors hypothesized that every subject would be able to identify at least the first five letters (20% saturation) by the time all five candles were lit (50 lux). The first five letters had the most contrast with the white printer paper background, so we predicted that these letters would be most commonly correctly identified because they are the darkest. On the other hand, it was predicted that very few, if any, subjects would be able to see the last five letters (3% saturation) at any of the levels of light. The prediction that all of the subjects would identify at least the first five letters with 50 lux of light was correct. In addition, 96% of the subjects identified more than the first five letters. The number of letters identified with all five lights on ranged from 4 to all 25 letters.

We hypothesized that, in general, the younger subjects would have better contrast sensitivity and would identify the letters at the lower saturation levels better, since their eyes are younger and stronger. On average, the subjects who were under 40 identified 18 letters by the fifth light. On average, the subjects who were over 40 identified 13 letters. Three subjects, all in the younger age group, were the only individuals to identify any of the letters presented at the lowest contrast (3% saturation). Other contrast sensitivity experiments that have been conducted in regular room light levels and did not involve different levels of low light found a decline in contrast sensitivity as a person gets older (10). Studies have shown significant differences in the performance levels of a younger age group (age 20-30 years) in comparison with an older age group (age 50-87 years) (11).

Many subjects mentioned that they could see the letters easier when they were not looking at them directly. This is because rod cells are missing at the very center of the human retina and instead, extend to the periphery of the retina (9).

This experiment included several systematic errors. For example, the exact amount of time each subject took at each interval to study the letters varied, including the length of the interval in complete darkness. Also, the

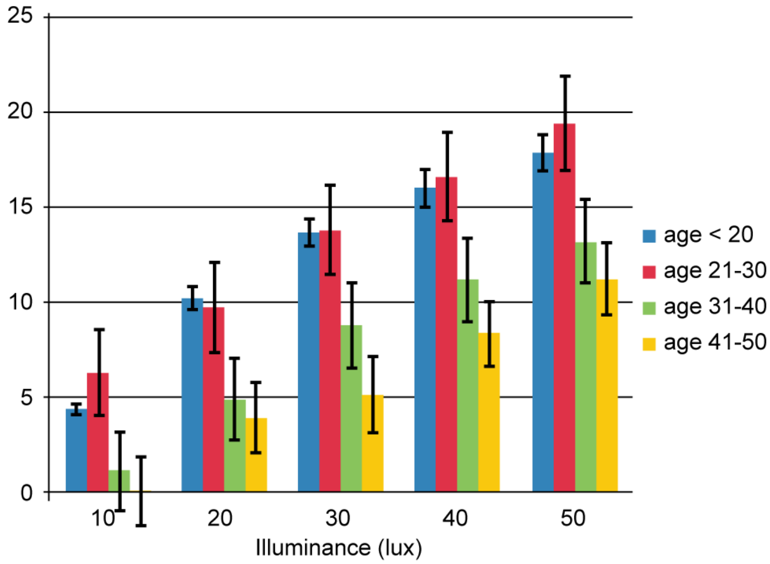

Figure 3: Total number of letters identified at each level by age group . The lux levels are indicated by the x-axis, and the number of letters identified are shown by the y-axis. This is an average out of 25 possible letters for each of the four age groups.

amount of time each subject was in the bright light of the kitchen varied. One potential measurement error was that the light meter was not sensitive enough to accurately measure the light intensity at the subjects' seat, so the measurement of the illumination (10-50 lux) was taken 10 cm away from the light sources.

Errors that could have affected the experiment are that the exact eye sight and vision corrections for each subject varied and the size of the subject's shadow cast by the light onto the table where the letter card was may have made some of the letters harder to see or appear different from one person to another. Some subjects were more reluctant to guess or change their guesses because they wanted to name the correct letter and not make errors.

Future experiments based off of this study could include the use of different colors of letters. In this case, yellow would have less contrast with the white background than a dark blue would have. Different tests could be done with a black background for different contrasts of gray to black letters. This data would be compared to the data from a white background test.

Methods

Subjects were tested in a dark, basement room with no windows. Four-watt light bulbs were placed in five small electric plug-in candles attached to a power strip so they could easily be turned on. A table was set up with candles secured in a tight row along the edge. A large table and chair were placed across the room so that the chair was five meters from the light sources. One candle was plugged in and the light meter was used to measure the number of lux, with the light meter 10 cm away from the lights. One candle was added at a time, and the total amount of lux when each candle was plugged in was recorded. The lux levels were 0, 10, 20, 30, 40, and 50 lux. The lights and tables remained in the same position for all test subjects. The same contrast sensitivity test was used for all fifty subjects. The subjects consisted of young and adult friends and relatives of the student author, included a mixture of males and females, and were divided into 4 different age groups: under 20, 20-39, 40-59, and over 60 (see **Figure 2**).

To conduct the experiment, subjects sat at the chair near the big table. The test card, modeled off of the SLOAN Vision Test Book (12), was printed on a Xerox 8 1/2 by 11 piece of multipurpose paper (See **Figure 1**) and backed with a piece of black poster board. It was placed in front of the subject with all of the lights off. With no candles plugged in, the subject was asked to identify any letters he or she could see and the results (this was the control situation) were recorded. One candle was plugged in, and the subject was asked to identify any and all of the letters that he or she could see and the results were recorded. The next candles were plugged in one at a time. After the light from the new candle was on, the subject was asked to identify any letters that he or she could see and the results were recorded. The experiment was complete when the subject had reported the letters he or she could see with all five candles plugged in.

Acknowledgments

I would like to thank my mom for helping me format my chart of letters, conducting some of my tests, and for editing my work. I would also like to thank my family for allowing me to use our basement and for socializing with my subjects and offering suggestions of whom I should call to be test subjects.

I would like to thank all my subjects for taking part in my testing process and overcoming their fear of failure to help me complete my project. I would like to thank my subjects for their patience because I was only able to

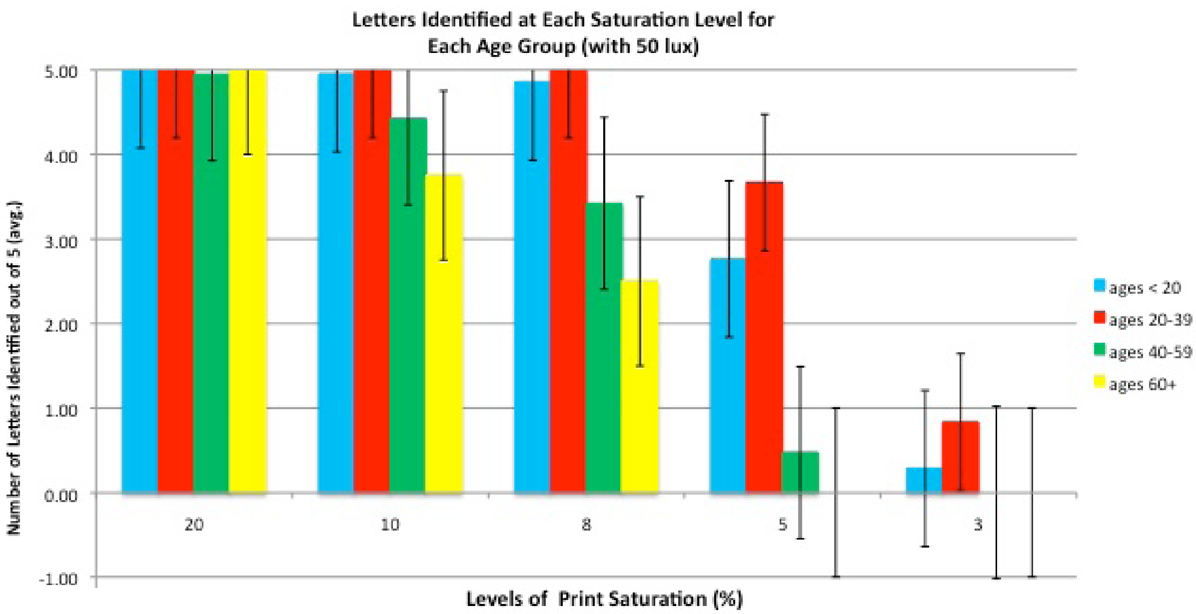

Figure 4: Letters identified at each contrast level for each age group (with 50 lux). The x-axis is the level of print saturation, where the higher saturation has higher contrast. The y-axis is the average number of letters identified out of five for each of the four age groups

test one subject at a time so the waiting subjects had to be entertained by my family.

I would like to acknowledge the help I had in conducting my tests: the aid of someone turning the overhead lights off in the dark room and flipping over the card with the letters on it.

I would like to thank the judges at the Wilde Lake High School science fair, the Howard County STEM fair, and the Baltimore Science Fair for listening to my presentation and providing feedback and comments on my project.

Finally, I would like to thank my middle school Earth science teacher, Mr. Mackin, for loaning me the light meter and my high school Biology and AP biology teacher, Ms. Franckowiak, for supplying comments on all of the components of my paper.

References

1. James Elkins. *How To Use Your Eye*s. New York: Routledge. 2000. Print.
2. C. R. Nave. "Light and Vision." *Hyperphysics.* Georgia State University, 1998. Web. 2 Oct. 2011. http://hyperphysics.phy-astr.gsu.edu/.
3. "Sight." *Segment One of Human Body: Pushing The Limits* Discovery Channel 2008. DVD.
4. Seymour Simon. *Eyes and Ears*. London: Harper Collins Publishers. 2003. Print.
5. Frances Futterman. *Understanding and Coping with Achromatopsia.* Berkeley: The Achromatopsia Network, 2000. Print.
6. David Macaulay. *The Way We Work, Getting To Know The Amazing Human Body*. Boston: Houghton Mifflin Company. 2008. Print.
7. Alice Roberts. *The Complete Human Body, The Definitive Visual Guide.* New York: DK Publishing. 2010. Print.
8. Gary Heiting. *Contrast Sensitivity Testing*. All About Vision, Feb. 2012. Web. 20 Jan. 2014. http:// http://www.allaboutvision.com/eye-exam/contrast-sensitivity.htm.
9. R. L. Windsor, C. A. Ford, and L. K. Windsor. *Achromatopsia.info.* The Low Vision Centers of Indiana, 2010. Web. 2 Oct. 2011. http://achromatopsia.squarespace.com/.
10. Y. Tang and Y. Zhou. "Age-related decline of contrast sensitivity for second-order stimuli: Earlier onset, but slower progression, than for first-order stimuli," *Journal of Vision,* 2009, vol. 9, no. 7, article 18. Association for Research in Vision and Ophthamology. 31 July 2009. Web. 2 Oct. 2011. http://www.journalofvision.org/.
11. J. E. Ross, D. D. Clarke, and A. J. Bron. "Effect of age on contrast sensitivity function: uniocular and binocular findings," *British Journal of Ophthalmology,* 1985, vol. 69, no. 1, pp. 51–56. *National Center for Biotechnology Information.* Jan. 1985. Web. 2 Oct. 2011. http://www.ncbi.nlm.nih.gov/guide/.
12. "SLOAN Contrast Sensitivity Vision Test Flipbook." *Precision-vision.com.* Precision Vision, 2011. Web. 2 Oct. 2011. http://precision-vision.com/.