The Effect of Bicycle Color on Visibility

Ellen Szubski
Department of Psychology
Clemson University

Latonya Housie
Department of Computer Science
Clemson University

Eric Switzer
Department of Computer Science
Clemson University

Ryan Monaghan
Department of Business
Clemson University

Abstract
In 2015, 45,000 bicyclists were injured from collisions with vehicles [5]. Using a Gazepoint GP3 eye tracker, we conducted an experiment to determine which color bicycle helps cyclists become more visible to drivers during the day in an urban environment. 9 participants with good vision viewed images of different colored bicycles (black, blue, yellow, white) from near and far distances on a computer screen. Although no significant differences were found, the near blue bicyclist had the lowest and best reaction time of all of the colors, followed by the black bicycle, the yellow bicycle, and the white bicycle according to group means. No significant reaction was found between distance and bicycle color on the total time spent on an image. However, we did find that the yellow and black bicycles appear to be robust to distance. This pattern could suggest that regardless of distance, the yellow and black bicycles are found in the same amount of time. Also, we found that the more experienced drivers tended to respond faster to seeing the yellow bicycle images indicating a possible learned association of the color yellow with bicycle safety. This study had the limitations of small sample size and eye tracker calibration errors. Future studies should expand upon these preliminary findings to determine the relationship between bicycle color and distance in terms of bicycle safety.

Keywords
bicycle safety, eyetracking, driving safety, bicycle visibility

1 Introduction
More and more people have started cycling for health and transportation reasons. With more people on the road, bicyclist and car collisions are on the rise and becoming a significant problem. In 2015, an estimated 45,000 people were injured in bicyclist/vehicle collisions [5]. Of these collisions, there was an increase of 729 bicyclist fatalities to 818 bicyclist fatalities in 2015 [5]. 47% of bicyclist fatalities occurred during the daytime and 70% of fatalities occur in urban environments [5]. Drivers often report not noticing a bicyclist until it was too late to avoid a collision [6], which makes it vital for bicyclist to increase their visibility and for the driver to see the cyclist to as soon as possible. There are various ways to increase bicyclist visibility during the daytime through active means like tail lights and fluorescent colored clothing, meaning that the cyclist much actively put a visibility aid on their body or bicycle to increase their visibility.

The National Highway Traffic Safety Administration recommends that a bicyclist should wear fluorescent or brightly colored clothing during the day to be better noticed by drivers and to increase bicyclist visibility [5]. Both brightly colored clothing and taillights require the cyclist to have the forethought to put something on either their bicycle or to wear something. A significant challenge to cyclist visibility are the lack of education on the significance of being seen by drivers, the detrimental effects of wearing dark clothes, and refusal to wear visibility aids such as reflectors for the purpose of being fashionable [2]. Bicyclists need to be aware of how common vehicle and bicycle collisions are and what visibility aids can be implemented to avoid collisions. Hagel et al. (2007), found in an observational study that around a third of the cyclists observed actually wore a bright color on the majority of the torso while riding. The vast majority of cyclists observed were not wearing a bright color, which could have increased their visibility. Coloring the bicycle instead of having the cyclist complete an additional action, could offer a passive solution to increasing bicyclist visibility. A brightly colored bicycle color would not require an additional action on the cyclist's part to remember before their ride and may offer a solution to increasing bicyclist visibility. To our knowledge, no published research has addressed the specific daytime visibility benefits of various colored bicycles.
The purpose of this study is to determine which color bicycle helps bicyclist become more visible to drivers during the day in an urban environment. Participants will view images photographed from near and far distances of a cyclist on various colored bicycles on a computer screen. Their eye-movements will be tracked in order to gain insight on when the observer locates the bicyclist using a Gazepoint GP3 Eye-Tracker.

It is predicted that the fluorescent yellow colored bicycle will be found faster than the black colored bicycle. We predict that the blue bicycle will be found faster than the black bicycle. It is also predicted that the bicyclist photographed from a closer distance will be found more quickly than the bicyclist photographed at a further distance.

2 Background

There is a small but growing amount of research that addresses various visibility aids such as fluorescent clothing that riders may utilize to increase their visibility during daytime. Schieber, Willan and Schlorholtz (2006) conducted a study to determine the attentional conspicuity of fluorescent signs verses not fluorescent signs using eye trackers. In this study, participants were fitted with eye trackers and told to inspect various 4x4 inch plates and answer questions about the targets after the presentation of the targets. Schieber, et al. (2006), found that the fluorescent target was more likely to attract initial fixations from the participant than the non-fluorescent targets. This suggests that fluorescent colors automatically attract or "grab" visual attention over non-fluorescent colors.

Lahrmann and Madsen (2015) utilized the attention grabbing quality of fluorescent material in their study. Half of the participants in their study were instructed to wear fluorescent yellow jackets while the other half of participants were instructed to wear their normal riding gear during their daily rides. Lahrmann and Madsen (2015) found that the cyclists who wore the fluorescent yellow jackets reported 53% fewer crashes than the bicyclists who were not given a yellow jacket. Cyclists, with the addition of a brightly colored yellow jacket, were able to increase their chances of avoiding collisions. However, another study found that the 30% of bicyclists who actually wear fluorescent colors while cycling, were more likely to avoid collisions injuries [8].

Even motorcyclist can utilize the attention grabbing quality of fluorescent material. Wells et al. (2004) conducted a study assessing factors that contribute to motorcyclists and car collisions in urban environments. Using crash report data, surveys, and interviews with motorcyclists, they found that a motorcyclist was 37% more likely to avoid a collision with a vehicle while wearing fluorescent colors than a motorist not wearing fluorescent colors in urban environments during the day.

McIntyre, Gugerty, and Duchowski (2011), used eye tracking technology to compare the attention grabbing qualities of red taillights verses yellow taillights in motor vehicles. Participants, while wearing eye trackers, were instructed to press the spacebar on a keyboard if the cars on the computer monitor pressed on their breaks. They found that searching for red taillights among many yellow taillights decreases reaction time in comparisons to searching for red taillights among red taillights suggesting that the more contrast a target has with its surrounding, the easier and faster it will be found [4].

3 Method

3.1 Participants

Approximately 12 participants (7 males) who are between the ages of 21 and 27 (M=22 years, SD=2 years), have good vision (while wearing corrective lenses, if normally worn), and have normal color vision were eligible to participate in this study. Participants with any self-reported visual impairments were excluded. Four participants were excluded from analysis because of methodological issues. The four participants were excluded because of incomplete or absent eye tracking data, resulting in nine participants with usable data for this experiment.

Because the nature of this experiment is a visual search task, participants must be able to demonstrate a base level of visual acuity and be able to discriminate various colors to complete the task. If participants were unable to meet this requirement, they were excluded from the experiment. Participants were recruited through emails and general announcements in various classes at Clemson University.

3.2 Design

This experiment is a 2 (Bicyclist Distance: Near and Far) x 4 (Bicycle Color: Black, White, Yellow, and Blue) within subjects design. Each participant saw all four bicycle colors photographed at the near distance and the far distance. Participants also saw six novel images of similar roadway environments as the images containing a bicyclist that do not contain a bicyclist. These six images were randomly repeated to equal a total of 24 images including the 8 bicycle images. The purpose of presenting the images in random order is to control for order effects. The time it takes each participant to fixate on the bicyclist will be recorded as the main dependent variable. A verbal confirmation of "yes" or "no" from the participant will also be recorded, along with a key press on the space bar to indicate if the participant detects a bicyclist.

Figure 1: Bicyclist on a black bike from a far distance.

Figure 2: Bicyclist on a white bike from a far distance.

Figure 3: Bicyclist on a yellow bike from a far distance.

Figure 4: Bicyclist on a blue bike from a far distance.

Figure 5: Bicyclist on a black bike from a nearer distance.

Figure 6: Bicyclist on a white bike from a nearer distance.

Figure 7: Bicyclist present: Yellow Bike (Near distance)

Figure 8: Bicyclist present: Blue Bike (Near distance)

Figure 9: Absent Cyclist

Figure 10: Absent Cyclist

Figure 11: Absent Cyclist

Figure 12: Absent Cyclist

Figure 13: Absent Cyclist

Figure 14: Absent Cyclist

4 Materials

4.1 Apparatus

The images will be presented to participants on a 22 inch Dell monitor with a resolution of 1680 x 1050. Participants' gaze will be tracked during each experimental session using a Gazepoint GP3 Eye-Tracker offering an accuracy of 1 degree of visual angle and a sampling rate of 60 Hz according to the manufacturer. The Gazepoint GP3 Eye-Tracker is a binocular pupil/corneal reflection eye tracker.

5 Procedure

Each participant will be greeted in the lab and read a script about the study. They will then read an informational letter approved by Clemson University Institutional Review Board. The participant will be given the opportunity to ask any questions he/she may have about the experiment. Once the participant has finished reading the letter, they will answer demographic questions about their age, gender, or any visual impairments that may skew the results of the experiment. Participants will then be set up on a 22 inch Dell computer and fitted to the Gaze Point eye tracker. To increase the accuracy of the data collected from the eye tracker, the user will be asked to calibrate the eye tracker using an image of nine numbered circles. After calibration, the participant will view images with and without a cyclist. Participants are asked to identify if the image contains a cyclist by pressing the space key on the keyboard and verbally confirming with either a "yes" or a "no." An experimenter recorded the verbal response. Participants will then take a short pen and paper survey concerning what they saw on the computer screen, as well as giving a brief summary of their driving experience administered by an experimenter. Once this is completed, participants will be thanked and dismissed.

6 Results

6.1 Time to Fixation

A repeated measure ANOVA with a Greenshouse-Geisser correction determined that the near bicycle color did not significantly differ in reaction time to the bicycle between the four colors (black, white, yellow, and blue) (F (1.919,15.355)=1.336, p=.291). Post hoc test using the Bonferroni correction found that the black bicycle was not significantly different from the yellow (p=.487), white (p=1.00), or blue bicycles (p= 1.00). The blue bicycle was not significantly different than the yellow (p=.863) or white bicycle (p=.562). Lastly, the yellow bicycle was not found to be significantly different that the white bicycle (p=1.00). Due to calibration errors, data from the far bicycles were unobtainable, as all participants' fixations missed the stimulus AOI for time to first fixation on the far bicycles.

Though the near bicycle colors were not found to be statically different from each other, there is an interesting pattern concerning near bicycle color. The near blue bicyclist had the lowest and best reaction time of all of the colors (M=.895 seconds, SD=.298 seconds) followed by the near black bicycle (M=1.063 seconds, SD=.477 seconds), the near yellow bicycle (M=1.318 seconds, SD=.740), and the near white bicycle (M=1.327, SD=.534), as indicated in Figure 15.

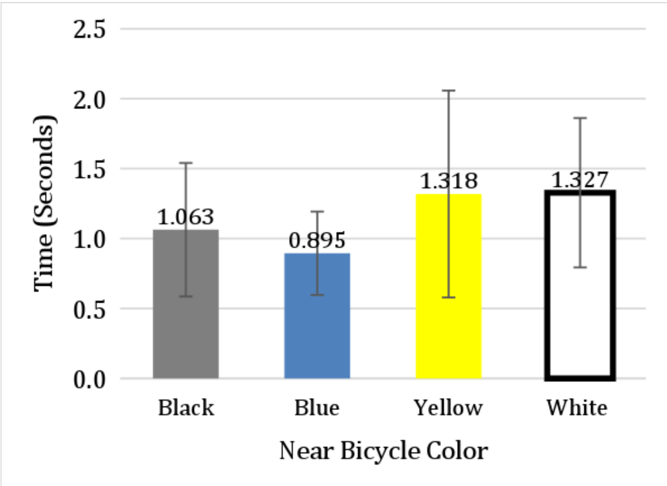

Figure 15: Mean time to first fixation for near bicycle colors.

6.2 Total Time on the Image

Total time on the image is a secondary measure for bicycle visibility as participants were instructed to press the spacebar once they found the image. The total time spent on an image indicated reaction time from when the participant was presented with the image to the time when they found the bicyclist. A two-way repeated measures ANOVA was performed to assess the effect of distance and bicycle color on the total time spent on the image. There was not a significant interaction between distance and bicycle color, F (3)=1.677, p=.199. Although we did not find a statistically significant effect, we did find that blue had the fastest reaction time for the near images and black had the fastest reaction time for the far distance. Other bicycle color total times can be found in Table 1. However, we did find an interesting pattern, as the yellow and black bicycles appear to be robust to distance as shown in Figure 16.

	Near		Far	
	M	SD	M	SD
Black	2.009	0.491	2.189	0.436
Blue	2.089	0.566	3.905	3.723
Yellow	2.286	1.201	2.284	0.406
White	2.338	1.233	2.716	0.597

Table 1: Means and Standard Deviations total time spent on an image for each bicycle color and distance.

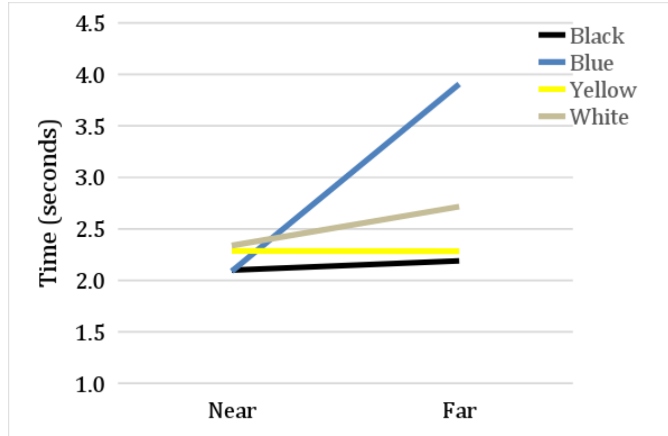

Figure 16: Total time spent on an image.

6.3 Post Experimental Questionnaire

Participants reported that they have been driving for an average of 5.44 years (SD=3.43 years) and they reported driving an average of 5.26 hours per week (SD=4.02 hours) 77.8% of participants consider themselves to be an experience driver while 11.1% consider themselves to be an expert driver and 11.1% consider themselves to be a beginner driver as indicated in Figure 17. A correlation between level of driver experience and reaction time to spotting the yellow bicycle was found to be significant, $r(7)= -.682$, p=.043.

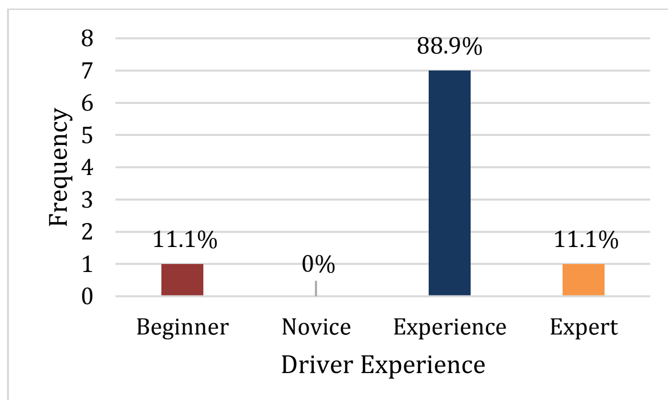

Figure 17: What level of experience do you have with driving?

The blue bicycle was reported as being the easiest to see by 55.6% of the participants as indicated in Figure 19. 88.9% of participants preferred the blue colored bicycle as shown in Figure 19.

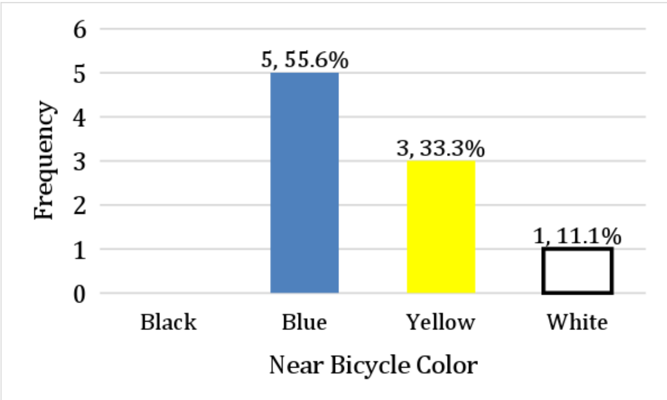

Figure 18 : Frequency of participants response to the question "Which color bicycle was easiest to see?"

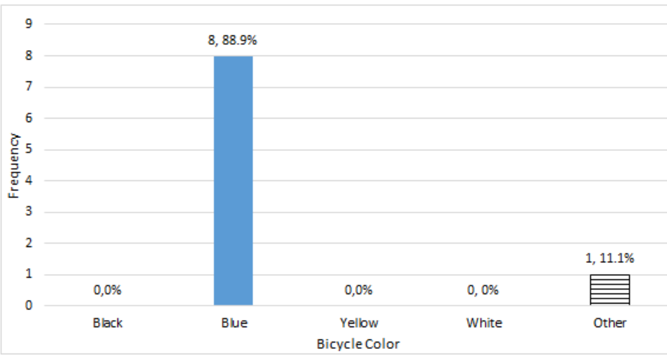

Figure 19: Frequency of participant's response to the question "Which color bicycle did you prefer?"

7 Discussion

Calibration errors prevented results from being accurately recorded for all of the far bicyclists. When calibrating the participants for the experiment, a problem occurred where each participant could not be accurately calibrated for the right side of the screen. This error caused all participants to miss our far AOIs for the far cyclist positioned on the far right of the screen. Another problem with the far AOIs, was that its AOI size was much smaller than the near AOIs. The smaller target added to the difficulty of getting hits for the far AOIs since the participants were not accurately calibrated.

Bicycle colors for the near cyclist did not significantly differ in reaction time between the four colors (black, white, yellow, and blue). In post hoc comparison, none of the bicycle colors differed in reaction time from any of the other bicycle colors. This could be due to the small sample size which offers a low experimental power. However, we did find that the near blue bicyclist had the lowest and best reaction time of all of the colors followed by the black bicycle, the yellow bicycle, and the white bicycle according to group means. Even though this is not a significant effect, it is a promising pattern to expand upon in future studies with a larger sample size.

No significant reaction was found between distance and bicycle color on the total time spent on a image. This contradicts past research which found that fluorescent material attracts attention faster than non fluorescent material [6];[3]. Although not statistically significant, blue had the fastest reaction time for the near images and black at the fastest reaction time for the far distance according to the group means. The lack of a statistically significant effect is most likely due to a small sample size.

Through further analysis, the yellow and black bicycles appear to be robust to distance. This pattern could suggest regardless of distance, the yellow and black bicycles are found in the same amount of time. This could mean that when it comes to yellow and black colored bicyclist, distance is not a major influencing factor, suggesting that yellow and black colored bicycles could increase bicyclist visibility and therefore safety. The robust to distance pattern of the fluorescent yellow bicycle is supported by past research conducted by Schieber, Willan and Schlorholtz (2006), where it was found that fluorescent colors immediately attracted the driver attention over non-fluorescent colors.

Interestingly, the blue bicycle was reported as being the easiest to see out of the four colors and the most preferred by participants even though participants took longer to fixate on the blue bicycles in the image. Blue may have been the preferred color by the participants for reasons unrelated to the experiment (ex. favorite color) and could have introduced bias. Bicycle designers can use this information and increase the amount of blue in their bicycle designs and athletic apparel for cyclists. Designers can apply this information to a variety of popular colors.

The more experience with driving the participant reported, the less amount of time they spent on the yellow bicycle images, and therefore the faster they spotted the yellow bicycle. The correlation suggest that driver experience may be related to the shorter reaction times of finding yellow colored bicycles. This could be due to a learned association from experience. Many visibility aids are fluorescent colored and the association that experienced drivers have with seeing visibility aids on the road could help drivers find yellow colored bicyclist faster.

Though we had the limitations of a small sample size and calibration errors of the eye tracker, the design of the experiment and hypothesis are good tools for testing how bicycle colors affect visibility of the rider to others and should be expanded upon in future studies in order to influence changes in bicycling safety. This particular study could be replicated with larger sample sizes and more accurate eye tracker calibration. The study could, with increased accuracy, determine the effect of bicycle color in visibility. It is important that cyclists be as safe as possible when riding their bicycles amongst vehicle traffic and pedestrian traffic, as they are highly susceptible to injury if they are not visible enough.

8 References

[1] Hagel, B. E., Lamy, A., Rizkallah, J. W., Belton, K. L., Jhangri, G. S., Cherry, N., & Rowe, B. H. (2007). The prevalence and reliability of visibility aid and other risk factor data for uninjured cyclists and pedestrians in Edmonton, Alberta, Canada. *Accident Analysis & Prevention*, *39*(2), 284-289.

[2] Khorasani-Zavareh, D., Bohm, K., Khankeh, H., Talebian, M.T., Mohammadi, R., Bigdeli, M., & Castren, M. (2014). Why should being visible on the road? A challenge to prevent road traffic injuries among pedestrians in Iran. *Journal of injury and violence research*, *7*(2), 93-94.

[3] Lahrmann, H., & Madsen, T. K. O. (2015). The safety impact of a yellow bicycle jacket. *Safety Science.*

[4] McIntyre, S., Gugerty, L., & Duchowski, A. (2012). Brake lamp detection in complex and dynamic environments: Recognizing limitations of visual attention and perception. *Accident Analysis & Prevention*, *45*, 588-599.

[5] National Center for Statistics and Analysis. (2017). Bicyclists and other cyclists: 2015 data. (Traffic Safety Facts. Report No. DOT HS 812 382). Washington, DC: National Highway Traffic Safety Administration.

[6] Räsänen, M., & Summala, H. (1998). Attention and expectation problems in bicycle–car collisions: an in-depth study. *Accident Analysis & Prevention*, *30*(5), 657-666.

[7] Schieber, F., Willan, N., & Schlorholtz, B. (2006, October). Fluorescent colored stimuli automatically attract visual attention: An eye movement study. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*(Vol. 50, No. 16, pp. 1634-1637). Sage CA: Los Angeles, CA: Sage Publications.

[8] Thornley, S. J., Woodward, A., Langley, J. D., Ameratunga, S. N., & Rodgers, A. (2008). Conspicuity and bicycle crashes: preliminary findings of the Taupo Bicycle Study. *Injury Prevention*, *14*(1), 11-18.

[9] Wells, S., Mullin, B., Norton, R., Langley, J., Connor, J., Jackson, R., & Lay-Yee, R. (2004). Motorcycle rider conspicuity and crash related injury: case-control study.