The Quantification of Bicyclist Conspicuity Using Eye-Tracking Technology

Darlene Edewaard
Department of Psychology
Clemson University

Ryan Detweiler
Department of Computer Science
Clemson University

Chao Booth
Department of Criminal Justice
Clemson University

Abstract

Bicyclists face a high risk of being involved in collisions with motor vehicles when cycling in daytime conditions. Thus, bicyclist conspicuity is an important issue to consider when assessing the safety of bicyclists in daytime conditions. Fluorescent clothing has previously been found to provide safety benefits but has never been examined with regard to conspicuity during the day. The present study investigated the daytime conspicuity benefits of brightly colored clothing using still images of roadway environments and eye tracking technology. Thirteen participants searched for bicyclists wearing either black, blue, or yellow jerseys in 30 images of daytime roadway environments (6 images containing a bicyclist and 24 not containing a bicyclist) while their gaze was tracked via an eye tracker to obtain the time it took each participant to find the bicyclists. Results indicated that participants took significantly less time to find bicyclists presented at near distances than bicyclists presented at far distances, $F(1,12) = 5.00$, $p < 0.05$, partial $\eta 2 = 0.29$. In additions, results from a post-experiment survey revealed that the bicyclists that wore yellow jerseys in the images were rated as being more conspicuous than the bicyclists with blue or black jerseys. While further research on how useful eye trackers are in assessing bicyclist conspicuity is warranted, this study suggests that fluorescent yellow jerseys may enhance bicyclist daytime conspicuity.

Introduction

Crashes between bicyclists and motor vehicles have become more prevalent over recent years as more individuals have turned to cycling as a means of recreation and/or transportation. Approximately 50,000 bicyclist injuries and 729 bicyclist fatalities were reported in the United States in 2014 (NHTSA, 2016). In addition, the majority of these reports were from crashes that occurred on urban roadways during daylight conditions (NHTSA, 2016). Thus, NHTSA (2016) recommended that bicyclists wear fluorescent or brightly colored clothing when riding in daytime environments to help drivers become aware of their presence from safe distances. Through surveying cyclists about riding habits and crash prevalencies, Thornley, Woodward, Langley, Ameratunga, and Rodgers (2008) found that cyclists that wore fluorescent clothing had a lower crash risk in general and also a lower risk of severe injury from crashes than cyclists that did not wear fluorescent garments while riding in daylight hours. This suggests that brightly colored clothing may provide safety benefits for cyclists who ride on open roadways with motor vehicles during the day.

Bicyclist laws mandate that bicyclists ride in the same direction as motor vehicle traffic. Therefore, the most common type of bicyclist crash is a collision in which the bicyclist is struck by a motor vehicle from behind (Hutchinson & Lindsay, 2009). Because bicyclists face a high risk of being hit from behind, enhancing rear conspicuity is important for improving bicyclist safety.

The purpose of this study was to investigate the extent of which various colored bicyclist jerseys influence observers' abilities to fixate and recognize a cyclist's presence in urban roadway environments. Observers viewed images of daytime roadway environments that either had a bicyclist present or not on a computer screen. The bicyclists in the images were photographed from behind (rear-view) at two different distances and wore various colored jerseys (e.g., fluorescent yellow, fluorescent blue, and black jerseys). While viewing the images, the observers' gaze was tracked using an eye tracker, and the time-to-bicyclist-fixation was recorded to quantify the conspicuity of the bicyclists wearing the different colored jerseys. The use of an eye tracker to collect data on participants' fixations while they were searching for bicyclists was a novel way to assess bicyclist conspicuity. By obtaining participant reaction times and eye fixation data for finding bicyclists in images, visual and attentional strategies that observers use to search for bicyclists may be better understood.

This study attempted to provide insight into the question of whether there are certain color jerseys that bicyclists can wear to make themselves more noticeable to drivers during the day. It was predicted that the cyclists wearing fluorescent colored jerseys would be fixated on faster than the cyclists wearing black jerseys. Furthermore, the cyclist photographed from a closer distance was expected to be found more quickly than the cyclist photographed from the farther distance. However, the time it took observers to find the cyclists wearing black jerseys was not expected to differ between the two distances from which the cyclists appeared in the photographs.

Background

To this date, there is a surprising lack of empirical studies that investigate the on-road conspicuity advantages of brightly colored bicyclist clothing. With regard to the limited literature pertaining to bicyclist conspicuity, various methods have been used to study bicyclist conspicuity, including archival, on-road, and laboratory methods. It is evident from the sparse number of articles on bicyclist safety that many researchers have assessed police reports of bicycle/motor vehicle crashes, had bicyclists complete surveys, or observed cyclists riding naturally on open roadways instead of conducting experiments (de Rome, Boufous, Georgeson, Senserrick, & Ivers, 2014; McGuire & Smith, 2000; Poulos, Hatfield, Rissel, Flack, Murphy, Grzebieta, & McIntosh, 2015; Raftery & Grigo, 2013). From observations, survey responses, and crash report analyses, it was found that very few cyclists wore brightly colored clothing while actively cycling on open roadways (McGuire & Smith, 2000; Poulos et al., 2015; Raftery & Grigo, 2013). In addition, de Rome et al. (2014) found that younger cyclists were less likely to wear brightly colored clothing than older cyclists. This suggests that cyclists may be unaware of the potential safety benefits of making themselves more visible to drivers by wearing high visibility materials.

One field study examined the benefits of bicyclists wearing a high-visibility fluorescent yellow jacket, as opposed to wearing their normal riding apparel, when cycling with traffic for one year. Bicyclists in the High-Visibility Jacket Group and Normal Riding Apparel Group were asked to report any crashes they had with motor vehicles. The results indicated that the bicyclists who wore the high-visibility jacket were involved in 53% fewer crashes than the bicyclists who wore their regular cycling apparel (Lahrmann & Madsen, 2015). This indicates that fluorescent yellow tops may enhance bicyclist conspicuity, but what is still unknown is the time it took drivers to recognize the bicyclists in the roadways with the high-visibility jacket versus the bicyclists who wore other colored tops.

In terms of laboratory studies assessing bicyclist conspicuity, images of roadway environments containing bicyclists have been shown to be useful stimuli. One study done by Matthews and Boothby (1980) compared red rear reflectors to red taillights in terms of participant detection. Photographs of cyclists with a standard rear reflector or a taillight mounted to the back of their bikes were taken in visually cluttered and uncluttered environments. The cyclists were positioned at two different distances (60 and 120 meters), and photographs were taken of the roadways without cyclists as well, to serve as control images. Participants were asked to respond to each of the 150 images with a “yes” or a “no” to indicate whether or not a cyclist was present in each photograph. The results suggested that participants’ performance was better for the images featuring a cyclist with a taillight, in comparison with the images containing a cyclist with a rear reflector (Matthews & Boothby, 1980).

A visual search paradigm was used in Matthews and Boothby’s (1980) study. Other studies have successfully implemented this paradigm to examine participants’ reaction times for detecting various stimuli in complex roadway environments, such as traffic signs (Ho, Scialfa, Caird, & Graw, 2001) and car brake lights (McIntyre, Gugerty, & Duchowski, 2012). Taken together, these three studies suggest that experiments using photographs of cyclists in roadway environments can be conducted to answer research questions pertaining to bicyclist conspicuity.

The use of an eye tracker to study observers’ behavior in response to being tasked with searching for target stimuli in complex environments has also been shown to be successful (e.g., Ho et al., 2001; McIntyre et al., 2012). Ho et al. (2001) analyzed the number of fixations, as well as their durations, that participants made on images of roadways that either had a traffic sign present or absent in order to further assess how younger and older participants searched through the roadway images. McIntyre et al. (2012) collected data on the number of fixations that participants made on the images of a roadway environment containing cars with different colored brake lights, as well as the fixation durations and distances between fixations. Of these measures, the number of fixations that participants make in a visual search task has been found to be useful for determining the effectiveness of search strategies because of its strong relationship to reaction time (Ho et al., 2001; Scialfa, Thomas, & Joffe, 1994). Therefore while an eye-tracker has never yet been used to assess bicyclist conspicuity, it was predicted that implementing an eye tracker might be an effective method to assess observers’ abilities to search for bicyclists in images of complex roadway environments by obtaining data on eye fixations.

Methods

Participants

Sixteen undergraduate students were recruited to take part in this experiment. These participants (twelve female and four male) varied in age between 19 and 28 years (mean age = 20.3 years). Of the 16 participants, data sets from three participants were incomplete due to calibration complications (two participants) or missing a bicyclist (one participant), and therefore, the data from these participants were excluded from the analyses. The analyses contained the data from the remaining 13 participants. As part of the screening process, participants were required to have normal visual acuity with optical corrective devices, if needed. Only participants who read the informational letter and gave verbal consent were allowed to participate in the experiment. Each participant was told that their participation was voluntary and that they could terminate their participation at any time with no penalty. As compensation, participants were given course credit in their experimental psychology class.

Design

This experiment followed a 3 (Bicyclist Jersey: Black, Fluorescent Yellow, and Fluorescent Blue) x 2 (Bicyclist Distance: Near and Far) within subjects design, such that each participant saw each of the bicyclists wearing the three different colored jerseys photographed at each of the two distances. Two distinct roadway environment images that each contained a bicyclist (one positioned near to the camera and one position far away from the camera) were selected and digitally manipulated so that three separate versions were created of each image: one with the bicyclist wearing a black jersey; one with the bicyclist wearing a blue jersey; and one with the bicyclist wearing a yellow jersey. Thus, participants were presented with six roadway images that contained a bicyclist. To control for the participants' memory of the two roadway environments, six separate images of different roadway environments without a bicyclist present were presented along with the six images that contained cyclists. These six non-bicyclist roadway environments were presented four times each during the experimental sessions, while six the images containing bicyclists were only presented one time each. In total, each participant viewed 30 images during the experiment; six containing a bicyclist and 24 not featuring a bicyclist. The photographs were presented in a random order to control for an order effect. The time it took participants to fixate on the bicyclist (time-to-bicyclist-fixation) in each image containing a bicyclist was recorded along with the number of fixations that participants made on each cyclist. Survey responses pertaining to the participants' prior cycling experience and opinions on the jersey color that they thought was most conspicuous and preferable were also recorded.

Figure 1: Images a – f are the six roadway environments that do not feature bicyclists, while images g – l are the six roadway environments that contain a bicyclist with either a black, blue, or yellow jersey.

a. No Bicyclist Present

b. No Bicyclist Present

c. No Bicyclist Present

d. No Bicyclist Present

e. No Bicyclist Present

f. No Bicyclist Present

g. Cyclist Present: Black Jersey (Far Distance)

h. Cyclist Present: Blue Jersey (Far Distance)

i. Cyclist Present: Yellow Jersey (Far Distance)

j. Cyclist Present: Black Jersey (Near Distance)

k. Cyclist Present: Blue Jersey (Near Distance)

l. Cyclist Present: Yellow Jersey (Near Distance)

Materials

Photographs of six different urban roadways with traffic were selected from Google Images. The portions of the roadways featured in each photograph were straight and flat, and they each contained numerous motor vehicles. Two of the photographs contained a bicyclist; one near to the camera that was used to take the photograph and one far away from the camera. The color of the cyclists' shirts was altered using GIMP to be either black, bright yellow, or bright blue (see Figure 1 g - l). All images were normalized with regard to size and resolution. A masking screen was created also using GIMP, which consisted of a gray background with a fixation cross in the middle. This screen was presented for five seconds before each of the 30 roadway images appeared during the experimental sessions.

Apparatus

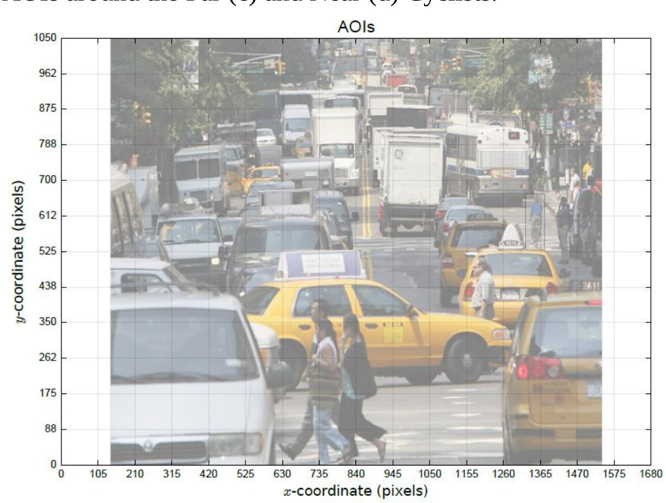
The images were presented to participants on a 22 inch Dell monitor with a resolution of 1680 x 1050. Participants' gaze was tracked during each experimental session using a Gaze Point GP3 Eye-Tracker offering an accuracy of 1 degree of visual angle and a sampling rate of 60 Hz.

Procedure

Participants were greeted by the researchers in a computer laboratory at the beginning of their experimental session, and they were seated in front of one of the computers in the room. The participants were then given an informational letter to read, and once they verbally agreed to take part in the experiment, the researchers then obtained demographic information for each participant. Instructions about the experimental task were then given verbally to the participants. Specifically, participants were instructed to look at the fixation cross in the middle of each masking screen, which was presented for five seconds before each roadway image presentation, and they were told to "search for any person on or with a bicycle" in the images, when the masking screen disappeared. They were then told that if they found a cyclist they would verbally state "yes" or if they determined that there was no cyclist present in the image they would verbally state "no", and the researcher would mark their answers on a score sheet. Participants were instructed to press the space bar once they finished their search for bicyclists in each image and repeat the process until all 30 images were presented.

After each participant indicated that he or she understood the instructions, the eye tracker was calibrated to each participant using a five point calibration technique. After the calibration of the eye tracker was complete, the participants began the testing session, and once they finished responding to each of the 30 images, they completed a three question survey asking them to indicate which color jersey was most conspicuous, which color jersey they preferred, and how much prior experience they had with cycling. After filling out the survey, they were debriefed, thanked, and dismissed.

Figure 2: Images a and b depict the initial AOIs around the Far (a) and Near (b) Cyclists. Images c and d depict the expanded AOIs around the Far (c) and Near (d) Cyclists.



a. The Far Blue Jersey Cyclist with the old AOI

b. The Near Blue Jersey Cyclist with the old AOI.

c. The Far Blue Jersey Cyclist with the expanded AOI.

d. The Near Blue Cyclist with the expanded AOI.

Analyses and Results

Areas of interest (AOIs) were manually created around the bicyclists in each of the six roadway images containing cyclists so that the AOI fit tightly around each cyclist (See Figure 2a and 2b). These initial AOIs yielded complete data sets consisting of at least one fixation in each of the six AOIs for only six participants. Upon examining the scan paths each participant made on each cyclist image, it was apparent that calibration issues caused participants fixations to appear laterally displaced on either side of the cyclists for the remaining seven participants. Therefore, we expanded each AOI by 50 pixels on all four sides (See Figure 2c and 2d). This produced 13 usable data sets with at least two fixations per cyclist.

Two 3 (Bicyclist Jersey: Black, Fluorescent Yellow, and Fluorescent Blue) x 2 (Bicyclist Distance: Near and Far) Repeated Measures ANOVAs were conducted (one to determine the effects of the two variables on time-to-first-bicyclist-fixation and the other to assess the effects of the two variables on the total number of fixations participants made on the cyclists).

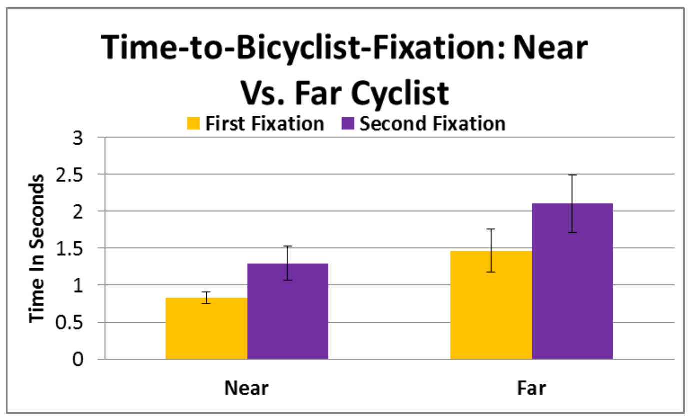


Figure 3: The graph depicts the time in seconds that it took participants to make their first and second fixations on the bicyclists at the Near and Far Distances.

Time-to-First-Bicyclist-Fixation Results

A significant main effect of Bicyclist Distance was revealed on the time-to-first-bicyclist-fixation, $F(1,12) = 5.00$, $p < 0.05$, partial $\eta2 = 0.29$. The cyclists photographed from the Near Distance (M = 0.83 sec, SD = 0.08) were found significantly faster than the cyclists photographed from the Far Distance (M = 1.47 sec, SD = 0.29) (See Figure 3). The effect of Bicyclist Jersey on time-to-first-bicyclist-fixation was not significant, $F(2,24) = 0.001$, $p = 1.00$, n.s. In addition, the interaction between Bicyclist Jersey and Bicyclist Distance on time-to-first-bicyclist-fixation was not significant, $F(2.24) = 0.90$, $p = 0.42$, n.s.

Number of Fixations Per Bicyclist Results

The effect of Bicyclist Distance on the number of fixations participants made on each bicyclist was not significant, $F(1,12) = 1.37$, $p = 0.27$, n.s. The effect of Bicyclist Jersey on the number of bicyclist fixations was also not significant, $F(2,24) = 0.09$, $p = 0.92$, n.s. Finally, the interaction between Bicyclist Jersey and Bicyclist Distance on the number of bicyclist fixations was not significant, $F(2.24) = 0.54$, $p = 0.59$, n.s. However, it was found that participants made approximately two fixations per cyclist on average (M = 2.35, SD = 0.18).

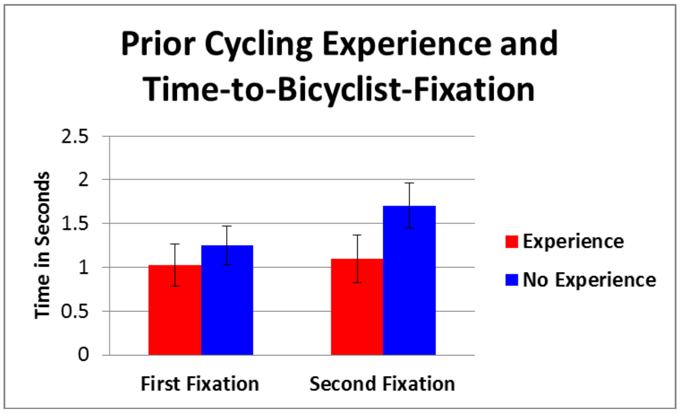


Figure 4: The graph depicts the average time in seconds that it took participants with and without prior cycling experience to make their first and second fixations on the bicyclists.

Additional Analyses and Results

Results of the post-experiment survey indicated that seven participants had previous cycling experience, while six did not. Therefore, an additional 2 (Bicyclist Distance) x 3 (Jersey Color) Repeated Measures ANOVA was conducted on the time-to-first-bicyclist fixations with Previous Cycling Experience added in as between subjects factor. All effects and interactions were not significant ($p > 0.05$), but participants with prior cycling experience (M = 1.03 sec, SD = 0.24) tended to find the bicyclists two milliseconds faster on average than participants who had no previous cycling experience (M = 1.25 sec, SD 0.22) (See Figure 4).

Another 2 (Bicyclist Distance) x 3 (Jersey Color) Repeated Measures ANOVA was conducted to assess the effects of Distance and Color on the time it took participants to make their *second* fixation on the bicyclist (time-to-second-bicyclist-fixation). This was because the first fixations made on the bicyclists do not necessarily signify that the participants recognized that the bicyclist was present. This analysis revealed a significant effect of Bicyclist Distance on the time-to-second-bicyclist-fixation, $F(1,12) = 6.38$, $p < 0.05$, partial $\eta2 = 0.35$. Similar to the effect of Bicyclist Distance on the time-to-first-bicyclist-fixation, the bicyclists at the Near Distance (M = 1.30 sec, SD = 0.23) were found significantly faster than the bicyclists at the Far Distance (M = 2.10 sec, SD = 0.40). See Figure 3. All other effects and interactions were not significant ($p > 0.05$).

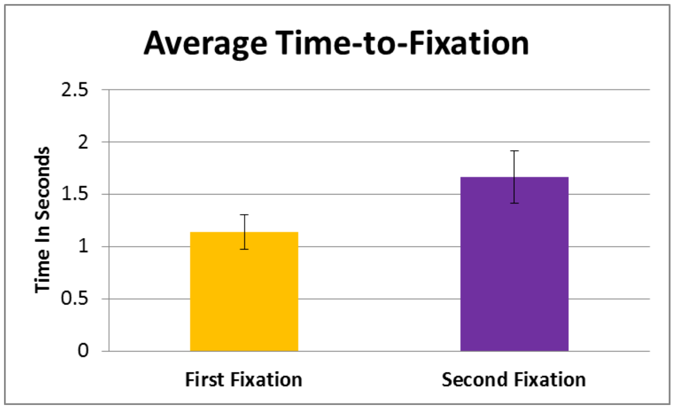


Figure 5: The graph portrays the average time in seconds that it took participants to make their first and second fixations on the bicyclists.

Finally, a 2 (Fixation: First Fixation and Second Fixation) x 2 (Bicyclist Distance) x 3 (Jersey Color) Repeated Measures ANOVA was conducted to assess the differences between the first and second fixations that participants made on the bicyclists with regard to the time it took them to make each fixation from the moment that each image appeared. This analysis revealed a significant Fixation on the time it took participants to make the first and second fixations, $F(1, 11) = 6.295$, $p < 0.05$, partial $\eta2 = 0.36$. A significant amount of time transpired between participants' first fixation on the bicyclists (M = 1.14, SD = 0.164) and their second fixation on the bicyclists (M = 1.66 sec, SD = 0.253). See Figure 5. The effect of Bicyclist Distance on the time-to-bicyclist-fixation was also significant, $F(1,11) = 5.63$, $p < 0.05$, partial $\eta2 = 0.34$. Again, the bicyclists at the Near Distance (M = 1.04 sec, SD = 0.09) were found significantly faster than the bicyclists at the Far Distance (M = 1.76 sec, SD = 0.33). All other effects and interactions were not significant ($p > 0.05$).

Discussion

This study examined the daytime conspicuity benefits of brightly colored cycling clothing. Specifically, we analyzed the time it took participants to find bicyclists wearing different colored jerseys featured at two different distances in still images of roadway environments. An eye tracker was used to measure the time it took participants to look at the bicyclists in the images, which is a novel approach to assessing bicyclist conspicuity. This study is the first of its kind.

It was initially hypothesized that the bicyclists featured at the Near Distance would be found faster than the bicyclists featured at the Far Distance, and the results supported this prediction. Participants took, on average, seven milliseconds longer to find the bicyclists at the Far Distance relative to the Near Distance. This could be due to the fact that the Far Cyclist subtended a smaller visual angle in comparison with the Near Cyclist. Another potential explanation for this finding may be that the Far Cyclist was featured on the right side of the roadway, whereas the Near Cyclist was featured on the left side of the roadway closer to the position of the fixation screen cross. However, this finding yielded from using still roadway images follows real-world trends; closer targets are typically found more quickly than farther targets.

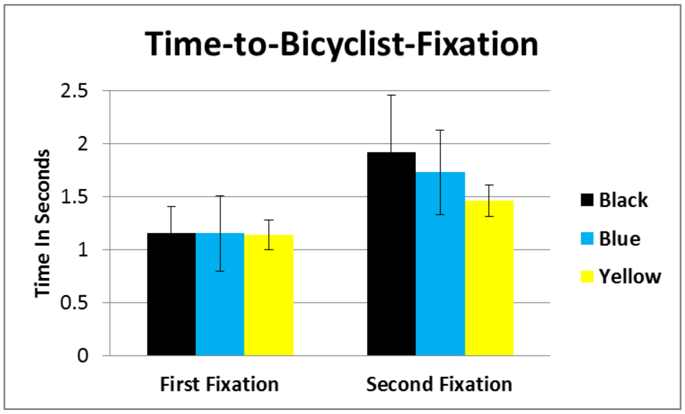


Figure 6: The graph portrays the average time in seconds that participants took to make their first and second fixations on each of the three different bicyclists.

The results of this study were expected to indicate that bicyclists wearing brightly colored clothing would be found significantly faster than bicyclists wearing dark clothing. However, this hypothesis was not supported by the data. Regarding the time it took participants to first fixate on the bicyclists, participants tended to take the same amount of time to first fixate on the bicyclists with the black, blue, and yellow jerseys, but participants seemed to make the second fixation faster for the bicyclist with the yellow jersey followed by the bicyclist with the blue and black jerseys. Since it is more likely that the time leading up to the second fixation may be more representative of the time it takes a person to recognize what they are seeing, it may be that participants were more quickly able to recognize the cyclist with the yellow jersey relative to the blue and then black jersey wearing cyclists. See Figure 6. Since the effect of Jersey Color was not significant, these interpretations are inconclusive and warrant further research.

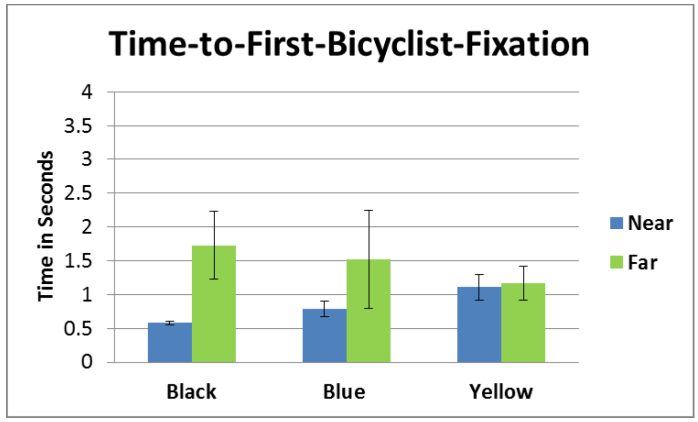


Figure 7a: The graph depicts the average time in seconds that it took participants to make their first fixation on each of the three bicyclists at each distance.

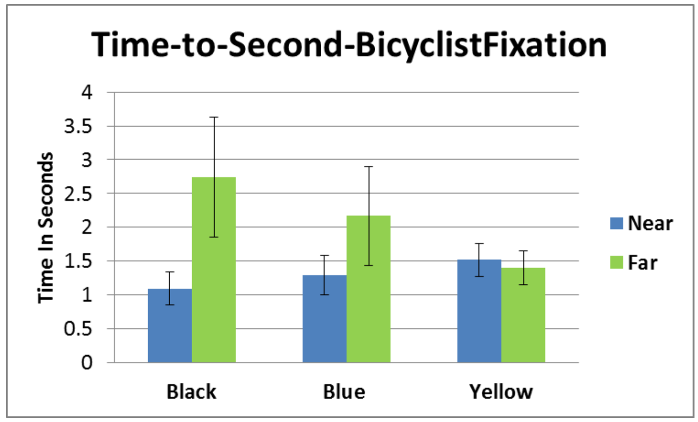


Figure 7b: The graph depicts the average time in seconds that it took participants to make their second fixation on each of the three bicyclists at each distance.

The interaction between Bicyclist Distance and Jersey Color was also hypothesized to be significant. Specifically, it was predicted that the time taken to find the cyclists wearing yellow and blue jerseys would decrease from the farther distance to the closer distance, while the time needed to find the cyclists wearing the black jersey was not expected to differ between the two distances. This hypothesis was also not supported by the data. This interaction was not significant in both the analysis pertaining to the time-to-first-bicyclist-fixation and the analysis for the time-to-second-bicyclist-fixation. However, the trend in the data suggests that at the Near Distance the bicyclists wearing the black, blue, and yellow jerseys were all found in approximately the same amount of time. At the Far Distance, differences (though not significant) between the time it took participants to find each cyclist became more pronounced. Participants tended to take a longer amount of time to find the cyclist with the black jersey followed by the cyclist with the blue jersey and finally the cyclist with the yellow jersey. See Figure 7 a and b. Although these results are also inconclusive, it appears that the yellow jersey was the most robust to the effects of distance.

Another interesting trend in the data, though also not significant, pertained to the previous experience that participants had with cycling. Participants with prior cycling experience tended to find the cyclists faster than those participants who had no prior experience with cycling. When comparing the time taken to make the first and second fixations on the bicyclists, participants with and without cycling experience took roughly the same amount of time to make their first fixations on the cyclists, but participants with cycling experience were generally quicker to make the second fixations on the bicyclist than their non-experienced counterparts.

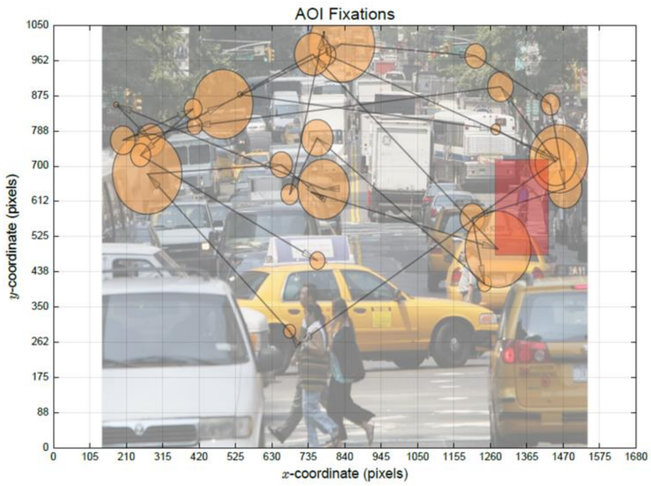


Figure 8: Scan path of Far Blue Jersey Cyclist from participant 18.

Figure 9: Scan path of Far Blue Jersey Cyclist from participant 11.

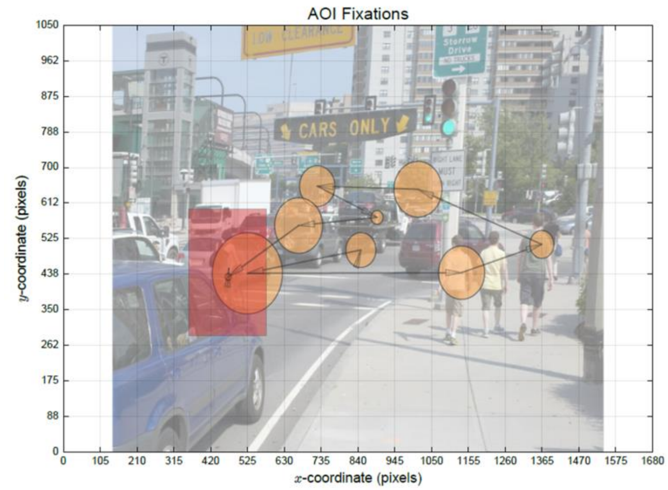


Figure 10: Scan path of Near Blue Jersey Cyclist from participant 11.

All 13 participants responded to each of the six bicyclists, but an interesting observation from the scan paths of the participants is that many of the participants tended to make more fixations on the bikes as opposed to the bicyclist. It seemed as though participants adopted a search strategy that opted for searching for a bike initially followed by finding the person on the bike. This search strategy would account for the non-significant Jersey Color effects because if the "bike" was the initial target that participants searched for they would take the same amount of time to find each cyclist with a different colored jersey. Another interesting observation involving a participant whose data were excluded from the analyses was that this particular participant failed to respond to one of the cyclists (the Far Blue Jersey Cyclist – See Figure 8). Figures 9 and 10 depict the scan paths from another participant on the Near and Far Distance images. The scan path in Figure 8 shows that this participant made fixations near the cyclist and grazed over the cyclist without "seeing" it. This indicates that the participant was inattentionally blind to this cyclist, and it demonstrates that there are limitations to human attention. Therefore, real-world drivers are at risk for not attending to everything that they see in a roadway environment, even important obstacles such as bicyclists.

From the post-experiment survey, eleven out of thirteen participants (85%) chose the yellow jersey when asked "which jersey color was the most conspicuous" and "which jersey color do you prefer", while the remaining two participants chose the blue jersey. All the participants that chose the yellow jersey stated that the reason for their choice was because the yellow jersey "stood out the most." It may be that an association exists between yellow clothing and safety due to yellow being the "go-to" color for high-visibility safety vests. This finding that the yellow jersey was chosen as being the most conspicuous aligns with the trend (though non-significant) found in the Jersey Color analyses. Furthermore, the trends in our data and the results of the post-experiments survey also follow the results of the study conducted by

Lahrmann and Madsen (1980); that fluorescent yellow clothing can enhance bicyclist conspicuity. Therefore, yellow jerseys may improve bicyclist daytime conspicuity, relative to blue and black jerseys.

Limitations and Future Research

This study followed a within subjects design, such that each participant responded to all 30 roadway images. While there were many presentations of roadway images that did not contain bicyclists, participants still may have remembered the locations of the three cyclists wearing different colored jerseys in the Near and Far Distance images, and this may explain the ceiling effect that we obtained for the Jersey Color results. The small samples size obtained for this experiment may have also contributed to the non-significant findings. A between subjects design could be applied to a future version of this experiment, such that each participant sees only one cyclist at each of the two distances (two cyclists total per experimental session), and this might produce different results because the memory of the participants would be more controlled.

The Near and Far Cyclists were both not on the same side of the road. The Near Cyclist was on the left side of the screen and the Far Cyclist was on the right side of the screen. Future versions of the study could contain images of Near and Far Cyclists that are presented on the same side of the roadway to control for the location of cyclist presentation. Furthermore, the roadway images in the present experiment were not controlled for clutter, and similar future studies should present roadway images with bicyclists that contain the same amount of clutter. Also, the Near Distance image contained a blue car that partially occluded the cyclist, and it may be that the blue of the bicyclist's jersey in the Blue condition may have clashed with the blue color of the vehicle, making the Blue Jersey Bicyclist harder to find due to diminished contrast. Finally, the use of a chin rest for participants to stabilize their head movements might have prevented the calibration issues experienced in this study. The limitations in this experiment provide opportunities to improve this study for future renditions.

Conclusions

This study suggests that eye tracking technology may be a useful tool for quantifying bicyclist conspicuity. The results of this study indicate that wearing yellow jerseys can enhance bicyclists' daytime conspicuity. Not only was the yellow jersey rated as being the most conspicuous and preferred color in comparison with black and blue jerseys, but the yellow jersey was also the most robust to distance. In other words, participants took the same amount of time to find the Yellow Jersey Bicyclist at both the Near and Far distances, whereas they tended to take more time to find the Blue and Black Jersey Bicyclists at the Far Distance in comparison to the Near Distance. In addition, participants tended to find the Yellow Jersey Bicyclist faster than the Blue and Black Jersey Bicyclists at the Far Distance. In order to better ensure that drivers have enough time to react to bicyclists ahead, it is important that bicyclists are conspicuous from far distances. Yellow jerseys may provide a way for bicyclists to enhance their daytime conspicuity which would allow drivers to notice their presence from safe distances. Additional on-road research efforts pertaining to the daytime conspicuity benefits of fluorescent yellow clothing are ongoing.

References

de Rome, L., Boufous, S., Georgeson, T., Senserrick, T., & Ivers, R. (2014). Cyclists' clothing and reduced risk of injury in crashes. *Accident Analysis & Prevention, 73*, 392-398.

Ho, G., Scialfa, C. T., Caird, J. K., & Graw, T. (2001). Visual search for traffic signs: The effects of clutter, luminance, and aging. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 43*(2), 194-207.

Hutchinson, T.P. & Lindsay, V.L. (2009). Pedestrian and cyclist crashes in the Adelaide Metropolitan Area (Report #CASR055). *Adelaide, Australia: Centre for Automotive Safety Research.*

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

Matthews, M.L., & Boothby, R.D. (1980). Visibility of cyclists at night: laboratory evaluation of three rear warning devices. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 24* (1), 129-133.

McGuire, L, & Smith N. (2000). Cycling safety: injury prevention in Oxford cyclists. *Injury Prevention 6.4*: 285-287.

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.

National Center for Statistics and Analysis. (2016). Bicyclists and other cyclists: 2014 data. (Traffic Safety Facts. Report No. DOT HS 812 282). *Washington, DC: National Highway Traffic Safety Administration.*

Poulos, R. G., Hatfield, J., Rissel, C., Flack, L. K., Murphy, S., Grzebieta, R., & McIntosh, A. S. (2015). Characteristics, cycling patterns, and crash and injury experiences at baseline of a cohort of transport and recreational cyclists in New South Wales, Australia. *Accident Analysis & Prevention, 78*, 155-164.

Raftery, S. J., & Grigo, J. A. (2013). The conspicuity of South Australian cyclists: implications for safety (No. CASR113).

Scialfa, C. T., Thomas, D. M., & Joffe, K. M. (1994). Age-related changes in the eye movements subserving feature search. *Optometry and Vision Science*, *71*, 736-742.

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.