RESEARCH & DEVELOPMENT

Considering Conspicuity for North Carolina Department of Transportation Light Trucks

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NCDOT Project 2020-33
FHWA/NC/2020-33
October 2022

Technical Report Documentation Page

1. Report No. 2020-33	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Considering Conspicuity for North Carolina Department of Transportation Light Trucks Final Report		5. Report Date October 2022 6. Performing Organization Code
7. Author(s) Brian Sylcott, PhD		8. Performing Organization Report No.
9. Performing Organization Name and Address East Carolina University		10. Work Unit No. (TRAIS) 11. Contract or Grant No. FHWA/NC/2017-45
12. Sponsoring Agency Name and Address North Carolina Department of Transportation Research and Development Unit 104 Fayetteville Street Raleigh, North Carolina 27601		13. Type of Report and Period Covered Final Report August 1, 2019 – July 31, 2022 14. Sponsoring Agency Code 2020-33
Supplementary Notes:		

16. Abstract

A 2014 change in vehicle appearance guidelines forwent custom bright yellow paint job in favor of the factory standard white color for NCDOT light duty trucks. This change raised some concerns about vehicle conspicuity, or the vehicle's ability to draw attention to itself. The addition of high visibility markings was offered as a possible solution. This work used an eye-tracking system to test a variety of color options for the markings in a simulated driving environment. Results showed that, in general, there were not statistically significant differences in the time to first fixation, fixation count, and average fixation duration between the different color combinations. The results suggest that none of the tested color combinations would perform significantly better than one another at improving conspicuity.

17. Key Words Visibility Light Trucks Accidents		18. Distribution Statement	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 54	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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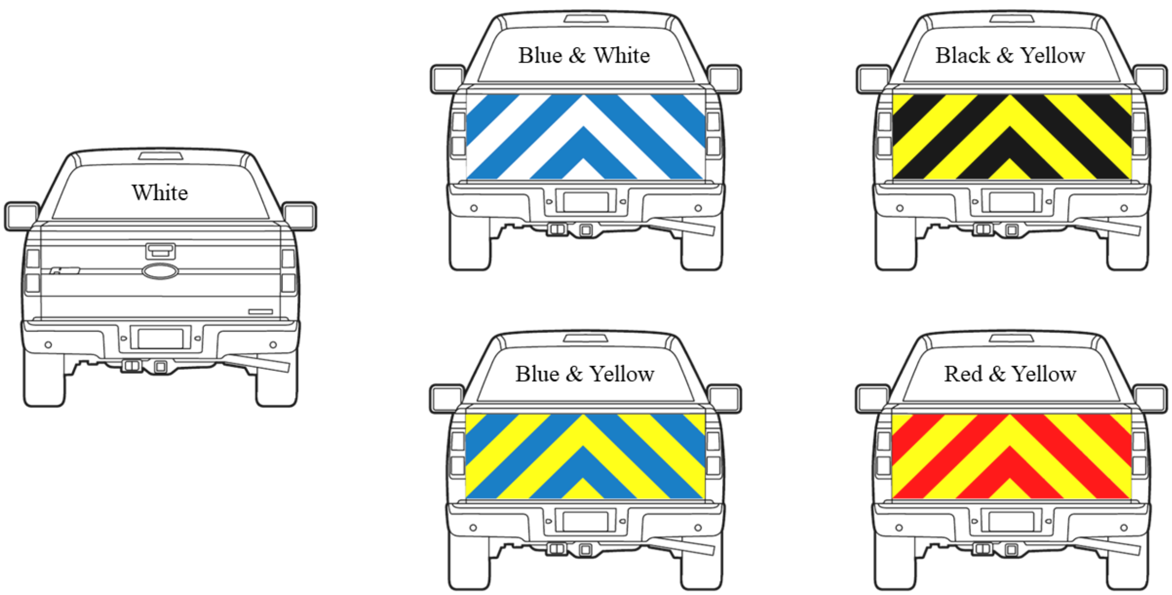

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EXECUTIVE SUMMARY

In 2014 the North Carolina Department of Transportation (NCDOT) vehicle guidelines changed to forgo the custom bright yellow paint job in favor of the factory standard white color for light duty trucks. This change has raised some concerns about vehicle conspicuity, or the vehicle's ability to draw attention to itself. The work described here was performed to characterize how different color high visibility markings affect the public's ability to identify NCDOT vehicles to minimize accidents that can occur due to misidentification.

In this work seven color combinations for high visibility markings were investigated with NCDOT employees. The top four designs were tested in a driving simulation environment. The test consisted of study participants driving along a predetermined path while different vehicle marking pattens appeared in their periphery. The test was performed once in clear conditions and again with fog to simulate low visibility conditions. An eye-tracking system was used to record each participant's visual attention throughout the drive. The metrics collected from the eye-tracking system included a count of fixations, the time to first fixation on each pattern, and the duration of the fixations. Results showed that, in general, there were not statistically significant differences in these metrics between the different color combinations. However, one notable exception was found in the clear driving condition. The blue & white chevron pattern was found to have a longer average fixation duration when compared to the red & yellow pattern or the plain white vehicle. This indicates that the blue & white pattern held the attention of the drivers longer than the other patterns. A similar experiment was completed in a virtual reality-based environment. The results from that task mirror those of the vehicle simulator. Differences in the metrics of interest for the various color combinations were found not to be statistically significant.

INTRODUCTION

Prior to 2014, the North Carolina Department of Transportation (NCDOT) would pay a premium to apply a custom bright yellow paint job, as shown in Figure 1, to their new trucks before putting them into service.

Figure 1: Example of NCDOT vehicle with yellow paint job [1]

The bright yellow color helped NCDOT vehicles stand out when on the road. However, color alone was not necessarily enough to identify the vehicles as belonging to NCDOT and this branding made the vehicles more difficult to sell once their service life had ended. Currently, new vehicles are shipped to NCDOT in the factory standard white color as shown in Figure 2.

Figure 2: Example of NCDOT vehicle with white paint job [1]

This change has raised some concerns about vehicle conspicuity. In this context, conspicuity refers to a vehicle's ability to draw attention to its presence, even when other drivers are not actively looking for it [2]. High levels of conspicuity can help the public easily identify and avoid collisions with NCDOT vehicles. The work described here was performed to investigate the efficacy of several color combinations for potential use in aftermarket vehicle marking.

Background

While in service NCDOT vehicles often need to make frequent stops and park in active travel zones. Facilitating a quick and accurate identification of NCDOT vehicles will allow the public to adjust their driving behavior accordingly and potentially reduce the risk of incident. Gaining inspiration from fire trucks, ambulances, and other rescue vehicles, NCDOT personnel have selected industry standard Battenburg and Chevron style patterns (shown Figures Figure 3 and Figure 4 respectively) to be added to their vehicles.

Figure 3: Battenburg style pattern on NCDOT vehicle [1]

Figure 4: Chevron style pattern on NCDOT vehicle [1]

While the general styles have been chosen, there are details about the design and implementation of the markings that must be specified. These details include aspects such as color, size, and position.

Numerous factors have been identified as contributing to the conspicuity of vehicles including retroreflective sheeting type, font style and size, and word count [3]. Retroreflective tape in particular has been shown to be effective at improving the visibility of heavy equipment. The National Highway Traffic Safety Administration sponsored a study of approximately 11,000 crash cases that occurred between 1997 and 1999. In dark conditions, retroreflective tape was found to reduce side and rear impacts that resulted in fatalities or injuries by as much as 44% [4]. Retroreflective markers can come in a range of reflective intensities and can be organized into countless shapes and patterns that can communicate different messages to drivers. A down-and-away chevron pattern for instance, may communicate "danger" or "slow down" as it is often used on traffic barriers [5].

Color is an important factor that can affect conspicuity. For example, in the U.S., firetrucks are usually red or red and white. However, some studies suggest that with all else being equal, lime-yellow and white firetrucks have a lower probability of visibility related accidents and are therefore statistically safer than red or red and white ones [6], [7]. Nevertheless, no single color choice will provide optimal conspicuity in all possible scenarios [8]. A preliminary investigation conducted by NCDOT personnel concluded that the impact of color and pattern choice was not as significant as uniformity and reflectiveness [1]. This work carried out a structured experiment to verify those findings.

As it would be difficult to test all possible variations in the field, driving simulators have proven to be a viable alternative. Driving simulators consist of hardware representative of a vehicle cabin, and a display that gives the sense of optical flow. Simulators that use virtual environments have proven to be capable of accurately replicating the driving experience [9]. These experiences are not limited to ideal driving conditions. Simulators are also an effective means of testing driver responses to potential hazards as patterns of behavior observed in experimental conditions are similar to those observed in the real world [10]. These types of simulators can give insight into the strategies drivers take to remain safe while driving in the presence of hazards [11].

METHODOLOGY

Color Survey

There were seven color combinations in consideration for use on the NCDOT vehicle markings, black & yellow, red & yellow, black & white, yellow & white, orange & yellow, blue & yellow, and blue & white. Before conducting the simulation study, it was necessary reduce the number of combinations in consideration to limit fatigue on study participants. To accomplish this a survey was developed in Qualtrics and distributed to NCDOT employees. The survey consisted of a single question that asked participants to rank the combinations they felt stood out the most. The images used in the survey are shown in Figure 5.

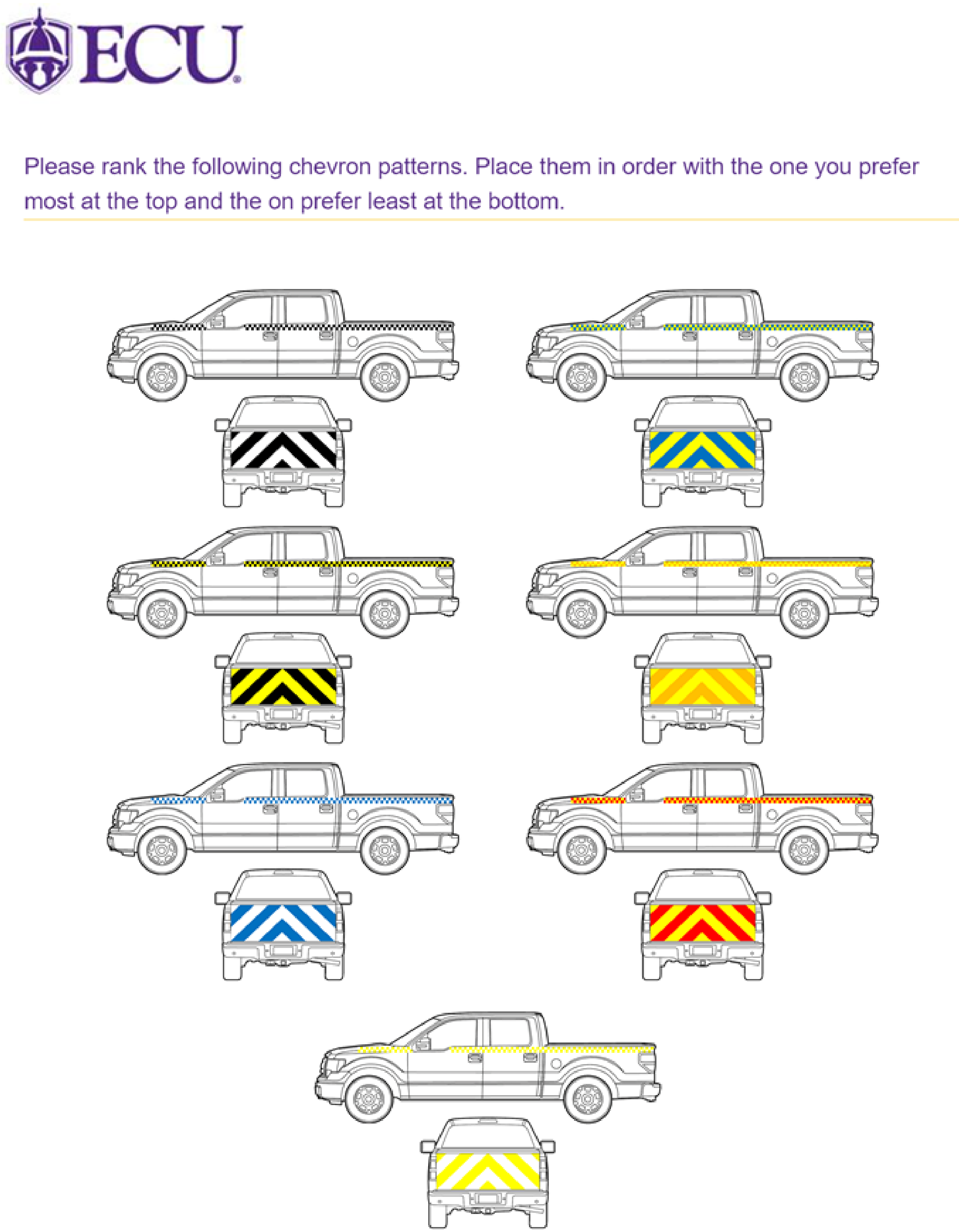

Figure 5: Images from color combination survey

The results from the survey of 203 participants are listed in Table 1.

Table 1: Survey Responses Ranking Color Combinations

Rank	*Black & White*	*Black & Yellow*	*Blue & White*	*Blue & Yellow*	*Orange & Yellow*	*Red & Yellow*	*Yellow & White*
1	25	26	72	30	5	44	2
2	20	56	34	48	15	24	6
3	11	70	23	45	22	23	10
4	20	25	28	41	46	29	15
5	16	14	28	18	65	24	37
6	26	9	14	13	41	35	64
7	85	3	4	8	9	24	69
Average	**4.97**	**2.92**	**2.82**	**3.20**	**4.53**	**3.82**	**5.69**

Table 1 shows the number of participants that ranked each color combination at positions 1 through 7. The four highest ranking color combinations were blue & white, black & yellow, blue & yellow, and red & yellow. These combinations were selected to be tested in the driving simulation experiment.

Population

40 subjects were recruited for this driving studies from in and round the Greenville, NC area. Of those 40, 6 subjects were excluded from the data analysis due poor data quality resulting from bad recordings. The average age of the subjects included in the analysis was 44.5 years. There were 19 male and 15 female participants. For participants that reported the information, the average length of time they held a valid license was greater that ~25 years. Participants were compensated with a $25 Amazon gift card for their participation in the study.

Driving Simulator Study

The driving simulation experiment was designed to determine if there was a difference in conspicuity between the top ranked color combinations. The study had participants drive along a predetermined path while images of vehicles with different chevron patterns on the rear were presented on screen.

Subjects that who wanted to participate in the study expressed their interest by completing a Qualtrics-based screening survey. The survey consisted of three questions:

- Are you at least 18 years of age?
- Do you have normal or corrected-to-normal vision?
- Do you currently have a valid driver's license?

Subjects that answered yes to all three questions were given the opportunity to continue on to complete a demographics survey and were contacted about enrolling in the study based on the order their inquiry was received. This study was approved by the Internal Review Board at East Carolina University (ECU). The study was conducted on the campus of ECU in the Research for Older Adult Driver Initiative laboratory. Before conducting the experiment, a member of the research team would explain the study and have each subject sign the consent form. Next, subjects were seated in the vehicle simulator. This simulator consists of steering and pedal controls and an ultrawide display. Once seated, each subject was fitted with the eye-tracking system. This study used the Tobii Glasses 2, a wearable eye-tracking solution with a 100 Hz sampling frequency. A prescription lens kit was used to correct vision for subjects who wore glasses. A photo of the experimental setup is shown in Figure 6.

Figure 6: Vehicle simulator experimental setup

The study consisted of a practice drive to orient subjects to the controls followed by a drive in clear conditions and a drive in low visibility conditions resulting from dense fog. The eye-tracking system was calibrated prior to each drive. The structure of the experiment is depicted in Figure 7.

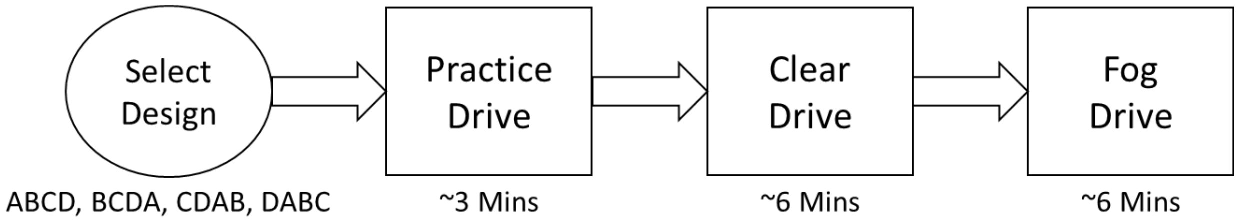

Figure 7: Vehicle simulator experimental design order

While simulating driving in the clear and low visibility conditions images of the rear of a truck appear in the top right-hand side of the screen. A total of eight images were shown to the subjects at fixed intervals during the clear and fog drives. Subjects were instructed to count the number of truck images presented during the drive. The order the images were displayed in is shown in Figure 8. The pattern was white, color, color, white, color, white, color, white. To reduce the effects of order bias, the presentation order of the four color combinations was counterbalanced across subjects in the pattern ABCD, BCDA, CDAB, DABC, where A = blue & white, B = black & yellow, C = blue & yellow, and D = red & yellow.

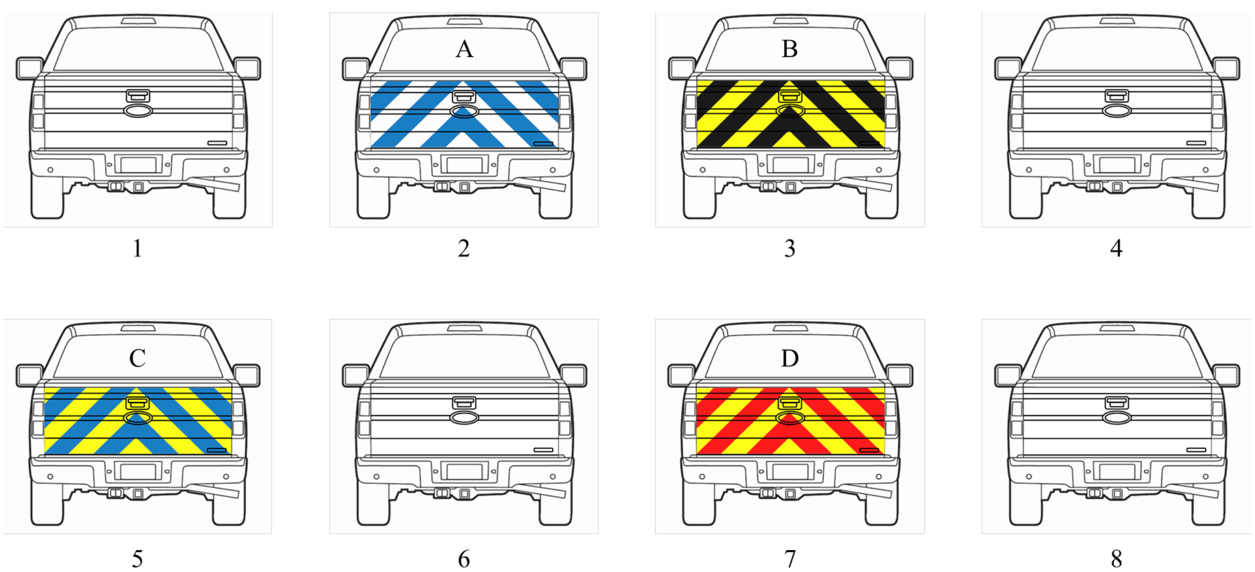

Figure 8: Example vehicle presentation order (ABCD)

The eye-tracking system recorded the gaze pattern of each subject as they completed the drives. After completing the low visibility drive, subjects removed the eye-tracking glasses and exited the vehicle simulator.

Virtual Reality Study

After completing the vehicle simulator portion of the study subjects were seated at the virtual reality (VR) station. Here subjects were fitted with HTC Vive Pro Eye head mounted display. This is a full functioning VR display with built in eye-tracking capabilities. The system was used to display a custom-built environment where subjects drove along a straight path. while encountering vehicle traffic flowing in the same direction as the subjects were traveling. The traffic consisted of nine white pickup trucks. Four of these trucks had colored chevrons affixed to their rear. The pattern of the trucks was white, white, color, color, white, color, white, color, white. To reduce the effects of order bias, the presentation order of the four color combinations was counterbalanced across subjects in the pattern ABCD, BCDA, CDAB, DABC, where A = blue & white, B = black & yellow, C = blue & yellow, and D = red & yellow. The subjects controlled the vehicle in the VR environment using a Logitech G923 wheel and pedals Set. The experimental setup is shown in Figure 9.

Figure 9: VR experimental setup

The eye-tracking system built into the headset recorded the gaze pattern of each subject as they completed a clear, followed by a low visibility drive. At the conclusion of the study, subjects removed the headset and exited the lab.

RESULTS

Vehicle Simulation

The data recorded by the eye-tracking system during the vehicle simulation study allowed for the analysis of fixations on the images presented to the subjects. Fixation refers to the instance where a subject focuses on a specific area within their visual field. The metrics of interest for this study include fixation count, time to first fixation, and fixation duration.

Fixation count is the number of times the subject focuses on the target. Table 2 gives a count of how many subjects fixated on the color combinations at least once when they were presented. Each color combination was shown twice to each of the 34 subjects included in the analysis, once in the clear condition and once in the fog condition. However, the white truck was presented to each subject eight times, four in the clear condition and four in the fog condition.

Table 2: Count of Subjects Who Fixated At Least Once

	Blue & White	*Black & Yellow*	*Blue & Yellow*	*Red & Yellow*	*First White*
Clear	9	12	11	12	19
Fog	12	9	10	12	16
Total	21	21	21	24	35

As some subjects fixated on the color combinations more than once during it's presentation, Table 3 shows the total number of fixations on each of the color combinations. Here, a count for the first two white images is reported separated from the total of all eight.

Table 3: Total Fixation Count

	Blue & White	*Black & Yellow*	*Blue & Yellow*	*Red & Yellow*	*First White*	*Total White*
Clear	18	18	17	17	58	116
Fog	14	18	16	16	26	79
Total	32	36	33	33	84	195

Time to first fixation is the difference in time between the appearance of the target and the point at which the subject first focuses on the target. The average time to first fixation for each of the color combinations is reported in Table 4.

Table 4: Average Time to First Fixation in Milliseconds

	Blue & White	*Black & Yellow*	*Blue & Yellow*	*Red & Yellow*	*First White*	*Total White*
Mean Clear	841.00	1947.67	1795.64	958.08	1396.58	1488.51
Mean Fog	1667.42	1496.89	701.10	1260.67	1669.38	1631.83
Mean Overall	1313.24	1754.48	1274.43	1109.38	1521.29	1553.28

Fixation duration is a measure of the amount of time subjects spend focused on the target. The average fixation duration for each of the color combinations is reported in Table 5.

Table 5: Average Fixation Duration in Milliseconds

	Blue & White	*Black & Yellow*	*Blue & Yellow*	*Red & Yellow*	*First White*	*Total White*
Mean Clear	288.67	257.92	236.18	162.25	208.37	196.35
Mean Fog	239.58	237.44	198.30	190.83	268.13	217.68
Mean Overall	260.62	249.14	218.14	176.54	235.69	205.99

Virtual Reality

From the data collected with the VR headset's eye-tracking system the fixation count and duration were able to be computed. These values are reported in Tables 6 and 7 respectively.

Table 6: Count of Subjects Who Fixated At Least Once (VR)

	Blue & White	*Black & Yellow*	*Blue & Yellow*	*Red & Yellow*
Clear	8	11	11	10
Fog	13	16	15	13
Total	21	27	26	23

Table 7: Average Fixation Duration in Milliseconds (VR)

	Black & Yellow	*Blue & White*	*Blue & Yellow*	*Red & Yellow*
Mean Clear	334.71	483.15	279.31	305.53
Mean Fog	259.86	401.22	542.17	204.18
Mean Overall	288.37	434.60	430.96	248.24

DISCUSSION

Vehicle Simulator

Fixation count can be used to address one of the first questions about the color combinations. The counts listed in Table 2 provide an indication of whether the specific color combinations drew the attention of the subjects at all. A hit was recorded if the subject fixated on the image at least once during it presentation. Since each color combination was presented twice to each of the 34 subjects, the max count for this metric was 68 fixations. The number of times each of the different color combinations was fixated on one or more times was similar, indicating not much difference in the different pattern's ability to grab a driver's attention. The number of times the first white image was fixated on one or more times was slightly higher. This could be the result of it being the first image to be presented in all the designs. This trend extended to the total fixation count reported in Table 3. Here, the total number of fixations for each image was tallied. Many of the color combinations experienced more that one fixation. However, there was not a large difference in the total fixation count between the various color combinations. As the white images were fixated on by more subjects, it is reasonable that the total fixation count for white is higher that the color combinations. The additional column, Total White, considers that the white truck was presented to each subject four times in each condition.

The time to first fixation values reported in Table 4 give an indication of how quickly each of the images drew the subject's attention. A one-way ANOVA analysis was performed in SPSS to determine if the differences in times between the color combinations were statistically significant. The analysis found none of these differences to be significant, indicating that each pattern drew the driver's attention in the same relative amount of time.

The average fixation duration times reported in Table 5 provide a measure of how long the images held the subject's attention. A one-way ANOVA analysis was performed in SPSS to determine if the differences in duration between the color combinations were statistically significant. The analysis found statically significant differences in the clear condition between the black & yellow and red & yellow, the blue & white and red & yellow, and the blue & white and white images. These findings indicate that the blue & white pattern held the attention of the subjects longer than the other color combinations while not pulling the driver's attention away from the road for too long.

Virtual Reality

The results from the VR study echoed those of the vehicle simulator study. The number of times each of the different color combinations was fixated on one or more times was relatively similar as shown in Table 6. This indicates that no specific color combination drew the driver's attention much more than any other.

The average fixation duration for each of the color combinations is reported in Table 7. A one-way ANOVA analysis was performed in SPSS to determine if the differences in duration between the color combinations were statistically significant. This analysis found none of the differences to be statistically significant. The data collected during the VR experiment did not reveal any color combination to perform better or worse than any other.

CONCLUSION

This study was designed to investigate any differences in how drivers respond to different potential color combinations for high visibility vehicle markings. Vehicle simulators have been used in a variety of scenarios to study and ultimately gain a better understanding of driver behavior in a safe environment. The results from this study found that, in general, there were no statistically significant differences in the performance of the different color combinations on the metrics of interest. However, the blue & white pattern was found to have a slightly longer average fixation duration than some other pattens, indicating that it held the attention of driver for a longer period of time. Based on these results, there does not appear to be a substantial difference in the conspicuity of the tested color combinations. Further investigation is required to establish the best practices for the NCDOT fleet of light trucks.

ACKNOWLEDGEMENTS

I would like to acknowledge East Carolina University students and faculty that contributed to this work, Morgan McDonald, Alec Ducharme, Meagan Denny, Avery Vose, Jonathan Echerd, and Dr. Anne Dickerson. I would also like to thank the North Carolina Department of Transportation for funding this work.

REFERENCES

[1] Division Nine Forsyth Maintenance, “Equipment Visibility Proposal,” 2015.
[2] S. Cook, C. Quigley, and L. Clift, “An assessment of the contribution of retro reflective and fluorescent materials,” *UK Department of Environment, Transport, and Regions*, 1999.
[3] H.-J. Schmidt-Clausen, *Retroreflective marking of vehicles*, vol. 7. Herbert Utz Verlag, 2000.
[4] C. Morgan, “The Effectiveness of Retroreflective Tape on Heavy Trailers,” 2001.
[5] U.S. Fire Administration and International Fire Service Training Association, “Emergency Vehicle Safety Initiative,” 2014.
[6] S. S. Solomon and J. G. King, “Influence of color on fire vehicle accidents,” *Journal of Safety Research*, vol. 26, no. 1, pp. 41–48, 1995, doi: 10.1016/0022-4375(95)00001-1.
[7] S. S. Solomon, “Lime-yellow color as related to reduction of serious fire apparatus accidents: The case for visibility in emergency vehicle accident avoidance.,” *Journal of the American Optometric Association*, 1990.
[8] U.S. Fire Administration and International Fire Service Training Association, “Emergency Vehicle Visibility and Conspicuity Study,” 2009.
[9] L. Meuleners and M. Fraser, “A Validation Study of Driving Errors Using A Driving Simulator,” *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 29, pp. 14–21, 2015, doi: 10.1016/j.trf.2014.11.009.
[10] G. Underwood, D. Crundall, and P. Chapman, “Driving simulator validation with hazard perception,” *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 14, no. 6, pp. 435–446, 2011, doi: 10.1016/j.trf.2011.04.008.
[11] P. Konstantopoulos, P. Chapman, and D. Crundall, “Driver’s visual attention as a function of driving experience and visibility. Using a driving simulator to explore drivers’ eye movements in day, night and rain driving,” *Accident Analysis and Prevention*, vol. 42, no. 3, pp. 827–834, 2010, doi: 10.1016/j.aap.2009.09.022.