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An Investigation of Lighting Schemes to Improve sUAS Conspicuity

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16. Abstract

Increasing the visual detection and recognition range of Unmanned Aircraft Systems (UAS) and small UAS (sUAS) is vital for the safety of the National Airspace System (NAS). The last line of defense for collision avoidance is visual see-and-avoid, particularly, if/when automated Detect and Avoid (DAA) mechanisms are either not in place or have failed. As sUAS flights increase, air traffic controllers (ATC), visual observers (VO), and pilots must be able to see and track unexpected static and dynamic sUAS with enough time to perform an avoidance maneuver. One method of increasing the detection/recognition range is through intensifying the conspicuity of sUAS design through optimizing lighting methods.

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
CAMI	Civil Aerospace Medical Institute
CIE	Commission Internationale de l'Eclairage
DV	Dependent Variable
FAA	Federal Aviation Administration
GLMM	Generalized Linear Mixed Model
Hz	Hertz
IRB	Institutional Review Board
IV	Independent Variable
MMAC	Mike Monroney Aeronautical Center
RGB	Red-Green-Blue Color Code
sUAS	Small Unmanned Aircraft System
UAS	Unmanned Aircraft System
SWaP-C	Size, weight, power, and cost

Introduction

With the proliferation of small Unmanned Aircraft Systems (sUAS) there is an increased need to ensure that they are integrated into the National Airspace System safely. One factor in accomplishing this task is to make sUAS as visually conspicuous as possible. Increased conspicuity increases safety by lessening the possibility of collisions with other aircraft, with people, and with other objects. The research described in this report is a follow-on task from a review of literature on making sUAS more conspicuous to both pilots of manned aircraft that might be flying in the same airspace as well as to people on the ground that might be potentially in close proximity to these aircraft (Hu, et al., in review). The literature review included 112 research papers that were classified into one of four strategies for increasing conspicuity: *Paint Color*, *Lighting Effectiveness*, *Environmental and Weather*, and *Psychology and Physiology*. The current study focuses on just one of those strategies, lighting effectiveness, as a method to improve aircraft conspicuity.

External lighting for manned aircraft serves multiple purposes. Navigation lighting, also called position lighting, is used to indicate an aircraft's direction of movement to outside observers. It includes a green and red light located on the right and left wingtip respectively, as well as a white light located on the tail of the aircraft. Landing lights are similar to automobile headlights and are white lights used to illuminate the runway for the pilot. Finally, anti-collision lights are usually either a red or white rotating beacon on the top of the aircraft, or strobing white lights located on the wingtips.

For most UAS, anti-collision lighting would be of the highest importance. Many systems would not need landing lights because the pilot is not controlling the aircraft from the perspective of the aircraft. These lights might interfere with the landing procedure if they inadvertently shine in the pilot's eyes. Also, many of these systems have an automated landing procedure that does not require illumination of the landing area for the pilot. Navigation lighting can be useful for certain types of aircraft, especially fixed-wing models. However, unmanned rotorcraft systems can change directions without requiring a longitudinal rotation, thus making the notion of a front and back of the aircraft indeterminate with no clear way to indicate the direction of travel using a fixed lighting scheme.

The literature review by Hu et al. (2022) offered several recommendations regarding UAS lighting schemes. They recommended the following.

- Strobe lighting should be utilized in place of steady stream lighting.[1]
- Bright Strobe Lights should be located on the top and bottom of the sUAS in place of position lighting.

[1] Bullough, Zhu, & Narendran, 2012; Gerathewohl 1953.

- Lighting on the bottom of a sUAS/UAS during bright sunlight conditions may reduce the conspicuity.[2] It may be best to allow the operator to control differentially the lighting on the top and bottom of the sUAS/UAS.
- Variations in strobe stimulus color should be in place to account for background contrast changes.[3]
- LED lights are generally a better option than incandescent lighting.
  - LED lightsoutperform incandescent lights in terms of size, weight, power, and cost (SWaP-C).[4]
  - LED lights are often easier to detect than incandescent lights.[5]

The current research is a follow-on to the Hu et al. (2022) literature review. The original plan was to conduct a real-world study looking at some of the recommendations and expand those recommendations to include specific lighting and strobe rates. Unfortunately, conducting a real-world study had to be postponed because of the COVID-19 pandemic. Instead, we conducted a computer-based study that allowed little to no person-to-person interaction with the participants.

A set of independent variables (IVs) was selected based on the findings from the literature review. This set included Stimulus Color, Flash Rate, Background, and Relative Movement of the light from the observer. The Background condition was further separated into Time-of-day and Environment conditions, which included Rural, Urban, and Sky.

We were interested in several questions with this research, as follows:

1. Which colors are most effective in both day and night conditions and across a variety of backgrounds?
2. Is an alternating color pattern as effective as a single colored light?
3. Which alternating color pattern is the most effective?
4. Under which environment condition/s are lights easiest to locate?
5. What colors are most effective for each environment?
6. Are some colors more effective at night than during the day?
7. Are flashing lights more conspicuous than steady lights?
8. Are flashing lights more conspicuous than steady lights in day backgrounds as opposed to night?
9. Does increasing the flash rate lead to an increase in conspicuity?
10. Are lights moving across the field of view more easily noticed than lights moving toward the observer?

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[2] Jacob et al., 2018.
[3] Hobbs, 1991.
[4] Gu, Baker, and Narendran, 2007.
[5] Bullough, 2012; Bullough 2017.

11. Are flashing lights more effective than steady lights when the stimulus is approaching the observer as opposed to moving across the field of view?
12. Under which background condition(s) are lights easiest to locate?

The literature review suggested at least partial answers to several of these questions, but not all of them. For example, white strobe lighting during night conditions has been shown to be highly effective at increasing conspicuity (Graham, 1989; Dolgov et al., 2012); however, it has little to no effect on conspicuity during daylight conditions (Hobbs, 1991; Projector, 1962; Wallace et al., 2019). Other research, however, has demonstrated that flashing lights were more conspicuous than steady lights, especially in daylight conditions (Edewaard, Szubski, Tyrrell & Duchowski, 2019). Bullough, 2011 found the color of the light has very little effect on conspicuity in night conditions. In general, increased brightness leads to increased conspicuity, but research has also shown that bright lighting can also lead to discomfort for the viewer (Bullough, 2011). Finally, Davoudian (2011) showed that the presence and density of background lighting at night has a significant effect on conspicuity.

Purpose

The primary purpose of the current research was to confirm some of the previous findings identified in Hu et al. (2022) and to shed some light on other questions. The results of the current research will be used to inform, frame, and apply the most important aspects of the findings to a planned follow-on real-world study. The ultimate goal is to provide policy makers with information that will be useful in the development of guidelines and standards for the use of lighting on future UAS.

Method

COVID-19 Considerations

This research effort was conducted during the COVID-19 pandemic, which required remote data collection to adhere to social distancing and other COVID-safe practices. During the latter portion of the data collection effort, the Civil Aerospace Medical Institute (CAMI) Institutional Review Board (IRB) approved limited in-person data collection. In-person participants had to affirm that they had received a second dose of the COVID-19 vaccination more than two weeks prior to the experiment session. Researchers similarly provided evidence of vaccination with at least a two-week period between proctoring and the last vaccine dose. Furthermore, participants and researchers alike were required to wear masks and maintain social distance. After each participant completed the experiment, all surfaces were disinfected and time was allotted between participants for clean air exchange to take place in the room. In-person participants completed the study in the same manner as those participating remotely. There were no reports of COVID-19 infection among participants or researchers associated with the in-person data collection effort.

Participants

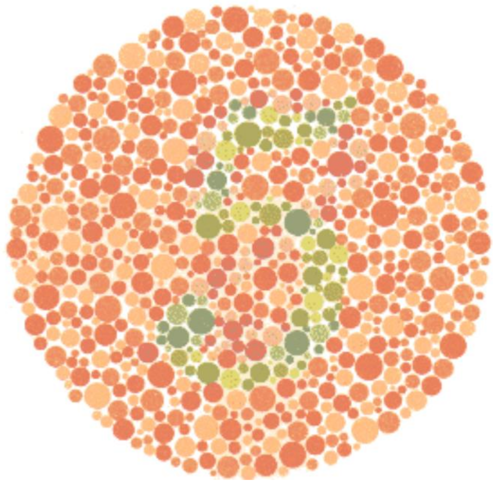
Initially, participants were contacted and invited to participate in the study through the Federal Aviation Administration (FAA) internal email system, recruiting Federal employees within the Mike Monroney Aeronautical Center (MMAC), located in Oklahoma City, OK. Because of the nature of the study, it was determined that the diverse Federal employee sample pool at MMAC would not differ from the general aviation population in terms of visual acuity and color vision traits, as well as the ability to detect and respond to visual stimuli. An initial email invitation provided information and requirements to participants in the study (*see* **Error! Reference source not found.**). If the participant met these requirements and was interested in participating, they would complete the pre-study survey including demographic questions via a link enclosed in the invitation email (*see* **Error! Reference source not found.**). All federally employed participants participated in the study outside of normal duty hours and were compensated $50 for their time.

Before beginning the actual experiment, each participant was tested for normal visual acuity and normal color vision. A modified Snellen Chart was used to ensure participants had normal or corrected-to-normal visual acuity. The modified Snellen Chart presented a single letter at a time at a size of 5 arcminutes for 20/20 vision, accounting for a viewing distance of 22-inches. The reduction in letter size as a function of viewing distance can be described by Equation 1 (Howett, 1983). Passing criterion for the vision test was set at 50% correct responses.

$$W = 2d \tan\frac{\theta}{2} \qquad (1)$$

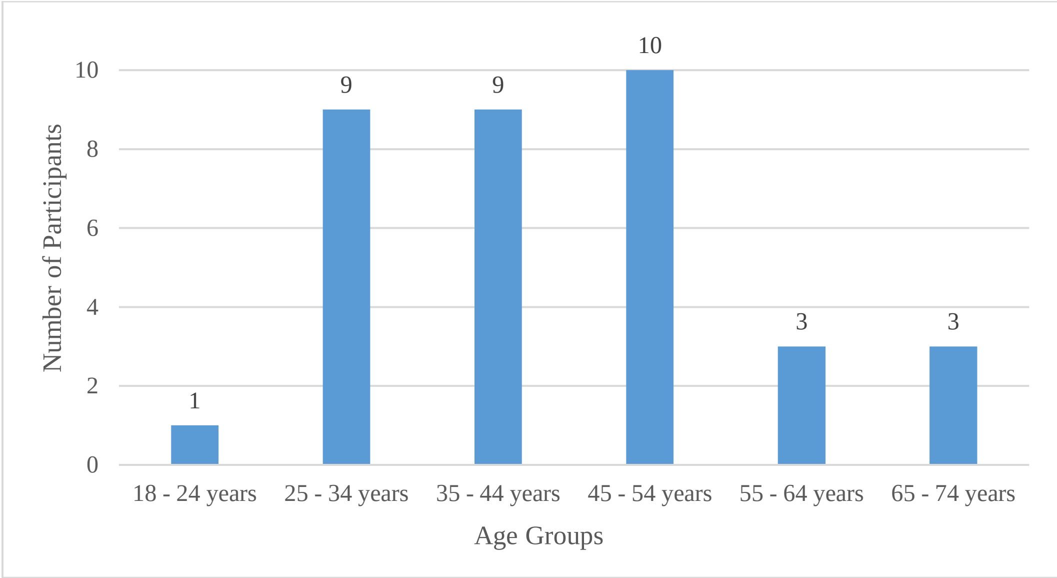
W = required height/width of the letter presented
Θ = angle subtended by the letter (Snellen specified 5 arcminutes for 20/20 vision)
d = distance from viewer's eye to the chart
Normal color vision was tested using a modified Ishihara Test (see Figure 1for an example tile from the Ishihara color vision test). Participants were required to correctly identify 80% of the tiles to pass the test.

Figure 1. *Example Palette from the Ishihara color vision test presented to participants at the beginning of the study session.*



In total, 40 participants were recruited for the study. Of these, two participants did not pass the color vision test; two were excluded for missing a significant portion of the trials at the beginning of the study (> 8% of trials); and one was excluded for completing the experiment on a different size screen (14-inch screen size) than the rest of the participants (15.5 inch screen size). After these exclusions, the final sample size was 35 participants (18 males, 51.5%; 17 females, 48.5%). Age ranges for the participants appear in Figure 2. Four participants indicated having a pilot certificate; three held private pilot certificates, one of which was instrument rated. An additional participant held a commercial certificate with an instrument rating.

Figure 2. *Number of participants per age group.*



Testing Apparatus

The research team developed the stimulus presentation and data recording program using the Python (v 3.8.3) programming language. An online survey tool was used to gather demographic data. All participants completed the study using an FAA-provided Dell laptop with a 15.5-inch screen with a resolution of 1920 x 1080 with no external monitors attached. As an added check, a program function captured screen size and resolution. Screen brightness was set to the maximum level by the testing application and participants were asked to perform the study in a quiet room with low ambient lighting and with either no or well-covered windows. Participants were asked to ensure the laptop monitor was at eye-level and at a distance of 22-inches.

Experimental Design

The experimental design included five independent variables (IVs). The first IV, Stimulus Color, consisted of five single colors (Red, Green, Blue, Pure White, and Off White) and two rotating 3-color combinations (Red, Blue, Pure White [RBPW] and Red, Blue, Off White [RBOW]). Locations of each of the single colors are shown on the Commission Internationale de l'Eclairage (CIE) chromaticity diagram (see Figure 3). Table 1 displays the Red, Green, and Blue (RGB) values used programmatically for each of the single stimulus colors.

Figure 3. *CIE chromaticity diagram of colors used as stimuli.*

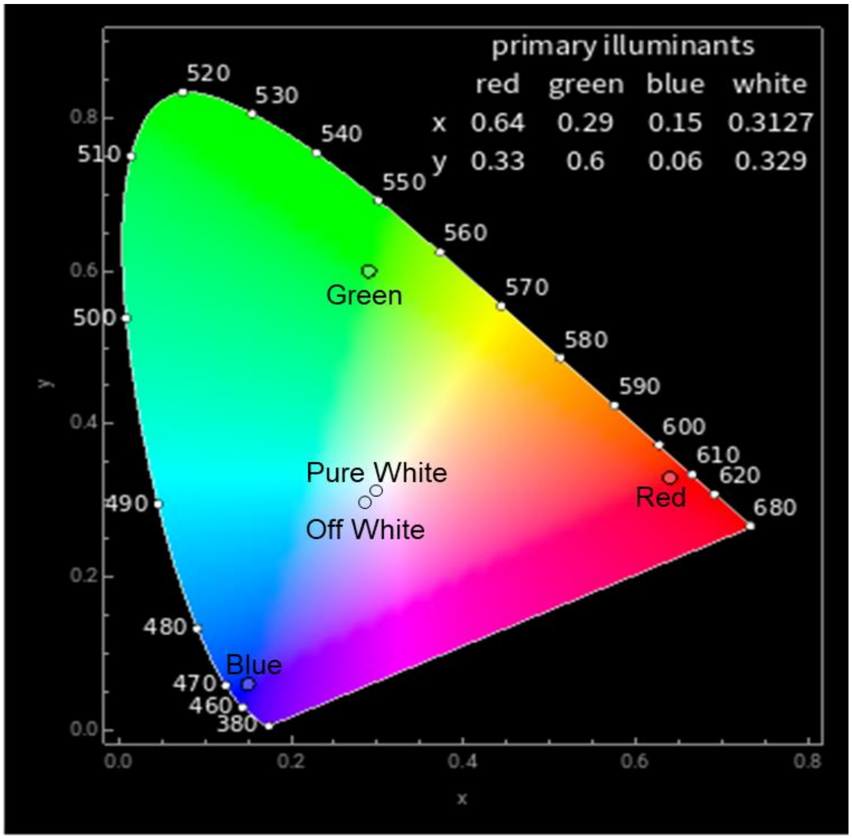


Table 1. *RGB codes of colors used as stimuli.*

Stimulus Color	Red Value	Green Value	Blue Value	Presented Color
Red	255	0	0	
Green	0	255	0	
Blue	0	0	255	
White	255	255	255	
Off-white	180	186	217	

The second IV manipulated in the experiment was the Flash Rate of each stimulus. For single color stimuli, there were 3 levels of Flash Rate, 0 Hertz (Hz) (steady light), 2 Hz, and 4 Hz. There could be no 0 Hz condition for the rotating lights, so for those stimuli, there were only the 2 Hz and 4 Hz conditions. Combining the Stimulus Color and Flash Rate conditions together resulted in 19 individual combinations that were tested in the study as follows.

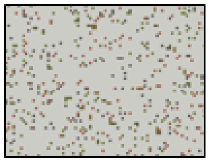
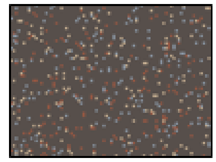
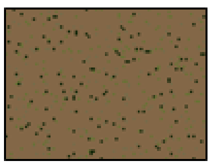
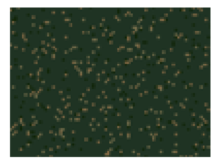
- 5 Single color (Red, Green, Blue, Pure White, Off White) – 0 Hz
- 5 Single color (Red, Green, Blue, Pure White, Off White) – 2 Hz
- 5 Single color (Red, Green, Blue, Pure White, Off White) – 4 Hz
- 1 Rotating Multi-color (Red, Blue, Pure White) 2 Hz
- 1 Rotating Multi-color (Red, Blue, Pure White) 4 Hz

- 1 Rotating Multi-color (Red, Blue, Off White) 2 Hz
- 1 Rotating Multi-color (Red, Blue, Off White) 4 Hz

The third IV was Relative Movement of the stimulus to the observer. There were two levels of relative movement, horizontally across the screen either left to right or right to left or directly toward the observer (i.e., at a stationary point on the screen but growing larger over time). Based on an eye distance of 22 inches from the screen and with an assumption of a diffused lighting size of 6 x 6 inches in the real world, the 6 x 6 pixel stimuli represented a simulated distance of 250 feet from the observer; moving 1 pixel horizontally per approximately 3.6 milliseconds was equivalent to a relative speed of 15 mph. In the condition where movement was toward the observer, the stimuli were presented at a size of 5 x 5 pixels, representing a simulated distance of 312 feet. The stimuli increased by one pixel every two seconds (i.e., 6 x 6 pixels after 2 seconds of presentation). The stimulus size shown after 4 seconds of onset was 7 x 7 pixels, simulating a distance of 223 feet. The simulated average approaching speed toward the observer was approximately 15 mph, ranging between 13 and 17 mph.

The fourth and fifth IVs were both manipulations of the background against which stimuli were presented. The fourth IV was Time-of-day (Day or Night) and the fifth IV was Environment (Urban, Rural, or Sky). The combination of these variables required the development of 6 different backgrounds. To simulate Rural and Urban environments, we used abstracted imagery that consisted of a primary background color with 10% randomly generated color squares representing objects typically present in each environment (e.g., concrete and brick colors for Urban; soil and foliage colors for Rural). Figure 4shows examples of the backgrounds t used, along with RGB codes of the various colors included in each of the backgrounds. Given 19 different stimuli combinations, 2 types of relative movement, and 6 background combinations, 228 trials were constructed for the study.

Figure 4. *Backgrounds used in the study, including RGB codes for specific color features.*

Day Conditions	Night Conditions
Urban Environment  Concrete in sunlight (204, 204, 199) background with 10% of clutter including Red brick 1 (151, 87, 66) Brown shingle (87, 79, 75) Green foliage 1 (102, 114, 52)	Urban Environment  Brown shingles (87, 79, 75) background with 10% of clutter including Red brick 1 (151, 87, 66) White metal building (in Shadow) (139, 152, 166) Concrete (In Shadow) (199, 176, 146)
Rural Environment  Dark soil (131, 103, 71) background with 10% of clutter including Light soil (104, 113, 56) Green foliage (102, 114, 52) Green foliage (heavy shadow) (16, 36, 7)	Rural Environment  Green foliage (in shadow) (31, 51, 35) background with 10% of clutter including Green foliage (heavy shadow) (16, 36, 7) Brown foliage 1 (129, 104, 68) Light soil 1 (116, 108, 74)
Sky Environment  Clear day sky (61, 120, 197) background without clutter	Sky Environment  Clear night Sky (0, 0, 0) background without clutter

Procedure

After participants consented to participate in the experiment, they typed their unique participant identification number into the program prompt box, received via email (*see* **Error! Reference source not found.**).

After the vision tests, 228 experimental trials were presented in a randomized order (broken into 6 sessions of 38 trials each) to allow for breaks between each session. Each trial began when the participant pressed the space bar on the keyboard. The background scene appeared first, followed by the appearance of the stimulus, which randomly appeared two to four seconds afterwards. The background scene remained on the screen for 6 seconds. Participants were instructed to locate the stimulus on the screen and press the space bar as soon as they detected it. After pressing the space bar, the background scene and stimulus disappeared and was replaced by a 3 x 3 grid. Using the mouse, the participant selected the location where they believed the light was located. The screen cleared and a message appeared instructing the participant to be ready to begin the next trial. The participants did not receive any feedback regarding success or failure at locating the stimulus. Completion time varied between participants, but the estimated completion time was approximately 45 minutes.

After completing the experimental trials, the participant uploaded their data to a survey tool and provided information for compensation in a separate website. All data was sent to an email of the 3rd party contractor, Cherokee Nation 3-S. No personal identifying information other than email address was included in the data file Performance data was coded by the participant's ID number.

Results

Analysis Methodology

Two primary dependent variables (DVs), Detection Rate and Response Time, were collected for the study. To conduct the analyses, it was necessary to separate the complete dataset into two parts. Dataset 1 consisted of trials where only single colored stimuli were used, with all flash rates included (0 Hz, 2 Hz, 4 Hz), but did not contain the multicolor stimuli which did not have a 0 Hz level. Because the multicolor stimuli (e.g., RBOW and RBPW) required a flash rate, Dataset 2 consisted only of trials with a flash rate of 2 or 4 Hz and excluded those without a steady light (0 Hz) condition. Note that Datasets 1 and 2 consisted of partially overlapping stimuli which influenced the selection of statistical procedures as explained below.

Detection Rate

Detection Rate was classified into three categories associated with the type of response the participant provided; Hit, False Alarm, or Miss. The response was considered a Hit if the participant responded to the stimulus within the allotted six second time window and correctly identified the box the stimulus appeared (in the 3x3 matrix presented after participant indicated detection). To control for minor errors in locating the stimulus, if a wrong box was selected, but the stimulus was within 10% of the dividing line on the x-axis (64 pixels) or 5% of the y-axis (18 pixels) of the selected box, it was also scored as a Hit. A response was identified as a False Alarm if the participant responded before the light stimulus was presented, incorrectly identified the box where the stimulus appeared, or the box was not within defined criteria (i.e., 10% on the x-axis and 5% on the y-axis). If the participant did not respond within the six second allotted timeframe, the response was considered a Miss. Only Hits were included in the analyses of detection rate. Across all variables, the overall detection rate was 88.8%.

A chi-square analysis was performed on the Detection Rate count data. For pairwise comparison between each level of IVs, a Bonferroni correction was applied.

Response Time Analysis

The analyses of Response Time data only included Hit responses. Generally speaking, a one-way Analysis of Variance (ANOVA) is considered robust to violations of homogeneity of variance and normality assumptions (Lix et al., 1996; Mena et al., 2017; Pearson, 1931). However, other researchers have argued that error rates of two or higher order ANOVAs are sensitive to unequal variance, even more so when a non-normal distribution is present (Erceg-Hurn & Mirosevich, 2008; Harwell et al., 1992). For such instances, nonparametric analysis or data transformation techniques commonly are used to address violations of parametric assumptions. However, such methods have limitations when analyzing continuous variables with interactions. For example, Kruskal-Wallis tests require the distributions to be the same across all cells in the analysis, and rank transformations are not robust enough for factorial designs (Judd et al., 1995)

Non-normal and heterogeneous conditions often are produced with response time data. Thus, a Generalized Linear Mixed Model (GLMM) analysis of repeated measurements was performed to provide a more robust method to extrapolate results. The GLMM models for Dataset 1 and 2 applied the data to a normal distribution using an identity link function with a square root application based on the premise of identifying the lowest Akaike Information Criterion (AIC) values of 4,601.583 (Dataset 1) and 4,177.640 (Dataset 2) (Dunn & Smyth, 2005; Iyit, 2018; Temple, 2018). For ease of interpretation, all figures are graphed with estimated averaged raw scores.

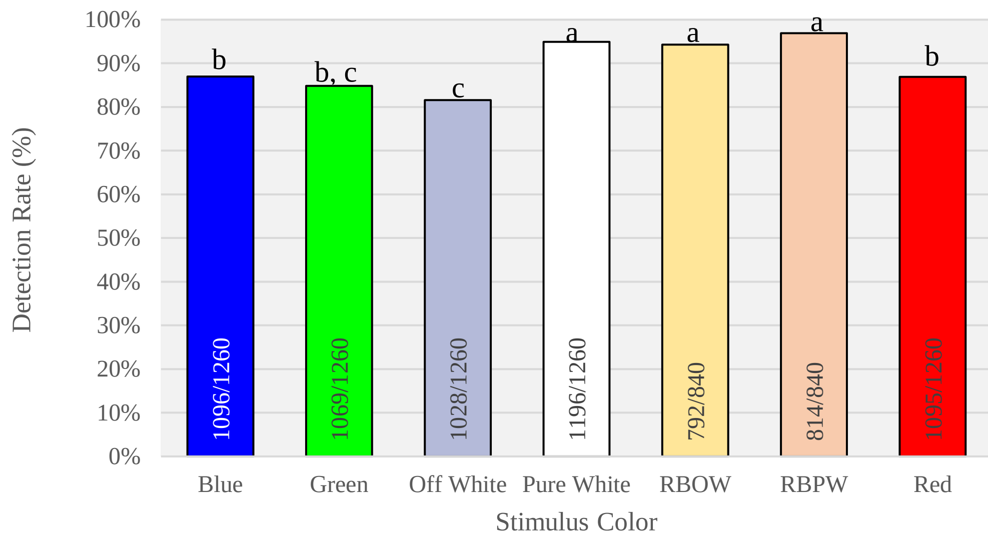
The following results are ordered by the research questions that were listed in the introduction. All analyses are presented in terms of one or more research questions.

Research Question 1

- Which lights are most effective in both Day and Night conditions, all Flash Rates, and across a variety of background types?

A chi-square analysis showed that detection rates between stimulus colors were significantly different (X^2 (6, N = 7980) = 223.651, p < 0.0001). Post hoc analysis of a chi-squared test with Bonferroni correction showed that participants had significantly higher detection rates for Pure White, RBOW, and RBPW than the other colors. Figure 5 provides the Hit rate by color across all environments and Time-of-day conditions for ease of understanding regardless of the different number of trials across colors. The numbers in each bar indicate the percentage of Hit responses within the total number of trials, while a letter on the top of each bar shows which colors have similar detection rates and which have significantly different detection rates.

Figure 5. *Detection rate for each Stimulus Color across all other Factors.*



For the Dataset 1 response time analysis, Pure White elicited the quickest response time from participants across all conditions (M = 0.961, SE = 0.010), followed by Green (M =1.041, SE = 0.012), Off White (M = 1.060, SE = 0.013), Blue (M = 1.211, SE = 0.011), and lastly Red (M = 1.299, SE = 0.011) (see Figure 6). A pairwise comparison revealed that the estimated response time with Pure White color was significantly shorter than all other colors ($p < 0.0001$ for all comparisons). Pairwise comparisons and their associated p values are located in Table 2.

Figure 6. *Average of estimated response time for each stimulus color in Dataset 1 across all Environments, Flash Rates, and Time-of-day.*

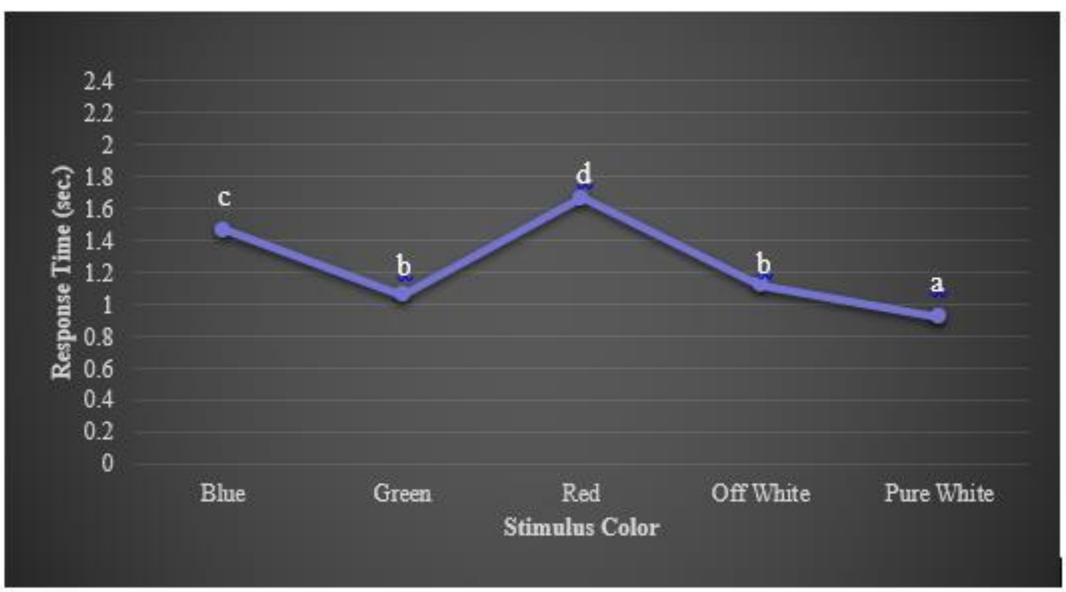


Table 2. *Estimated response time pairwise comparisons for Stimulus Colors included in Dataset 1.*

Stimulus Color Comparisons	Contrast Estimate	Adjusted *p*-value
Pure White – Blue	-0.251	$p < 0.0001$
Pure White – Green	-0.080	$p < 0.0001$
Pure White – Red	-0.338	$p < 0.0001$
Pure White – Off White	-0.100	$p < 0.0001$
Green – Blue	-0.171	$p < 0.0001$
Green – Red	-0.258	$p < 0.0001$
Green – Off White	-0.020	$p = 0.242$
Off White – Blue	-0.151	$p < 0.0001$
Off White – Red	-0.238	$p < 0.0001$
Blue – Red	-0.087	$p < 0.0001$

Similar findings were identified in the Dataset 2 analyses. Pure White also elicited the quickest response ($M = 0.961$, $SE = 0.015$), followed by Green ($M = 1.011$, $SE = 0.014$), and Off White ($M = 1.052$, $SE = 0.015$). Pairwise comparisons revealed that the estimated response time of Pure White was significantly quicker than all other colors, followed by Green and Off White. Figure 7 provides the average estimated response time by color in Dataset 2, with Table 3 outlining the comparisons and *p*-values.

Figure 7. *Average of estimated response time for each stimulus color in Dataset 2 across all environments and time-of-day conditions.*

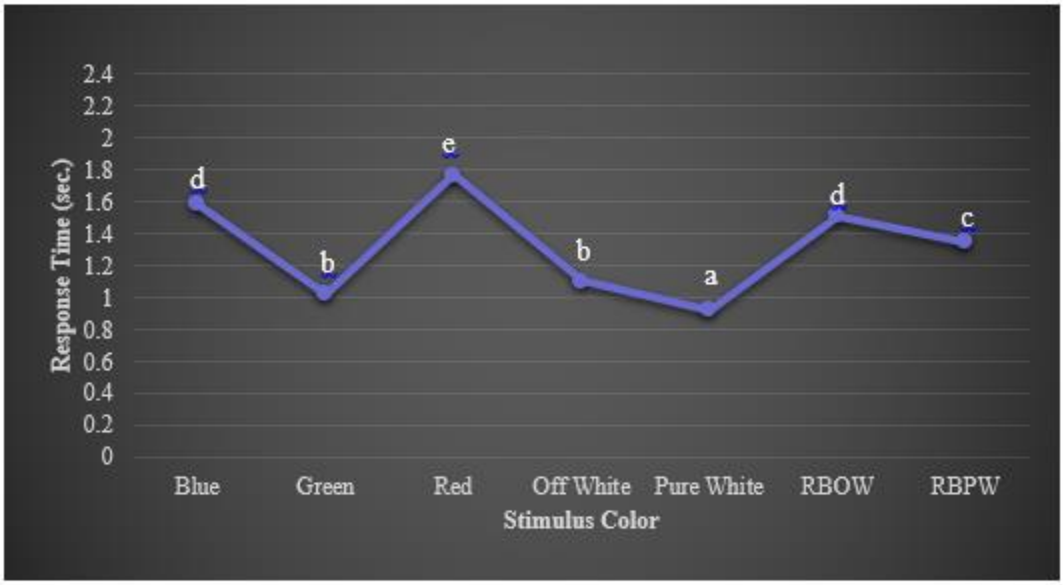


Table 3. *Estimated response time pairwise comparisons for stimulus colors included in Dataset 2.*

Stimulus Color Comparisons	Contrast Estimate	Adjusted *p*-value
Pure White – Blue	-0.300	$p < 0.0001$
Pure White – Green	-0.050	$p = 0.024$
Pure White – Red	-0.366	$p < 0.0001$
Pure White – Off White	-0.091	$p < 0.0001$
Pure White – RBOW	-0.270	$p < 0.0001$
Pure White – RBPW	-0.199	$p < 0.0001$
Green – Blue	-0.250	$p < 0.0001$
Green – Red	-0.316	$p < 0.0001$
Green – Off White	-0.041	$p = 0.083$
Green – RBOW	-0.220	$p < 0.0001$
Green – RBPW	-0.149	$p < 0.0001$

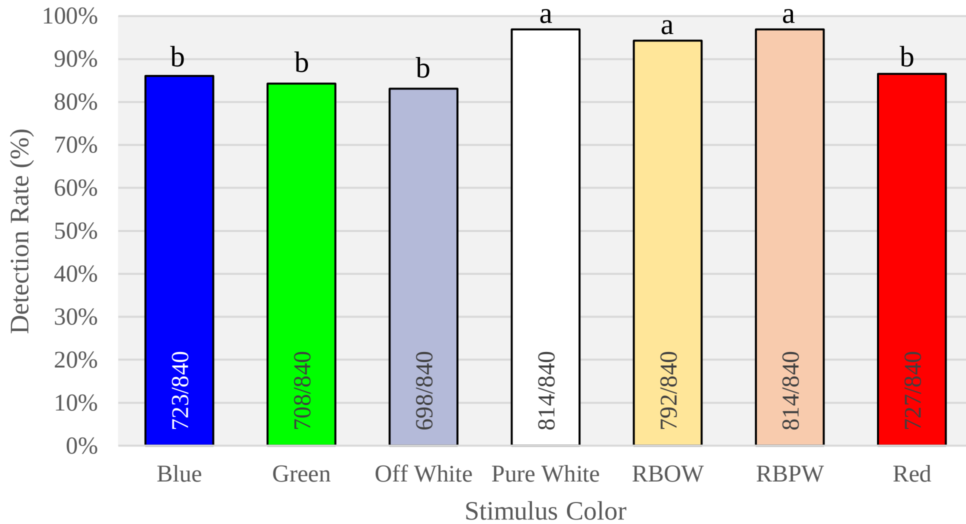
Stimulus Color Comparisons	Contrast Estimate	Adjusted *p*-value
Off White – Blue	-0.209	$p < 0.0001$
Off White – Red	-0.275	$p < 0.0001$
Off White – RBOW	-0.179	$p < 0.0001$
Off White – RBPW	-0.108	$p < 0.0001$
Blue – Red	-0.066	$p = 0.001$
Blue – RBOW	0.030	$p = 0.093$
Blue – RBPW	0.101	$p < 0.0001$
RBPW – RBOW	-0.070	$p < 0.0001$

Research Question 2

- Is an alternating color pattern as effective as a single colored light?

The results for this research question only includes Dataset 2 due to exclusion of the 0 Hz Flash Rate. The chi-square analysis results showed that detection rates between stimulus colors were significantly different (X^2 (6, N = 5880) = 201.304, $p < 0.0001$). Post hoc analysis with a Bonferroni correction applied revealed that Pure White, RBOW, and RBPW have significantly higher detection rates than Green, Off White, Blue, and Red (See Figure 8).

Figure 8. *Detection rate for each stimulus color included in Dataset 2.*



When comparing response times for single and multicolor stimuli , Pure White (*M* = 0.961, *SE* = 0.012, all *p* values < 0.0001); Green (*M* = 1.011, *SE* =0.014, all *p* values < 0.0001); and Off White (*M* = 1.052, *SE* = 0.015, all *p* values < 0.0001) prompted faster estimated response times than the multicolor stimuli of RBPW (*M* =1.160, *SE* =0.012) and RBOW (*M* =1.231, *SE* =0.012) (see Figure 7).

Research Question 3

- Which alternating color pattern is the most effective?

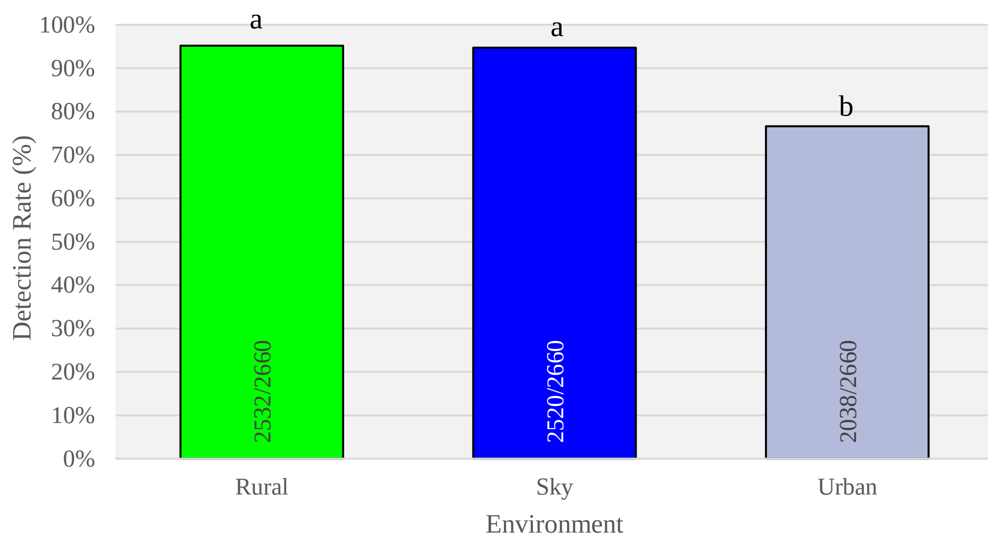
No significant difference existed between detection rates of RBOW and RBPW ($p > 0.05$) (Figure 8). Conversely, RBPW (*M* =1.160, *SE* =0.012) did provoke a significantly faster estimated response time ($p < 0.0001$) than the RBOW stimulus (*M* =1.231, *SE* =0.012) (Figure 7).

Research Question 4

- Under which environment condition(s) are stimuli easiest to locate?

According to the chi-square analysis with detection rate, participants correctly located stimuli significantly differently across environments (X^2 (2, N = 7980) = 602.606, $p < 0.0001$). This analysis included all stimulus colors and flash rates (Datasets 1 and 2). Post hoc analysis results revealed that the detection rates in the Rural and Sky environments were significantly higher than the Urban environment (see Figure 9).

Figure 9. *Detection rate for each environment.*

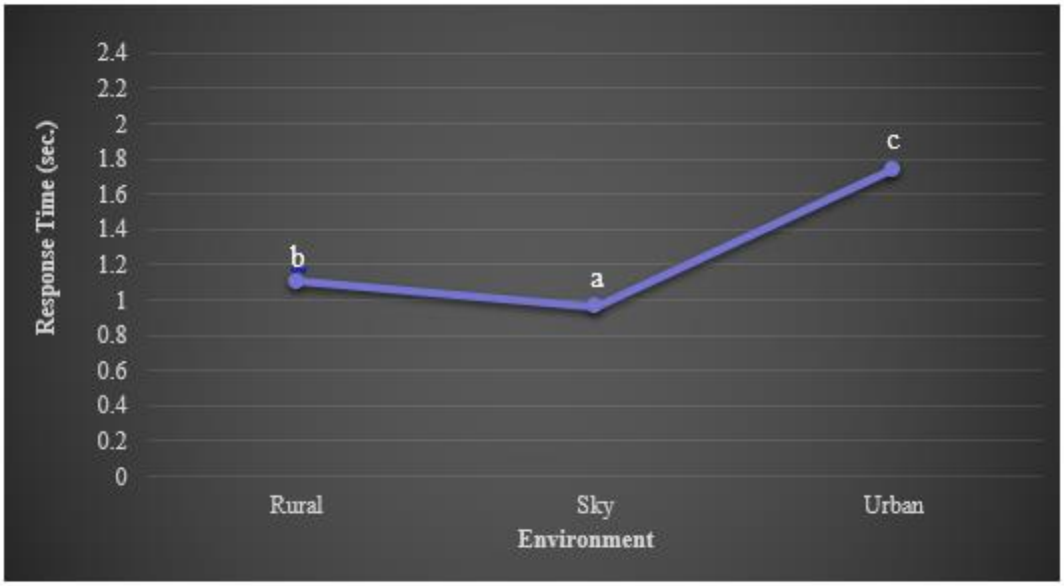


Estimated response time analysis of Dataset 1 (no multicolor lights) showed that stimuli in the Sky environment (*M* = 0.978, *SE* = 0.008) were detected the fastest; followed by Rural (*M* = 1.046, *SE* = 0.008), and Urban (*M* = 1.32, *SE* = 0.008), Table 4 provides pairwise comparison results and their associated *p*-values for each environment type. The average estimated response time is depicted in Figure 10.

Table 4. *Response time pairwise comparisons for environments included in Dataset 1.*

Environment Comparisons	Contrast Estimate	Adjusted p-value
Sky – Rural	-0.068	$p < 0.0001$
Sky – Urban	-0.343	$p < 0.0001$
Rural – Urban	-0.274	$p < 0.0001$

Figure 10. *Average of estimated response time for each environment included in Dataset 1.*

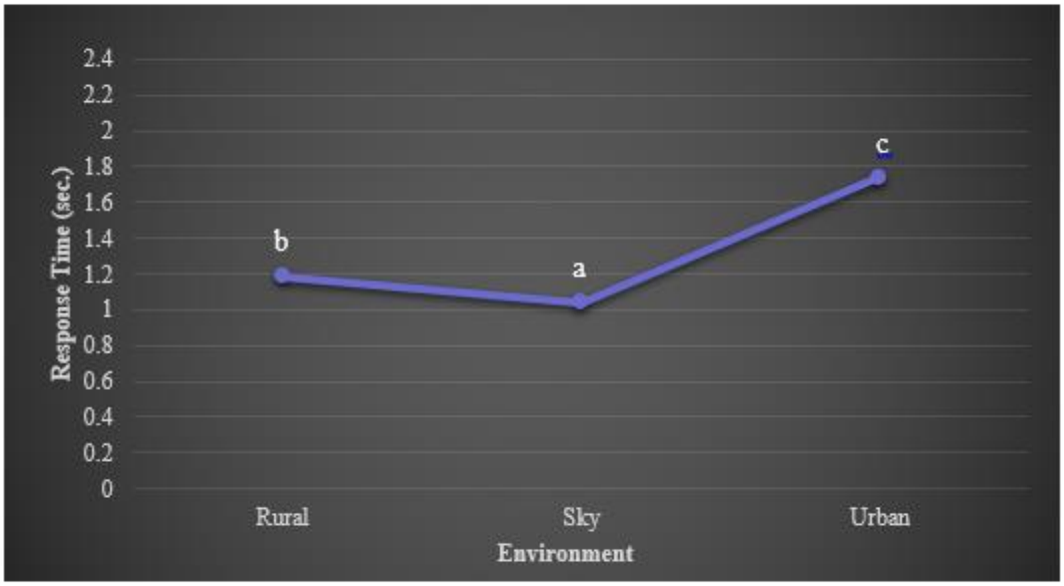


Similar patterns emerged for Dataset 2. Stimuli in the Sky environment (*M* = 1.020, *SE* = 0.008) were detected the fastest; followed by Rural (*M* = 1.091, *SE* = 0.008), and Urban (*M* = 1.319, *SE* = 0.010). Table 5provides results of pairwise comparisons and their associated *p*-values for each environmental background. The average estimated response time for each environment is depicted in Figure 11.

Table 5. *Estimated response time pairwise comparisons for environments included in Dataset 2.*

Environment Comparisons	Contrast Estimate	Adjusted *p*-value
Sky – Rural	-0.072	$p < 0.0001$
Sky – Urban	-0.299	$p < 0.0001$
Rural – Urban	-0.228	$p < 0.0001$

Figure 11. *Average of estimated response time for each environment included in Dataset 2.*

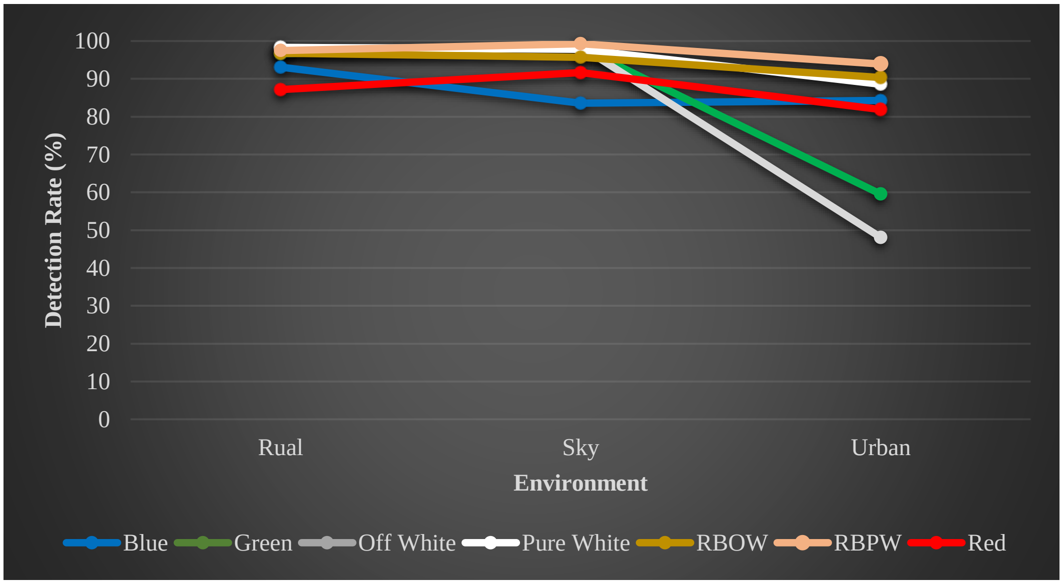


Research Question 5

- What colors are most effective for each environment?

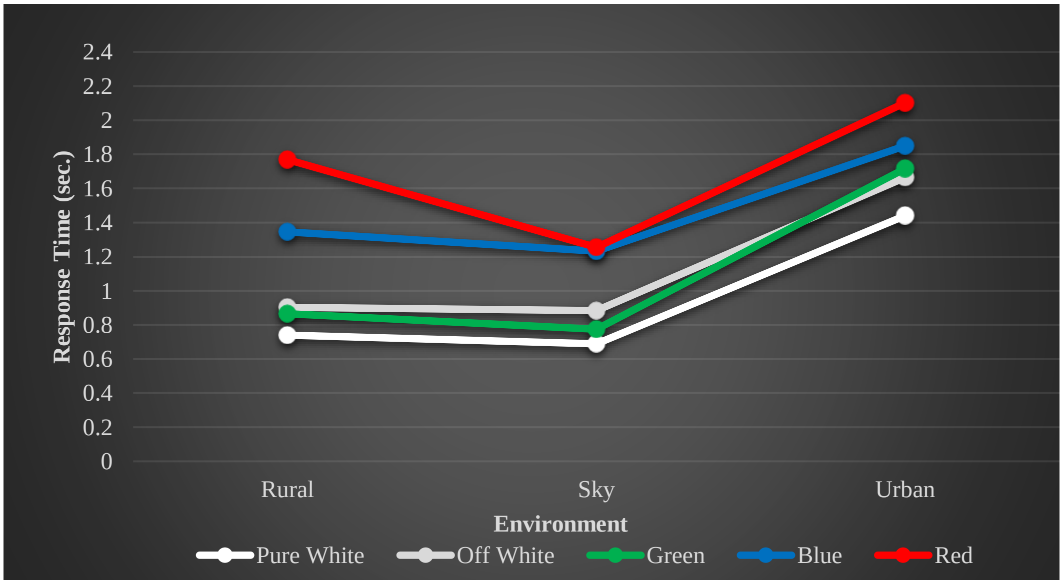
A chi-square analysis revealed that detection rates between stimulus colors were significantly different for Sky and Urban environments, but not the Rural environment. Pure White, RBPW, and RBOW provided the highest detection rate regardless of environment as (see Figure 12).

Figure 12. *Detection rate by stimulus color and environment.*



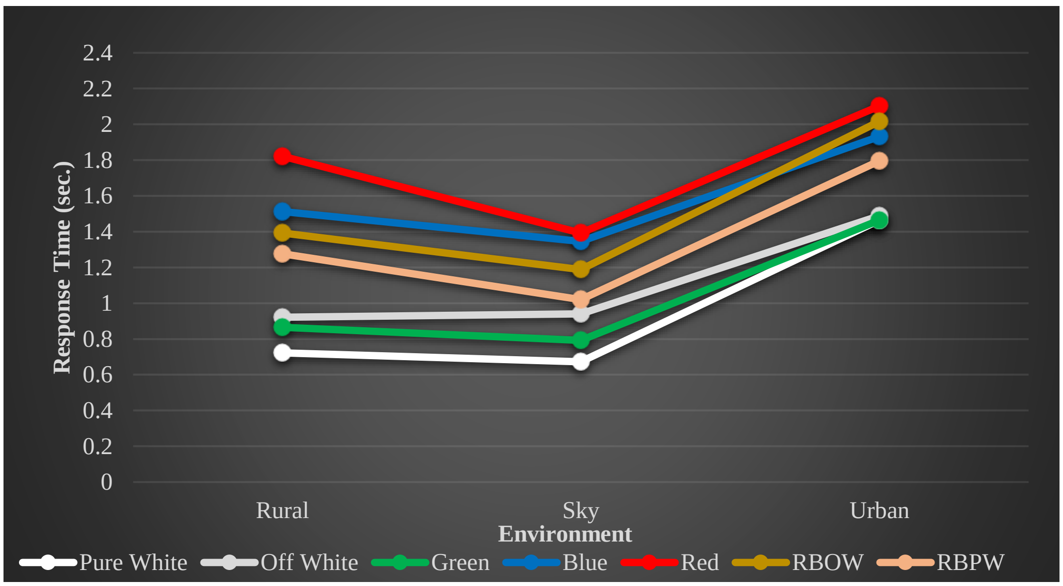
For Dataset 1, Pure White elicited the quickest estimated response time within each environment (M_{rural} = 0.855, *SE* = 0.018; M_{Sky} = 0.827, *SE* = 0.018; M_{Urban} = 1.20, *SE* = 0.019), followed by Green in the Sky and Rural environments (M_{rural} = 0.938, *SE* = 0.018; M_{Sky} = 0.884, *SE* = 0.018) with Off White being second quickest in the urban environment (M_{Urban} = 1.288, *SE* = 0.028) (see Figure 13).

Figure 13. *Average of estimated response time for each stimulus color within environment for Dataset 1.*



Regarding the multicolor lights for Dataset 2 analysis, interestingly, performance of colors we tested was relatively the same across environments. For example, Pure White was responded to the fastest (M_{rural} = 0.852, SE_{rural} = 0.021; M_{Sky} = 0.825, SE_{Sky} = 0.021; M_{Urban} = 1.206, SE_{Urban} = 0.022), followed by Green across all the environments (Figure 14), and Red was consistently the slowest response time (See more patterns or trend of all colors few intersecting lines in the figures.

Figure 14. *Average of estimated response time for each stimulus color within environment for Dataset 2.*

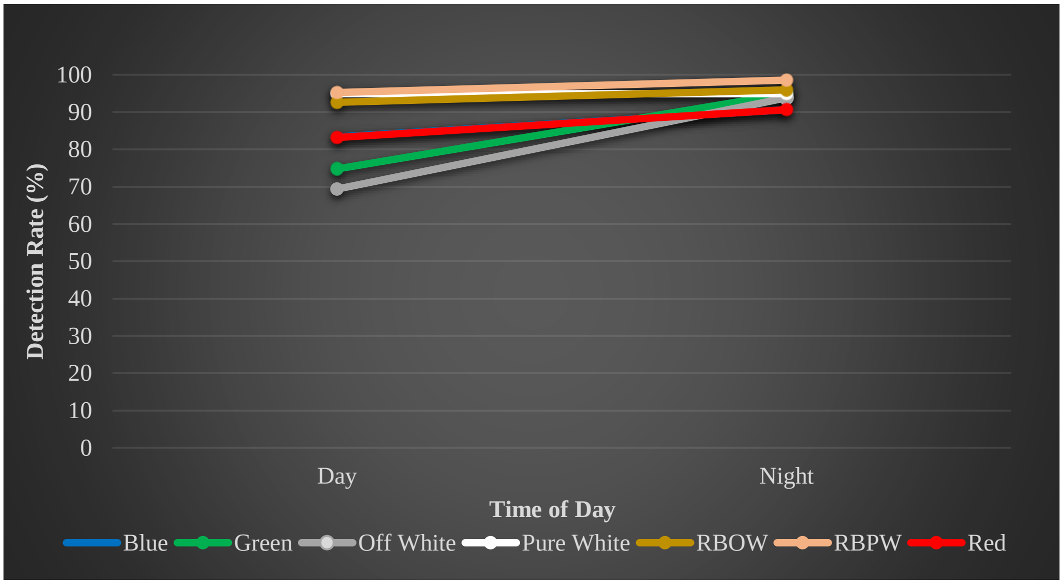


Research Question 6

- Are some colors more effective at night than during the day?

The colors with the highest detection rate are Pure White, RBOW, and RBPW in Day and Night conditions, which are not significantly different from one another but had a significantly higher detection rate than the other colors in both day (X^2 (6, N = 3990) = 256.938, p < 0.0001), and night conditions (X^2 (6, N = 3990) = 44.735, p < 0.0001) (see Figure 15).

Figure 15. *Detection rate by stimulus color within day and night conditions.*

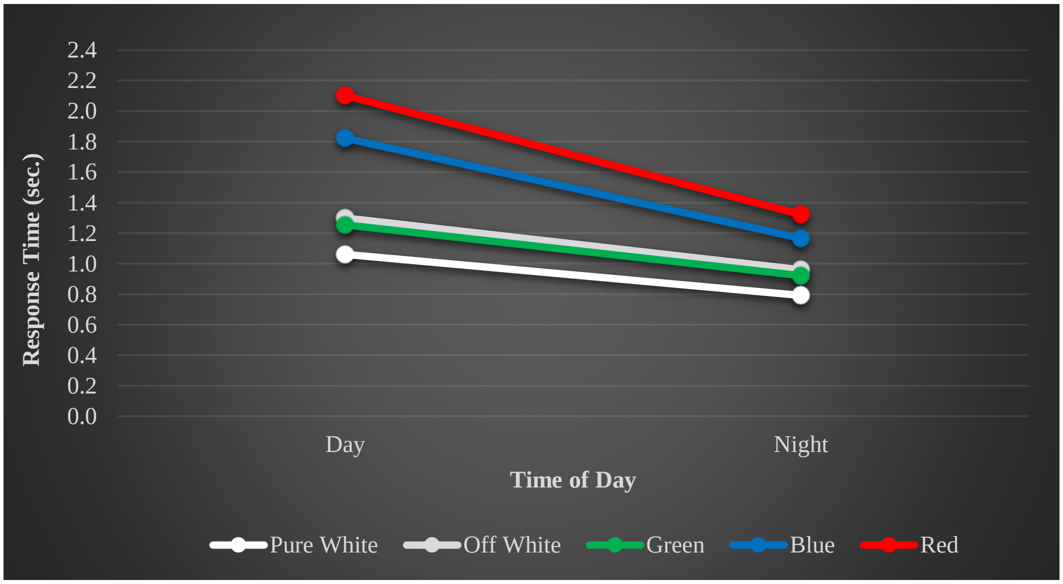


Response time analysis for Dataset 1 revealed all colors provoked faster estimated response times during night conditions vs. day conditions, with no color performing significantly better. A significant interaction was present between Flash Rate and Time-of-day condition in Dataset 1 ($F(2, 5{,}431) = 7.135$, $p = 0.001$). Simple effects are provided in Table 6. Figure 16 depicts the average estimated response time by color within Time-of-day.

Table 6. *Estimated response time pairwise comparisons between day and night conditions for each stimulus color in Dataset 1.*

Stimulus Color	Time-of-day Comparison	Contrast Estimate	Adjusted *p*-value
Blue	Day - Night	0.270	$p < 0.0001$
Green	Day – Night	0.153	$p < 0.0001$
Red	Day – Night	0.303	$p < 0.0001$
Off White	Day – Night	0.164	$p < 0.0001$
Pure White	Day – Night	0.139	$p < 0.0001$

Figure 16. *Average of estimated response time by Stimulus Color within Time-of-day for Dataset 1.*

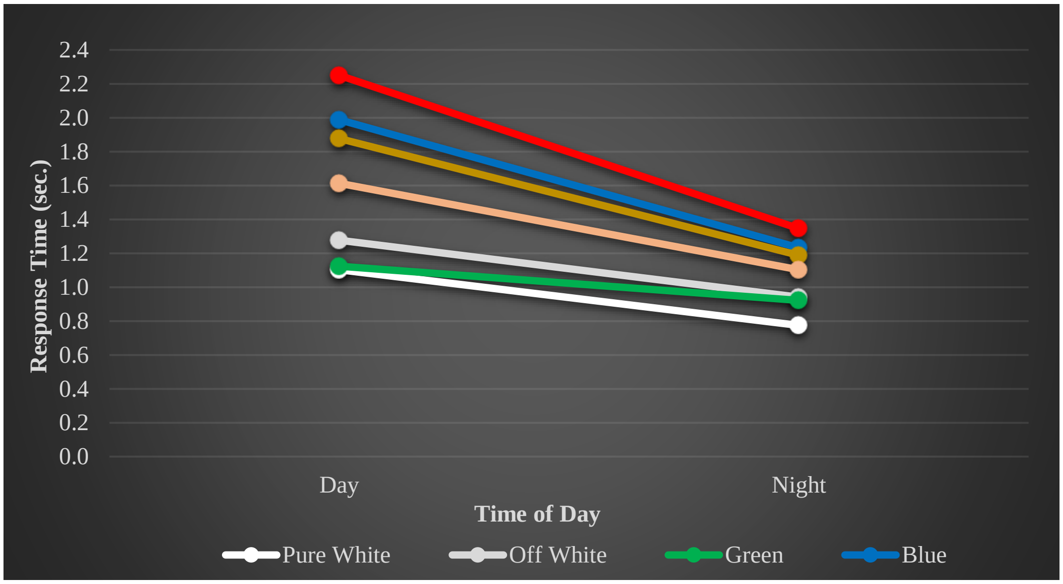


Dataset 2 produced similar results, however, no significant interaction was present. All colors provoked significantly faster estimated response times during night conditions ($F(1, 5{,}220) = 490.693$, $p < 0.0001$). Table 7outlines the comparisons for each color within Time-of-day condition. The average estimated response times are graphed in Figure 17.

Table 7. *Estimated response time pairwise comparison between Day and Night backgrounds for each stimulus color in Dataset 2.*

Stimulus Color	Time-of-day Comparison	Contrast Estimate	Adjusted *p*-value
Blue	Day - Night	0.299	$p < 0.0001$
Green	Day – Night	0.101	$p < 0.0001$
Red	Day – Night	0.337	$p < 0.0001$
Off White	Day – Night	0.162	$p < 0.0001$
Pure White	Day – Night	0.170	$p < 0.0001$
RBOW	Day – Night	0.273	$p < 0.0001$
RBPW	Day – Night	0.215	$p < 0.0001$

Figure 17. *Average of estimated response time by Stimulus Color within Time-of-day for Dataset 2.*

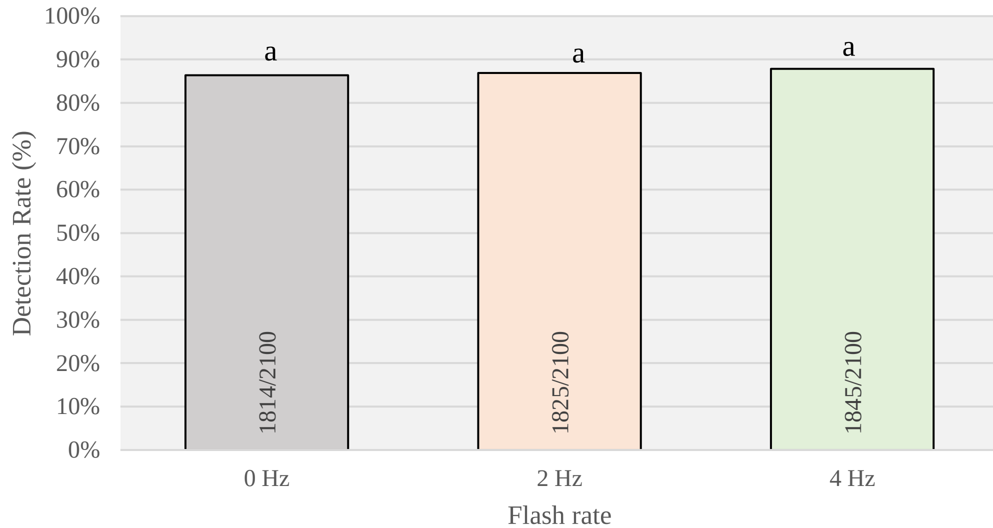


Research Question 7

- Are flashing lights more conspicuous than steady lights

Only Dataset 1 was included in the analysis due to steady lights not being included in Dataset 2. A chi-square analysis revealed that the detection rate did not differ between flash rates (X^2 (2, N = 6300) = 2.086, p = 0.352). Figure 18 provides depicts the detection rate per Flash Rate (0 Hz, 2 Hz, 4 Hz).

Figure 18. *Detection rate across flash rates.*

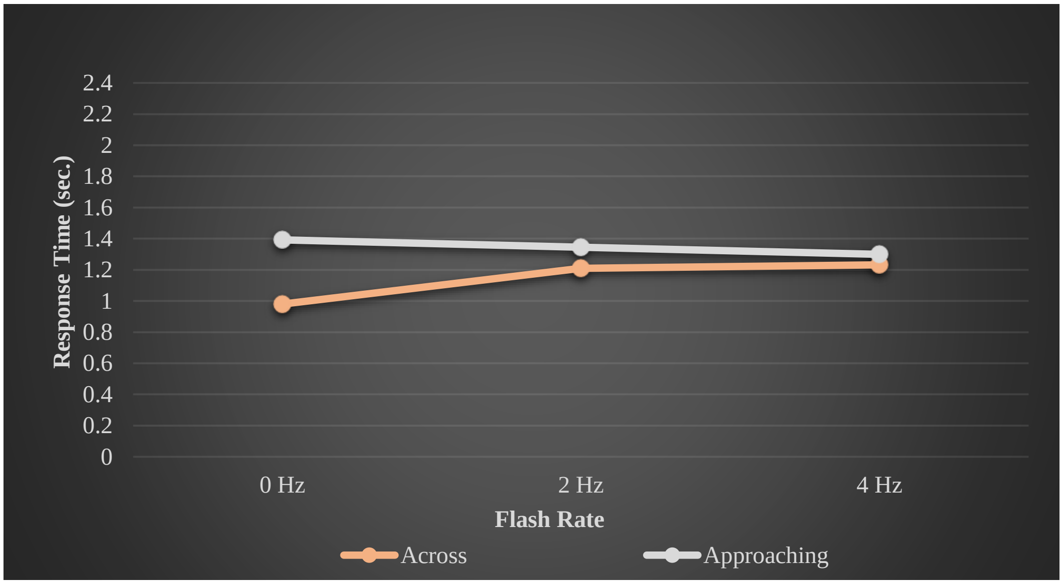


In regard to estimated response time, an interesting result emerges. When the stimulus was approaching the viewer, faster flash rates seemed to decrease the estimated response time; however, the effect was not significant. When the stimulus was moving across the screen, participants responded significantly faster to a steady light than flashing lights; however, increasing the flash rate did not significantly affect estimated response time. A significant interaction was observed between Flash Rate and Relative Movement (F (2, 5,431= 23.183, $p < 0.0001$) (See Table 8 for simple effects). Figure 19 shows the average estimated response time for each flash rate within type of relative movement.

Table 8. *Estimated response time pairwise comparisons for Flash Rate by Relative Movement.*

Relative Movement	Flash Rate Comparison	Contrast Estimate	Adjusted *p*-value
Approaching	0 Hz – 2 Hz	0.018	p = 0.593
	0 Hz – 4 Hz	0.034	p = 0.161
	2 Hz – 4 Hz	0.016	p = 0.593
Across	0 Hz – 2 Hz	-0.111	p < 0.0001
	0 Hz – 4 Hz	-0.118	p < 0.0001
	2 Hz – 4 Hz	-0.007	p = 0. 686

Figure 19. *Average of estimated response time by Flash Rate within Relative Movement.*

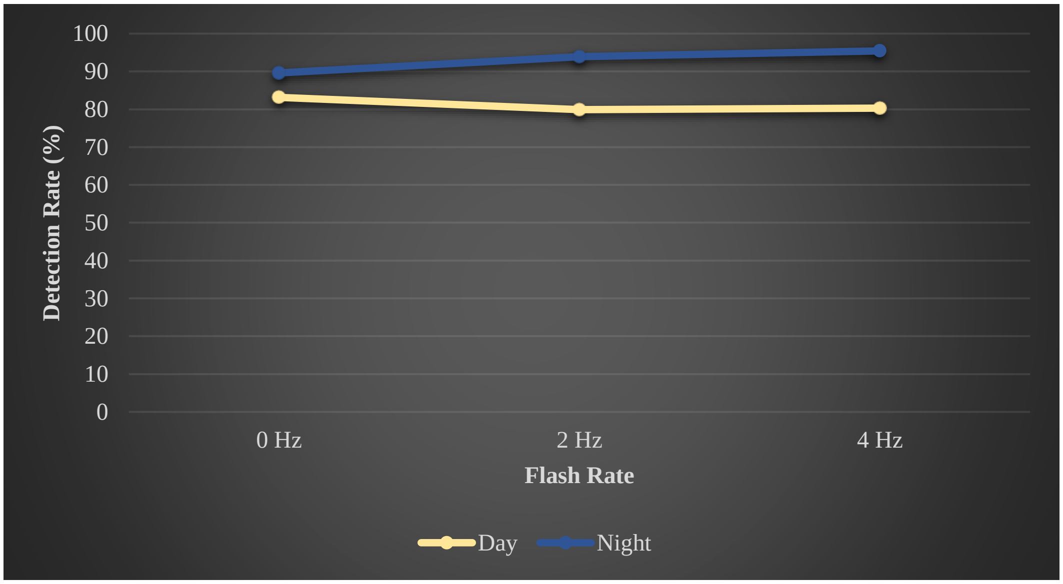


Research Question 8

- Are flashing lights more conspicuous than steady lights during day conditions as opposed to night?

For this research question, only Dataset 1 was included (steady lights were not included in Dataset 2). Flash Rate did not have a significant effect on detection rate during day conditions ((X^2 (2, N = 3150) = 4.293, p = 0.117). Conversely, Flash Rate did have a significant effect on observer detection rate during night conditions ((X^2 (2, N = 3150) = 29.208, p < 0.0001), as the higher Hz flash rates increased detection rate (Figure 20).

Figure 20. *Detection rate by Flash Rate within Time-of-day.*

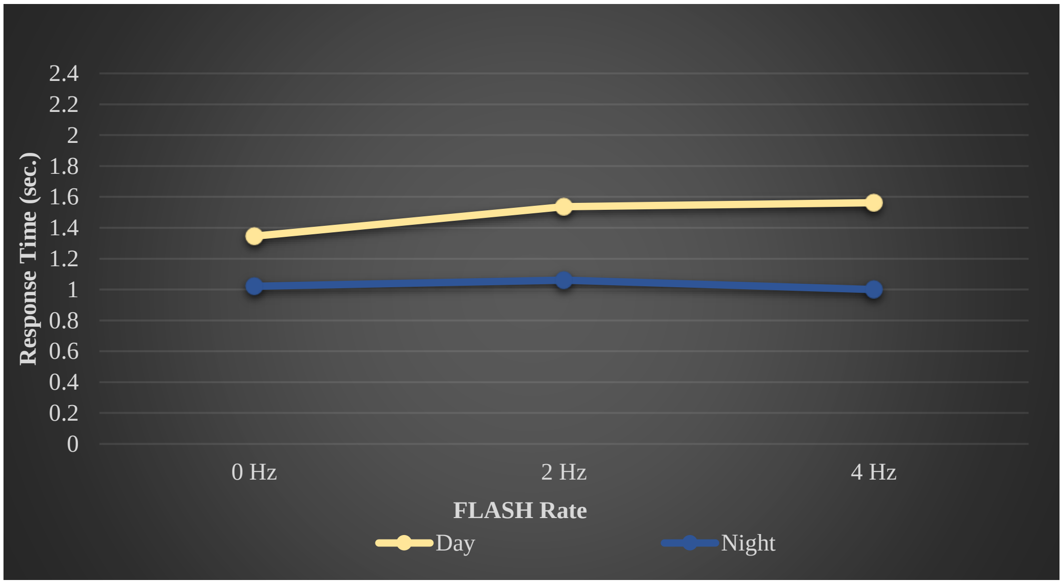


To answer this question, only effects from Dataset 1 are presented due to a significant interaction between Flash Rate and Time-of-day conditions (F (2, 5431= 7.135, $p = 0.001$). Simple effect comparisons within Time-of-day conditions are located in Table 9. Figure 21 shows the average estimated response time within the Time-of-day condition. Flashing lights led to a significantly slower estimated response times when compared to steady lights during Day conditions; however, increasing the flash rate from 2 Hz to 4 Hz did not show significant differences in estimated response times.

Table 9. *Estimated response time pairwise comparisons for Flash Rate by Time-of-day for Dataset 1.*

Time-of-Day Condition	Flash Rate Comparison	Contrast Estimate	Adjusted *p*-value
Day	0 Hz – 2 Hz	-0.071	$p < 0.0001$
	0 Hz – 4 Hz	-0.087	$p < 0.0001$
	2 Hz – 4 Hz	-0.017	$p = 0.352$
Night	0 Hz – 2 Hz	-0.022	$p = 0.363$
	0 Hz – 4 Hz	0.003	$p = 0.845$
	2 Hz – 4 Hz	0.025	$p = 0.354$

Figure 21. *Average of estimated response time by Flash Rate within Time-of-day for Dataset 1.*

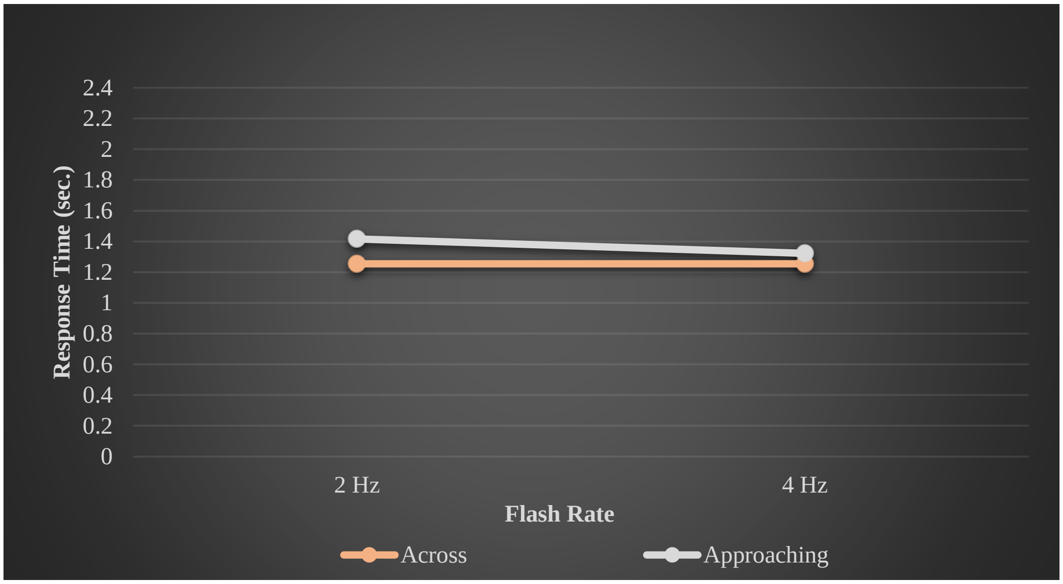


Research Question 9

- Does increasing the Flash Rate lead to an increase in conspicuity?

In terms of detection rate, Flash Rate had no significant effect (X^2 (2, N = 6300) = 2.086, p = 0.352) (See Figure 18). A significant interaction was present between Relative Movement and Flash Rate for Dataset 1 (F (2, 5431= 23.183, p < 0.0001)) (Figure 19) and Dataset 2 (F (1, 5220= 5.345, p = 0.021)) (Figure 22). Table 8 provides the simple effect comparisons of Flash Rate within Relative Movement.

Figure 22. *Average of estimated response time across Flash Rate within Relative Movement included in Dataset 2.*

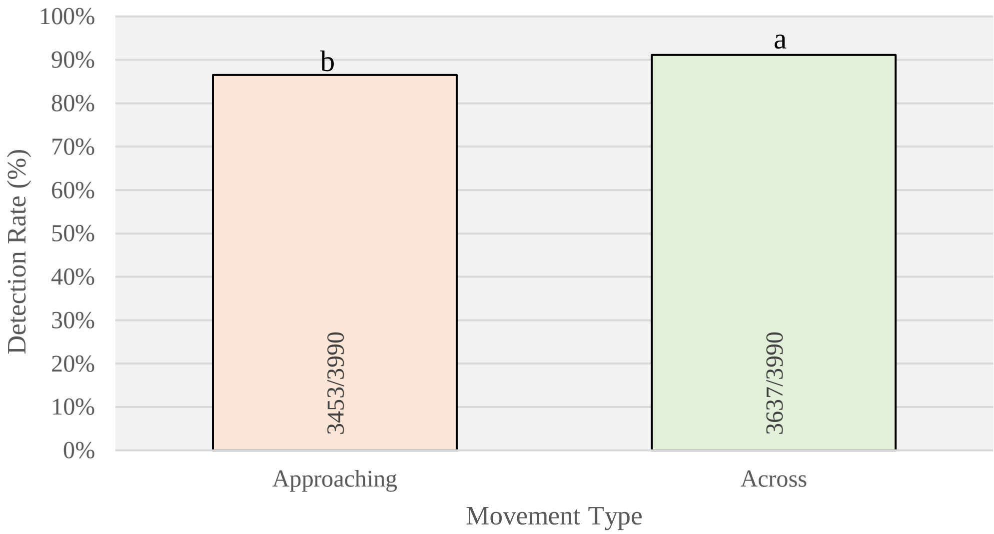


Research Question 10

- Are lights moving across the field of view more easily noticed than lights moving toward the observer?

In terms of detection rate, stimuli moving across the field of view were detected significantly more often (X^2 (1, N = 7980) = 42.816, p < 0.0001) (See Figure 23).

Figure 23. *Detection rate by Relative Movement.*



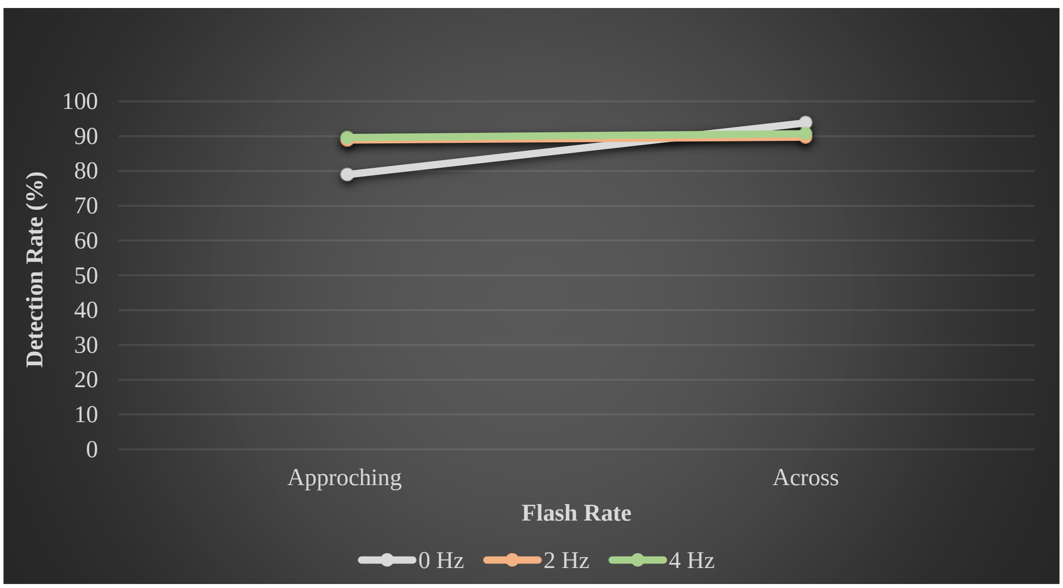
As previously mentioned in Research Question 9, a significant interaction was present between Relative Movement and Flash Rate for Dataset 1 (F (2, 5431= 23.183, $p < 0.0001$)) (Figure 19) and Dataset 2 (F (1, 5220= 5.345, $p = 0.021$)) (Figure 22). Table 8 provides the simple effect comparisons of Flash Rate within Relative Movement.

Research Question 11

- Are flashing lights more effective than steady lights when the stimulus is approaching the observer as opposed to moving across the field of view?

A chi-square analysis was conducted on both datasets and revealed that a flash rate of 2 and 4 Hz had a significantly higher detection rate than 0 Hz when the stimulus is moving towards the observer (X^2 (2, N = 3990) = 70.754, $p < 0.0001$). Conversely, 0 Hz had a significantly better detection rate than 2 and 4 Hz when the stimulus was moving across the screen (X^2 (2, N = 3990) = 13.298, $p = 0.001$) (Figure 24).

Figure 24. *Detection rate by Relative Movement and Flash Rate.*



A significant interaction was present between movement type and Flash Rate for both Dataset 1 (F (2, 5431= 23.183, $p < 0.0001$)) (Figure 19) and Dataset 2 (F (1, 5220= 5.345, p = 0.021)) (Figure 22).

Research Question 12

- Under which background condition(s) are lights easier to locate?

The detection rate analysis included both datasets. Results indicated the Night Sky background was the easiest to detectable stimuli (Figure 25). For response time analysis, in Dataset 1, Night Sky allowed the fastest responses with an average estimated response time of

(M = 0.825, SE = 0.011) followed by the Night Rural background (M = 0.978, SE = 0.011) (Figure 26). Analysis of response time in Dataset 2, stimuli were located the fastest in the Night Sky background (M =0.828, SE =0.011) followed by the Night Rural background (M =1.000, SE =0.011) (Figure 27).

Figure 25. *Detection rate by background.*

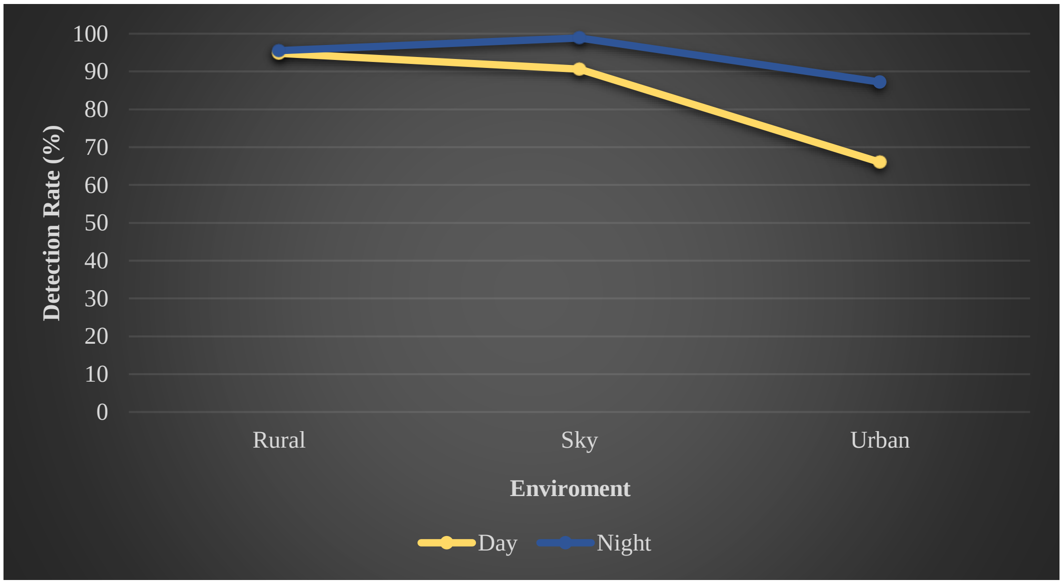


Figure 26. *Response time by background and Time-of-day included in Dataset 1.*

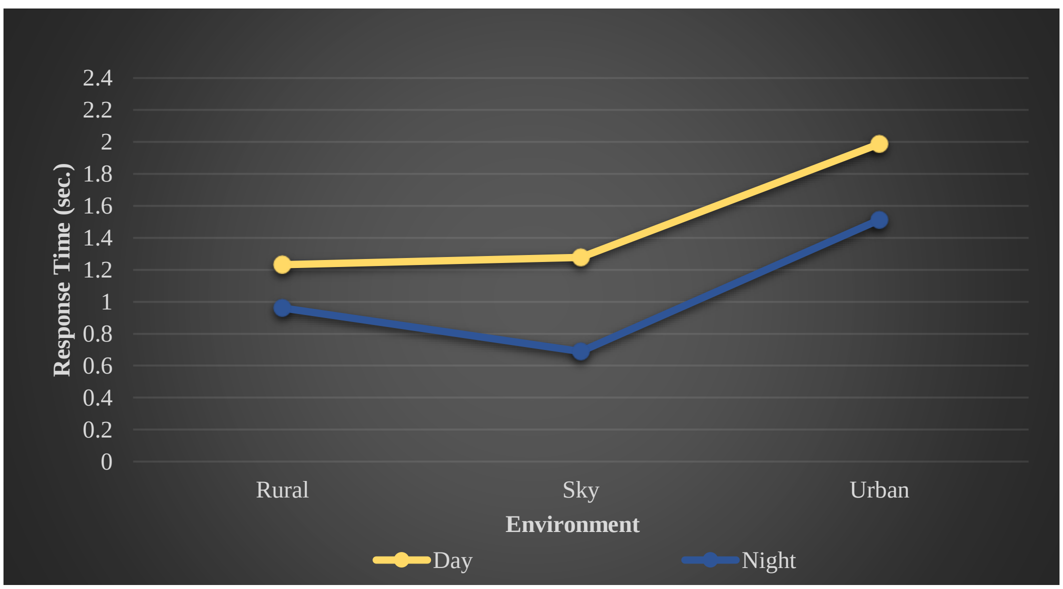
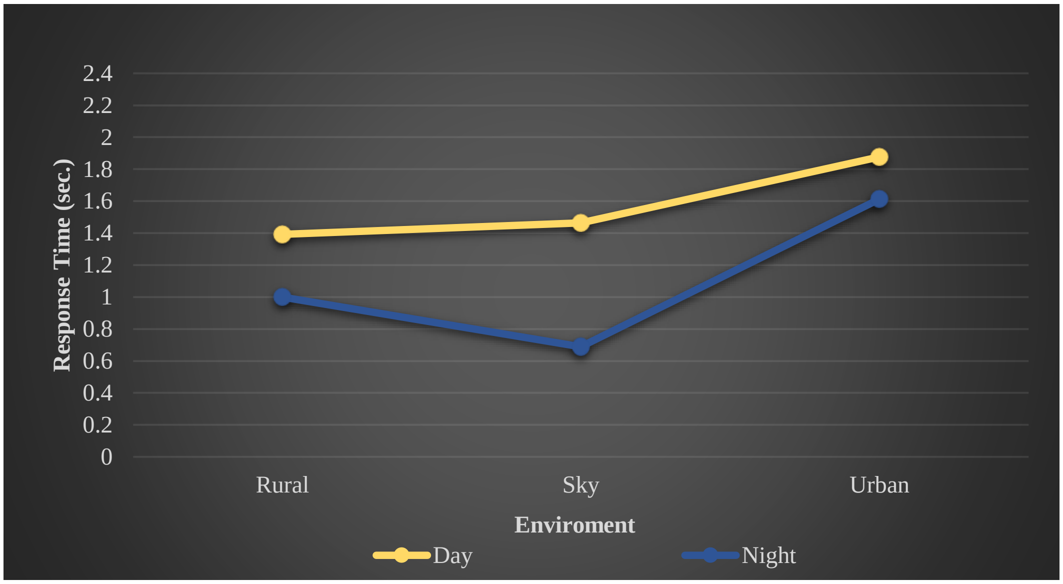


Figure 27. *Response time by background and Time-of-day included in Dataset 2.*



Discussion and Conclusions

This analysis examined the effect of lighting color on conspicuity. There are limitations and benefits to note. Of primary concern is using a computer display to present the stimuli and the inability to mimic some of the real-world lighting conditions on a computer display. This is especially true for contrast ratios connected with sunlight conditions. However, conducting the experiment on a computer display allowed us to control the background colors more carefully. As well, we did not have to worry about differential ambient lighting conditions, the effects of shadows, and other potential environmental factors (e.g., dust) that could interfere with viewing of the stimuli.

Finding that pure white was the most effective color (Question 1) across all of the conditions was not surprising, given the research that has shown that increasing brightness also increases conspicuity (e.g., Bullough, 2011). Pure white was the brightest of the colors that were tested in this study. However, none of the backgrounds contained pure white as a distractor color, and it has been shown that background lights can have a negative effect on detectability (Davoudian, 2011).

The two multicolor combinations were found to be as detectable as pure white (Question 2), with no difference found between the multicolor combinations (Question 3).However, response times for multicolor combinations were significantly slower than response times for pure white. One possible explanation could be that the multicolor combinations increased detectability relative to other single-color stimuli (except pure white).One of the three colors would likely be visible at some point across all of the backgrounds, but not necessarily right away as it moved across the display or toward the observer. This would ensure its detectability but would not ensure a faster response time.

One somewhat unexpected finding from the study was the minimal effect of flashing lights on conspicuity. As an overall effect across colors, backgrounds and movement, flashing lights showed no change from steady lighting on either detectability or response time (Question 7). This was true for both 2Hz and 4 Hz flash rates, with no significant difference between the 2 and 4Hz rates (Question 9).

We attempted to dig deeper into the effect of flashing versus steady lights by testing main effects and interactions. We looked at whether a differential effect existed for flashing lights for day vs. night backgrounds (Question 8). In terms of detection rate, we found that flashing lights were more detectable than steady lighting for night backgrounds but made no difference during day backgrounds. This result is consistent with previous research (e.g., Dolgov et al., 2012; Hobbs, 1991) but conflicts with other findings (e.g., Edewaard et al., 2019).

We tested whether a differential effect existed for flashing lights based on relative movement of the stimulus (Question 11). We found that the flashing conditions led to greater detectability than a steady light when the stimulus was moving directly toward the observer, whereas the steady lighting was more detectable when the stimulus was moving across the screen.

Overall, the results supported our expectations. The finding that stimuli moving across the field of view are easier to locate than stimuli moving directly toward the observer (Question 10) has been supported by many studies (e.g., Hobbs, 1991, Wallace et al., 2019). In addition, single-color, clear sky backgrounds, day or night, with no distracting lights were also expected to lead to better and faster stimulus detection, which is what we found (Questions 4 and 12). While these findings do not offer any new information, they do serve to support the validity of a computer-based study that can be used to suggest possible follow-on studies using actual systems.

One possible explanation for these findings is that the effect of relative movement was stronger than that provided by a flashing stimulus, at least for this study, and masked the effect of the flashing stimulus. In fact, flashing the stimulus might have taken away some of the effect of relative movement because the moving stimulus was not always visible. However, when relative movement is removed, the flashing light provides a more salient change in the stimulus than a steady light, thus leading to greater detectability.

One final issue that this study addressed was whether there were some colors/color combinations that were the most effective under some backgrounds but not others (Questions 5 and 6). The issue here is whether we should recommend having one color for one type of environment or time-of-day but a different color for a different environment or time-of-day. Based on the findings from this research, we cannot make such a recommendation. As was stated earlier, pure white and the two multicolor combinations were found to be the most effective under all of the background conditions that were tested. Unfortunately, the limitations of the types of background conditions that could be tested in a computer-based study do not allow us to conclude that these colors/color combinations are invariably the best.

Based on the findings from this research, the following conclusions can be made regarding sUAS lighting recommendations.

1. Pure white lighting, or a combination of red, blue, and either pure white or off-white are recommended lighting options for sUAS.
2. Flashing lights are more effective than steady lighting when directly approaching an observer and thus is recommended to account for potential collision courses with the observer.
3. Steady lighting is more effective than flashing lights in the detection of relative movement and would assist visual observers, pilots, and bystanders in the detection of sUAS in cases where the aircraft is not on a direct collision course with the observer.

Noting that computer-based research is limited, future research on lighting requirements using actual sUAS lighting configurations under real-world outdoor conditions is recommended. Such a study should examine the effect of background lighting on detectability, whether there is a need for lighting during daylight hours, and whether there are ways to enhance detectability using lighting when trying to locate the aircraft from below while looking into a bright sky. Researchers should also investigate whether there is a need to distinguish some types of sUAS (e.g., emergency, police, fire) using specific lighting options, and what those options might be. When looking at these issues, consideration should be given to at least three different perspectives, the UAS operator and/or ground observers, air traffic controllers in an elevated ATC cab, and general aviation pilots.

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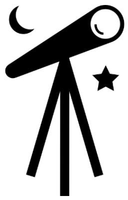
Appendix A

Invitation Email



"Martha, get me NASA on the phone!

I've just discovered a new planet!

No, wait – false alarm! *It's just Billy's new drone!*"

Dear colleague,

The FAA is conducting research into potential options for marking drones with lights, and we need your help!

This study involves looking at scenes on a laptop and identifying when a drone is present. Recent evidence has shown that seeing small unmanned aircraft systems (sUAS) from the cockpits of traditionally piloted aircraft can be extremely difficult. To align the integration of sUAS with the FAA's mission of providing the safest and most efficient aerospace system in the world, we are studying how best to equip sUAS with efficient lighting that is discernable and detectable in various environments.

We need FAA employees with normal (or corrected-to-normal) vision and normal color vision to participate in this study. Only those holding a current FAA PIV badge are eligible.

Participation is voluntary and you can participate from home if you are on telework status! The experiment will be conducted on your government-provided laptop from your current work location. The study will take no more than 1 hour of your time and you will be compensated $50!

Here is the fine print for eligibility:

- Must be an FAA employee with a PIV card and participant while not on pay-status
- Must have normal (or corrected-to-normal) vision and normal color vision
- Must complete the study on your FAA-provided laptop
- Must use your laptop monitor (disconnected from external monitors)
- Must be located in a location without windows or with well-covered windows to reduce ambient light
- Must be able to set your laptop monitor at your eye level and measure 22 inches from your head positon (length of 2 sheets of standard Letter-size printer paper)
- Must wipe off laptop screen before participating

Interested? Please follow the link below for more information and instructions to participate.

Link Removed

Appendix B

Pre-Study Survey

Welcome to the FAA's UAS Visibility Study. Thank you for your interest in the UAS visibility study. Your participation is greatly appreciated.

Please note there are a few requirements that must be met before continuing.
Requirements to participate: Must be an FAA employee (with a PIV card), participating off the clock or are a requited in-person participant with a researcher present.
Must complete the study on a FAA-provided laptop
Must use the laptop monitor (disconnect external monitors from your FAA-provided laptop).
Must set your laptop monitor at your eye level and 22 inches from your head position (length of 2 sheets of standard letter-sized printer paper)
Must be located in a quiet location without windows or with well-covered windows to reduce ambient light
Must have normal (or corrected to normal) visual acuity and normal color vision
Must clean laptop screen to remove dust and/or smudges

○ I can meet these requirements at this time and would like to proceed

○ I cannot meet these requirements at this time

1) Do you have a current FAA PIV badge?

○ Yes

○ No, I am participating in-person with access to an FAA-provided laptop

○ No, I do not have access to a FAA-provided laptop

2) Which of these statements best applies to you?

○ I am a federal employee participating off the clock (not on pay status)

○ I am not a federal employee and participating in-person

○ I am not a federal employee participating off the clock

3) Please indicate how you are participating in the study by selecting the appropriate response below.

- ○ Participating remotely with FAA PIV
- ○ Employee at the Mike Monroney Aeronautical Center (MMAC) - participating in-person and my normal work location is at MMAC
- ○ I have been recruited to participate in-person and can verify I am fully vaccinated (at least 2 weeks since the last dose of the vaccination)

4) Thank you for agreeing to participate in this study.
Please provide your first name, last name, and email address. If you are a FAA employee, please provide your FAA email address. The information you provide will not be associated with your survey responses. This information is being collected as a requirement for informed consent and to ensure that you are compensated. An email will be sent to the provided email that will include your participant ID, a link to the study program location, and payment information. *Note: The email from Qualtrics may take up to 10 minutes to receive. You may also need to check the junk email folder if the email does not appear in your inbox.*

- ○ First Name ________________________________
- ○ Last Name ________________________________
- ○ Email Address ______________________________

5) Age:

- ○ 18 - 24 years
- ○ 25 - 34 years
- ○ 35 - 44 years
- ○ 45 - 54 years
- ○ 55 - 64 years
- ○ 65 - 74 years
- ○ 75+ years

6) What is your gender?

- ○ Male
- ○ Female

7) Are you an Air Traffic Control Academy student?

- ○ Yes
- ○ No

8) How long have you been at the academy? (Question was shown if responded ‘Yes’ to question 7)

- ◯ 1 - 3 weeks
- ◯ 4 - 6 weeks
- ◯ 7 - 9 weeks
- ◯ 10 - 12 weeks

9) Are you a current or retired air traffic controller?

- ◯ Yes
- ◯ No

10) How long have you been or were you a controller? (Question was shown if responded ‘Yes’ to question 9)

- ◯ 1 - 5 Years
- ◯ 6 - 10 years
- ◯ 11 - 15 years
- ◯ 16 - 20 years
- ◯ 21 - 25 years
- ◯ 26 - 30 years
- ◯ 31 or more years

11) What types of facilities have you worked? (Check all that apply) (Question was shown if responded ‘Yes’ to question 9)

- ☐ Airport Traffic Control Towers
- ☐ Terminal Radar Approach Control
- ☐ Air Route Traffic Control Centers (ARTCC)
- ☐ Combined Control Facilities (TRACON/TRACAB)

12) Are you a pilot?

- ○ Yes
- ○ No

13) What ratings and certificates do you hold? (Check all that apply) (Question was shown if responded ‘Yes’ to question 12)

- ☐ Sport Pilot
- ☐ Recreational Pilot
- ☐ Private Pilot
- ☐ Instrument Rating
- ☐ Commercial Pilot
- ☐ Flight Instructor
- ☐ Airline Transport Pilot

14) How many hours have you flown as pilot-in-command (PIC)? ((Question was shown if responded ‘Yes’ to question 12)

_______ Hours

15) Your participation is greatly appreciated. Before moving forward with the study, please check that you meet each of the following requirements again by checking them off. If you cannot check off every item on the list, please exit the study by closing your web browser because you cannot meet the requirements of the study.

- [ ] Complete the study on a FAA-provided laptop
- [ ] Disconnect all external monitors from the FAA-provided laptop
- [ ] Located in a quiet location without windows or with well-covered windows to reduce ambient light
- [ ] Set your laptop monitor at your eye level and 22 inches from your head position (length of 2 sheets of standard Letter-size printer paper)
- [ ] Clean laptop screen to remove dust and/or smudges

Appendix C

Instruction Email

Thank you for participating in UAS Visibility - BPD08 study.

Your participant ID is P1621516592271.

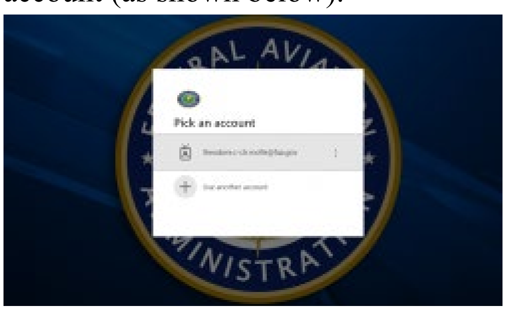
Before you click the link provided in this email, please fully read the provided instructions.

The study application is best downloaded using Google Chrome. If your default browser is already set to Google Chrome, you may continue by clicking the link below and following the provided instructions.

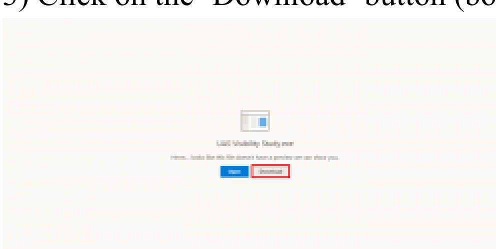
If your default web browser is set to another application (e.g., Microsoft Edge, Internet Explorer) please use Google Chrome to download the study application. To find Google Chrome on your computer press the windows key or click in the search bar and type 'Chrome'. Once Chrome's icon appears, press enter to open. When the browser opens, copy the web address provided (***Link Removed***) and past into the address bar of Google Chrome and follow the instructions below.

Google Chrome Instructions:
1) To begin the study, please download the study application located on FAA SharePoint ***Link Removed***

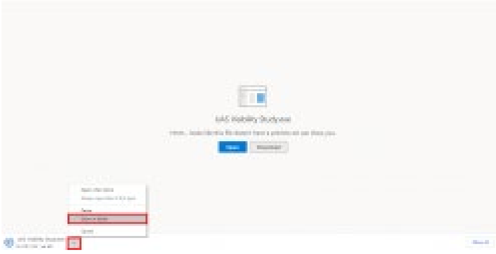
2) Once FAA SharePoint opens, select your organization as FAA and select you FAA email account (as shown below).



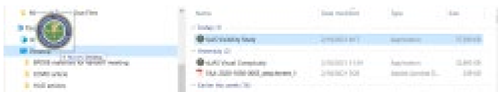
3) Click on the 'Download' button (boxed in red below).



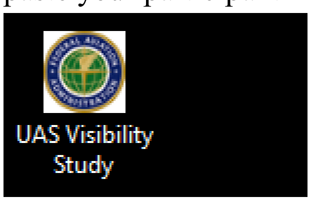
4) Once the UAS Visibility application has completed the download, click the up arrow and click 'Show in folder' (as shown below):

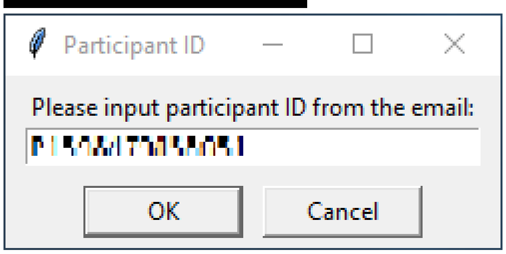


5) The file explorer window will open with your browser's default download location (e.g., 'Download folder). Once the file explorer window opens, click and drag the UAS Visibility application to your Desktop, as shown in the image below.



6) Copy your participant ID number at the top of this email by highlighting the number and pressing CTL+C. Navigate to your desktop, and open the program (icon displayed below), then paste your participant ID into the box provided pressing CTL+V (as shown below).





Instruction inside the application will guide you through the remainder of the study.
Once again thank you for participating in UAS Visibility - BPD08 study.

If you experience any technical difficulties while participating in the study including but not limited to difficulties with the UAS Visibility application, loss of internet connection, or a computer reboot, please contact Hunter Klevgard at: ***Link Removed***

If you experience any difficulties with the Qualtrics survey tool please contact Ted Mofle at:

Email: ***Link Removed***

Phone: 405-xxx-xxxx