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Connoted hazard and perceived importance of fluorescent, neon, and standard safety colors

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ABSTRACT

Objective: The perceived hazard and rated importance of standard safety, fluorescent, and neon colors are investigated.
Background: Colors are used in warnings to enhance hazard communication. Red has consistently been rated as the highest in perceived hazard. Orange, yellow, and black are the next highest in connoted hazard; however, there is discrepancy in their ordering. Safety standards, such as ANSI Z535.1, also list colors to convey important information, but little research has examined the perceived importance of colors. In addition to standard safety colors, fluorescent colors are more commonly used in warnings. Understanding hazard and importance perceptions of standard safety and fluorescent colors is necessary to create effective warnings.
Methods: Ninety participants rated and ranked a total of 33 colors on both perceived hazard and perceived importance.
Results: Rated highest were the safety red colors from the American National Standard Institute (ANSI), International Organization for Standardization (ISO), and Federal Highway Administration (FHWA) together with three fluorescent colors (orange, yellow, and yellow-green) from 3 M on both dimensions. Rankings were similar to ratings except that fluorescent orange was the highest on perceived hazard, while fluorescent orange and safety red from the ANSI were ranked as the highest in perceived importance.
Conclusion: Fluorescent colors convey hazard and importance levels as high as the standard safety red colors.
Application: Implications for conveying hazard and importance in warnings through color are discussed.

1. Introduction

Hazards, such as toxic chemicals, pinch points in machinery, and electrocution are present in the environment. When hazards are not designed out or guarded against, warnings are frequently used to convey information about the hazard, consequences and instructions to avoid property damage, injury, or death (Chapanis, 1994; Wogalter et al., 2015). Color can influence warnings and other hazard communications in several ways. They can serve to capture attention and add conspicuousness to signs to help them stand out from the environment (Burns and Pavelka, 1995; Wogalter and Vigilante, 2006; Wogalter et al., 2015). In addition to capturing attention, adding color to warnings can make them easier to comprehend and more memorable than their achromatic counterparts (McDougald and Wogalter, 2014; Young and Wogalter, 1990). Participants were more likely to remember a warning that was presented with orange highlighting than a warning that was non-highlighted (Young and Wogalter, 1990). Lastly, color present in warnings can influence behavioral compliance (Braun and Silver, 1995). Participants who interacted with a pool water test kit were more likely to wear gloves when there was a red warning present then when the warning was presented in black; however, there was no difference in behavioral compliance between a warning printed in black or printed in green (Braun and Silver, 1995). These results suggest that colors can enhance warnings, but different colors connote different levels of hazard.

Red is consistently rated as the highest in perceived hazard compared to other colors (Braun and Silver, 1995; Borade et al., 2008; Griffith and Leonard, 1997; Smith-Jackson and Wogalter, 2000; Wogalter et al., 1998). After red, then the next highest rated

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colors are orange, yellow, and black; however, various studies find somewhat different ordering within this group (Braun and Silver, 1995; Borade et al., 2008; Griffith and Leonard, 1997; Smith-Jackson and Wogalter, 2000; Wogalter et al., 1998). Orange was rated the second highest color in a few studies followed by yellow and/or black (Braun and Silver, 1995; Borade et al., 2008); while other studies did not find a significant difference in the rankings of orange and yellow (Chapanis, 1994). The remaining studies found yellow as the next highest connoted hazard after red (Griffith and Leonard, 1997; Smith-Jackson and Wogalter, 2000; Wogalter et al., 1998). After these three colors (orange, yellow, and black), the next highest are magenta, blue, brown, green, white, and gray (Smith-Jackson and Wogalter, 2000; Wogalter et al., 1998). Although there is discrepancy on the levels of perceived hazard of colors, standards have provided guidelines of connoted hazard levels.

Colors are often paired with signal words in warnings. ANSI Z535.1 specifies pairs of words and specific colors to indicate different levels of hazard. Red is paired with the word DANGER to indicate the highest of 3 levels. It is intended to indicate a hazardous situation that if not avoided will result in death or serious injury. The middle level of hazard according to the ANSI system, orange, is paired with the signal word, WARNING, to indicate a hazardous situation that if not avoided could result in death or serious injury. The lowest level of hazard in the ANSI system is the color, yellow. It is paired with the signal word, CAUTION, to indicate a hazardous situation that if not avoided could result in minor or moderate injury (Wogalter et al., 2015; ANSI Z535.1, 2012). The recommendations of the standard do not necessarily match what has been found in previous studies. Red and DANGER were rated the highest in connoted hazard; however there is no difference between the orange/WARNING and yellow/CAUTION combinations (Chapanis, 1994). The discrepancy in hazard connotations of the colors requires further investigation.

In addition to hazardousness, ANSI Z535.1 specifies signal words that are intended to indicate non-hazardous conditions, paired with non-hazardous colors such as green and blue. Examples of warnings that are informative, but not hazardous, are roadway signs with a blue background and a white letter H in the center of them. This type of sign is used to inform drivers about the location of a nearby hospital, which is generally not considered a hazard, but is important when needed. Color perception research has focused on connoted hazard of colors and there has been limited research examining the perceived importance of colors. Therefore, this research was developed to understand whether color can be used to connote different levels of importance.

Finally, in recent decades, there has been an increase in the use of fluorescent colors in highway sign contexts (Hawkins et al., 2000; Wogalter et al., 2015). Ultraviolet (UV) light interacts with fluorescent colors making them appear brighter and more conspicuous than non-fluorescent colors (Burns and Pavelka, 1995). Research by Scheiber et al. (2006) found that fluorescent colors elicited more initial fixations than non-fluorescent highway colors, suggesting they are more salient and more likely to attract attention. Although fluorescent colors have these characteristics, little is known about their connoted hazard or perceived importance.

Only one study has investigated the perceived hazard of fluorescent colors as compared to non-fluorescent colors (Tomkinson and Stammers, 2000). Participants rated fluorescent red the highest in perceived hazard, followed by fluorescent orange, fluorescent yellow, and orange, which were equal in ratings, and then red, fluorescent green, yellow, and green. This study, however, did not fully specify the details of the colors used. Consequently, it is difficult to replicate the method and stimuli used in the study. These researchers also did not investigate the perceived importance of fluorescent colors. With the expanding number of colors used to convey hazard, it is important to examine the perception of each color.

This study investigates the perceived hazard and importance of fluorescent and safety colors. The primary focus of this study is to assess the connoted hazard and perceived importance ratings of standard safety and fluorescent colors. This study will also expand on previous color rating research by assessing a secondary dimension: color ranking. Both color ratings and color rankings have been used to assess perceived hazard (Chapanis, 1994). Similar trends of perceived hazard were found between the rating and ranking data; however, the results have yet to be replicated. This study will examine the pattern of hazard and importance ratings and rankings to determine whether these measures could potentially be used interchangeably.

2. Method

2.1. Materials

Colors were chosen from the American National Standard Institute (ANSI Z535.1), International Organization for Standardization (ISO 3864-4), United States Department of Transportation Federal Highway Administration (FHWA), 3 M Company, and Pantone neon colors.

Munsell Color (Grand Rapids, Michigan) produces 8.5 × 11 in (22 × 28 cm) sheets of safety colors per the specifications listed in ANSI Z535.1 (2012), a U.S. standard for color use in warning signs, labels and tags. The following colors were used: safety red, safety orange, safety yellow, safety green, safety blue, safety purple, safety brown, safety gray, safety black, and safety white.

Natural Color System (NCS), European Color Standard (RAL), Munsell, and British Standard (BS 5252) color equivalents are listed for the International Organization for Standardization (ISO 3864-4: Graphical Symbols – Safety Colours and Safety Signs (2011)) safety colors. RAL color sheets were used. Specifically, the following colors were used: RAL 3001, RAL 1003, RAL 6032, RAL 5005, RAL 9003, and RAL 9004 for red, yellow, green, blue, white, and black, respectively. Additionally, RAL 2010 (signal orange), not listed in the ISO standard, was used for testing to remain consistent with other safety color groups.

Pantone® (Pantone LLC, Carlstadt, NJ) colors were used for the Federal Highway Administration (FHWA) and the Neon color groups. Color specifications for FHWA are listed in their *Manual on Uniform Traffic Control Devices* webpage (2013) to accurately print the colors used in their pavement-marking and sign materials. The following FHWA colors and corresponding Pantone shades were used: red (187), orange (152), yellow (116), green (342), blue (294), pink (198), purple (259), yellow-green (382), and brown (469). Prior to 2010, Pantone LLC printed a set of fluorescent colors available in the Fluorescents and Metallic category. In 2010, Pantone rebranded and moved the fluorescent colors into their Neons and Pastels Collection. From this point forward, these fluorescent colors will be referred to as the Neon colors. The color names and shades included were green (802), blue (801), purple (814), and yellow green (809). The FHWA and Neon colors were printed using a Pantone certified printer in the North Carolina State University (NCSU) Design School. Color accuracy was confirmed with the Pantone Formula Guide obtained from the North Carolina State University Design Library.

The 3 M Company (St. Paul, Minnesota) provided 4 × 6 inch (10 × 15 cm) samples of colors for use in this study. The three colors in this group were fluorescent orange, fluorescent yellow, and fluorescent yellow-green. Table 1, below, provides a summary of the colors used in this study along with the color system, color

Table 1
Colors used in the study for each standard, along with their color system, color system name, and color system reference number. Pantone colors for the FHWA and Neon categories do not have a color name.

	ANSI (Munsell)	ISO (RAL)	FHWA (Pantone)	Neon (Pantone)	3 M
Red	Safety Red 7.5R 4/14	Signal Red 3001	187	–	–
Orange	Safety Orange 5YR 6/15	Signal Orange 2010	152	–	Fluorescent Orange 4084
Yellow	Safety Yellow 5Y 8/12	Signal Yellow 1003	116	–	Fluorescent Yellow 4081
Green	Safety Green 7.5G 4/9	Signal Green 6032	342	802	–
Blue	Safety Blue 2.5PB 3.5/10	Signal Blue 5005	294	801	–
Pink	–	–	198	–	–
Purple	Safety Purple 10P 4.5/10	–	259	814	–
Yellow Green	–	–	382	809	Fluorescent Yellow Green 4083
Brown	Safety Brown 5YR 2.75/5	–	469	–	–
Gray	Safety Gray N 5/	–	–	–	–
Black	Safety Black N 1.5/	Signal Black 9004	–	–	–
White	Safety White N 9/	Signal White 9003	–	–	–

system name, and color system reference number.

A total of 33 colors were used. For each of these colors, two 4 × 6 inch (10 × 15 cm) sections were affixed to cardstock. One set of colors was pasted on white cardstock and a second set of colors was pasted on black cardstock. The cardstock was cut to 4.5 × 6.5 inch (12 × 17 cm) cards, providing a 0.25 inch overall border around each color. Cardstock was used to ensure all cards had the same consistency and firmness when presented to the participants. Additionally, both black and white cardstock was used to provide a neutral background for all of the colors and to control for any effect of background brightness contrast. The background colors of black and white had minimal effects on the perceived hazard and importance ratings or rankings. If an effect was present, it is reported in the Results section. For tracking purposes, each color was labeled with a letter and a number. The labels were hidden from the participants to minimize bias.

2.2. Participants

An a prior power analysis with the following parameters (large effect size of 0.40, alpha of 0.05, and power of 0.08) suggested that 86 participants would be sufficient. Given this recommendation, ninety undergraduate students (41 males, 49 females) were recruited from North Carolina State University. Students were given course credit for their participation. The participants had a mean age of 19.4 years ($SD = 1.74$). The majority of participants were Caucasian (64) followed by Asian (19), African American (4), Native American (4), Hispanic/Latino (3), and Middle Eastern (2). Six participants reported two or more races. Seventy-eight participants reported English as their primary language. Participants were also evaluated for color vision using the Ishihara test (Pickford, 1944). None of the participants were found to be color vision deficient.

2.3. Procedure

The experiment took place in a quiet closed door office with ambient fluorescent lighting similar to an everyday office setting. A Sekonic L-358 flash meter indicated that the 140 × 140 inches (356 × 356 cm) room had 320 lux of light provided by two Philips Day-Brite Fluorescent Parabolic Troffer Lights, with three Philips 32-Watt 700 Series Alto Fluorescent Tubes in each light.

Qualtrics (Version 12.018, Provo, Utah), a survey collection website, recorded participants' responses. After obtaining informed consent from participants, participants were asked a set of demographic questions (age, sex, race, and primary language). Then, participants completed the Ishihara color vision test, followed by the color rating section, and the color ranking section.

Participants rated the level of perceived hazard and perceived importance for each color. Because participants were not safety professionals, definitions of hazard and importance were derived from a general dictionary reference. Perceived hazard was defined as "being risky or dangerous" and perceived importance was defined as having "great significance or value." Ratings were made on a scale from 1 to 10. Anchors were given at the endpoints. A rating of "1" was labeled as "not at all hazardous" or "not at all important" for perceived hazard and perceived importance, respectively. A rating of "10" was labeled as "extremely hazardous" or "extremely important" for perceived hazard and perceived importance, respectively. The use of a bipolar standard visual analog scale (VAS) is consistent with scale construction recommendations reported by Lee et al. (2010) and according to Moors et al. (2014), end labelling (i.e., VAS) is likely to result in extreme response styles which is important for getting participants to avoid picking the middle rating values.

Participants either rated all of the colors on perceived importance and then on perceived hazard or perceived hazard and then on perceived importance. The order was counterbalanced to minimize any biases or effect due to order. Participants were handed the color cards one at a time by the research assistant to examine and rate them. The presentation order of the 33 colors was randomized by the survey website for each participant during the ratings of perceived hazard and perceived importance. Color border was manipulated between-subjects. Participants reviewed the colors all mounted on a white border or all mounted with a black border.

Upon completion of all color ratings, participants ranked the colors on perceived hazard and importance. Participants were handed the set of 33 colors and asked to rank colors in order from of most hazardous to least hazardous, and then in order from most important to least important or did the same task with importance first followed by hazard. Participants were given as much time as needed to order the cards and encouraged to use the large desk to lay the cards out. Once participants were satisfied with the ordering of the colors on one dimension, they handed the set to the experimenter and then started the next dimension. Following the completion of all rankings, participants were debriefed and thanked for their participation.

3. Results

The results section is organized into two main sections: color ratings and color rankings. In the color ratings section, an analysis of variance (ANOVA) was conducted to compare the mean ratings of colors contained in each color system for perceived hazard and perceived importance. A second ANOVA analysis compared the mean ratings of each color system by color. For the rank order data, a Friedman Test was used due to the ordinal nature of these data. A second Friedman Test was conducted to compare the mean rankings of each color system by color. Finally, a Spearman's Rho correlational analysis of the color rating and ranking data of perceived hazard and perceived importance is given.

3.1. Color ratings

3.1.1. Perceived hazard by color system

An ANOVA was conducted for each color system by color. If the ANOVA revealed a significant effect, a Tukey's Honestly Significant Difference (HSD) post-hoc test was performed at $p < 0.05$ to analyze significant differences among the means. Table 2 lists the mean and standard deviation of each color's perceived hazard ratings.

The ANSI and ISO colors showed a significant pattern of means [$F(9, 880) = 67.37, p < 0.001; \eta^2 = 0.41; F(6,623) = 56.11, p < 0.001, \eta^2 = 0.35$, respectively]. Red was the highest rated color of each group and was significantly higher than the remaining colors. Orange and yellow were the next highest rated colors with no significant difference between them, but both significantly higher than the remaining colors. Black was the next highest rated color and was rated significantly higher than the remaining colors. Purple, brown, green, blue, gray, and white were the lowest rated colors of ANSI with no significant difference among them. Blue, green, and white were the lowest rated of the ISO group and did not significantly differ from one another. ANSI colors were rated higher with the black background than the white background [$F(1, 880) = 4.48, p = 0.035, \eta^2 = 0.01$]; however, there was no interaction effect between background and perceived hazard rating. There was no difference in ratings with the black and white backgrounds for the ISO group.

The FHWA followed a similar pattern as ANSI and ISO [$F(8, 801) = 50.23, p < 0.001, \eta^2 = 0.33$]. Red was rated the highest color and significantly higher than the remaining colors. Orange and yellow were the next highest rated colors. Orange was significantly higher than the remaining colors. Yellow was not significantly different from yellow-green. Yellow-green was significantly higher than the remaining colors on rated perceived hazard, with the exception of pink. Pink was significantly higher than the remaining colors, with the exception of purple. Purple was not significantly different from blue, green, and brown which were the lowest rated colors. FHWA colors were rated higher with the black background than the white background [$F(1, 792) = 5.60, p = 0.018, \eta^2 = 0.01$]; however, there was no interaction effect between background and perceived hazard rating.

In the neon color set, yellow-green was rated the highest on perceived hazard and significantly higher than the remaining colors [$F(3, 356) = 35.95, p < 0.001, \eta^2 = 0.23$]. Green was the next highest rated and significantly higher than the lowest rated colors, purple and blue. The 3 M fluorescent color set did not show significant differences among the three colors [$F(2, 267) = 2.67, p = .071, \eta^2 = 0.02$]. Neon and 3 M colors were rated higher with the black background than the white background [$F(1, 352) = 4.64, p = 0.032, \eta^2 = 0.01; F(1, 264) = 4.85, p = 0.029, \eta^2 = 0.02$, respectively]; however, there was no interaction effect between background and perceived hazard rating.

Table 2
Mean ratings of perceived hazard.[a] Standard deviations are shown in parentheses.

	Mean Hazard (SD)				
	ANSI	ISO	FHWA	Neon	3 M
Red	7.5 (2.7)	7.0 (2.9)	7.3 (2.7)	–	–
Orange	6.1 (2.5)	5.7 (2.5)	6.0 (2.4)	–	7.9 (2.4)
Yellow	5.7 (2.3)	5.3 (2.3)	5.4 (2.3)	–	7.3 (2.3)
Green	2.5 (1.6)	2.5 (1.7)	2.5 (1.7)	3.8 (2.5)	–
Blue	2.4 (1.6)	2.4 (1.5)	2.7 (1.6)	2.5 (1.6)	–
Pink	–	–	4.0 (2.5)	–	–
Purple	2.7 (1.9)	–	3.2 (2.3)	3.1 (2.2)	–
Yellow- Green	–	–	4.3 (2.5)	5.7 (2.4)	7.1 (2.3)
Brown	2.6 (2.1)	–	2.6 (2.1)	–	–
Gray	2.4 (2.0)	–	–	–	–
Black	3.9 (3.2)	4.2 (3.2)	–	–	–
White	2.1 (2.0)	2.3 (2.2)	–	–	–

[a] A rating of “1” was labeled as “not at all hazardous” and a rating of “10” was labeled as “extremely hazardous.”

3.1.2. Perceived hazard by color name

ANOVAs were conducted across groups for color of the same hue (e.g., all colors named “red”) on perceived hazard. There was no significant difference among the three safety red colors [$F(2, 267) = 0.81, p = .446, \eta^2 = 0.01$]; however, colors mounted on the black background were rated significantly higher than those on the white background [$F(1, 264) = 6.62, p = 0.011, \eta^2 = 0.02$]. There was no interaction effect between background color and perceived hazard ratings.

The 3 M fluorescent orange, fluorescent yellow, and fluorescent yellow-green were all rated significantly higher than the remaining orange, yellow, and yellow-green colors, respectively [$F(3, 356) = 15.04, p < 0.001, \eta^2 = 0.11; F(3, 356) = 14.81, p < 0.001, \eta^2 = 0.11; F(2, 267) = 29.82, p < 0.001, \eta^2 = 0.18$, respectively]. There was no significant difference among the remaining orange colors and the yellow colors. Orange and yellow colors mounted on black backgrounds were significantly higher than those on a white background, [$F(1, 352) = 10.92, p = 0.001, \eta^2 = 0.03; F(1, 352) = 4.63, p = 0.032, \eta^2 = 0.01$, respectively]. There was no interaction effect between background color and ratings.

The neon yellow-green color was rated significantly higher than the FHWA yellow-green. Additionally, neon green was rated significantly higher than the remaining greens, which did not differ from one another. The remaining colors gray, blue, purple, brown, black, and white did not show any significant differences across color systems.

3.1.3. Perceived importance by color system

Table 3 presents the mean and standard deviation of each color's perceived importance ratings. ANSI, ISO, and FHWA red was rated the highest in perceived importance and significantly higher than the remaining colors in their groups, [$F(9, 890) = 32.72, p < 0.001, \eta^2 = 0.25; F(6, 623) = 11.48, p < 0.001, \eta^2 = 0.10; F(8, 801) = 36.85, p < 0.001, \eta^2 = 0.27$, respectively]. In the ANSI colors, yellow was

Table 3
Mean ratings of perceived importance.[a] Standard deviations are shown in parentheses.

	Mean Importance (SD)				
	ANSI	ISO	FHWA	Neon	3 M
Red	8.3 (1.9)	7.7 (2.1)	7.8 (2.1)	–	–
Orange	6.0 (2.1)	5.5 (2.4)	6.1 (2.3)	–	7.7 (2.4)
Yellow	6.3 (2.2)	6.0 (2.5)	6.5 (2.2)	–	7.3 (2.4)
Green	5.8 (2.5)	5.8 (2.6)	5.8 (2.6)	4.8 (2.4)	–
Blue	4.8 (2.3)	5.0 (2.5)	4.7 (2.4)	4.3 (2.5)	–
Pink	–	–	4.0 (2.4)	–	–
Purple	3.5 (2.0)	–	3.5 (2.1)	3.5 (2.1)	–
Yellow- Green	–	–	4.3 (2.4)	5.3 (2.3)	7.1 (2.6)
Brown	3.6 (2.4)	–	3.5 (2.4)	–	–
Gray	3.7 (2.5)	–	–	–	–
Black	5.8 (3.1)	5.8 (2.9)	–	–	–
White	5.1 (3.1)	4.9 (3.1)	–	–	–

[a] A rating of "1" was labeled as "not at all important" and a rating of "10" was labeled as "extremely important".

rated the next highest and significantly higher than the remaining colors except for orange, black, and green. Orange was the next highest color and significantly higher than the remaining colors except for black, green and white. Black, green, and white were the next highest rated colors and significantly higher than the rest of the colors except for blue. Blue and gray were rated the next highest. Blue was significantly higher than the remaining colors; however, gray was not significantly different from brown and purple, which were the lowest rated in the group. The ISO group did not follow the same ordering as ANSI. There were no significant differences in perceived importance ratings among the ISO colors, with the exception of red.

In the FHWA colors, the second tier of colors in perceived importance include yellow, orange, and green which were significantly higher than the remaining colors except for green which was not significantly different than blue. Blue was not significantly different from yellow-green, and pink. Blue was significantly higher than purple and brown. Yellow-green and pink did not significantly differ from the lowest rated colors of purple and brown.

Yellow-green and green were the highest rated in perceived importance of the neon colors [$F(3, 356) = 9.41$, $p < .001$, $\eta^2 = 0.07$]. Yellow-green was significantly higher than the remaining colors. Green did not differ from blue, but was significantly higher than purple, which was the lowest rated color. Neon colors were rated higher when mounted on black background than white backgrounds [F (1, 352) = 9.94, p = 0.002, $\eta^2 = 0.03$]. There was no interaction between background color and rating. The 3 M fluorescent colors did not show any significant differences among the three colors in perceived importance [F (2, 267) = 1.36, p = .257, $\eta^2 = 0.01$].

3.1.4. Perceived importance by color name

Similar to perceived hazard, there were no significant differences among the reds in perceived importance (F (2, 267) = 1.88, p = .154, $\eta^2 = 0.01$). Fluorescent orange was significantly higher than the remaining oranges, which did not differ across systems (F (3, 356) = 14.98, $p < .001$, $\eta^2 = 0.11$). Fluorescent yellow and FHWA yellow were the highest rated yellows (F (3, 356) = 4.77, p = .003, $\eta^2 = 0.04$). Fluorescent yellow was significantly higher than ANSI and ISO yellows; however, there was no significant difference among the FHWA, ANSI, and ISO yellows. ANSI, ISO, and FHWA greens were all significantly higher than neon green in perceived importance (F (3, 356) = 3.89, p = .009, $\eta^2 = 0.03$). Fluorescent yellow-green was significantly higher than neon yellow-green, which in turn was significantly higher than FHWA yellow-green (F (2, 267) = 30.31, $p < 0.001$, $\eta^2 = 0.19$). Blue, purple, brown, black, and white did not show any significant differences; however, purple was rated higher on a black background than a white background (F (1,264) = 5.06, p = 0.025, $\eta^2 = 0.02$).

3.1.5. Summary of color ratings

Table 4 presents the highest rated colors in perceived hazard and importance (F (32, 2937) = 63.40, $p < 0.001$, $\eta^2 = 0.41$; F (32, 2937) = 28.89, $p < 0.001$, $\eta^2 = 0.24$, respectively). There was no statistical difference among these high-rated colors; they are ordered from highest to lowest on their absolute mean values. Colors were rated higher in perceived hazard and importance on the black background than the white background [F (1, 2904) = 18.68, $p < 0.001$, $\eta^2 = 0.01$; F (1, 2904) = 7.53, p = 0.006, $\eta^2 = 0.003$, respectively]. There was no interaction effect between background color and rating.

3.2. Color rankings

3.2.1. Perceived hazard by color system

A Friedman Test was conducted to determine if there were differences in color rankings of perceived hazard in each group. If a statistical effect was shown then a post hoc analysis of Wilcoxon signed-rank test was used to examine the differences between the colors involved. Table 5 displays the mean perceived hazard rankings and their standard deviations.

According to the Friedman test, there was a statistically significant effect in color rankings for the ANSI group, χ^2 (9) = 389.92, $p < 0.001$. Post hoc analysis using Wilcox signed-rank test revealed that red ranked higher than the remaining colors. Orange and yellow were the next highest ranked colors and both were significantly higher than the remaining colors. Black was the next highest and was significantly higher than the remaining colors. Purple, blue, and green were ranked the next highest colors. They were not significantly different from each other, but were significantly higher than brown, gray, and white. Brown, gray, and white were the lowest ranked colors and were not significantly different from one another.

There was a significant effect in color ranking in the ISO color group, χ^2 (6) = 267.82, $p < 0.001$. The Wilcoxon signed-rank test revealed that red was the highest ranked color and significantly higher than the remaining colors. Orange was the next highest ranked color and significantly higher than the remaining colors. Yellow was the third highest ranked color and significantly higher than green, blue, black, and white. Black was the fourth highest ranked color and significantly higher than the rest of the colors. Green and blue were the next highest ranked colors. They were not significantly different from each other, but were significantly higher than the lowest ranked color, white.

The rankings of the FHWA group showed a significant effect, χ^2 (8) = 328.24, $p < 0.001$. Red was ranked the highest and significantly higher than the remaining colors. Orange was the next highest ranked colors and higher than the remaining colors. Yellow was the next highest ranked color and significantly different from

Table 4
Name of highest rated colors on perceived hazard and perceived importance.

Hazard	Importance
3 M Fluorescent Orange	ANSI Red
ANSI Red	FHWA Red
3 M Fluorescent Yellow	ISO Red
FHWA Red	3 M Fluorescent Orange
3 M Fluorescent Yellow Green	3 M Fluorescent Yellow
ISO Red	3 M Fluorescent Yellow Green

Table 5
Mean rankings of perceived hazard.[a] Standard deviations are shown in parentheses.

Mean Hazard (SD)					
	ANSI	ISO	FHWA	Neon	3 M
Red	5.9 (5.5)	7.4 (6.3)	9.6 (7.1)	–	–
Orange	11.2 (4.9)	12.2 (5.5)	10.8 (5.0)	–	4.2 (6.0)
Yellow	11.0 (5.2)	13.3 (5.0)	12.3 (5.3)	–	5.6 (5.7)
Green	22.7 (5.2)	22.6 (4.6)	22.6 (5.2)	16.3 (7.6)	–
Blue	22.5 (4.9)	23.1 (5.1)	22.8 (5.9)	20.9 (7.2)	–
Pink	–	–	19.1 (8.1)	–	–
Purple	22.2 (6.9)	–	21.1 (6.2)	21.6 (6.4)	–
Yellow- Green	–	–	15.2 (6.6)	12.0 (6.1)	6.3 (6.5)
Brown	24.9 (6.6)	–	24.9 (6.7)	–	–
Gray	26.0 (7.5)	–	–	–	–
Black	18.7 (11.0)	19.5 (11.0)	–	–	–
White	26.1 (8.7)	26.6 (8.2)	–	–	–

[a] A ranking of "1" was labeled as "most hazardous" and a ranking of "33" was labeled as "least hazardous".

green, blue, pink, purple, yellow-green, and brown. Yellow-green was the fourth highest ranked color and ranked significantly higher than the remaining colors. Pink was the next highest and was significantly higher than the rest of the colors. Purple was the next color, but was not significantly higher than green. Purple was ranked higher than blue and brown. Green and blue were not significantly different, but were significantly higher from the lowest ranked color, brown.

The Pantone Neon colors were significantly different in their perceived hazard rankings, χ^2 (3) = 206.57, $p < 0.001$. Yellow-green was the highest and significantly higher than the remaining colors. Green was the next highest ranked color and different from blue and purple. Blue and purple were the lowest and not significantly different from one another.

The fluorescent colors of 3 M were significantly different in their rankings, χ^2 (2) = 34.02, $p < 0.001$. Fluorescent orange was ranked significantly higher than fluorescent yellow and yellow-green. There was no significant difference between yellow and yellow-green.

3.2.2. Perceived hazard by color

There was a significant effect of red, χ^2 (2) = 73.49, $p < 0.001$. Specifically, ANSI red was ranked the highest and significantly different from FHWA red and ISO red. ISO red was the next highest ranked color and was significantly different than FHWA red.

The four colors of orange showed significant differences in rankings, χ^2 (3) = 122.97, $p < 0.001$. Fluorescent orange ranked higher than ANSI, ISO, and FHWA orange. FHWA was the next highest ranked orange and not significantly different than ANSI orange. FHWA was significantly higher than ISO. There was no significant difference between ANSI and ISO orange.

Yellow showed a significant effect of perceived hazard, χ^2 (3) = 120.09, $p < 0.001$. Fluorescent yellow was significantly higher than ANSI, ISO, and FHWA yellow. ANSI's yellow was the next highest and significantly higher than FHWA's and ISO's yellow. FHWA yellow was the next highest ranked and significantly higher than ISO yellow, which was the lowest ranked yellow.

Fluorescent yellow-green was significantly higher than the remaining yellow-green colors, χ^2 (2) = 120.56, $p < 0.001$. Neon yellow-green was the next best and significantly higher than FHWA's yellow-green. Yellow-green was ranked higher with a black background than a white background (F (1, 264) = 8.20, $p = .005$). There was no interaction effect between color rank and background color.

Neon green was ranked significantly higher than the remaining greens, χ^2 (3) = 50.09, $p < 0.001$. There was no difference in perceived hazard rankings among the ISO, ANSI, and FHWA greens. Similarly, neon blue was significantly higher than ISO, ANSI, and FHWA blue, χ^2 (3) = 8.25, $p = 0.04$. ANSI was the next highest ranked blue. ANSI was not significantly different from FHWA, but it was significantly higher than ISO blue. There was no difference between FHWA and ISO blue. Blue was ranked higher with a white background than a black background (F (1, 352) = 4.25, $p = .039$). There was no interaction effect between color rank and background color. There was no significant difference in the colors, purple, brown, black, and white; however, white was ranked higher on a black background than a white background (F (1, 176) = 7.07, $p = .009$). There was no interaction effect between color rank and background color.

3.2.3. Perceived importance by color system

Table 6 displays the mean perceived importance rankings of each colors along with their standard deviations in parenthesis. There was a significant effect of perceived importance rankings of the colors in the ANSI group, χ^2 (9) = 210.46, $p < 0.001$. Red was the highest and was significantly different than the other colors. Yellow was the next highest; however, it was not significantly different from orange, green, and black. Orange, green, black, and blue were the next highest and did not differ from each other, but were ranked higher than the remaining colors. White was the next highest and was significantly different than gray, brown, and purple which were the lowest ranked colors. There was no difference among gray, brown, and purple in ranked importance.

ISO colors also showed a significant effect in perceived importance, χ^2 (6) = 90.53, $p < 0.001$. Red was ranked the highest color and significantly different than the remaining colors. Yellow, green, and orange were ranked the next highest. These three colors were not significantly different from each other. Yellow and green were ranked higher than the remaining colors; however, orange was not significantly different than black. Black and blue were not significantly different from each other, but both colors were ranked higher than white.

Similarly, FHWA colors had a significant effect, χ^2 (8) = 223.98, $p < 0.001$, with red as the highest ranked color and significantly different than the remaining colors. Yellow and green were the next highest, with no significant difference between the two colors. Yellow was ranked significantly higher than the remaining colors. Green was not significantly different from orange, blue, and yellow-green, but was ranked higher than the remaining colors. There was no difference among orange, blue, and yellow-green; however, they were significantly higher than pink, purple, and brown. Pink,

Table 6
Mean rankings of perceived importance.[a] Standard deviations are shown in parentheses.

Mean Importance (SD)					
	ANSI	ISO	FHWA	Neon	3 M
Red	6.9 (5.8)	8.2 (6.5)	11.0 (7.3)	–	–
Orange	15.0 (7.1)	16.4 (6.7)	15.9 (7.3)	–	9.7 (10.4)
Yellow	14.3 (7.5)	14.8 (6.1)	13.7 (6.3)	–	10.8 (10.6)
Green	16.4 (8.4)	15.2 (7.6)	15.6 (8.2)	16.5 (8.0)	–
Blue	17.3 (7.2)	17.4 (7.5)	17.2 (7.5)	19.4 (8.2)	–
Pink	–	–	24.4 (6.9)	–	–
Purple	24.5 (6.7)	–	24.1 (6.4)	23.8 (6.4)	–
Yellow- Green	–	–	18.0 (8.2)	16.6 (8.5)	10.4 (10.4)
Brown	24.4 (8.3)	–	24.5 (8.2)	–	–
Gray	22.5 (9.7)	–	–	–	–
Black	17.3 (11.0)	18.0 (10.9)	–	–	–
White	20.2 (10.8)	20.5 (10.8)	–	–	–

[a] A ranking of "1" was labeled as "most important" and a ranking of "33" was labeled as "least important".

purple, and brown were the lowest ranked and there was no difference among the colors.

There was also a significant effect in the neon colors, χ^2 (3) = 50.04, p < 0.001. Neon green and neon yellow-green were ranked the highest with no significant difference between the two. Green and yellow-green were significantly higher than blue and purple. Neon blue was significantly higher than purple, which was the lowest ranked.

The 3 M fluorescent color group revealed a significant effect, χ^2 (2) = 9.87, p = 0.007. Fluorescent orange and fluorescent yellow-green were ranked the highest. Fluorescent orange was significantly different than fluorescent yellow; however, there was no difference between yellow and yellow-green.

3.2.4. *Perceived importance by color*

A Friedman Test was conducted on each color hue to determine if there were differences across colors. If a significant difference was detected, the Wilcoxon Signed-Rank test was used to identify where the differences lied. The colors red, orange, yellow, and yellow-green had a significant effect across groups, while no differences were detected in green, blue, purple, brown, black, and white. Green was ranked significantly higher on a white background than a black background (F (1, 352) = 6.10, p = .014). There was no interaction effect between color rank and background color.

ANSI red was ranked significantly higher in perceived importance than both ISO and FHWA red, χ^2 (2) = 54.60, p < 0.001. ISO red in turn was also ranked significantly higher than FHWA red. Fluorescent orange was ranked the highest and significantly higher than ANSI, FHWA, and ISO orange, χ^2 (3) = 55.07, p < 0.001. ANSI and FHWA orange were ranked the next highest and did not have any significant differences between the two colors. ANSI orange was significantly higher than ISO orange; however, there was no difference between FHWA and ISO orange. Similarly, fluorescent yellow was ranked highest and was significantly higher than ANSI, FHWA, and ISO yellow, χ^2 (3) = 27.64, p < 0.001. No significant difference was found among ANSI, FHWA, and ISO yellow. Fluorescent yellow-green was significantly higher than neon yellow-green and FHWA yellow-green, χ^2 (2) = 40.69, p < 0.001. There was no difference between the neon and FHWA yellow-greens.

3.2.5. *Summary of color rankings*

The Friedman Test was conducted to evaluate all 33 colors in perceived hazard and importance rankings. There was a significant effect in rankings of perceived hazard, χ^2 (32) = 1489.98, p < 0.001. Fluorescent orange was ranked higher than the remaining colors. A significant effect was also found in perceived importance, χ^2 (32) = 735.04, p < 0.001. ANSI red was the highest and significantly higher than all the colors except for fluorescent orange. Fluorescent orange was higher than all the colors with the exception of ISO red, FHWA red, and fluorescent yellow-green.

3.2.6. *Relation of color ratings and rankings'*

Spearman's Rho analysis was conducted to examine the relationship between the color ratings and rankings for perceived hazard and importance. Table 7 displays the correlations. It is important to note that for ratings, higher numbers indicate higher hazard or importance, while lower numbers in rankings indicate higher hazard. Negative correlations were seen between the rankings and ratings of both perceived hazard and perceived importance. Therefore, participants were relatively consistent with their perceived hazard and perceived importance rankings and ratings, but the correlations were not perfect suggesting that there are some differences between dimensions.

Table 7
Correlational Analysis of perceived hazard and perceived importance ratings and rankings.

	Hazard Rating	Hazard Ranking	Importance Rating
Hazard			
Rating			
Ranking	-0.66*		
Importance			
Rating	0.37*	-0.37*	
Ranking	-0.35*	0.41*	-0.56*

*indicates p < 0.001.

4. Discussion

This study examined the perceived hazard and importance of fluorescent and standard safety colors. The results showed that red is the highest rated color in perceived hazard and importance in the ANSI, ISO, and FHWA groups. Orange and yellow were rated the second highest in perceived hazard in the ANSI, ISO, and FHWA groups. Orange and yellow were also in the second highest tier of perceived importance in the ANSI and FHWA groups, but they were not the second highest tier of perceived importance for the ISO group. Both orange and yellow did not differ from the remaining colors in the ISO colors. Additionally, black was in the third highest tier for perceived hazard in the ANSI and ISO groups. There is no black color in the FHWA group.

The 3 M fluorescent and neon color groups were rated higher in perceived hazard for orange, yellow, green, and yellow-green. No differences were seen in blue and purple. Only orange and yellow-green fluorescent colors were rated higher in perceived importance than the ANSI, ISO, and FHWA groups. The fluorescent yellow was not significantly different from the FHWA yellow. Neon green, blue, and purple were not significantly different from the ANSI, ISO, and FHWA colors.

These results are consistent with previous research showing red to be the highest in perceived hazard (Borade et al., 2008; Griffith and Leonard, 1997; Mayhorn et al., 2004; Smith-Jackson and Wogalter, 2000; Wogalter et al., 1998). Additionally, the results align with the only other study involving fluorescent colors, specifically that fluorescent colors are rated higher in perceived hazard than their standard safety color counter parts (Tomkinson and Stammers, 2000).

This study also explored the perceived hazard and importance rankings of colors. This side by side analysis of colors by the participants allowed them to compare colors directly and order them from most hazardous to least hazardous and from most important to least important. Although the perceived hazard and perceived importance rankings and ratings are significantly correlated (although not perfectly so), ranking data could provide another dimension that may not be accessible from the rating data. One example could be seen through the perceived hazard and perceived importance of the red colors. There were no significant differences in the rating data; however, the ranking data of the red colors displayed differences that revealed with post hoc analysis that ANSI red is significantly higher in perceived hazard and in perceived importance than both FHWA and ISO red. Additionally, when comparing all the colors for perceived hazard and perceived importance, the three safety reds and three fluorescent colors all ranked the highest with no significant difference. Examining the ranking data of all 33 colors, fluorescent orange was ranked the highest in perceived hazard and significantly different from the remaining colors. ANSI red and fluorescent orange were ranked the highest in perceived importance. Fig. 1 below displays the rating and raking data of perceived hazard and importance.

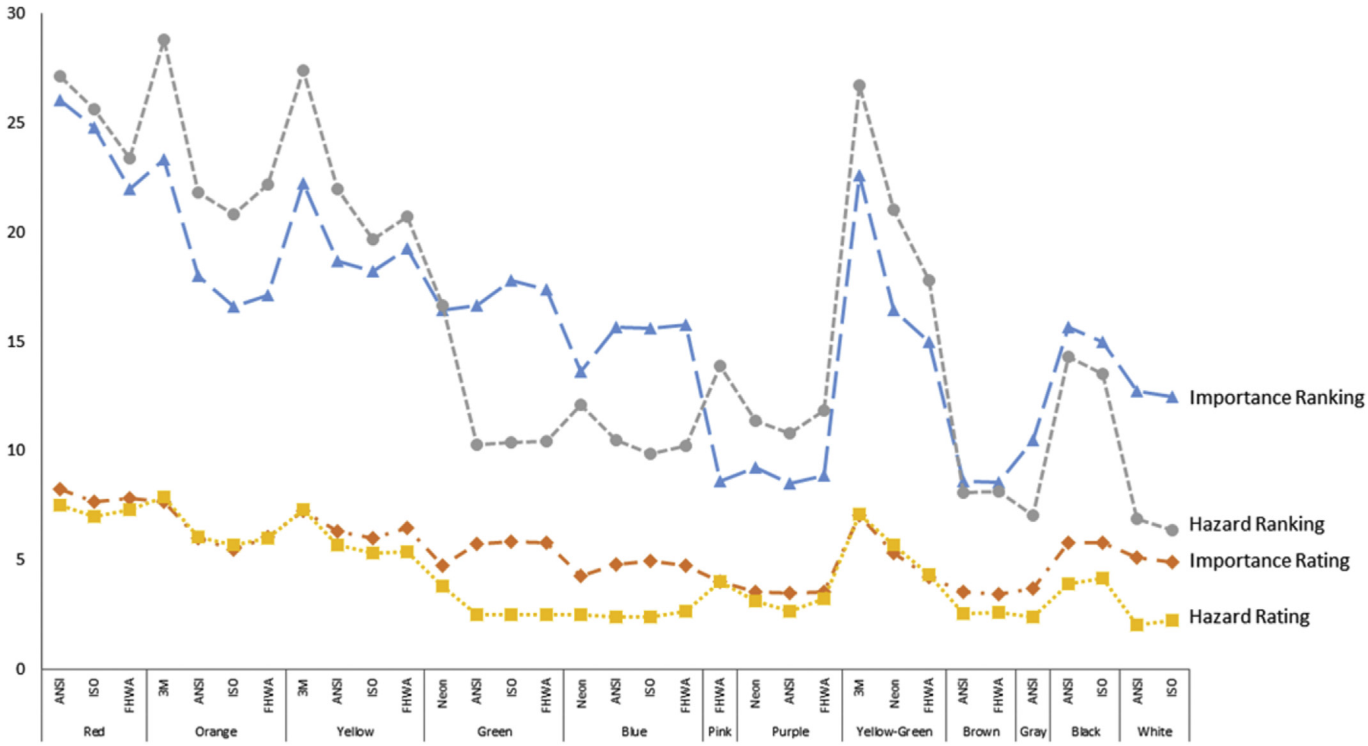

Fig. 1. Plots of perceived hazard and importance rating and ranking data. The colors are listed on the x-axis. The values on the y-axis represent the rating and ranking values. A rating of 1 indicates "least important" or "least hazardous" and a rating of 10 indicates "most important" or "most hazardous". Ranking data was reverse coded to indicate 1 as the "least important" and "least hazardous" and 33 was the "most important" or "most hazardous".

The results from this study could inform selection of colors from standards when creating warnings and other hazard communication signage. Potential applications of this could include signs used in laboratories to identify dangerous equipment, product labels that may contain toxic ingredients, and electrocution hazards. This study could also provide a more unified color standard for warnings using only the hues of color that portray the most perceived hazard or importance, depending on the nature of the message.

The results from this study could also help inform the standards used to convey levels of hazard. Currently, ANSI Z535 lists three signal word panels with associated colors to portray different levels of hazard. Specifically, red is paired with the word DANGER to indicate the highest level of hazard, orange is paired with WARNING to indicate the next highest level of hazard, and yellow is paired with CAUTION to indicate the lowest level of hazard. Although three levels are defined in the ANSI standard, previous color rating studies have suggested that participants typically consider the second and third level of hazard to be interchangeable with both colors and signal words (Wogalter et al., 2015). In the current study, orange and yellow were not significantly different in hazard ratings for all four color groups tested (ANSI, ISO, FHWA, and 3 M); however, when examining the hazard ranking data, participants ranked orange higher in perceived hazard than yellow for three of the four color groups (ISO, FHWA, and 3 M). This suggests that participants rate both yellow and orange high in hazard, but when they are compared side by side, participants rank orange higher in hazard than yellow. The ranking data demonstrated that orange and yellow yielded a measurable difference, albeit small, which was not evident in previous color rating studies.

A few limitations need to be considered. One is the exclusive use of undergraduate participants. Previous research suggests generalizability to other participant pools. For example, safety color rating data has shown similar patterns among industrial workers and adult community volunteers as compared to college students (Wogalter et al., 1998). Also similar results were found between students and office workers in ratings of fluorescent colors and safety colors (Tomkinson and Stammers, 2000). Undergraduate students also showed similar safety color rating results with Spanish-speaking users (Smith-Jackson and Wogalter, 2000). However, it should be noted that any perceptions, connotations and beliefs regarding colors may be due to learning (e.g., exposure to old TSA color coding) or cultural norms. Because there is limited research on cross cultural differences in the use of colors in warnings, future research might examine these color beliefs across different cultures in an effort to develop more inclusive warnings (Mayhorn et al., 2014).

Another limitation is the inability to print fluorescent red. Fluorescent red is not a true red; it is a pink hue and likely would not produce high hazard scores. Although fluorescent red was reported to have the highest hazard ratings in the Tomkinson and Stammers (2000) study, there were no specifications on how this color was produced or what it looked like. Therefore, we were unable to produce the color in the present study. Future research including fluorescent red, if it could be produced, would be useful.

Finally, this study evaluated colors individually, using either black or white backgrounds. In actual applications, colors in warnings are often paired with signal words and possibly other colors. In future research it would be useful to examine combinations of two or more colors. It might also be important to assess how perceptions of color vary in different kinds and levels of lighting.

Colors are frequently included in warnings aiding their noticeability and connotation of hazard. Safety red and fluorescent colors were rated the highest in perceived importance and perceived hazard. Fluorescent orange was ranked the highest in perceived hazard among 33 colors, whereas ANSI red and fluorescent orange were ranked as the two most important colors. This study extends the color perception literature and reviews an alternative method in measuring the perceived hazard and perceived importance of colors. From a more practical perspective, it is our hope that these results will also provide a comprehensive reference to practitioners tasked with creating safety signage.

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