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ABSTRACT

This paper presents the results of an online survey of licensed driver's comprehension of the right turn signal displays with a focus on the flashing yellow arrow (FYA) and also including the circular green and red and red arrow. Recruitment postcards were mailed to a random sample of 9,872 residents in Oregon. The online survey yielded 399 responses. The open-ended responses were coded for comprehension and analyzed. The results suggest that FYA for right turns is well understood by Oregon drivers despite its current novelty (only two locations at the time of the research). Importantly, survey respondents were more likely to recognize the yielding requirement of the permissive movement and associate the yielding with pedestrians with the FYA over the CG display. The research also confirmed that the expected driver response to the red arrow display for right-turns is not well understood (only 52% of the respondents correctly stated the expected driver response). Binary logistic regression modeling revealed that the driver's age and their educational level were significant factors in comprehension.

KEYWORDS: Right-Turns, Driver comprehension, Traffic signal displays, Flashing yellow arrow, Pedestrian safety, Signal design

INTRODUCTION

The design of phasing schemes at multimodal signalized intersections are complex, multifaceted transportation engineering problems. Providing permissive turn phasing generally decreases the delay for motor vehicle traffic but can decrease the safety for other users as turning vehicles are the primary collision risk for non-motorized users. When turning movements need to be controlled or managed, proper driver response to the traffic control is critical. There is general understanding that drivers better understand the yielding required of permissive left turns when the flashing yellow arrow (FYA) is used as the display. Although FYA for right-turn arrows has been allowed by the MUTCD since the introduction of the display, there is little published research on either driver comprehension or behavioral responses in this context.

This paper presents the results of an online survey of licensed drivers that explored driver comprehension of FYA for right turn displays. Driver comprehension of other displays for right-turns (the circular green (CG) and red (CR) and the red arrow displays (RA)) was also explored. Respondents to the online survey were recruited by postcards sent to residents of the state of Oregon. A brief background of relevant research is presented in the next section, followed by a description of the survey methods and data. The results are presented, which are then discussed.

BACKGROUND

Previous research has assessed driver comprehension of signal display indications in two ways – using survey-based methods and conducting driving simulator studies. Table 1 presents a summary of the relevant research studies, including their objective, methods and key conclusions. A review of the literature found one prior work that has evaluated driver comprehension of the FYA for right-turns. Ryan et al. studied the effectiveness of flashing yellow arrows for right turn applications using a large scale static evaluation and driver simulator study (Ryan et al. 2019).

Over 200 respondents participated in their static evaluation, and 24 participants undertook the driver simulator exercise. Their results revealed that drivers understood the meaning of FYA and exhibited safe behavior when they encountered the FYA indication during the simulator study. Of the studies that have utilized surveys to understand drivers' comprehension of signal displays, the majority explored PPLT phasing (Asante and Williams, 1993; Bonneson, 1993; Noyce and Kacir, 2001; Drakopoulos and Lyles, 2001; Brehmer et al. 2003; Noyce and Smith, 2003; Knodler et al. 2005, 2006a, 2006b, 2007; Henery and Geyer, 2008; Schlattler et al. 2013). Only a recent study by Boot et al. (2015) evaluated driver comprehension for a new flashing pedestrian indicator. All of studies that used surveys were either administered as independent static evaluations or as a follow-up for drivers who had completed driving simulator experiments. Most of these surveys were computer-based and consisted of static images of intersections with combinations of various signal displays. The questions were usually presented as multiple-choice options. The sample size in these surveys varied significantly from 2,465 drivers (Noyce and Kacir, 2001) to 34 drivers (Noyce and Smith, 2003), with most of the responses between 100-300 for each alternative explored.

The research summarized in the Table 1 pointed to the FYA as having the highest driver comprehension of the yielding requirement of the permissive turn and found fewer fail critical responses when compared to the alternatives of the CG or flashing CR or CY displays. The five-section cluster display resulted in the lowest comprehension rates as compared to other horizontal and vertical configurations, and older drivers had lower comprehension rates for permitted left-turn displays. Two of the studies (Henery and Geyer, 2008; Schlattler et al. 2013) found that the addition of supplemental signs with traffic signal increased comprehension measured in the survey.

However, since the supplemental sign contained the desired response to the signal indication, it may have biased the results.

DATA AND METHODS

An online survey was developed to obtain both open-ended and multiple-choice responses to questions about traffic signal displays for right-turns. The survey, distribution methods, and records handling were reviewed and approved by Portland State University's IRB (163752 IR). The survey consisted of 21 questions. All survey questions were presented neutrally to allow respondents to provide meaningful positive or negative answers regarding their comprehension of the signal display indication. Past questions on other surveys of FYA comprehension and other displays were used as a guide (Knodler 2006, Boot et al. 2015). The first section of the survey included open-ended questions, which asked respondents to report their understanding of right turn signal display indications with specific questions on the comprehension of circular green (CG), green arrow (GA), circular red (CR), red arrow (RA), and flashing yellow arrow for right turns (FYA_{RT}) indications. The question for each display was phrased:

> "*Imagine that you are approaching the intersection in the lane farthest to the right and planning to TURN RIGHT. What action would you take based on the current signal display? Please type your response in the box below and be as descriptive as possible*".

In these questions, respondents have presented a computer image of an intersection from a driver's perspective and instructed to assume that they were turning right. The survey used computer-generated images of an intersection with a dedicated right-turn lane similar to Boot et al. (2015). The use of computer-generated images was chosen to control the other objects in the scene that might influencing comprehension (e.g. pedestrians) and to remove any location-specific bias. In constructing the image, the scale of the signal heads was slightly enlarged to make the displays more prominent in the image. In the survey, the FYA display image was animated and flashed approximately once per second. While no pedestrian is present at the near-side quadrant, one was visible on the far side of the intersection. Two versions of intersection images were developed: one with a right turn only sign (RTO) and the other without. The images used for the steady circular green comprehension question with and without RTO are presented in Figure 1.a) and 1.b). The survey was designed such that half of the respondents were randomly administered the version with the RTO sign and the other half were administered the version without the sign.

In the second section, respondents were given a set of multiple-choice questions and asked to provide their reasoning for what they perceived as similarities or differences between 1) the CR and RA and 2) the CG and FYA signal indications. The third and final section of the survey consisted of multiple-choice demographic questions on the respondent's income and education levels, driving habits, and visual capabilities.

Sampling Scheme

A sampling scheme was designed based on the proportion of the population in each county in Oregon. Table 2 shows the scheme that was used to identify the proportion of households in each county. A sample size of 10,000 respondents was selected to generate sufficient responses for analysis, assuming a 6 to 8% response rate reported for a similar postcard / online design (Currans et al. 2015). A random sample of addresses within each county was purchased through Info USA then subjected to an address cleansing process during which incorrect/missing addresses were discarded from the sample. This procedure resulted in a final sample size of 9,874 households, to which recruitment materials were sent.

Recruitment Strategies

A recruitment postcard containing pertinent information about the survey objectives that included the online link was sent to each respondent. The postcard invited participants to take part in a driver comprehension study for the Oregon Department of Transportation on traffic signals for right-turns. Each household was assigned a unique ID number, which the respondents were required to enter while answering the survey. Survey responses were never linked to the names of the respondents; however, the ID number was used in spatial analysis. Recipients were given the option of providing their contact information at the end of the online survey to be entered into a drawing for one of five $100 gift cards to a large online retailer.

Response Rates

A total of 416 respondents clicked the online link to begin the survey, and 399 respondents completed the survey. Table 2 also shows the response rate by county and the percentage of the sample in the response. The overall calculated response rate was 4%, though the actual rate is unknown since no postcards were returned as undeliverable due to the postage option selected. The county-level response rate is more varied, ranging from no responses to 10% of the postcards sent. Inspection of the difference column shows that the percentage of sample response has good alignment with the percentage of population with the exception of the mostly urban counties near the Portland metropolitan area (Clackamas, +3.1%, Multnomah, +7.7%, Washington -3.9%, Marion, -3.2%). The spatial distribution of responses is shown in Figure 2. Overall, the sample was reasonably representative of the overall Oregon population distribution).

RESULTS AND ANALYSIS

Of the 399 people that responded to the survey, 397 people provided some or all of the requested demographic information. Information about the basic characteristics of the survey respondents, along with percentages for Oregon from the Census Bureau, are presented in Table 3. Older, educated white males were overrepresented as survey respondents as compared to 2010 census estimates for Oregon (U.S. Census). Survey respondents were 61% male as compared to the total population of 49%. Survey respondents also skewed older than the general population, with broader representation in the 55-64 and 65+ categories. Survey respondents were 93% white/Caucasian compared to 79% reported in the census. The U.S. Census American Community Survey (ACS) data reports that approximately 30% of Oregonians have a Bachelor's degree or higher. In the sample, over 65% of respondents had this level of education. The ACS reports that 89.5% of residents have a high school education or higher. In our sample, 98% of the respondents had this level of education. About 71% of the survey respondents reported household incomes of less than $100,000 which compares well to the Census data of 75%.

Respondents were asked to indicate how frequently and how much they drove, how long they have held a driver's license, whether the driver's license was issued by the state of Oregon if they were color deficient and/or used corrective glasses or contacts. Table 4 shows the sample characteristics based on the responses to these questions. Respondents tended to drive multiple times in a week (97%), and most respondents were licensed for over 10 years (96%), with nearly all of them holding an Oregon driver's license (98%). A total of 58% of the respondents reported that they drove more than 10,000 miles each year. A small sample of the respondents (3%) indicated that they were color deficient and a majority of them also indicated that they used corrective glasses or contacts for vision (65%).

Open-Ended Question Coding

Since the survey contained open-ended questions that were designed to assess the comprehension of various signal display indications, the responses had to be categorized for further analysis. The responses were coded as correct, partially correct, or incorrect by two researchers working independently, based on criteria that were established for assessing the correctness of the responses (Table 5). Interrater reliability was assessed using Cohen's kappa coefficient κ, a statistic that measures interrater agreement for categorical items. This coefficient is calculated as follows in equation 1.

$$\kappa = \frac{\Pr(a) - \Pr(e)}{1 - Pr(e)} \tag{1}$$

Where Pr(a) represents the actual observed agreement, and Pr(e)represents the chance agreement. Pr(e) is calculated using the following formula (equation 2)

$$\Pr(e) = \frac{\left(\frac{cm^1 * rm^1}{n}\right) + \left(\frac{cm^2 * rm^2}{n}\right)}{n} \tag{2}$$

Where cm^1 is column 1 total, cm^2 is column 2 total, rm^1 is row 1 total, rm^2 represents row 2 total, and n is the number of observations.

This statistic can range between -1 and +1, where 0 represents the amount of agreement that is due to random chance, and 1 represents a perfect agreement between the raters (McHugh 2012). Kappa statistic values between 0.61-0.80 indicate substantial agreement, and those between 0.81-1.00 represent almost perfect agreement. The Cohen's kappa statistic was calculated for the steady circular green, steady green arrow, steady circular red, steady red arrow, and flashing yellow arrow questions separately for with and without the "Right Turn Only" sign responses. Table 6 shows the estimated values of the kappa statistic for each of the trials. For all questions except the green arrow, one independent coding trial was conducted and the kappa values are shown in Table 6. For the green arrow question, two coding trials were conducted. Following the estimation of the kappa statistic (trials 1 and 2), the entire research team met to discuss and resolve the coding discrepancies by arriving at a shared consensus for all responses.

Comprehension Rates

Survey respondents were asked to imagine themselves as a driver in the right lane and asked to describe their resulting course of action when faced with the following display indications – steady green circular ball (CG), steady green arrow (GA), steady red circular ball (CR), steady red arrow (RA), and flashing yellow arrow for right turns (FYA_{RT}). The resulting responses for each question were coded as correct, partially correct, or incorrect based on the criteria developed as described earlier and shown in Table 5.

Descriptive Analysis

Table 7 presents the results of the coding exercise. Overall, 399 respondents (196 responses with RTO sign, 203 responses without sign) provided answers to questions pertaining to each of the signal display indications. The table is arranged with the protected (GA) and permissive displays (GA, CG, and FYA_{RT}) on the top and the red displays (CR and RA) on the bottom for comparison. Around 30% of the respondents did not completely state that the GA represents a protected movement and that they would not need to yield to pedestrians and other vehicles. The most common incorrect/missing perception was that they needed to yield to pedestrians while a steady green arrow was displayed. While we coded this response as partially correct, we note that this is a fail-safe response as many respondents indicated that they prefer to be cautious and check for pedestrians prior to turning. Interestingly, the presence of the right-turn only sign increased the correct response rate by 11% and was statistically significantly different.

For the CG display, correct responses were coded for 73% of the respondents who indicated that they would turn right and yield to pedestrians in the crosswalk. However, a total of 25% of respondents stated that they had the right-of-way to proceed but did not include any descriptions of yielding to pedestrians prior to turning (coded partially correct). A small proportion of respondents (2%) indicated they would stop prior to turning. Small differences were noticed between responses with and without the RTO sign, with a lower proportion of drivers (69% vs. 76%) indicating that they would yield to pedestrians, with the right turn only sign compared to those without the right turn only sign. However, these differences were not statistically significant. Similar comprehension rates were found for the FYA_{RT}. A total of 76% of the respondents understood the purpose of the FYA_{RT} indication and stated that they would turn right after yielding to any pedestrians in the crosswalk. A higher proportion of correct responses were observed when the right turn only sign was present (81%) compared to when it was absent (72%) but was not statistically significant. The primary difference between the FYA_{RT} and the CG was that 20% of respondents indicated that they would stop before turning. This incorrect response is a fail-safe error. In other words, when presented with the FYA_{RT}, respondents either stated that they recognized the required yielding condition or would stop first, both responses that appear to support increased pedestrian safety.

For the red displays, 83% of respondents provided the correct response to the CR indication with little difference between those viewing images with and without the right turn only sign. Of the incorrect responses, the most common was some variation of "come to a stop and wait for a circular green or green arrow." Legal driver response to the RA varies from state to state. In the Pacific NW states of Oregon, Washington, and Idaho, vehicle codes do not differentiate between the RA and CR in expected driver response. California requires drivers faced with the RA to stop and remain stopped. In the context of Oregon vehicle codes, the RA display was incorrectly interpreted by 34% of respondents with the RTO sign and 46% without the RTO sign. The most common incorrect/missing response was again fail-safe, with the perception that drivers needed to remain stopped until the indication changed to green. The comprehension rate was the lowest of all the signal displays explored for controlling right turns.

Binary Logit Model

A logistic regression model was developed to further explore the probability of the participant's correct/incorrect responses. Statistical analysis was performed using Minitab 16.2.4 software. The binary logistic regression technique labels the response variable with two outcomes (dichotomy) that are often labeled as "0" and "1" instead of numeric. In this study, the dependent variable was denoted as y=1 for correct response and y = 0 for incorrect response. Thus, the probability that a participant will respond correctly to a particular signal or not can be modeled as a logistic distribution by the following form (equation 3):

$$\log\left[\frac{p}{1-p}\right] = \alpha + \beta_i X_i \qquad (3)$$

Where p is the probability that participant will respond correctly for a particular signal, α is the intercept, and β_i is the model coefficient for each independent variable X_i

To identify the participant's response to different signal indications, five binary logistic regression models were developed to analyze factors that influence participant comprehension response. More specifically, binary logistic regression was employed to model responses (dependent variable), using signal indication characteristics, and the demographic variables (independent variables) as defined in Table 2 and 3. A stepwise procedure was used to select significant predictors and exclude insignificant ones from the final models. Significant variables in the final models were age, gender, miles driven per year, driving license, years holding driving license, education, and sign's present. Table 8 summarizes the descriptive statistics of the significant variables in the final models.

For each of the five models, the response variable was the individual response to the signal type given the presented scenario. All estimated parameters included in the models were statistically significant, and all signs were conceptually plausible. Additionally, most of the common variables among the five models had similar signs (i.e., variables that increased the probability of responding correctly to particular signal generally increased a correct response rate in other signals, and vice versa). A positive (or negative) sign for the coefficient in the models suggested that an increase in this variable increased (or decreased) the probability of responding correctly to the assigned question. Finally, to determine how effectively the model describes the outcome variables, three different goodness-of-fit tests (Deviance, Pearson, and Hosmer-Lemeshow) were considered. The Hosmer-Lemeshow test is more appropriate when the data is formatted in a binary response (Homser and Lemeshow, 2013). If the p-value for the test is not significant (P-value > 0.05), this indicates that the model fits the data well. The computed P-values from the chi-square distribution of the five models were insignificant (see Table 9). These values imply that the binomial distributions predict the outcome variables accurately.

The odds ratio (OR) was used to determine differences in the response of the participant, either comprehended the presented scenario correctly or incorrectly. The OR that is equal to EXP (β_i) is defined as the relative amount (odds) of a participant responding correctly for a particular scenario divided by the odds of a participant responding incorrectly for the same scenario. If the magnitude is greater than 1, the likelihood of correct response increases when the value of the independent variable is increased by 1 unit and vice versa when it is less than 1. For categorical independent variables, the odds ratios represent the comparison of the correct response likelihood between different levels of the factors, such as the respondent having an Oregon driving license or not. Table 9 shows the binary logistic regression estimates of individual correct/incorrect responses. The “-“sign indicates that this variable was not statistically significant and was therefore not included in the model.

Older respondents are less likely to generate a correct answer from a given scenario than older younger for all five indications (CG, GA, CR, RA, and FYA_{RT}). Participants with a high school degree are less likely to respond correctly than others. Finally, if respondents drive less than 10,000 miles per year, they are less likely to respond to the CR scenario correctly.

Participants holding a driver's license for more than 10 years are more likely to respond correctly to GA and CG scenarios. The presence of right turn sign tended to increase the likelihood that a participant would respond correctly for FYA_{RT} and RA scenarios. Male respondents are twice as likely to get a correct response for the FYA_{RT} scenario as are female. Additionally, Oregon driver license holders are 5.39 times more likely to respond with a correct answer than others for FYA_{RT} scenario.

DISCUSSION

This research explored Oregon driver’s comprehension of various signal indications for right-turns. Given the importance of improving pedestrian safety at intersections, it is essential to understand how drivers comprehend various signal displays and the factors that significantly impact the comprehension rates. The first useful observation from this research is that most respondents understood FYA_{RT} display even though it is currently uncommon in Oregon (only two known installations at the time of the survey). The stated comprehension was high, especially of the yielding requirement of the permissive movement. This is most likely partially explained by

Oregon driver's familiarity with the FYA displays for left turns. Oregon was an early adopter of the display and implemented it for permissive left-turns as early as 2001. For the FYA_{RT} the incorrect responses were a fail-safe comprehension error with drivers indicating they would stop. In contrast, around 25% of drivers did not include the concept of yielding when presented with the CG. While these drivers would likely yield when encountering a pedestrian in actual driving, the advantage of the FYA_{RT} display appears to be that driver's better associate this display with yielding.

Another important finding, though not the initial motivation for this research, is that there is a significant misunderstanding of the required driver response for the steady red arrow signal. In Oregon, the proper expected response from a driver for both displays is the same. However, it is clear that many drivers expect that the arrow display is requiring a different response. A recent survey of the right-turn on red arrow policies across the U.S. revealed that a majority of the states (35) permitted right-turns on a red arrow, and 15 states prohibited it (Hassan, 2016). The source of confusion is likely due to the different driver expectations for the same display for left and right-turns. While drivers are expected to stop and remain stopped when faced with a red arrow for left-turns, they are allowed to stop and proceed if they find a safe gap for right-turns in Oregon. The confusion with the circular and arrow displays is similar to the different driver expectations for the circular green and green arrow signal displays. The MUTCD defines the appropriate driver response to the steady green arrow as identical to that of the circular green: proceed after yielding to conflicting vehicles and pedestrians. However, it also forbids use of the arrow with any conflicting movement, so, in practice, motor vehicles are always provided an exclusive movement with this display. However, this is not the case with the red arrow movement, where drivers are expected to stop, yield to pedestrians and proceed only if a safe gap is found.

The difference in comprehension rates with and without the “Right Turn Only” lane control sign is not easily explained. For the two statistically significant different comprehension rates (GA and RA) in the descriptive comparisons, respondents presented with the sign had improved comprehension rates. The logit modeling found that the presence of the right turn only sign increased the likelihood of a correct response to the FYA_{RT} and RA displays by 1.59 and 1.67 times, respectively. Henery et al. (2008) found improved comprehension with a supplemental sign “Left Turn Yield on FYA” but as the RTO sign contains no additional information about responses it is not clear what the mechanism for improved comprehension is. One hypothesis is that the sign quickly clarifies which signal head is for right-turns and may allow for additional time to respond to the question or understand the situation. However, the sign did not notably improve comprehension for the other displays, and, as such, this hypothesis is weak.

The context of the survey and the age and education levels of this sample should be considered in the transferability of the results to other jurisdictions. First, FYAs for left-turns have been used in Oregon for nearly two decades and likely contributed to the high comprehension exhibited in the survey. Second, the logistic modeling found age and education to be predictors or comprehension, and our survey sample was overrepresented in these two categories. However, the work by Ryan et al. (2019) also found strong comprehension and better yielding to pedestrians with the FYA_{RT}.

CONCLUSIONS

In summary, this research provided the first look at the comprehension rates of drivers with the FYA_{RT} display. The results obtained show high comprehension of the yielding response required by the FYA indication for permitted right turns and provides support for operating FYA in permitted or protected-permissive mode for right turn operations. Traffic engineers could also explore the use of the FYA_{RT} when pedestrians are present, and geometry and signal operations allow for a separate signal head controlling right-turning traffic. Significant confusion was exhibited by drivers when faced with the red arrow display for right-turn movements. The use of R10-17a "RIGHT ON RED ARROW AFTER STOP" sign at locations with red arrows for right-turn indications may help alleviate the confusion. A better solution would be to pursue uniformity in vehicle codes as suggested by FHWA (2001).

There are a few limitations to this research. As the results are based on survey data, the usual limitations about the representativeness of the sample apply. Since the recruitment of the subjects was via U.S. mail, it was not as representative of younger adults and skewed towards white men and an older population compared to most recent Census distributions. Self-selection of respondents may also skew the results towards more interested or informed drivers. Future research could consider in-person intercept surveys or a hybrid postcard and social media distribution campaign to improve the sample representativeness. The survey analysis was based on coding the presence or absence of words in the open-ended responses. A more interactive survey or focus group approach could elicit additional understanding of driver yielding comprehension. Additionally, respondents in Oregon may be familiar with the law in California, where steady red arrow laws require drivers to stop and remain stopped until the green indication due to travel or population migration. While this study shows the results from a stated preference experiment, actual driver responses may be different. In a follow-up study, however, Jashmi et al. (2019) confirmed these findings in a driver simulation environment.

DATA AVAILABILITY STATEMENT

Some or all data, models, or code generated or used during the study are available from the corresponding author by request (de-identified survey response data, survey instrument, model analysis code).

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FIGURE CAPTION LIST

Fig. 1 a). Steady Green Circular Ball Question Image (without Right Turn Only Sign). Source: Hurwitz et al. 2018

Fig. 1 b). Steady Green Circular Ball Question Image (with Right Turn Only Sign). Source: Hurwitz et al. 2018

Fig. 2. Geographic Distribution of Respondents. Source: Hurwitz et al. 2018

TABLE CAPTION LIST

Figure 1. a) Steady Green Circular Ball Question Image (without Right Turn Only Sign)

Source: Hurwitz et al 2018

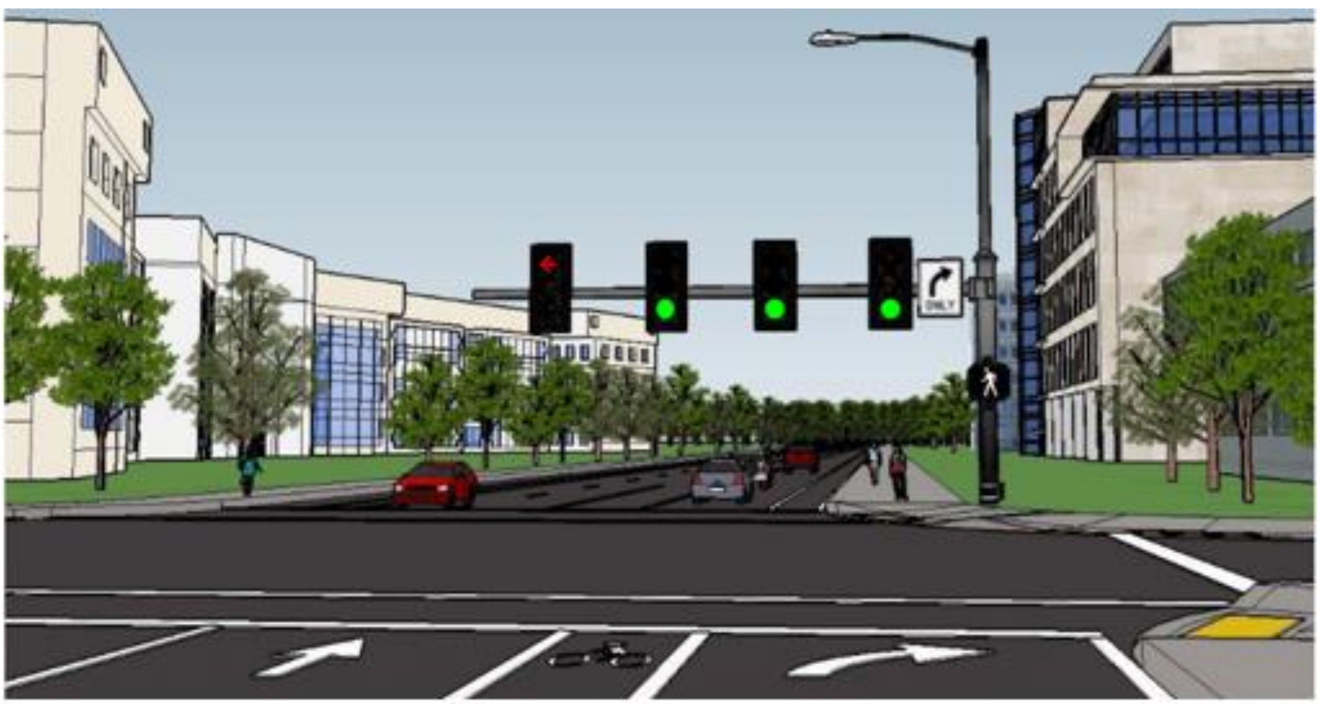

Figure 1. b) Steady Green Circular Ball Question Image (with Right Turn Only Sign)

Source: Hurwitz et al 2018

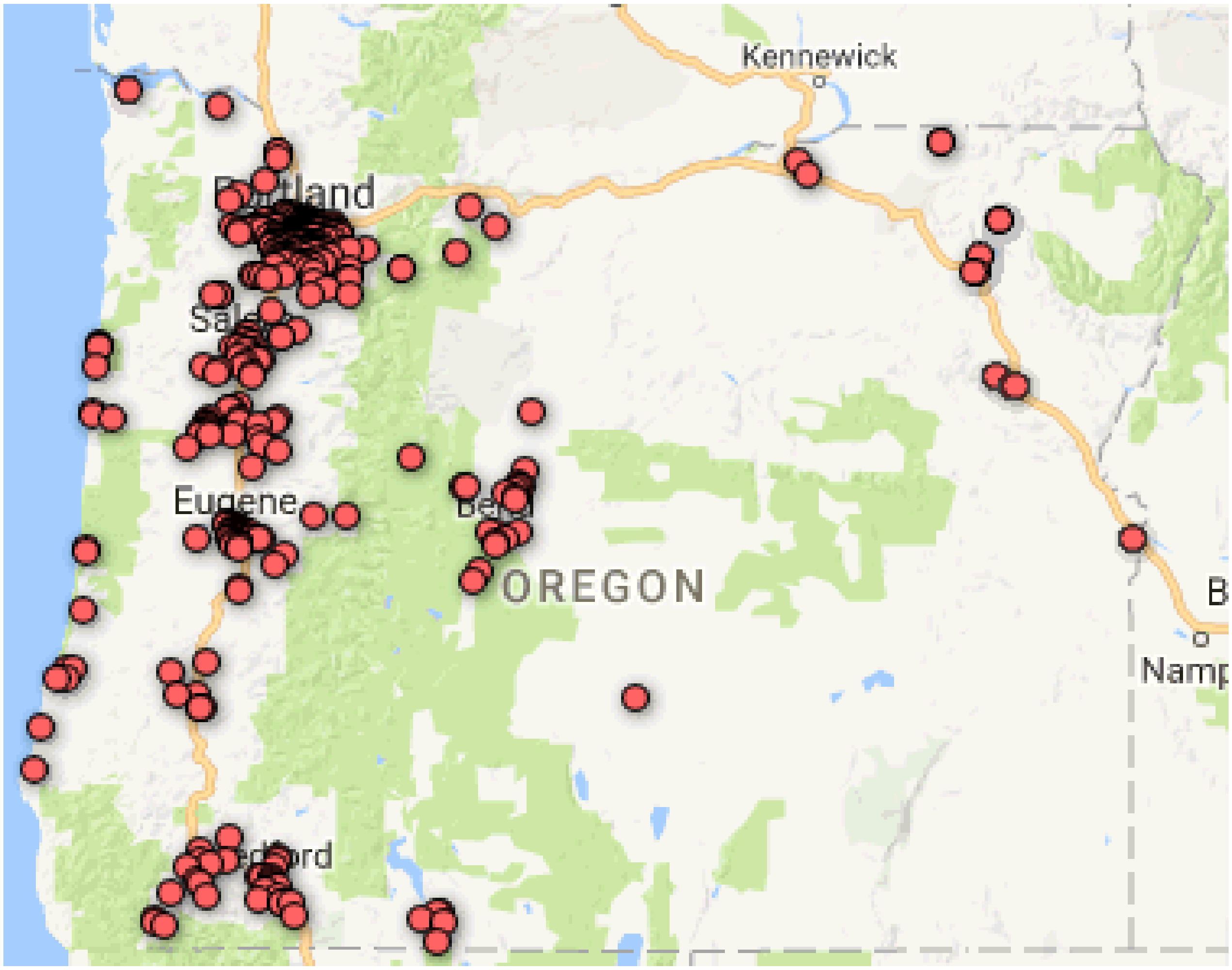

Figure 2. Geographic Distribution of Respondents

Source: Hurwitz et al 2018

Table 1. Summary of Literature Review Findings

Study	Objective	Methodology	Key Findings
Asante and Williams, 1993	Evaluated simultaneous use of green arrow indication with CG or CR in the five-section PPLT display.	• Field studies were conducted at more than 100 sites. • Surveys were mailed to 6,000 Texas residents and 902 surveys were returned.	• 80% of Texas drivers correctly understood the GA protected indication when presented in a five-section horizontal display. • Higher comprehension rates when only the GA was displayed compared to when both GA and CG were displayed. • Recommended against using simultaneous displays of GA and CR indications in a five-section PPLT display.
Bonneson, 1993	Evaluated driver comprehension of protected and permitted signal indication in the five-section horizontal, vertical and cluster display for PPLT signal displays in Nebraska.	• Surveys with 115 responses received for each display/indication combination.	• GA indication in the five-section cluster display had the highest level of driver understanding. • GA with the CG indication in a five-section horizontal display had a higher level of driver understanding. • Comprehension rates were lower by 10% when the protected indication with simultaneous indication was shown.
Noyce and Kacir, 2001	Evaluated driver understanding of protected and PPLT displays including simultaneous GA and CR or CG indications and those with green arrow indications only as part of NCHRP 493	• Computer-based driver survey that was completed by 2,465 drivers at eight locations. • A total of 73,950 survey responses were received pertaining to 200 different survey scenarios.	• Simultaneous display of the CA and CR indications in a five-section PPLT signal display during a protected left-turn phase significantly reduced driver comprehension and increased driver error. • Simultaneous display of the GA and CG indications also reduced driver comprehension when compared to the green arrow only indication, although the differences were not statistically significant. • Drivers over the age of 65 had lower comprehension rates.
Drakopoulos and Lyles, 2001	Evaluated driver comprehension of left-turn signals.	• Static survey of 191 respondents using slides.	• Comprehension was found to deteriorate with age. • Flashing signals were not well understood.
Brehmer et al. 2003	Evaluated driver comprehension of static PPLT signal displays following driver simulator experiments as part of NCHRP 493.	• Six static computer-based evaluations of 436 drivers for twelve PPLT signal displays using either five-section cluster, five-section vertical or four-section vertical displays were conducted.	• Overall, driver comprehension was high (83%). • Permissive indication comprising of both FYA and CG/FYA simultaneous indication had significantly more correct responses than displays with CG indication only.

Study	Objective	Methodology	Key Findings
			• Displays with CG had higher fail-critical responses than displays with either FYA or CG/FYA permissive indications. • Statistically significant differences in comprehension rates were also observed with respect to age, education, and driving experience.
Noyce and Smith, 2003	Evaluated driver comprehension and response to combinations of five-section PPLT signal displays (horizontal, cluster, and vertical) and permissive left-turn indications (CG, flashing CR, flashing CY, FYA, flashing RA indications in five-section signal displays	• Driving simulator experiment followed by a computer-based static survey. • Thirty-four drivers were presented with 15 PPLT signal displays on a computer.	• Type of five-section PPLT signal arrangement has little effect on driver comprehension of the permissive left-turn operation. • Type of permissive indication used in the five-section PPLT display had significant effect on driver comprehension. • CG, FYC, and FYA had higher comprehension rates. • Five-section horizontal arrangement with FYA had the highest level of driver comprehension.
Knodler et al. 2005	Evaluated driver comprehension and behavior with an FYA permissive indication when they appear simultaneously with another indication in the same signal display	• Driving simulator experiment followed by a computer-based static survey and an independent static survey of 264 respondents.	• Four-section vertical signal display for FYA was preferred. • Retrofit of the five-section cluster display did not impact comprehension rates.
Knodler et al. 2006a	Evaluated impact of FYA on pedestrians including driver comprehension of the need to yield to pedestrians and pedestrians' recognition of crossing opportunities	• Driving simulator experiment followed by a computer-based static survey and an independent static survey of 139 respondents.	• Higher comprehension regarding yielding to pedestrians was observed in the static environment than the simulator. • CG permissive indication was associated with a higher number of "GO" responses, while FYA was associated with a higher number of "YIELD" responses at T-intersections.
Knodler et al. 2006b	Evaluated driver comprehension of FYA permissive indications compared with FRA indication at locations with wide medians	• Driving simulator experiment followed by a computer-based static survey and an independent static survey of 264 drivers.	• FYA indication was associated with a high level of driver comprehension. • Compared to FYA, FRA resulted in significantly fewer fail-critical errors at intersections with wide medians.
Knodler et al. 2007	Quantified the impact of solid yellow arrow (SYA) resulting from exposure to FYA on driver comprehension	• A computer-based survey of 212 drivers conducted both pre and post training.	• No evidence to suggest that FYA negatively affects the driver's understanding of the SYA.

Study	Objective	Methodology	Key Findings
			• Differences between responses pre and post training were not fail-critical.
Henery and Geyer 2008	Evaluated driver comprehension of FYA indication using four and five-section heads	• Computer-based survey of 204 drivers consisting of questions on the FYA indication and left turn yield on green signal with R10-12 sign	• Driver comprehension of CG with supplemental R10-12 sign higher than FYA without the sign.
Schlattler et al. 2013	Evaluated driver comprehension of FYA indications	• Online static survey of 363 drivers that included both protected and permitted indications of PPLT phasing.	• High comprehension rates were found for CG and FYA permissive left-turn indications. Some fail-critical responses were observed with CG indication. • Use of a supplemental sign (left-turn yield on flashing arrow) increased driver comprehension of FYA and reduced fail-critical responses.
Boot et al. 2015	Evaluate a new flashing pedestrian indicator (FPI) that alternated between a yellow arrow and a pedestrian symbol	• Two online static surveys of 45 and 46 drivers. The first survey evaluated the comprehension of the flashing pedestrian indicator, and the second survey evaluated drivers' responses to actions when faced with FPI and other signal indications.	• Drivers generally understood the meaning of FPI; however confusion was observed among drivers proceeding through the intersection. • FPI was associated with significantly more yielding to pedestrians.
Ryan et al. 2019	Evaluate the effectiveness of FYA for right turn applications	• An online static survey consisting of over 200 participants and driver simulator study consisting of 24 participants,	• Drivers have a strong comprehension of the FYA indication. • Drivers understood that when a circular green indication was paired with an FYA, they needed to yield as compared to a circular green indication alone. • Drivers also spent more time observing the FYA indication as compared to the circular green indication.

Table 2. Survey Sampling Scheme and Response Rates

County	Population	Percentage of Population	Number of Postcards Sent	Responses	Response Rate	Percentage of Sample Response	Difference in Percentage
Baker	16,425	0.41	41	4	10%	1.0	0.6
Benton	90,005	2.24	197	13	7%	3.3	1.0
Clackamas	397,385	9.90	983	52	5%	13.0	3.1
Clatsop	37,750	0.94	93	1	1%	0.3	-0.7
Columbia	50,390	1.26	131	5	4%	1.3	0.0
Coos	62,990	1.57	151	5	3%	1.3	-0.3
Crook	21,085	0.53	55	-	-	-	
Curry	22,470	0.56	55	1	2%	0.3	-0.3
Deschutes	170,740	4.25	422	17	4%	4.3	0.0
Douglas	109,910	2.74	273	8	3%	2.0	-0.7
Gilliam	1,975	0.05	4	-	-	-	
Grant	7,430	0.19	18	-	-	-	
Harney	7,295	0.18	17	-	-	-	
Hood River	24,245	0.60	59	2	3%	0.5	-0.1
Jackson	210,975	5.26	512	20	4%	5.0	-0.2
Jefferson	22,445	0.56	52	2	4%	0.5	-0.1
Josephine	83,720	2.09	211	11	5%	2.8	0.7
Klamath	67,110	1.67	161	5	3%	1.3	-0.4
Lake	8,010	0.20	20	1	5%	0.3	0.1
Lane	362,150	9.02	893	41	5%	10.3	1.3
Lincoln	47,225	1.18	116	7	6%	1.8	0.6
Linn	120,860	3.01	321	12	4%	3.0	0.0
Malheur	31,480	0.78	73	1	1%	0.3	-0.5
Marion	329,770	8.22	811	20	2%	5.0	-3.2
Morrow	11,630	0.29	30	-	-	-	
Multnomah	777,490	19.37	1885	108	6%	27.1	7.7
Polk	78,570	1.96	188	5	3%	1.3	-0.7
Sherman	1,790	0.04	4	-	-	-	
Tillamook	25,690	0.64	64	-	-	-	
Umatilla	79,155	1.97	194	4	2%	1.0	-1.0
Union	26,625	0.66	65	5	8%	1.3	0.6
Wallowa	7,100	0.18	18	-	-	-	
Wasco	26,370	0.66	66	1	2%	0.3	-0.4
Washington	570,510	14.21	1425	41	3%	10.3	-3.9
Wheeler	1,445	0.04	4	-	-	-	
Yamhill	103,630	2.58	262	7	3%	1.8	-0.8
Total	4,013,845	100.0	9,874	399	4%	100.0	

Table 3. Demographic Comparison between Survey and Census

Category	Demographic Variable	Survey Percentage	Census Percentage	Difference
Gender (n = 397)	Male	60.7	49.2	11.5
	Female	39.3	50.8	-11.5
Age (n = 399)	18-24	2.0	*	
	25-34	8.3	13.7	-5.4
	35-44	15.3	13.1	2.2
	45-54	14.5	14.1	0.4
	55-64	29.3	13.3	16.0
	65+	30.6	13.8	16.8
Race (n = 375)	American Indian or Alaska Native	0.5	1.1	-0.6
	Asian	2.1	3.6	-1.5
	Black or African American	0.5	1.7	-1.2
	Hispanic or Latino/a	2.4	11.7	-9.3
	White or Caucasian	92.5	78.5	14.0
	Other	1.9	3.3	-1.4
Income (n = 336)	Less than $25,000	9.2	23.6	-14.4
	$25,000 - $50,000	19.2	23.2	-4
	$50,000 - $75,000	21.4	17.0	4.4
	$75,000 - $100,000	21.1	11.5	9.6
	$100,000 - $150,000	19.6	13.4	6.2
	$150,000 - $200,000	6.3	5.7	0.6
	$200,000 or more	3.3	5.6	-2.3
Education (n = 380)	No schooling, or less than 1 year	0.0	4.1	-4.1
	Kindergarten, elementary grades (1-8)	0.0		
	High school (grades 9-12, no degree)	2.0	6.5	-4.5
	High school graduate (or equivalent)	6.1	24.5	-18.4
	Some college (1-4 years, no degree)	19.5	26.6	-7.1
	Associate degree	11.6	8.2	3.4
	Bachelor’s degree	34.7	18.9	15.8
	Master’s degree	20.3		
	Professional school degree	5.0	11.2	19.1
	Doctorate degree	5.0		

*Survey required respondents to be 18 or older. Census age groups are 15-19 (6.7%) and 20-24 (6.6%), so can not tabulate.

Table 4. Sample Characteristics

Category	Demographic Variable	Survey %
Driving Frequency	Less than 1 time per week	2.0
	1 time per week	0.8
	2 – 4 times per week	15.0
	5 – 10 times per week	32.1
	More than 10 times per week	50.1
Driver’s License	1 – 2 years	0.5
	3 – 5 years	1.5
	6 – 10 years	2.3
	10+ years	95.7
Miles Driven per Year	Less than 5,000	14.3
	5,000 – 9,999	27.8
	10,000 – 14,999	30.3
	15,000 – 19,999	16.8
	Greater than 20,000	10.8
Oregon Driver’s License	Yes	97.7
	No	2.3
Color Blind	Yes	2.5
	No	96.5
	Don’t want to provide this information/Don’t Know	1.0
Corrective Glasses or Contacts	Yes	65.0
	No	34.0
	Don’t want to provide this information/Don’t Know	1.0

Table. 5. Error Coding of Narrative

Display Indication	**Correct**	**Partially Correct**	**Incorrect**
Circular Green	Turn right with caution after yielding to pedestrians in the crosswalk	Turn right without stopping but failed to state that they would yield to pedestrians if present in the crosswalk	Stop before turning
Green Arrow	Turn right without stopping recognizing that the steady green arrow indication means a protected movement (or) Indicated that they would watch for pedestrians who may cross against the pedestrian Don't Walk signal	Check for pedestrians and turn right (or) slow down and check for pedestrians and other cross-traffic but did not recognize the protected movement in either case	Stop before turning
Circular Red and Red Arrow	Come to a complete stop and complete the turn when they found a safe gap or remained stopped if they failed to find a gap	Stop or turn right, without providing additional details	Stop and remain stopped until the green indication
Flashing Yellow Arrow	Turn right with caution after yielding to pedestrians in the crosswalk	Turn right without stopping or failed to state that they would yield to pedestrians if present in the crosswalk	Stop before turning

Table 6. Cohen's Kappa Coefficient Estimated Values

Category	Kappa Trial 1 (with)	Kappa Trial 1 (without)	Kappa Trial 2 (with)	Kappa Trial 2 without)	Kappa Trial 3 (with)	Kappa Trial 3 without)
Circular Green	0.86	0.88	1.00	1.00		
Green Arrow	0.77	0.65	0.75	0.74	1.00	1.00
Circular Red	0.79	0.84	1.00	1.00		
Red Arrow	0.89	0.91	1.00	1.00		
FYA	0.86	0.81	1.00	1.00		

Table 7. Percent of Comprehension by Coded Responses and Proportions Test

Coding of Response	GA				CG				FYA			
	Total	**with**	**without**	**p-value**	**Total**	**with**	**without**	**p-value**	**Total**	**with**	**without**	**p-value**
n	397	195	202		398	195	203		398	195	203	
Incorrect	4	3	4	0.47	2	2	2	0.78	20	16	23	0.11
Partially correct	33	28	37	0.06	25	28	21	0.1	4	3	5	0.21
Correct	63	68	58	0.03	73	69	76	0.14	76	81	72	0.05

Coding of Response	CR				RA			
	Total	**with**	**without**	**p-value**	**Total**	**with**	**without**	**p-value**
n	398	195	203		397	195	202	
Incorrect	10	10	9	0.26	40	34	46	0.02
Partially correct	7	9	5	0.2	7	8	7	0.77
Correct	83	81	85	0.76	52	58	46	0.01

Note: percentage responses rounded to the nearest integer for table, may not sum to 100%

Table 8: Definitions and summary statistics of significant variables in final models

Variable	Description	Mean	Standard Deviation
DLYR	Years of holding driver's license (0 = less than 10 years, 1 = More than 10 yrs)	0.95	0.20
Miles	Miles driven per year Low:(1 = less than 10,000 miles, 0 = Otherwise)	0.42	0.49
ORDL	Holding Oregon driving license (1 = yes, 0 = otherwise)	0.97	0.14
Gender	Gender (1 = Male, 0 = Female)	0.60	0.49
RTO	Signs (1 = with, 0 = without)	0.49	0.50
Education	Education HS:(1 = High school graduate or equivalent, 0 = Otherwise)	0.07	0.26
Age	Age of respondent	55.22	14.36

Table 9: Parameter estimates of the logistic regression model for correct/incorrect response

Variables	GA		CG		FYA_{RT}		CR		RA	
	Coef (OR)	**Z-Value**	**Coef (OR)**	**Z-Value**	**Coef (OR)**	**Z-Value**	**Coef (OR)**	**Z-Value**	**Coef (OR)**	**Z-Value**
Constant	4.62	3.43	3.48	2.69	0.25	0.27	3.54	4.64	0.45	1.03
Age	-0.07 **(0.93)**	-3.14	-0.03 **(0.97)**	-1.21	-0.02 **(0.98)**	-1.95	-0.01 **(0.98)**	-1.20	-0.01 **(0.99)**	-1.09
Gender	-	-	-	-	0.62 **(1.87)**	2.35	-	-	-	-
Signs	-	-	-	-	0.46 **(1.59)**	1.73	-	-	0.51 **(1.67)**	2.41
OR Driver's License	-	-	-	-	1.68 **(5.39)**	2.11	-	-	-	-
High School Education	-1.21 **(0.30)**	-1.80	-1.97 **(0.14)**	-2.53	-0.57 **(0.56)**	-1.26	-0.98 **(0.37)**	-1.94	-	-
Low Annual Miles	-	-	-	-	-	-	-0.87 **(0.42)**	-2.47	-	-
Years of Driver's License	2.99 **(19.93)**	2.72	2.39 **(10.92)**	2.11	-	-	-	-	-	-
Model Summary										
Number of Observations	267		298		377		367		368	
Deviance Test (P-value)	0.99		0.99		0.59		0.99		<0.001	
Pearson Test (P-value)	0.16		0.16		0.37		0.48		0.47	
Hosmer-Lemeshow Test (P-value)	0.10		0.24		0.52		0.30		0.96	

*OR: Odds Ratio