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EXAMINING DRIVER PREFERENCES FOR INTELLIGENT AUDIOVISUAL WARNINGS AT HIGHWAY-RAIL GRADE CROSSINGS

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EXAMINING DRIVER PREFERENCES FOR INTELLIGENT AUDIOVISUAL WARNINGS AT HIGHWAY-RAIL GRADE CROSSINGS

By

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Author Contribution Statement

The idea for this study was developed jointly by Dr. Elizabeth Veinott and Samantha Walker. The data collection, analysis, and writeup was conducted by Samantha Walker with input and edits from Dr. Elizabeth Veinott.

Definitions

Active Crossing: an HRGC with dynamic warning devices, such as gates, bells, and lights.

Activated Crossing: an active HRGC where the dynamic warning devices are in use.

Active Crossing Ahead Alert: This yellow audiovisual warning alerts the driver that there is an active crossing ahead and warning devices are activated.

Active Crossing Warning Violation: This red audiovisual warning alerts the driver that at current speeds and distance to the highway-rail grade crossing intersection, a crossing violation is predicted to be imminent.

Audiovisual Warning: A warning that contains an earcon or speech with a corresponding visual.

Grade Crossing: A crossing that intersects with a road on the same level

Message Length: Short (2-3 seconds) or Long (4-5 seconds) warning

Message Content: Warning (informing the driver of a situation) or Action (telling the driver to do something)

Passive Crossing: an HRGC with only static warning devices (signs, road markings)

Vehicle Stopped on Tracks Warning: This red audiovisual warning alerts the driver that they are on an active and activated rail crossing track and need to drive off immediately.

List of Abbreviations

ANOVA - Analysis of Variance

CV - Connected Vehicle

FRA - Federal Railroad Administration

HRGC - Highway-Rail Grade Crossing

IVAA - In-Vehicle Auditory Alert

ITS - Intelligent Transportation Systems

PCA - Principal Component Analysis

RCVW - Rail Crossing Violation Warning

V2I - Vehicle-to-Infrastructure

V2V - Vehicle-to-Vehicle

Abstract

Driver noncompliance and poor decision-making are known contributors to highway-rail grade crossing incidents and accidents. Recent advances in intelligent in-vehicle warning systems have provided new opportunities for improved safety at highway-rail grade crossings. Intelligent warning systems that can communicate between connected vehicles and the infrastructure (V2I) have been proposed to improve safety. However, limited human factors research has been conducted regarding how drivers might react to these in-vehicle warnings. This study evaluated driver preferences, use cases, and message design variations for in-vehicle audiovisual warnings for rail crossing warning violations by varying two message factors: message length and whether the message content is a warning or a call to action. Results indicated that both message length and message content affected driver preferences and perceived usefulness depending on the type of highway-rail grade crossing scenario. These results have implications for future research implementing rail crossing warning systems and driving simulator behavior research.

1. Introduction

Driver decision-making is a critical factor involved in driver behavior and driver safety, especially around highway-rail grade crossings (HRGCs) (Linja et al., 2020). Many incidents and accidents involving a train and a crossing vehicle that occur at an HRGC are due to driver inattention and poor decision-making (Lenné, 2011; Zhou et al., 2020). Between 2008 and 2017, over 19,000 accidents occurred between a train and a crossing vehicle at an HRGC in the United States (Federal Railroad Administration, n.d.). A total of 2,384 of these accidents occurred due to drivers making the conscious choice to drive around or through the crossing gates after they had been activated. There were 7,691 accidents where drivers did not stop for a train and 5,216 accidents where a driver stopped on the train tracks while a train was approaching. Many of these accidents occurred at an active crossing, where dynamic warning devices such as gates, lights, and bells were present (Federal Railroad Administration, n.d.). Despite the warning devices present, drivers continue to ignore these warnings and make poor decisions, leading to higher accident rates at HRGCs.

A highway-rail grade crossing (HRGC) is a rail crossing that intersects with a highway on the same level (Dulebenets & Goniewicz, 2021; FRA, 2019). There are two types of HRGCs: active and passive. Active crossing have dynamic warning devices, such as lights, bells, and gates installed, while passive rail crossings do not have these warning devices, and may only have signage to alert to driver of the presence of a train. Activated crossings are active crossings where dynamic warning devices are in use to signal that something is occurring at the rail crossing, such as a train approaching (FRA, 2019).

Dynamic (active) warning devices, such as bells, lights, and gates, have been added to many crossings as a way to improve driver safety and influence driver behavior at HRGCs. However, research has shown that drivers are not paying attention to the added warning devices when approaching and crossing the HRGC (Young, 2015). Young (2015) found that drivers were paying more attention to the behavior of other drivers to inform their decisions about how to behave at an HRGC. Driver uncertainty may also be an important factor that affects driver decision-making at HRGCs. Many drivers are unsure of how to behave when approaching and crossing an HRGC, which may lead to poor decision-making This also leads to higher rates of driver non-compliance to road rules and safety at HRGCs, ultimately contributing to higher rates of collisions at HRGCs (Beanland et al., 2017).

Driver noncompliance from expected driving behavior is one of the largest contributing factors to incidents and accidents involving train and road vehicles at HRGCs (Beanland et. al., 2017; Yeh & Multer, 2008). While solutions such as dynamic warning devices have been explored to improve safety, recent advancements in intelligent transportation systems (ITS) technology provide a different way of improving safety by implementing intelligent in-vehicle audiovisual warnings.

To mitigate the likelihood of driver noncompliance and poor decision-making at HRGCs, research has been conducted on the effectiveness of in-vehicle audio and visual warnings in influencing driver behavior and increasing driver safety. In-vehicle audio and or visual warnings, have been tested as effective tools for improving safety in many driving situations (Duan et al., 2023; Mortimer, 1991). However, very little research has been conducted on driver preferences for these in-vehicle warnings or how these preferences may influence the perceived usefulness of in-vehicle warnings. Two classes of warnings that were evaluated in this thesis include warnings varied by content, that is, the messaging provided in the warning that tells information to the driver, and the length of the audiovisual warning (short messaging vs. long messaging).

In the Rail Crossing Violation Warning (RCVW) System, a prototype warning system developed by the U.S. Department of Transportation, Federal Rail Administration (FRA) in partnership with Battelle, these types of intelligent warnings have been used to increase the capabilities of in-vehicle audiovisual warnings at different rail crossing scenarios (Neumeister et al., 2017; Withers & Utterback, 2021). This system has recently been tested in the field and in an on-the-road driver evaluation study (Zhang et al., 2023).

1.1 Audio and Visual In-Vehicle Warnings

In-vehicle auditory alerts are a prominent field of research for improving driver decision-making behavior. Research has shown that the addition of an audible warning can improve driver behavior in many situations, including traffic issues, speeding, distracted driving, and accident prevention (Duan et al., 2023; Chen et al., 2005, Yan et al., 2016). Audio warnings most commonly consist of an earcon (sound), speech, or a combination of an earcon followed by speech, also known as hybrid alerts (Blattner, 1989; Landry et al., 2019; Nadri et al., 2021).

Through the use of surveys and driving simulator studies, research has found that effective in-vehicle audio warnings are attention-capturing, distinctive, and do not lead to the driver turning them off (Baldwin, 2011; Yan et al., 2016). In driving simulator studies conducted by Baldwin (2011), driver's rated in-vehicle auditory warnings perceived urgency, annoyance, and perceived effectiveness. depended on the message content and intensity. Baldwin (2011) found that the messages tailored to a specific situation were more effective than general warnings. In addition to message content and intensity of the warning, other research has shown that frequency, environment and the timing of the warning relative to the location of the vehicle all impact how the warning is perceived, and thus its effectiveness (Gray, 2011; Hellier et al., 2002; Nadri et al., 2021; Nadri et al., 2023).

Visual warnings are another form of in-vehicle warning designed to influence driver behavior in many scenarios, including speeding, driver decision-making, and traffic issues (Hajiseyedjavadi et al., 2018; Mortimer, 1991). Visual warnings typically consist of an image that informs the driver of a change in their driving environment that requires a change in driver behavior (van der Heiden et al., 2019). Yang & Kim (2017) evaluated the effect of a visual stimulus in an on-road study on lane deviation and found that the added visual improved driver gaze behavior and did not affect cognitive workload. Similar to audio warnings, visual warnings are effective in influencing driver behavior without increasing the mental workload of the driver (Yang & Kim, 2017).

1.2 Intelligent Multimodal Warning Systems

Intelligent multimodal systems may improve driver safety by combining audio and visual warnings and tailoring the warning content and timing of the warning depending on the state of the environment. Intelligent in-vehicle warning systems further the effectiveness of in-vehicle warnings by increasing the vehicle intelligence of the vehicle itself and the surrounding environment (Harris et al., 1998). These warnings are unique as they adapt to changes in the environment and in the behavior of the driver, such as increasing in intensity if the driver continues to ignore the warning (Horberry et al., 2021). Intelligent warnings rely on connected vehicle technology. Connected vehicles (CVs) have the capability for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) connections and therefore are leveraged in studies with intelligent warning systems (Hsu & Jones, 2017). Intelligent in-vehicle warning systems can connect a CV to existing road infrastructure, providing a V2I connection, which provides drivers with knowledge about the state of the environment around the infrastructure before they approach it (Zhou & Zhang, 2021). These warnings have proven to be effective in altering driver behavior in many areas, including reducing driver distraction, lane deviation, and speed (Horberry et al., 2021; Starkey et al., 2020).

The implementation of intelligent in-vehicle audiovisual warnings has also been studied in the rail crossing context with driving simulator scenarios that can change depending on the context at the HRGC. Larue et al. (2015a) examined the effectiveness of multiple types of ITS warnings at HRGCs through the use of a driving simulator to determine what warnings impact driver behavior. The results showed that intelligent in-vehicle audio and visual warnings had the most significant impact on driver behavior, especially in comparison to on-road warnings.

Recently, Zhang et al. (2023) tested the effect of intelligent in-vehicle audiovisual warnings at HRGCs in an on-road study using the prototype RCVW system. Drivers drove a 12- mile loop with several HRGCs, some with the RCWV system in use, and then were interviewed about their experience. Results indicated that many of the participants found the prototype system to be beneficial to their attention at the HRGC. They also highlighted the potential usefulness of the RCWV system and in-vehicle intelligent audiovisual warmings for distracted drivers and unfamiliar routes.

Veinott et al. (2023) conducted an interview study with rail experts, and found that for in-vehicle warnings to be effective, the warning content and timing needed to match the road experience of the driver. In other words, the in-vehicle warning needs to be able to change to match what is happening in the surrounding environment and where the vehicle is on the road. Intelligent warnings are able to tailor these aspects of the warnings to support expected driver needs. While there is a small but growing body of research on intelligent in-vehicle audiovisual warnings, research regarding driver preferences for these warnings is limited (Dam et al., 2024; McCoy, 2023; Nadri et al., 2021). Earcon warnings alert the driver to a change in the situation that they may need to address, but do not provide the driver with additional information about what to do or what the state of the environment is. In critical situations that may occur at an HRGC, messages with speech that either warn the driver of a situation or call the driver to action may be preferred to a simple warning bell with the RCVW visual. Intelligent warnings could address this need for tailoring, but more research is needed. The purpose of this thesis is to conduct an initial study to explore message preferences based on core factors of intelligent warnings (e.g., timing, message length, message content).

While intelligent warnings have the potential to be effective, there may be unintended side effects that need to be considered in any intelligent warning system. For example, these warning systems may lead to overreliance on the system if used too frequently.. Tan et al. (2022) experiment showed that if a a driver is too reliant on a system, they may have an overall decrease in situational awareness, attention, and performance while driving. This is especially important to consider if the warning system fails or is not able to be used while driving. If drivers become over-reliant on an intelligent warning system and it is not in use, there may be an increased likelihood of collision (Tan et al., 2022). Intelligent warnings should not lead to a decrease in driver attention and perception due to overreliance, but rather assist drivers improve their behavior and increase safety. This thesis is intended to systematically examine what drivers prefer in an intelligent in-vehicle warning and understand what factors may help increase driver awareness and attention when approaching and crossing a highway-rail grade crossing.

1.3 Driver Preferences and Acceptance of In-Vehicle Warnings

In-vehicle warnings have been shown to be effective at altering driver behavior, but may only be effective if the driver is willing to adhere to the warning (Larue et al., 2015a; Nadri et al., 2021). Studies have been conducted to evaluate how drivers perceive in-vehicle warnings and the likelihood of acceptance into the vehicle as a method of understanding the effectiveness of in-vehicle warnings. Larsson et al. (2009) found that emotional responses to auditory warnings impacted the driver's behavior toward the warning, and thus impacted the effectiveness of the warning.

Nadri et al. (2021) conducted a subjective ratings study using driver preferences to evaluate the effectiveness of hybrid auditory alerts at HRGCs compared to earcon (sound) only and speech-only alerts. Twenty-four participants watched a scenario in a driving simulator, then heard 12 different warnings and made a series of 11 subjective ratings after each warning. Results indicated that aspects of the hybrid alert were perceived to be the most attention capturing, most accepted warning, and were rated the highest in hazard level. This study demonstrated that in-vehicle auditory alerts have the potential to be effective at altering driver behavior at highway-rail grade crossings.

Two of the most commonly evaluated emotional responses to in-vehicle warnings are urgency and annoyance (Baldwin, 2011; McCoy, 2023). These two responses are important factors to consider in driver preferences for in-vehicle warnings, as the urgency of the situation and the warning may affect the way a driver behaves. Similarly, the level of annoyance a driver feels toward the warning may influence them to turn the warning off, making it ineffective (Nadri et al., 2021). McCoy et al. (2023) evaluated driver preferences of annoyance and urgency by using in-vehicle audio, visual, and audiovisual alerts. To test this, they had 21 participants rate 32 warnings (8 visual, 8 audio, 16 audiovisual) on their perceived levels of urgency and annoyance after watching videos from a driving simulator of when these warnings would be used. The results of this study found that the context in which the warning is played affects the perception of the warning, and that color may affect the perceived urgency of the warning. While not in the same context as the current study, McCoy et al. (2023) shares a valuable insight into why driver preferences are important to consider in the design and implementation of in-vehicle warnings.

A recent study by Dam et al. (2024) used driver preferences to evaluate variations in message timing and message length for in-vehicle warnings in the rail crossing context. This study had 26 participants rating 16 audio warnings on 32 dimensions. The results of this study found that the timing of the warning and the length of the warning were dependent on the context and location of the driver, such as a shorter messaging being preferred closer to the crossing, and a longer messaging being preferred farther out from the crossing.

1.4 Rail Crossing Violation Warning System

The Rail Crossing Violation Warning (RCVW) System is a prototype system developed by the Department of Transportation, Federal Rail Administration, and the Battelle Memorial Institute to leverage connected vehicle (CV) connectivity (Neumeister et al., 2017; Withers & Utterback, 2021). This system provides a vehicle-to-infrastructure (V2I) connection that allows for communication between an approaching connected vehicle and the physical infrastructure of an HRGC to provide the driver with information about the state of the active crossing before they reach it. The RCVW system combines in-vehicle audiovisual warnings (earcon + visual) to alert drivers of the state of an active HRGC (Withers & Utterback, 2021). The alerts and warnings depend on the status of the vehicle and the HRGC. Currently, five visuals are included in the RCVW system. Two of these visuals provide system availability information (i.e., vehicle to infrastructure connection is in range or not). The three other prototype RCVW audiovisual warnings that are the focus of this thesis are described briefly below.

1.4.1 Active Crossing Ahead Alert

The Active Crossing Ahead Alert occurs when the RCVW system is available and the HRGC is activated (meaning bells, lights and gates are in use) (Figure 1). This alert informs drivers that there may be a train or other reason for the HRGC being activated at the crossing ahead. When this alert is displayed, no driving violation is anticipated. In the current experiment, this alert is referred to in shorthand as the *alert condition*.

Figure 1. Active Crossing Ahead Alert visual for RCVW System (Withers & Utterback, 2021)

1.4.2 Active Crossing Warning Violation

The Active Crossing Warning Violation is activated if a driving violation (e.g., high speed) is likely at an activated HRGC (Figure 2). This warning is more urgent and urges the driver to take action to avoid a violation at the HRGC. This warning is referred to in shorthand as the *violation condition* within the experiment conducted.

Figure 2. Active Crossing Warning Violation visual for RCVW System (Withers & Utterback, 2021)

1.4.3 Vehicle Stopped on Tracks Warning

The Vehicle Stopped on Tracks Warning indicates that the vehicle is actively stopped on the railroad tracks and must move immediately (Figure 3). Unlike the Active Crossing Ahead Alert and the Active Crossing Warning Violation, this warning is activated regardless of if the HRGC is activated. Within the experiment, this warning is referred to as the *on-tracks condition.*

Figure 3. Vehicle Stopped on Tracks Warning visual for RCVW system (Withers & Utterback, 2021)

2. Goals and Hypotheses

Intelligent in-vehicle audiovisual warnings have been studied in the rail crossing context through the use of driving simulators and on-road studies and have proven to be effective in changing driver behavior. However, little research has been conducted on driver preferences and perceived use cases for intelligent in-vehicle audiovisual warnings, and no research has been conducted on this using the recently developed RCVW prototype system. This thesis begins to explore whether replacing the earcon with a speech using warning messaging or action messaging is preferred by drivers at HRGCs. Driver ratings of emotional factors regarding in-vehicle audiovisual warnings has been studied previously, but studies have not evaluated perceived use-case scenarios for intelligent in-vehicle audiovisual warnings at HRGCs through open-ended responses in a rating study.

The purpose of this research is to evaluate three main research questions:

1. Does the message length and content (warning vs. action) affect driver reaction ratings for intelligent in-vehicle audiovisual warnings?
    a. Does it depend on the driver population (experienced vs. novice)?
2. Does the message length and content (warning vs. action) affect perceived driver usefulness for intelligent in-vehicle audiovisual warnings?
    a. Does it depend on the driver population?
3. Under what conditions do drivers think different warnings would be effective?

Research questions 1 and 2 will be evaluated by comparing the effect of message content and message length on preference ratings of meaningfulness, annoyance, distraction, urgency, and desire to turn off. These ratings will then be analyzed using a 2 (message length) x 2 (message content) x 2 (driver population) mixed-factorial ANOVA. Research question 3 will be evaluated using open-ended questionnaire responses.

The study was intended to gather information on driver preferences for in-vehicle audiovisual warnings at multiple HRGC scenarios, as outlined by the RCVW system. The three HRGC scenarios evaluated in this study were the active crossing ahead alert (alert condition), active crossing warning violation (violation condition), and the vehicle stopped on tracks (on tracks condition). This study also aimed to gain insight into what factors affect how drivers respond to in-vehicle warnings at HRGCs. It was hypothesized that driver preferences for in-vehicle warnings would vary across the three HRGC scenarios tested based on message content (warning or action messaging) and message length (short or long messaging).

3. Methods

This study examined driver preferences for intelligent in-vehicle warnings at highway-rail grade crossings through ratings and open-ended questions evaluating driver reactions to the warnings, use cases for the warnings, and appropriateness of the message design regarding message length and content.

3.1 Participants

Seventy-eight participants took part in this study (39 cis male, 36 cis female, 3 prefer not to say). Participants were recruited from Michigan Technological University's undergraduate psychology courses using SONA and through online recruitment via social media. Social media recruitment was shared through Facebook. Eligible participants needed to be at least 18 years old, have a valid U.S. driver's license for at least two years, have normal or corrected-to-normal hearing and vision, and be able to complete the study in English. Participants recruited via SONA received research credit for their participation. Participants average age and driving experience in the novice population and the experienced population differed. The novice population average age was 19 (M = 19.37 years, SD = 1.51) with 3.5 years of driving experience (M = 3.5 years, SD = 1.53). The experienced population averaged 59 years (M = 59.45 years, SD = 8.75), and had 43 years of driving experience (M = 43.75, SD = 9.61). The two samples of drivers were collected to evaluate the generalizability of the warning preferences.

To gain an understanding of how familiar participants may be with the rail context of the current study, participants estimated they crossed an average of 13.45 (M = 13.45, SD = 17.38) rail crossings per month in their hometown. Finally, 32 participants were from a rural area, 8 participants were from an urban area, and 38 were from a suburban area.

3.2 Experimental Design

This study used a 2 message length (short vs. long) x 2 message content (warning vs. action) x 2 driver population (experienced vs. novice) mixed-factorial analysis of variance design. Independent variables included message length and message content which were within-subjects variables, while driver population was between-subjects. The message length was either short (2-3 seconds) or long (4-5 seconds). Message content was either action (i.e. telling the driver what to do) or warning (i.e. informing the driver of a situation). The dependent variables included reaction ratings (meaningfulness, annoyance, distraction, urgency, and desire to turn off), use case ratings (usefulness in unfamiliar situations, familiar situations, rural areas, and urban areas), message design ratings (appropriateness of message length and message content), and coded data from the open-ended responses.

Audiovisual Warnings. A total of ten audio warnings were used in this study. Figure 4 shows the audio speech by condition used in this study for the three HRGC scenarios and their corresponding HRGC visuals. Conditions were randomized by HRGC scenario, and within each condition, the order of warnings was randomized.

Alert Condition - Active Crossing Ahead Alert			
	Warning Speech	Action Speech	RCVW Image
Short Speech	"Active Rail Crossing Ahead."	"Watch for train, rail crossing ahead."	
Long Speech	"Active rail crossing ahead. Proceed with caution."	"Watch for train, rail crossing ahead. Look left and right at crossing."	

Violation Condition - Active Crossing Violation Warning			
	Warning Speech	Action Speech	RCVW Image
Short Speech	"Rail crossing violation expected!"	"Slow down! Crossing violation expected!"	
Long Speech	"Going too fast! Rail crossing ahead! Violation expected!"	"Slow down, going too fast! Rail crossing violation expected!"	

On Tracks Condition - Vehicle Stopped on Tracks			
	Warning Speech	Action Speech	RCVW Image
Short Speech	"Car stopped on tracks!"	"Get off tracks! Move forward or back!	

Figure 4. Experimental conditions with audio message variations for each HRGC scenario

Reaction Questions. Participants first rated each audio on five preference variables: meaningfulness, distraction, urgency, annoyance, and desire to turn off, which may influence the effectiveness of an in-vehicle audio warning. All preference variables were rated on a scale from 0-10. These are standard preference variables used in a variety of audio ratings (Nadri et al., 2021).

Message Design and Use Case Questions. Rating questions were included to assess the appropriateness of warning length, warning content, and the usefulness of the warning in different driving situations (e.g., unfamiliar/familiar areas, rural/urban areas). All rating questions were presented on a scale from 0-10.

Open-Ended Questions to Assess Usefulness. In addition to subjective reaction and usefulness ratings, participants answered four open-ended questions to evaluate situations where providing audiovisual warnings would be effective.

1. When would you find this warning useful? Under what conditions?
2. Are there any driving situations where this warning might be annoying? Or might it result in you turning it off?
3. Please provide a brief explanation of your responses regarding rural and urban areas.

4. Imagine you are driving in inclement weather (heavy rain, heavy snow, etc.). Would you find this warning useful? If so, how?

Given these prototype warnings were designed to be part of an intelligent warning system, the open-ended questions were designed to further explore the potential applicability of the warnings in different driving scenarios.

It should be noted that the *on-tracks condition* only had one open-ended question regarding inclement weather. The other open-ended questions were not relevant since the warning is only activated in a very dangerous situation where a vehicle stops on the tracks, so they were not included. The alert and violation conditions contained all the open-ended questions because they could be activated in many different driving situations.

Attention Check Questions. Three attention-check questions were included to ensure participants were paying attention and reading questions entirely before responding. All attention check questions were designed to look similar to the open-ended questions but required the participants to respond with a certain word regardless of their actual response to the question. An example of one of the attention check questions is “Imagine you are driving with multiple passengers. Would you find this warning useful? Regardless of your answer, please enter ‘Wednesday’ in the space below”. These questions were distributed in random order, and required a different response word each time (e.g., “Wednesday”, “April”, etc.). Only participants with 2 out of 3 correct responses were included in the analysis. Based on this criterion, no participants were removed from the data analysis.

Open-ended Coding Scheme. Coding schemes were developed for each open-ended response question type. A total of five coding schemes were developed for the open-ended questions regarding usefulness, annoyance, rural/urban usefulness, inclement weather, and usefulness at passive HRGCs. Coding schemes were created and narrowed down to determine the top situations or conditions where drivers may find warnings useful. In a similar manner, responses about warnings not being useful were coded and analyzed for the top reasons warnings would not be useful in the HRGC scenarios.

3.3 Procedure

Participants were given access to the Qualtrics survey through an anonymous link which included informed consent and questions to determine eligibility. Once completed, participants were then asked about specific rail terms and received a short training for the RCVW visuals.

Participants were asked to define three technical rail terms as they understood them: active crossing, activated crossing, and passive crossing. Next, participants read a short training guide and completed a knowledge check questionnaire on the RCVW visuals to ensure that participants have an accurate understanding of the HRGC scenarios and the situations in which the audios being evaluated would be implemented (Appendix

A). When ready, participants were asked to complete three multiple-choice questions regarding the HRGC scenarios to demonstrate their understanding (Appendix A). If a participant responded incorrectly, they were redirected to the training guide to study and could retake the test.

Warning condition orders were randomized across participants. For each warning condition, participants watched a brief HRGC scenario video with the corresponding RCWV visual. These videos were recordings developed as part of Zhang et al. (2023) and provided for use in this study. Participants watched three HRGC videos, and after each video, participants listened to the audio warnings for that condition and rated each warning on the following dimensions: *meaningfulness*, *distraction*, *urgency*, *annoyance*, and *desire to turn off*. They next rated the appropriateness of the warning content, warning length, and the usefulness of the warnings in certain situations (e.g., urban settings, weather, etc.). Finally, participants answered a few open-ended questions about situations where the audio-visual warning may be useful and when it might be annoying. All ratings and open-ended questions can be found in Appendix B.

Once participants listened to all of the audio warnings and completed the appropriate questions for the first condition, they repeated this process for the other two HRGC conditions. After completion of all three conditions, participants evaluated the use of intelligent warnings and their potential effectiveness at passive HRGCs and completed one rating and one open-ended question. Finally, participants completed a standard demographics questionnaire that gathered information on age, gender, driving years since obtaining a valid U.S. license, hometown location (rural or urban area), and the average number of rail crossings crossed per month in the participant’s hometown.

4. Results

The rail terminology pretest accuracy percentages are in Table 1. For the ratings results, correlation matrices and principal component analyses (PCA) were run to first determine if ratings for each HRGC scenario were correlated with one another and to determine how much variability in the data was explained by each factor. Rating questions were analyzed using fit linear mixed-effect models in R studio to evaluate the reaction ratings, use case ratings, and message design ratings across all variations of each HRGC scenario and population group. Due to the limited driver population differences throughout the ratings results, the results below focus on the 2 message length vs. 2 message content design, and are presented this way graphically. Missing data were replaced with a mean score of the participant's responses for the audiovisual warning and rounded to the nearest whole number (Dodeen, 2003). Open-ended responses were coded using a developed coding scheme to characterize primary reasons and concerns with implementation if intelligent in-vehicle warnings, as well as to gather information about potential additional situations where drivers may desire an intelligent in-vehicle warning.

4.1 Rail Terminology Pretest

Participant understanding of technical terminology was for accuracy based on definitions of the terms from the Federal Railroad Administration and reported in Table 1 (FRA, 2019). Before the participants received the RCVW training, they were asked to define active crossing, activated crossing, and passive crossing before reading any additional information, including definitions of the terms.

Table 1
Percentage of Correct/Incorrect Responses for HRGC Terminology

	Active Crossing		Activated Crossing		Passive Crossing	
Participants (n = 78)	Correct	Incorrect	Correct	Incorrect	Correct	Incorrect
	16.7% (n = 13)	83.3% (n = 65)	34.5% (n = 30)	65.5% (n = 48)	24.6 % (n = 20)	75.4% (n = 58)

Results showed that a majority of people do not know these terms. For active crossing, 83.3 percent of participants incorrectly defined it. Examination of participant responses showed that the majority of participants who answered incorrectly defined an active crossing as a crossing that is in use. Participant definitions of activated crossings showed that 65.5 percent incorrectly defined the term. Incorrect responses reflected the same idea as in active crossings, as many participants who answered incorrectly for activated crossings also defined it as a crossing in use or with the potential for trains to cross. Finally, 75.4 percent of participants incorrectly defined passive crossings, with the most common definition being a crossing that is no longer in use. As these are technical terms, it is no surprise that the typical driver is unfamiliar with the terms.

4.2 Active Crossing Ahead Alert Condition

Responses in the alert condition (yellow) were analyzed using fit linear mixed-effect models and 2 (message length) x 2 (message content) x 2 (driver population) multivariate ANOVAs (analysis of variance) for each of the reaction ratings, use case ratings, and message design ratings. Again, due to the lack of driver population effects on ratings, the results reported below focus on the 2 message length x 2 message content (warning vs. action) on the subjective ratings.

4.2.1 Correlation Matrix and Principal Component Analysis

A correlation matrix was run to determine if any ratings were correlated with one another across the active crossing ahead alert condition (Figure 5). Ratings in this condition were highly correlated, meaning that the rating dimensions had a relationship that affected the ratings of the participants. In Figure 5, it is shown that rating dimensions such as the desire to turn off ("Off"), distraction ("Dist"), and annoyance ("Ann") were all highly positively correlated with one another, indicating that the ratings of each dimensions aligned with one another.

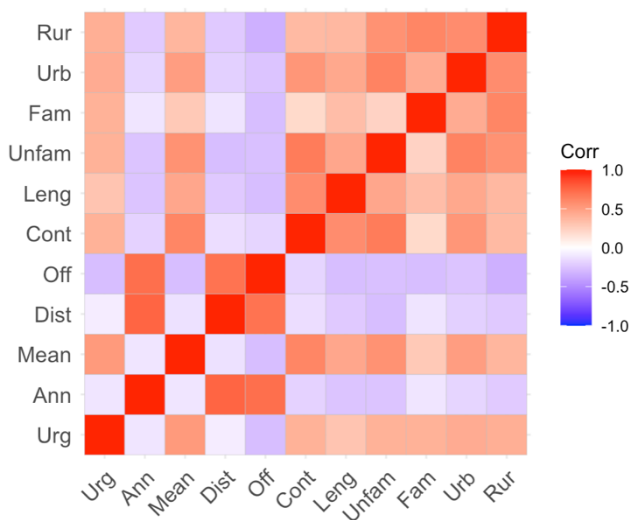

Figure 5. Correlation matrix for ratings results in the active crossing ahead alert condition

The ratings results in this condition were highly correlated (Figure 5). Table 2 shows all correlation values for the correlation matrix. A principal component analysis showed the 84.9 percent of the variance was explained by one dimension of the ratings (Figure 6). This again confirms that many of the ratings were correlated and that the participant ratings may be influenced by their rating of one dimension.

Table 2

Correlation Matrix for Rating Variable in the Active Crossing Ahead Alert Condition

	M	SD	1	2	3	4	5	6	7	8	9	10	11
1. Urgency	5.37	2.69	-										
2. Annoyance	4.34	2.86	-0.11*	-									
3. Meaningful	6.22	2.61	0.52	-0.11*	-								
4. Distraction	3.99	2.76	-0.08	0.76	-0.13*	-							
5. Turn Off	4.40	3.04	-0.28	0.72	-0.28	0.70	-						
6. Approp. Of Mess. Content	6.76	2.69	0.40	-0.19*	0.63*	-0.15	-0.18*	-					
7. Approp. Of Mess. Length	5.98	3.02	0.31	-0.25	0.46	-0.23	-0.28	0.58	-				
8.Use in Unfamiliar	6.94	2.76	0.40	-0.25	0.56	-0.28	-0.27	0.66	0.46	-			
9. Use in Familiar	3.23	3.15	0.40	-0.11*	0.28	-0.12*	-0.28	0.20	0.34	0.23	-		
10. Use in Urban	5.88	2.91	0.43	-0.18*	0.50	-0.20	-0.25	0.54	0.45	0.63	0.43	-	
12. Use in Rural	5.44	2.99	0.42	-0.22	0.38	-0.23	-0.34	0.36	0.37	0.56	0.62	0.58	-

*p<0.05

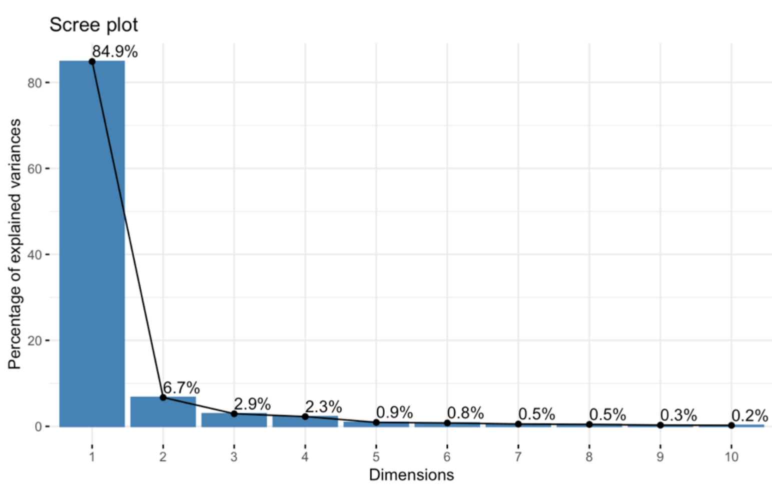

Figure 6. Scree plot for PCA variance in the active crossing ahead alert condition

4.2.2 Active Crossing Ahead Ratings Results

Reaction ratings included meaningfulness, annoyance, distraction, urgency, and desire to turn off. An overall 2 x 2 x 2 ANOVA was run to calculate the average rating for each type of rating (reaction ratings, use case ratings, and message design ratings). Table 3 shows the mean rating for each rating type in the active crossing ahead alert condition. Overall, participants rated the reaction ratings fairly low, indicating that there were not very strong factors that may influence driver preferences and use of warnings in this condition. The appropriateness of the message design had the highest rating in this condition, indicating the message content and message length impact driver preferences in this condition. Table 4 shows all mean reaction ratings for the active crossing ahead alert condition. Figure 7 shows the separate ANOVAs conducted to determine what the most preferred choice for audiovisual warning was for the active crossing warning violation. Open-ended responses were content coded for analysis.

Table 3

Average Ratings for Types of Ratings for Active Crossing Ahead Alert

Rating Type	Average Ratings	
	M	SE
Reaction Ratings	4.22	2.02
Use Case Ratings	5.37	2.34
Message Design Ratings	6.37	2.54

Overall Average Reaction Ratings. As the ratings dimensions were highly correlated, therefore an overall 2 x 2 x 2 ANOVA was calculated on the overall average reaction means. There was a statistically significant main effect of message content on the overall average reaction ratings, $F(1, 283) = 11.89$, $p = .0007$, $\eta^2_p = 0.04$. This indicates that there was a difference in rating between the warning messaging and the action messaging, with an overall preference for warning messaging in this condition. Message length also had a statistically significant main effect on the average reaction ratings, $F(1, 283) = 5.35$, $p = .02$, $\eta^2_p = 0.02$, indicating that the there was a difference in driver ratings of short and long messaging, with a preference for long messaging in this condition. Driver population had a statistically significant main effect on the average reaction ratings, $F(1, 283) = 11.16$, $p = .0009$, $\eta^2_p = 0.04$, indicating that the novice and experienced driving populations had different reaction ratings overall. In general, the novice driver population rated the active crossing ahead reaction ratings higher than the experienced driver population. Finally, the interaction between message length and message content on the overall average reaction ratings was marginally significant, $F(1, 283) = 3.602$, $p = .06$, $\eta^2_p = 0.01$, indicating that across all reaction ratings there was a small preference the long messaging and the warning messaging over the short messaging and action messaging for this condition.

Table 4
Means and Standard Errors of Reaction Ratings for Active Crossing Ahead Alert

Variable	Message Content and Length Combination							
	Short Warning		Long Warning		Short Action		Long Action	
	M	SE	M	SE	M	SE	M	SE
Experienced Population								
Meaningfulness	6.20	0.71	6.90	0.60	6.70	0.61	5.90	0.74
Annoyance	3.20	0.67	3.30	0.63	3.60	0.73	4.35	0.71
Distraction	2.85	0.68	3.15	0.64	3.25	0.71	4.00	0.68
Urgency	5.65	0.74	6.25	0.61	5.95	0.78	5.95	0.72
Desire to Turn Off	3.10	0.76	2.95	0.71	3.35	0.78	4.30	0.77
Novice Population								
Meaningfulness	6.15	0.33	6.72	0.31	6.24	0.32	5.52	0.34
Annoyance	3.65	0.30	4.29	0.34	4.43	0.35	6.00	0.38
Distraction	3.48	0.29	4.02	0.35	3.96	0.32	5.45	0.36
Urgency	5.02	0.33	5.57	0.33	5.12	0.31	4.96	0.34
Desire to Turn Off	3.84	0.32	4.27	0.36	4.67	0.36	6.17	0.39

Meaningfulness. There was a statistically significant interaction between message content and message length, $F(1, 231) = 12.72$, $p = .0004$, $\eta^2_p = 0.05$, indicating there was no difference of message content on short messaging, but there was a difference of message content on long messaging, indicating a preference for warning messaging. There was also a statistically significant main effect of message content on meaningfulness, $F(1, 231) = 6.49$, $p = .011$, $\eta^2_p = 0.03$, indicating that participants found the warning messaging to be more meaningful than the action messaging. Finally, there was no significant main effect of message length on meaningfulness, $F(1, 231) = 0.14$, $p = .71$, $\eta^2_p = 0.001$, or driver population on meaningfulness, $F(1, 76) = 0.22$, $p = .63$, $\eta^2_p = 0.001$.

Annoyance. There was a statistically significant main effect of message content on annoyance, $F(1, 231) = 28.37$, $p < .0001$, $\eta^2_p = 0.11$, indicating that participants found the action messaging more annoying than the warning messaging. There was also a statistically significant main effect of message length on annoyance, $F(1, 231) = 19.93$, $p < .0001$, $\eta^2_p = 0.08$, indicating that participants found the long messaging to be more annoying than the short messaging. Driver population also had a statistically significant main effect on annoyance, $F(1, 76) = 2.84$, $p = .092$, $\eta^2_p = 0.04$. The novice driver population found the warnings more annoying than the experienced driver population. Finally, there was a statistically significant interaction between message length and message content, $F(1, 231) = 4.25$, $p = .039$, $\eta^2_p = 0.02$, indicating that there was no difference in the message length on the warning messaging, but there was a difference in the message length on the action messaging on annoyance.

Distraction. There was a statistically significant interaction between message content and message length on distraction, F(1, 231) = 5.02, p = .025, η^2_p = 0.02. There was no effect of message length on distraction ratings for warning messages, but there was for action messaging. There was a statistically significant main effect of message content on distraction, F(1, 231) = 22.69, $p < .0001$, η^2_p = 0.09, indicating that participants generally found the action messaging more distracting than the warning messaging. There was also a statistically significant main effect of message length on distraction, F(1, 231) = 23.26, $p < .0001$, η^2_p = 0.09. Participants rated the long messaging as more distracting than the shorter messaging. There was no effect of driver population on distraction, F(1, 76) = 2.40, p = .12, η^2_p = 0.03.

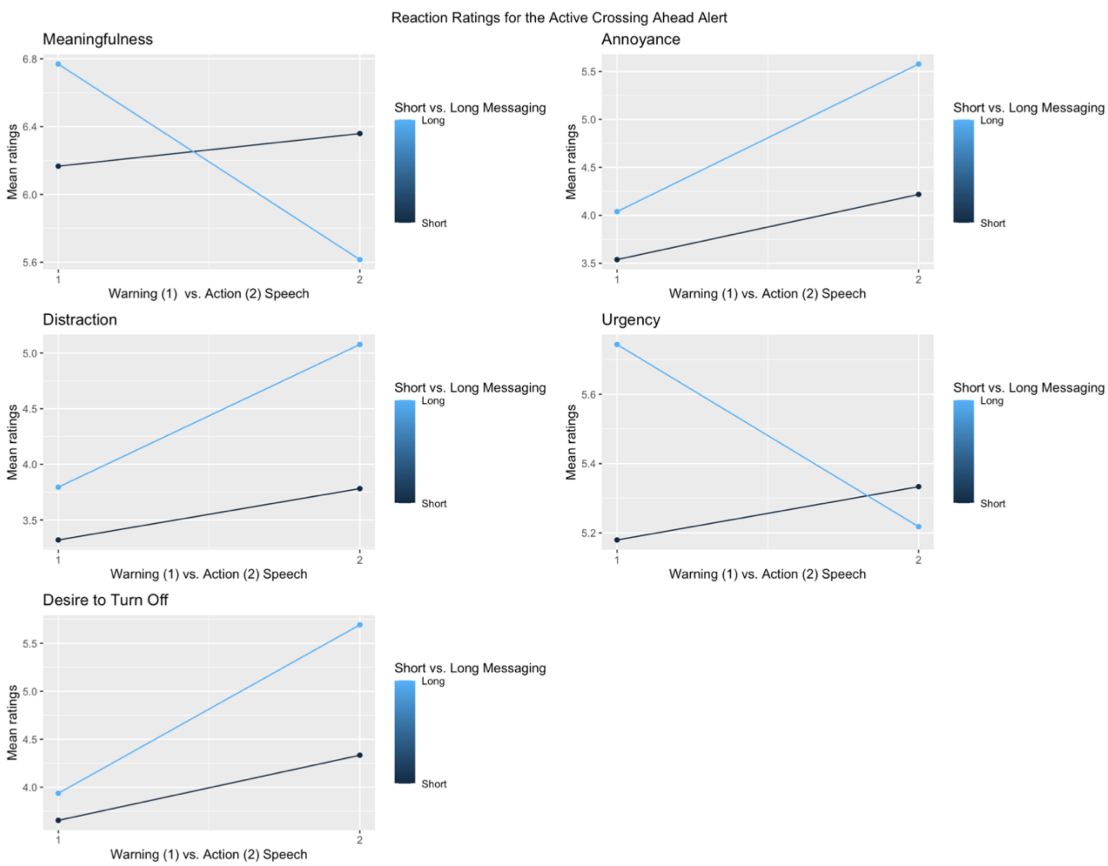

Figure 7. Reaction ratings results for the active crossing ahead alert condition

Urgency. There was no statistically significant main effect of message content, F(1, 231) = 0.74, p = .39, η^2_p = 0.001, or message length on urgency, F(1, 231) = 1.07, p = .29, η^2_p = 0.001. Neither affected drivers' ratings of urgency. There was also no statistically significant interaction between message content and message length on urgency, F(1, 231) = 2.46, p = .12, η^2_p = 0.01. Nor was there a main effect of driver population on urgency, F(1, 76) = 2.03, p = .15, η^2_p = 0.03. None of the variables affected urgency ratings in this scenario.

Desire to Turn Off. There was a statistically significant main effect of message content on the desire to turn off the audiovisual warning, $F(1, 231) = 31.85$, $p < .0001$, $\eta^2_p = 0.12$, indicating that participants had more desire to turn off the action messaging than the warning messaging. There was also a statistically significant main effect of message length on the desire to turn off the audiovisual warning, $F(1, 231) = 14.45$, $p = .00014$, $\eta^2_p = 0.06$. Participants had more desire to turn off the longer messaging than the shorter messaging. Driver population also had a statistically significant main effect on the desire to turn off the audiovisual warning, $F(1, 76) = 4.49$, $p = .034$, $\eta^2_p = 0.06$. The novice driver population has a higher desire to turn the warnings off than the experienced driver population. Finally, there was a statistically significant interaction between message content and message length on desire to turn off, $F(1, 231) = 6.22$, $p = .012$, $\eta^2_p = 0.03$, indicating that there was no difference between message length for the warning messaging, but there was an effect for the action messaging.

Use case ratings included ratings of usefulness in unfamiliar situations, familiar situations, rural settings, and urban settings. Across all variables, message content was a statistically significant main effect, indicating a preference for warning messaging (Figure 8). Table 5 shows all mean use case ratings by population for the alert condition.

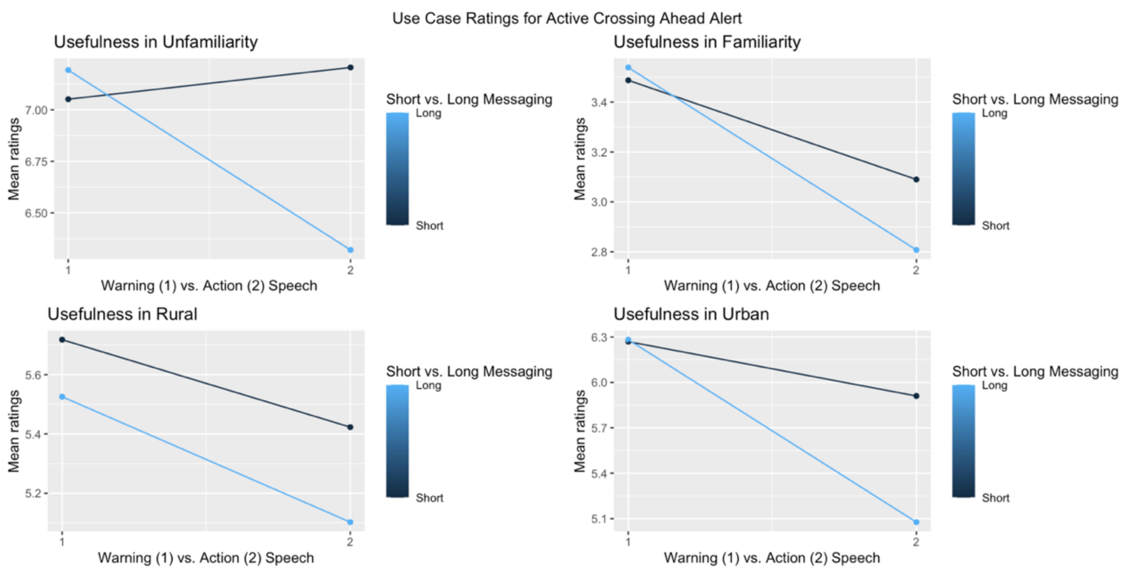

Figure 8. Use case ratings results for the active crossing ahead alert condition

Overall Average Use Case Ratings. Results from the 2 message content x 2 message length x 2 driver population ANOVA for overall use case ratings showed that there was a marginally statistically significant main effect of message content on the use case ratings for this warning, $F(1, 307) = 3.96$, $p = .05$, $\eta^2_p = 0.01$. This indicates that overall, the messaging was rated higher in use case scenarios over the action messaging in this condition. Driver population also had a statistically significant main effect on the average use case ratings, $F(1, 307) = 12.52$, $p = .0005$, $\eta^2_p = 0.04$, indicating that overall, the novice driver population rated the use case ratings higher than the experienced driver population. Message length was not significant across the average use case ratings, $F(1, 307) = 1.24$, $p = .26$, $\eta^2_p = 0.001$. Finally, the interaction between message length and message content was not significant on the overall average use case ratings, $F(1, 307) = 1.26$, $p = .26$, $\eta^2_p = 0.001$, indicating that across all reaction ratings there was no clear preference for one message content and message length over another.

Unfamiliar Situations. There was a statistically significant main effect of message content on the usefulness of the audiovisual warnings in unfamiliar situations, $F(1, 231) = 3.20$, $p = .07$, $\eta^2_p = 0.01$, indicating that participants found the warning messaging to be more useful in unfamiliar situations than the action messaging. There was also a statistically significant main effect of message length on the usefulness of the audiovisual warnings in unfamiliar situations, $F(1, 231) = 3.44$, $p = .04$, $\eta^2_p = 0.01$, indicating that longer messaging was more useful in unfamiliar situations than shorter messaging. Finally, there was a statistically significant interaction between message content and message length, $F(1, 231) = 6.54$, $p = .01$, $\eta^2_p = 0.03$, indicating that there was little difference in message content on short messaging, but there was a significant difference of message content on the long messaging. There was no significant main effect of driver population on usefulness in unfamiliar situations, $F(1, 76) = 0.19$, $p = .66$, $\eta^2_p = 0.001$.

Familiar Situations. There was a statistically significant main effect of message content on the usefulness of the audiovisual warnings in familiar situations, $F(1, 231) = 9.44$, $p = .002$, $\eta^2_p = 0.04$, indicating that warning messaging was more useful in familiar situations than action messaging. There was also a statistically significant main effect of driver population on usefulness in familiar situations, $F(1, 76) = 8.09$, $p = .004$, $\eta^2_p = 0.10$. The experienced driver population found the warnings more useful in familiar situations than the novice driver population. There was no significant main effect of message length on the usefulness of the audiovisual warnings in familiar situations, $F(1,231) = 0.39$, $p = .53$, $\eta^2_p = 0.001$. There was also no significant interaction between message content and message length, $F(1, 231) = 0.82$, $p = .36$, $\eta^2_p = 0.001$. These findings suggest that none of these factors affect driver preferences in familiar situations.

Rural Areas. There was a statistically significant main effect of message content on the usefulness of the audiovisual warnings in rural areas, $F(1, 231) = 3.82$, $p = .05$, $\eta^2_p = 0.02$, indicating that warning messaging was more useful in rural areas than action messaging. There was also a statistically significant main effect of driver population on usefulness in rural areas, $F(1, 76) = 8.30$, $p = .005$, $\eta^2_p = 0.10$. The experienced driver population found the warnings more useful in rural areas than the novice driver population. There was no significant main effect of message length on the usefulness of audiovisual warnings in rural areas, $F(1, 231) = 1.95$, $p = .16$, $\eta^2_p = 0.001$. There was also no significant interaction between message content and message length, $F(1, 231) = 0.12$, $p = .73$, $\eta^2_p = 0.001$.

Urban Areas. There was a statistically significant main effect of message content on the usefulness of the audiovisual warnings in urban areas, $F(1, 231) = 13.08$, $p =$

.0004, $\eta^2_p = 0.05$, indicating that warning messaging was more useful in urban areas than action messaging. There was also a statistically significant main effect of message length on usefulness in urban areas, $F(1, 231) = 3.60$, $p = .06$, $\eta^2_p = 0.02$, indicating that the shorter messaging was more useful in urban areas than the longer messaging. Finally, there was a statistically significant interaction between message content and message length, $F(1, 231) = 3.83$, $p = .05$, $\eta^2_p = 0.02$, indicating that there was little difference in message content for the short messaging, but there was a large difference in usefulness ratings for warning and action messaging for the longer messaging. There was no significant main effect of driver population on usefulness in urban areas, $F(1, 76) = 0.008$, $p = .93$, $\eta^2_p = 0.001$.

Table 5

Means and Standard Errors of Use Case Ratings for Active Crossing Ahead Alert

Variable	Message Content and Length Combination							
	Short Warning		Long Warning		Short Action		Long Action	
	M	SE	M	SE	M	SE	M	SE
Experienced Population								
Unfamiliarity	6.95	0.72	7.40	0.64	6.95	0.74	7.25	0.57
Familiarity	4.60	0.71	5.60	0.74	4.55	0.81	4.10	0.75
Rural	6.80	0.71	7.10	0.69	6.65	0.74	6.85	0.65
Urban	5.80	0.78	6.35	0.73	5.75	0.83	5.80	0.74
Novice Population								
Unfamiliarity	7.09	0.36	7.12	0.33	7.29	0.31	6.00	0.40
Familiarity	3.10	0.41	2.83	0.38	2.59	0.36	2.36	0.38
Rural	5.34	0.37	4.98	0.38	5.00	0.35	4.50	0.37
Urban	6.43	0.33	6.26	0.32	5.96	0.35	4.83	0.40

Message design ratings included ratings of the appropriateness of the message content and message length. Both message length and the interaction between message content and message length had a statistically significant main effect on message design (Figure 9). All mean message design ratings for both populations are listed in Table 6.

Overall Average Message Design Ratings. Results from the 2 x 2 x 2 ANOVA for overall message design ratings showed that there was a statistically significant main effect of message content on the message design ratings in this condition, $F(1, 307) = 7.70$, $p = .006$, $\eta^2_p = 0.02$. This indicates that in the overall message design ratings in this condition, the warning messaging was deemed more appropriate than the action messaging. Message length also had a statistically significant main effect across the average use case ratings, $F(1, 307) = 9.31$, $p = .002$, $\eta^2_p = 0.03$, indicating that the longer message length affected driver ratings for the appropriateness of the audiovisual warnings in this condition. Finally, the interaction between message length and message content had a statistically significant main effect on the overall average message design ratings, F(1, 307) = 7.83, p = .005, η^2_p = 0.02, indicating that across all message design ratings in this condition, all but the long action messaging was deemed appropriate. Driver population was not significant across the average message design ratings, F(1, 307) = 0.06, p = .81, η^2_p = 0.001, indicating that the novice and experienced driving populations did not differ in their ratings of appropriateness in this condition.

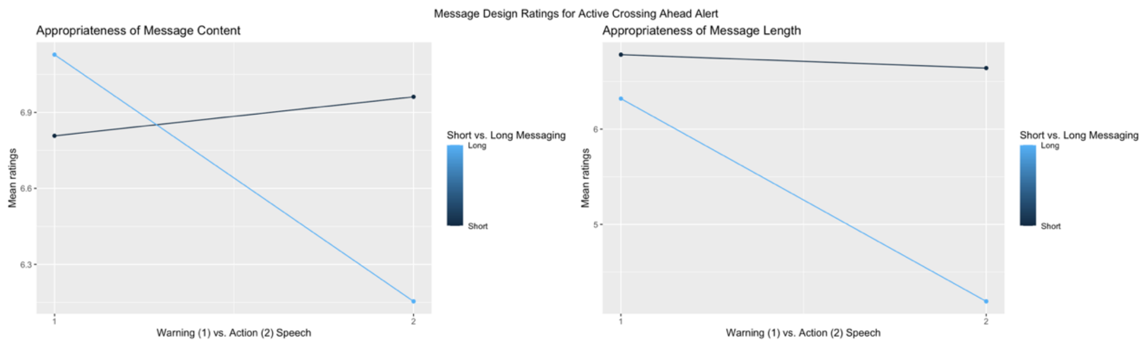

Figure 9. Message design ratings results for the active crossing ahead alert condition

Table 6

Means and Standard Errors of Message Design Ratings for Active Crossing Ahead Alert

Variable	Message Content and Length Combination							
	Short Warning		Long Warning		Short Action		Long Action	
	M	SE	M	SE	M	SE	M	SE
Experienced Population								
Content	6.65	0.73	6.75	0.71	6.45	0.71	5.90	0.71
Length	6.45	0.69	7.15	0.62	6.45	0.61	5.65	0.62
Novice Population								
Content	6.86	0.36	7.26	0.27	7.14	0.33	6.24	0.33
Length	6.90	0.38	6.03	0.37	6.71	0.34	3.69	0.90

Message Content. There was a statistically significant main effect of message content on the appropriateness of the message content, F(1, 231) = 3.76, p = .05, η^2_p = 0.02, indicating that warning messaging was deemed more appropriate than action messaging. There was also a statistically significant interaction between message content and message length, F(1, 231) = 7.10, p = .008, η^2_p = 0.03, indicating that there was a significant difference between message content on longer messaging. There was no significant main effect of message length on the appropriateness of message content, F(1, 231) = 1.32, p = .25, η^2_p = 0.001, indicating there was little difference between the appropriateness of the message content on the short messaging, but there was a difference in the appropriateness of the message content on the long messaging. Finally, there was no significant main effect of driver population on the appropriateness of message content, F(1, 76) = 0.62, p = .43, η^2_p = 0.001.

Message Length. There was a statistically significant main effect of message content on the appropriateness of message length, F(1, 231) = 16.74, $p < .0001$, $\eta^2_p = 0.07$, indicating that warning messaging was more appropriate than action messaging. There was also a statistically significant main effect of message length on the appropriateness of message length, F(1, 231) = 27.54, $p < .0001$, $\eta^2_p = 0.11$, indicating that shorter messaging was more appropriate than longer messaging. Finally, there was a statistically significant interaction between message content and message length, F(1, 231) = 12.84, $p = .0004$, $\eta^2_p = 0.05$, indicating there was a difference of message length on action messaging appropriateness, but not for warning. There was no significant main effect of driver population on the appropriateness of message length, F(1,76) = 1.45, $p = .23$, $\eta^2_p = 0.02$, both experienced and novice drivers had similar preferences for message length appropriateness.

4.2.3 Active Crossing Ahead Open-Ended Results

Drivers also provided open-ended answers to several questions to evaluate potential additional scenarios for when the intelligent warnings may be useful. These were coded and summarized.

Usefulness. Usefulness of the active crossing ahead alert was evaluated through an open-ended question asking participants if they would find the warning useful, and in what conditions they would find the warning useful. Results showed that 83.3 percent of participants found the warnings useful in this condition. The most prominent situations and reasons for finding warnings useful in this HRGC scenario included situations of low visibility and the likelihood of increasing awareness and attention to the environment when approaching and crossing an HRGC.

Annoyance. Participants were also asked about situations and reasons they would find these warnings annoying and want to turn them off in this HRGC scenario. The results showed that 65.4 percent of participants indicated some annoyance and potential to turn the warning off. The primary responses regarding annoyance and the desire to turn off the warning included that participants found the warning redundant and unnecessary, especially in familiar situations, and if the warning played multiple times throughout their drive. Those who did not find the warning annoying or want to turn the warning off indicated that it would be useful in low visibility and is brief enough to avoid being turned off.

Use in Urban and Rural Areas. Regarding the usefulness of warnings at urban and rural areas, 80.8 percent of participants indicated that warnings would be useful in both of these settings. Participants indicated that unfamiliarity with the location would make the warnings useful in both urban and rural areas. In urban areas, these warnings would be useful to increase awareness of the driver's surroundings, while the warnings would be useful in rural areas due to low visibility.

Usefulness in Inclement Weather. In regard to the usefulness of the active crossing ahead alert in inclement weather, 84.6 percent of participants found the warnings to be useful. The primary reasons for this warning being useful included the likelihood of low visibility, the ability to prepare for potential danger, and anticipate potential hazards farther out from the crossing. In inclement weather where actions such as slowing down or stopping may become more difficult, participants found the warnings useful to be notified early to have more time to perform the necessary actions.

4.3 Active Crossing Warning Violation Condition

Responses in the violation condition were analyzed using fit linear mixed-effect models and 2 (message length) x 2 (message content) x 2 (driver population) ANOVAs (analysis of variance) for the five reaction ratings, use case ratings, and message design ratings. Since there were so few statistically significant effects related to driver population the statistical analyses were reported for the 2 message length by 2 message content and collapsed across both driver populations. Open-ended responses were analyzed using thematic analysis based on the coding scheme described above.

4.3.1 Correlation and Principal Component Analysis

A correlation matrix was again run to determine if any rating dimensions were correlated to one another in this condition (Figure 10). In a similar manner to the active crossing ahead alert, there were many rating dimensions that were highly correlated to one another. Table 7 shows all correlation values for the correlation matrix.

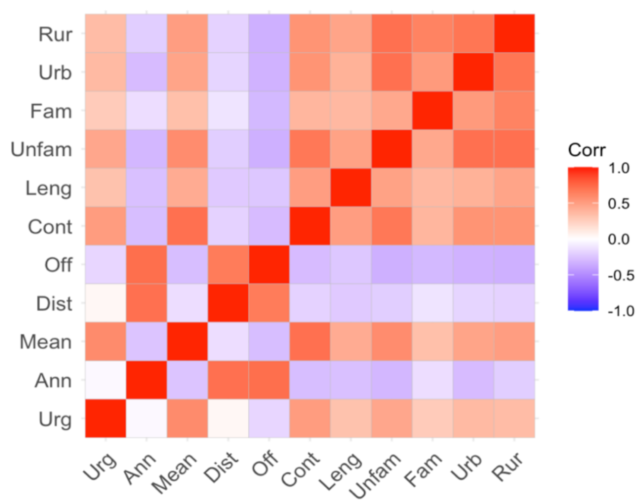

Figure 10. Correlation matrix for ratings results in the active crossing warning violation condition

Using the correlation matrix, a principal component analysis was run to examine the variance in the data. The results found that 88.1 percent of variance could be explained by a single dimension in this HRGC scenario, again indicating that the ratings were highly correlated and that the rating dimensions may influence one another (Figure 11).

Table 7

Correlation Matrix for Rating Variable in the Active Crossing Warning Violation Condition

	M	SD	1	2	3	4	5	6	7	8	9	10	11
1. Urgency	5.87	2.86	-										
2. Annoyance	5.46	3.08	-0.03	-									
3. Meaningful	5.74	2.76	0.59	-0.25	-								
4. Distraction	4.78	2.73	0.04	0.71	-0.14*	-							
5. Turn Off	5.30	3.23	-0.17*	0.72	-0.28	0.66	-						
6. Approp. Of Mess. Content	5.97	3.03	0.51	-0.28	0.71	-0.19*	-0.29	-					
7. Approp. Of Mess. Length	5.71	2.97	0.32	-0.27	0.43	-0.23	-0.24	0.50	-				
8.Use in Unfamiliar	6.46	3.01	0.46	-0.31	0.58	-0.21	-0.34	0.68	0.48	-			
9. Use in Familiar	3.49	3.01	0.27	-0.14*	0.33	-0.12*	-0.30	0.38	0.37	0.45	-		
10. Use in Urban	5.43	3.05	0.36	-0.29	0.47	-0.18*	-0.33	0.55	0.40	0.71	0.52	-	
12. Use in Rural	5.55	3.06	0.35	-0.21	0.50	-0.19*	-0.34	0.55	0.47	0.71	0.63	0.69	-

*p<0.05

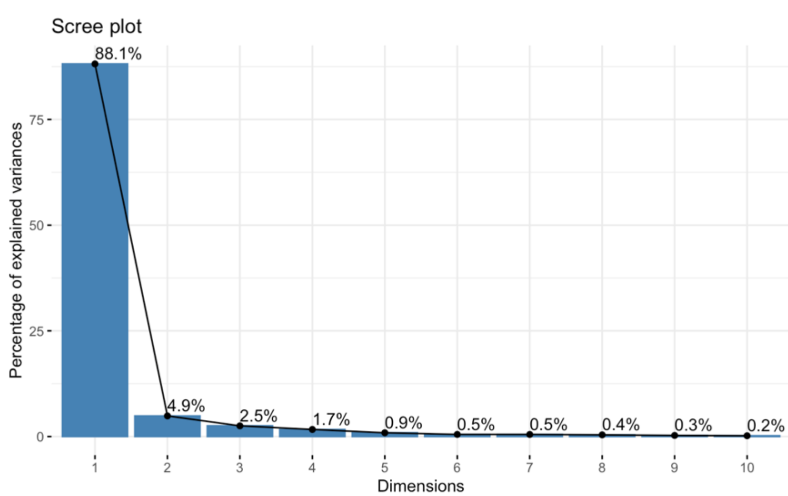

Figure 11. Scree plot for PCA variance in the active crossing warning violation condition

4.3.2 Active Crossing Warning Violation Ratings Results

Reaction ratings included ratings of meaningfulness, annoyance, distraction, urgency, and desire to turn off. Across all variables, message length had a statistically significant main effect. An overall 2 x 2 x 2 ANOVA was run to calculate the average rating for each type of rating (reaction ratings, use case ratings, and message design ratings). Table 8 shows the mean rating for each rating type in the active crossing warning violation condition. As in the active crossing ahead alert condition, the reaction ratings had the overall lowest rating, with message design being an important factor in driver preferences for intelligent in-vehicle warnings. Table 9 shows mean reaction ratings across all combinations of message content and length for the violation condition. Despite the ratings dimensions being highly correlated, the ANOVAs were still run to determine what the most preferred choice for audiovisual warning was for the active crossing warning violation. Figure 12 shows all of the reaction ratings results for the active crossing warning violation condition.

Table 8

Average Ratings for Types of Ratings for Active Crossing Warning Violation

Rating Type	Average Ratings	
	M	SE
Reaction Ratings	4.80	2.10
Use Case Ratings	5.23	2.56
Message Design Ratings	5.84	2.59

Overall Average Reaction Ratings. First, as the ratings dimensions were highly correlated, an overall 2 x 2 x 2 ANOVA was calculated with the overall average reaction means (individual items reverse coded when needed). Results from the ANOVA showed that there was a only statistically significant main effect of driver population on the reaction ratings of this condition, $F(1, 283) = 5.68$, $p = .02$, $\eta^2_p = 0.02$, indicating that overall, the novice drivers rated this warning as more annoying, distracting, and had a higher desire to turn the warning off than the experienced drivers. There was no significant effect of message content, $F(1, 283) = 0.94$, $p = .33$, $\eta^2_p = 0.001$, message length, $F(1, 283) = 1.22$, $p = .27$, $\eta^2_p = 0.001$, or an interaction between message length and message content, $F(1, 283) = 2.21$, $p = .14$, $\eta^2_p = 0.001$, on the overall active reaction ratings in the active crossing warning violation condition.

Table 9

Means and Standard Error of Reaction Ratings for Active Crossing Warning Violation

Variable	Message Content and Length Combination							
	Short Warning		Long Warning		Short Action		Long Action	
	M	SE	M	SE	M	SE	M	SE
	Experienced Population							
Meaningfulness	5.25	0.82	6.00	0.66	5.60	0.73	5.90	0.73
Annoyance	3.95	0.81	5.05	0.85	4.55	0.78	5.70	0.81

Distraction	3.70	0.70	4.50	0.70	3.25	0.61	4.10	0.66
Urgency	4.85	0.85	6.15	0.73	5.80	0.58	5.80	0.80
Desire to Turn Off	4.15	0.83	4.95	0.82	4.10	0.88	4.10	0.87
Novice Population								
Meaningfulness	4.57	0.34	5.93	0.34	6.38	0.30	6.19	0.32
Annoyance	5.38	0.38	5.90	0.37	5.07	0.33	6.43	0.39
Distraction	4.45	0.32	5.40	0.33	4.81	0.32	5.69	0.36
Urgency	4.86	0.37	6.55	0.33	6.57	0.29	5.79	0.37
Desire to Turn Off	5.55	0.35	5.98	0.41	5.27	0.35	5.74	0.42

Meaningfulness. There was no significant main effect of driver population on the meaningfulness of the audiovisual warnings, F(1, 76) = 0.013, p = .91, $\eta^2_p = 0.001$. Therefore, driver population was removed from the subsequent analyses and only the 2 message content x 2 message length results on the dependent measures are reported. There was a statistically significant main effect of message content on meaningfulness, F(1, 231) = 15.71, $p < .0001$, $\eta^2_p = 0.06$. Action messages were preferred to warning messages. There was also a statistically significant main effect of message length rating on meaningfulness, F(1, 231) = 8.93, p = .0028, $\eta^2_p = 0.04$, indicating that longer messages were rated more meaningful than shorter messages. Finally, there was a statistically significant interaction between message length and message content, F(1, 231) = 9.72, p = .0018, $\eta^2_p = 0.04$. Planned comparison indicated that the difference in message content was driven by the shorter message length. In other words, for the longer message there was no preference for warning vs. action but there was for the short messages. For shorter message, participants preferred action messaging than warning messaging.

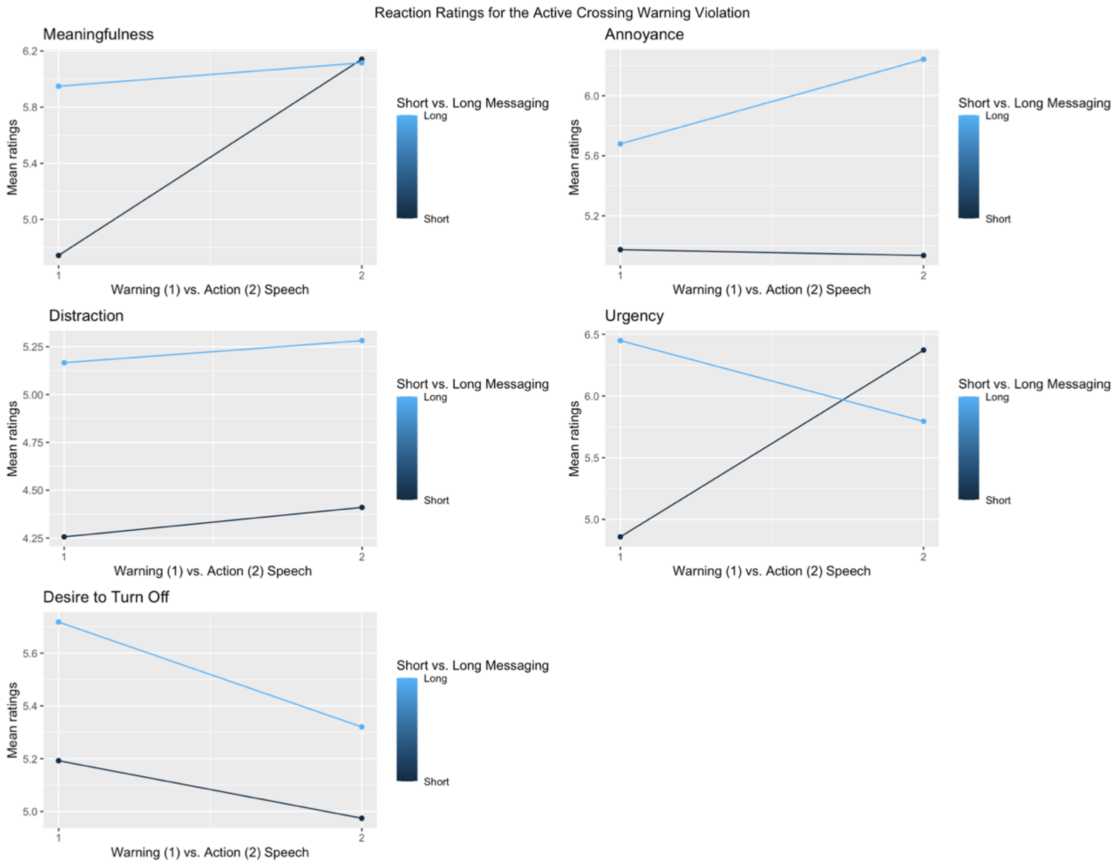

Figure 12. Reaction ratings results for the active crossing warning violation condition

Annoyance. There was a statistically significant main effect of message length on annoyance, $F(1, 231) = 22.03$, $p < .0001$, $\eta^2_p = 0.09$, indicating that longer messages were more annoying than shorter messages. There was no significant main effect of message content, $F(1, 231) = 1.50$, $p = .22$, $\eta^2_p = 0.001$, or driver population, $F(1, 76) = 1.72$, $p = .19$, $\eta^2_p = 0.02$, on the annoyance ratings for the *violation warning condition*. Message content of a warning or a call to action did not affect the annoyance ratings. Finally, there was also no statistically significant interaction between message length and message content, $F(1, 231) = 1.97$, $p = .16$, $\eta^2_p = 0.001$.

Distraction. There was a statistically significant main effect of message length on distraction, $F(1, 231) = 21.35$, $p < .0001$, $\eta^2_p = 0.08$, indicating that participants found the longer messaging to be more distracting than the shorter message. There was no significant main effect of message content on distraction, $F(1, 231) = 0.49$, $p = .49$, $\eta^2_p = 0.001$. There was also no significant interaction between message length and message content, $F(1, 231) = 0.01$, $p = .92$, $\eta^2_p = 0.001$. There was a statistically significant main effect of population on distraction, $F(1, 76) = 4.34$, $p = .039$, $\eta^2_p = 0.05$, indicating that the novice driver population found the alerts for the violation condition more distracting than the experienced driver population.

Urgency. There was a statistically significant main effect of message content on urgency, F(1, 231) = 4.29, p = .038, η^2_p = 0.02, indicating that participants found the action messaging to be more urgent than the warning message. There was also a statistically significant main effect of message length on urgency, F(1, 231) = 5.97, p = .014, η^2_p = 0.03 , showing interestingly that longer messaging were more urgent than shorter message. There was a statistically significant interaction between message content and message length, F(1, 231) = 27.31, p < .0001, η^2_p = 0.11, indicating that there was little difference in message content for longer message on urgency, but there was for shorter message. This suggests that the urgency rating is driving by the longer message, rather than the shorter message. Finally, there was no significant main effect of driver population on urgency, F(1, 76) = 0.24, p = .63, η^2_p = 0.001.

Desire to Turn Off. There was a statistically significant main effect of message length on the desire to turn off the audiovisual warning, F(1, 231) = 3.72, p = .054, η^2_p = 0.02. Participants reported being more likely to turn off the longer messaging than the shorter messaging, regardless of content. There was no significant main effect of message content on the desire to turn off, F(1, 231) = 1.85, p = .17, η^2_p = 0.001, or no interaction between message length and message content, F(1, 231) = 0.16, p = .69, η^2_p = 0.001.There was, however, a statistically significant main effect of driver population on the desire to turn off the audiovisual warning, F(1, 76) = 3.56, p = .059, η^2_p = 0.04. The novice driver population reported being much more likely to turn it off than the experienced population.

Use case ratings. These ratings evaluated the usefulness of the given audiovisual warnings based on familiar/unfamiliar situations and rural settings, and urban settings, and weather? Across all use case ratings, the interaction between message length and message content was statistically significant (Figure 13). Table 10 shows all mean use case ratings by driver population for the active crossing warning violation condition.

Overall Average Use Case Ratings. Results from the 2 x 2 x 2 ANOVA for overall use case ratings showed that there was a statistically significant main effect of driver population on the overall average use case ratings in this condition, F(1, 307) = 4.14, p = .04, η^2_p = 0.01, indicating that the novice driver population rated the use case ratings higher than the experienced driver population. There was also a statistically significant main effect of the interaction between message length and message content, F(1, 307) = 6.48, p = .01, η^2_p = 0.02, indicating that across all use case ratings, there was a preference for short action messaging in this condition. There was no significance of message content F(1, 307) = 1.42, p = .23, η^2_p = 0.001, or message length, F(1, 307) = 0.40, p = .98, η^2_p = 0.001, on the overall average usefulness in the active crossing warning violation condition.

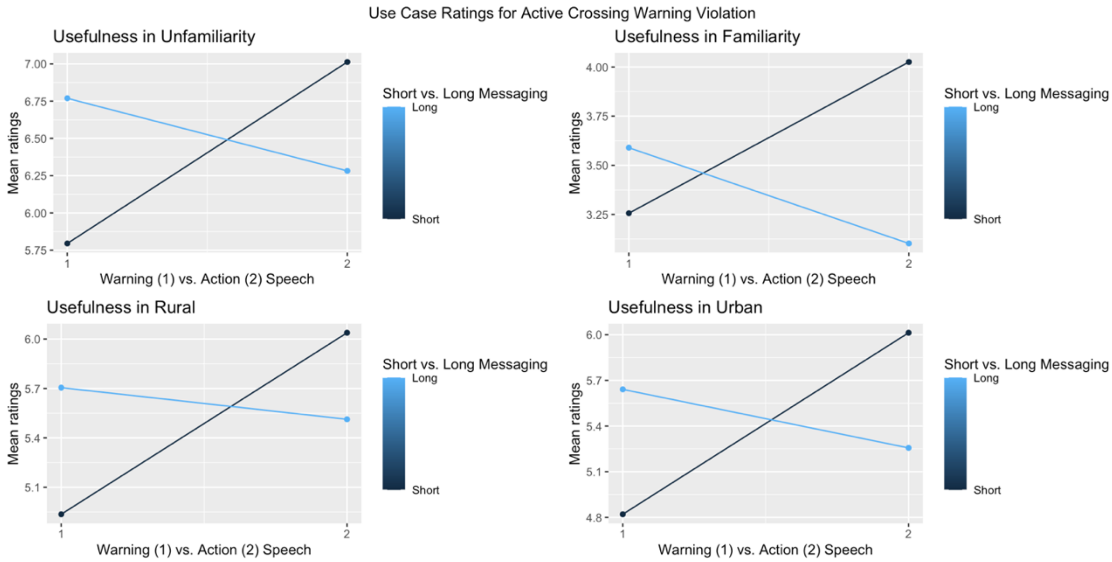

Figure 13. Use case ratings results for the active crossing warning violation condition

Unfamiliar Situations. There was a marginal significant main effect of message content on unfamiliarity, $F(1, 231) = 2.90$, $p = .090$, $\eta^2_p = 0.01$, indicating that participants found the action messaging more useful in an unfamiliar situation than the warning message. There was no main effect of message length on unfamiliarity, $F(1, 231) = 0.32$, $p = .57$, $\eta^2_p = 0.001$. There was a significant interaction between message length and message content, $F(1, 231) = 15.77$, $p < .0001$, $\eta^2_p = 0.06$, indicating that message content had once again showed little difference for longer messaging on unfamiliarity, but there was a difference for shorter messaging. This suggests that in unfamiliar driving contexts, an action message is preferred to a warning message for shorter messages, but there is no preference for longer messages. There was also no significant main effect of driver population on unfamiliarity, $F(1, 76) = 0.018$, $p = .89$, $\eta^2_p = 0.001$.

Familiar Situations. There was a statistically significant main effect of driver population on usefulness in a familiar situation, $F(1, 76) = 4.31$, $p = .038$, $\eta^2_p = 0.05$. Experienced population drivers thought the messages would be more useful than the novice population. There was a significant interaction between message length and message content, $F(1, 231) = 10.27$, $p = .0013$, $\eta^2_p = 0.04$, indicating once again that there was little difference in message content for longer messaging on usefulness in familiar situations, but there was for shorter messaging. There was no significant main effect of message content, $F(1, 231) = 0.52$, $p = 0.47$, $\eta^2_p = 0.001$, or message length, $F(1, 231) = 2.27$, $p = 0.13$, $\eta^2_p = 0.001$, on the usefulness of the audiovisual warnings in familiar situations.

Rural Areas. There was a statistically significant main effect of message content on the usefulness of the violation warning in rural areas, $F(1, 231) = 5.11$, $p = .024$, $\eta^2_p = 0.02$, but no main effect of message length, $F(1, 231) = 0.37$, $p = .54$, $\eta^2_p = 0.001$.

Participants in both driver populations found the action messaging more useful in rural areas than the warning messaging. There was a statistically significant main effect of driver population on usefulness in rural areas, $F(1, 76) = 2.80$, $p = .094$, $\eta^2_p = 0.04$. Experienced population drivers found the warnings to be much more useful in rural areas than novice population drivers. Finally, there was a significant interaction between message content and message length, $F(1, 231) = 10.35$, $p = .0013$, $\eta^2_p = 0.04$, indicating that there was little difference in message content for longer messaging on usefulness in rural areas, but there was a difference of message content on shorter messaging.

Urban Areas. There was a significant interaction between message content and message length, $F(1, 231) = 14.52$, $p = .00018$, $\eta^2_p = 0.06$, indicating that there was little difference in message content for longer messaging on violation warning usefulness in urban areas, but there was a difference of message content on shorter messaging. Once again, participants rated the action messaging more useful in urban areas for shorter speech related to the violation warning. Participants had no preference for warning versus action for the length longer messaging warning. There was a marginally significant main effect of message content on the usefulness of the audiovisual violation warning in urban areas, $F(1, 231) = 3.81$, $p = .051$, $\eta^2_p = 0.02$, indicating that participants found the action messaging more useful in urban areas than the warning messaging. There was no significant main effect of message length, $F(1, 231) = 0.02$, $p = .88$, $\eta^2_p = 0.001$, or driver population, $F(1, 76) = 0.15$, $p = .70$, $\eta^2_p = 0.001$,on the usefulness of the audiovisual violation condition warnings in urban areas.

Table 10
Means and Standard Errors of Use Case Ratings for Violation Condition

Variable	Message Content and Length Combination							
	Short Warning		Long Warning		Short Action		Long Action	
	M	SE	M	SE	M	SE	M	SE
	Experienced Population							
Unfamiliarity	6.30	0.84	6.70	0.73	6.60	0.75	6.00	0.85
Familiarity	4.15	0.73	4.65	0.74	4.85	0.76	4.40	0.73
Rural	6.20	0.76	6.25	0.74	6.25	0.76	6.85	0.74
Urban	5.35	0.82	5.70	0.76	6.00	0.75	5.45	0.78
	Novice Population							
Unfamiliarity	5.62	0.40	6.79	0.35	7.15	0.32	6.38	0.39
Familiarity	2.95	0.35	3.22	0.40	3.74	0.38	2.65	0.35
Rural	4.50	0.37	5.52	0.37	5.96	0.37	5.05	0.40
Urban	4.64	0.36	5.62	0.37	6.02	0.36	5.19	0.42

Message design ratings. These included ratings of the appropriateness of the message content and message length. and the interaction of message content and length (Figure 14). All mean message design ratings for both populations are listed in Table 11.

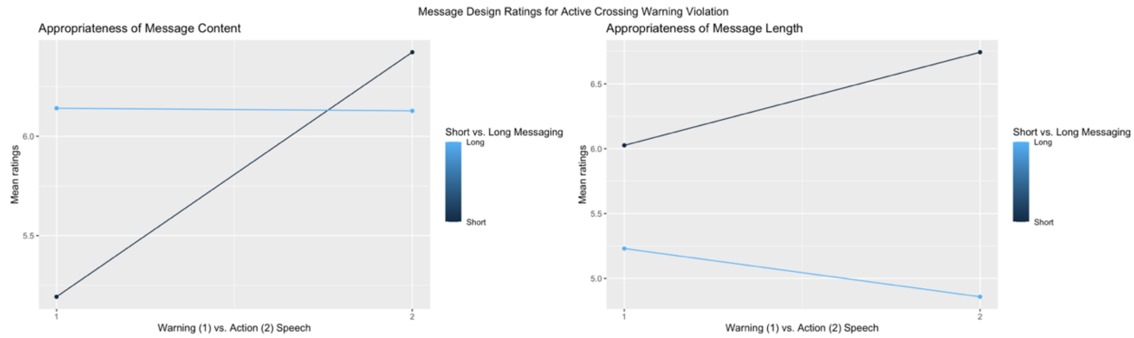

Figure 14. Message design ratings results for the active crossing warning violation condition

Overall Average Message Design Ratings. Results from the 2 x 2 x 2 ANOVA for overall message design ratings showed that there was a marginally statistically significant main effect of message length on the overall average use case ratings in this condition, $F(1, 307) = 3.02$, $p = .08$, $\eta^2_p = 0.001$, indicating that message length affected driver ratings for the appropriateness of the audiovisual warnings in this condition. Overall, shorter message length was deemed more appropriate in this condition than longer messaging. There was also a statistically significant main effect of the interaction between message length and message content, $F(1, 307) = 4.01$, $p = .05$, $\eta^2_p = 0.01$, indicating that across all message design ratings the short action messaging was deemed the most appropriate message design for the active crossing warning violation condition. There was no significance of message content $F(1, 307) = 1.80$, $p = .18$, $\eta^2_p = 0.001$, or driver population, $F(1, 307) = 0.66$, $p = .42$, $\eta^2_p = 0.001$, on the overall average usefulness in the active crossing warning violation condition.

Message Content. Message content (warning vs. action) affected ratings of message content. There was a statistically significant main effect of message content on the appropriateness of the message content, $F(1, 231) = 7.02$, $p = .0081$, $\eta^2_p = 0.03$. Generally, participants found the action messaging more appropriate than the warning messaging. There was a significant interaction between message content and message length, $F(1, 231) = 7.32$, $p = .0068$, $\eta^2_p = 0.001$indicating that there was no difference in the appropriateness of warning and action messaging for long messaging, but there was a strong preference for action messaging for the short messaging . However, there was no significant main effect of message length, $F(1, 231) = 2.02$, $p = .15$, $\eta^2_p = 0.001$, or driver population, $F(1, 76) = 0.27$, $p = .60$, $\eta^2_p = 0.001$on the appropriateness of message content.

Message Length. There was a statistically significant main effect of message length on the appropriateness of the message length, $F(1, 231) = 23.39$, $p < .0001$, $\eta^2_p = 0.11$. Participants found the short message length more appropriate than the longer messaging . There was also a significant interaction between message content and message length, $F(1, 231) = 4.86$, $p = .027$, $\eta^2_p = 0.02$. Planned comparison revealed that the pattern of results was different than in the previous analyses. There was no difference in the appropriateness of the message length between the warning and action messaging for short warnings, but there was a large difference for long warnings (Figure 14). Finally, there was no significant main effect of message content, $F(1, 231) = 0.49$, $p = .48$, $\eta^2_p = 0.001$, or driver population, $F(1, 76) = 2.39$, $p = .12$, $\eta^2_p = 0.03$, on the appropriateness of message length.

Table 11

Means and Standard Errors of Message Design Ratings for Active Crossing Warning Violation

Variable	Message Content and Length Combination							
	Short Warning		Long Warning		Short Action		Long Action	
	M	SE	M	SE	M	SE	M	SE
	Experienced Population							
Content	5.80	0.87	5.85	0.69	5.85	0.76	5.40	0.78
Length	6.25	0.61	6.05	0.56	6.60	0.55	6.55	0.65
	Novice Population							
Content	4.98	0.39	6.24	0.41	6.62	0.32	6.38	0.36
Length	5.95	0.36	4.95	0.43	6.79	0.31	4.27	0.42

4.3.3 Active Crossing Warning Violation Open-Ended Results

Usefulness. Participants were asked to evaluate the usefulness of intelligent in-vehicle warnings and provide driving situations where these warnings would be desired. The open-ended responses found that 79.5 percent of participants found the warnings useful in the HRGC scenario of the active crossing warning violation. Of these responses, the top situations where drivers believe warnings would be useful in this HRGC scenario include situations with low visibility (e.g., night, inclement weather, etc.), lack of attention to the environment and driver distraction, and when the driver is speeding. Participants who did not find the warnings useful in any situations predominantly stated that they did not understand what “violation” meant in the warning and found it to be too distracting and annoying to be useful, which aligns with the ratings results of this HRGC scenario.

Annoyance. Participants were asked to describe any situations where they would find these warnings annoying, or when they might like to turn the warnings off. In the violation condition, 42 percent of participants stated that they find these warnings annoying and would turn them off if given the option. Many of these responses indicated that they would be inclined to turn the warning off if they found it unnecessary for their current driving conditions, such as in familiar situations or if the warning has played more than once in their drive.

Usefulness in Urban and Rural Areas. In the use case scenarios, participants were asked to provide a rationale for their ratings of usefulness in urban and rural areas. The open-ended responses showed that 64.1 percent of participants found the warnings to be useful in urban and rural areas, however, they have different reasons as to why these warnings would be useful in each area. Participants who found the warnings useful in urban areas indicated that heavy traffic and low visibility (due to buildings, traffic, etc.) would be primary reasons why these warnings would be useful. On the other side, participants who did not find these warnings useful in urban areas indicated that urban areas were likely to have reduced speeds and more clear signage, so the warning would be redundant, and thus would be annoying. Regarding usefulness in rural areas, participants who found warnings in rural areas to be useful indicated that HRGCs may be difficult to spot due to lack of signage and attention, as well as a higher likelihood of speeding in rural areas than in urban areas. Participants who did not find the warnings useful in rural areas indicated that there was not enough information in the warning to make it useful in a rural area where signage might be scarce.

Inclement Weather. Finally, participants were asked to describe the usefulness of the warnings in situations where inclement weather (e.g., heavy rain, heavy snow, fog, etc.) may be present. In-vehicle warnings in inclement weather were deemed useful by 73.1 percent of participants. Most participants noted that the lack of visibility associated with inclement weather would increase the desire for a warning letting them know if they need to change their behavior prior to reaching an HRGC, which is a logical need for these warnings in this condition. An interesting finding from these results is that participants who did not find these warnings useful indicated that these warnings may be dangerous to play in the vehicle during inclement weather situations due to starling the driver or distracting them if the driver loses control of their vehicle, such as when roads are icy.

4.4 On-Tracks Condition

Responses in the on-tracks condition were analyzed using t-tests for each of the reaction ratings and message design ratings. Open-ended responses were analyzed using a developed coding scheme.

4.4.1 On-Tracks Condition Ratings Results

Reaction ratings included ratings of meaningfulness, annoyance, distraction, urgency, and desire to turn off. An overall 2 x 2 ANOVA was run to calculate the average rating for the two types of rating (reaction ratings and message design ratings). Table 12 shows the mean rating for each rating type in the on-tracks condition. The overall rating of the appropriateness of the message design indicates that the message length and message content are important factors to consider when designing a warning in the on-tracks condition. Table 13 shows all mean reaction ratings for the on-tracks condition. Across all reaction ratings, independent sample t-tests between the two conditions indicated that there were no significant differences between warning messaging and action messaging for the on-tracks condition.

Table 12

Average Ratings for Types of Ratings for On-Tracks Condition

Rating Types	Average Ratings	
	M	SE
Reaction Ratings	3.88	2.04
Message Design Ratings	6.82	2.34

Overall Average Reaction Ratings. First, as the ratings dimensions were highly correlated, an overall 2 x 2 ANOVA was calculated with the overall average reaction means (individual items reverse coded when needed). Results from the ANOVA showed that there was a statistically significant main effect of driver population reaction ratings in this condition, F(1, 140) = 4.11, p = .04, $\eta^2_p = 0.03$, indicating that overall, the novice driver population reaction ratings were higher than the experienced driver population for the on the tracks warning, indicating that the novice population found the warnings in this condition more annoying, distracting, and had a higher desire to turn the warning off compared to the experienced driver population. There was no significance of message content, F(1, 140) = 0.001, p = .97, $\eta^2_p = 0.001$ on the overall average reaction ratings.

Table 13
Means and Standard Errors of Reaction Ratings for On-Tracks Condition

Variable	Message Content and Length Combination			
	Short Warning		Short Action	
	M	SE	M	SE
	Experienced Population			
Meaningfulness	6.60	0.60	6.70	0.72
Annoyance	3.55	0.70	3.80	0.77
Distraction	3.35	0.69	3.00	0.70
Urgency	6.95	0.68	7.50	0.61
Desire to Turn Off	3.85	0.83	3.45	0.86
	Novice Population			
Meaningfulness	6.43	0.36	6.71	0.29
Annoyance	3.91	0.34	4.53	0.39
Distraction	4.09	0.37	4.64	0.35
Urgency	5.62	0.42	6.24	0.36
Desire to Turn Off	4.07	0.37	4.50	0.50

Meaningfulness. There was no significant difference between the meaningfulness of warning messaging and action messaging, t(153) = -0.55, p = 0.58.

Annoyance. There was no significant difference between the annoyance of warning messaging and action messaging, t(151.74) = -1.12, p = 0.26.

Distraction. There was no significant difference between the distraction of the warning messaging and action messaging, t(154) = - 0.69, $p = 0.49$.

Urgency. There was no significant difference between the urgency of the warning messaging and action messaging, t(151) = - 1.26, $p = 0.21$.

Desire to Turn Off. There was no significant difference between the desire to turn off the warning messaging and action messaging, t(145.79) = - 0.39, $p = 0.69$.

Table 14
Means and Standard Errors of Message Design Ratings for On-Tracks Condition

Variable	Message Content and Length Combination			
	Short Warning		Short Action	
	M	SE	M	SE
	Experienced Population			
Content	6.80	0.63	8.00	0.58
Length	6.45	0.63	7.65	0.52
	Novice Population			
Content	7.34	0.35	6.98	0.32
Length	6.41	0.39	5.96	0.35

Message design ratings included ratings of the appropriateness of the message content and message length. In both message design ratings, there were no significant differences between the warning messaging and action messaging for the on-tracks condition. Table 14 shows the mean message design ratings.

Overall Average Message Design Ratings. Results from the 2 x 2 ANOVA for overall message design ratings showed that there was no significance of message content, $F(1, 153) = 0.001$, $p = .99$, $\eta^2_p = 0.001$, or driver population, $F(1, 153) = 1.62$, $p = .20$, $\eta^2_p = 0.01$, on the overall average message design ratings in the vehicle stopped on tracks condition.

Message Content. There was no significant difference between the appropriateness of the message content and the warning messaging and action messaging, t(153.25) = - 0.09, $p = 0.93$.

Message Length. There was no significant difference between the appropriateness of the message length and the warning messaging and action messaging, t(152.78) = 0.06, $p = 0.95$.

4.4.2 On-Tracks Open-Ended Results

Inclement Weather. The only open-ended question for the on-tracks condition was regarding usefulness in inclement weather. The scenario of the car being stopped on the railroad tracks is incredibly dangerous regardless of if the train is activated or not, which many participants mentioned in their responses about usefulness of these warnings in this scenario. Around 80 percent of participants found warnings to be useful in the on-tracks condition regarding inclement weather. As expected, most of these responses indicated that the usefulness is due the dangerous situation occurring by being stopped on the tracks, and the likelihood of low visibility that may not make it clear if the car was stopped on the railroad tracks. Participants who did not find the warning useful in this HRGC scenario with inclement weather present indicated that the warning may be too distracting when the driver is trying to focus. Interestingly, many of these responses also indicated that these warnings were not urgent enough to gain attention quickly, and that repeating the warning instead of it playing once may make it more effective. This aligns with the ratings results on urgency and is important to note in regards to the design of these warnings.

4.5 Passive Crossing Usage

Passive crossing usage was evaluated through a rating question evaluating hypothetical usefulness and an open-ended elaboration question on the rating provided. The potential usage of intelligent in-vehicle audiovisual warnings at passive crossings was rated as fairly useful (M = 7.18, SD = 2.96).

4.5.1 Open-Ended Responses

Based on the open-ended responses, participants found the hypothetical implementation of intelligent in-vehicle audiovisual warnings to be useful at passive crossings. Out of 78 responses, 64 (82.05%) found intelligent warnings to be useful at passive crossings. Primary reasonings for finding these warnings useful included a lack of visibility at the crossing and issues regarding driver attention at the crossing. Passive crossings may be hard to spot without any physical warning devices, so these responses are in line with issues that occur at passive crossings.

While many participants found the implementation of intelligent in-vehicle warnings at passive crossings to be useful, 14 responses (17.95%) indicated that these warnings would not be useful. Many of these responses stated that less traffic at the crossing and the environment of the passive crossings (such as open fields), may make warnings unnecessary for drivers when at passive crossings. These responses indicated a higher likelihood of turning the warning off due to annoyance and feeling the warning was unnecessary for the situation.

5. Discussion

The results of this study found that message length and message content effect driver preferences for intelligent in-vehicle audiovisual warnings at HRGCs, depending on the HRGC scenario. Driver population differences are important to consider in the effectiveness of the implementation of in-vehicle warnings on the road. The tables below show an overview of the results for active crossing ahead alert (Table 15), and the active crossing warning violation (Table 16).

The active crossing ahead alert informs a driver that they are approaching an active and activated crossing, meaning that there is a train or other vehicle on the tracks as the driver is approaching. Table 15 summarizes the results of the ratings for this HRGC scenario, in which several patterns emerged about the driver preferences. First, participants showed a preference for warning messaging over action messaging, which is consistent with the driving situation described in this scenario, as well as results from a series of expert interviews conducted by Veinott et al., (2023). Second, longer messaging was found to be more annoying, distracting, and had a higher desire to turn off than shorter messaging, but no real preference for short or long messaging was determined. Finally, driver population did not differ a substantial amount, however, novice drivers rated the warnings as more annoying and had a higher desire to turn the warning off when compared to experienced drivers.

The active crossing warning violation is meant to warn drivers of an active and activated crossing ahead, and that there needs to be a change in the driver's behavior in order to safely stop at the crossing (e.g., slowing down quickly). Table 16 summarizes the results of the ratings for this HRGC scenario. Both novice and experienced drivers found the action messaging to be more appropriate, which aligns with the purpose of the active crossing warning violation. Long messaging was rated at more annoying, distracting, and had a higher desire to turn off rating. Finally, the short messaging was rated as more appropriate across a variety of driving situations, which again is consistent with the concerns of driving experts from Veinott et al., (2023) and the findings of Baldwin (2011).

Results of this study showed that driver preferences differ based on the HRGC scenario. Therefore, in the design of these intelligent in-vehicle warning systems, driver preferences may be useful in providing initial information about warning usage. However, driving with the warning in use in both driving simulations and real-world driving experience is still critical to evaluate the effectiveness of the warnings.

Table 15
Overview of Ratings Results for the Active Crossing Ahead Alert Condition

	Message Content	Message Length	Content x Length Interaction	Driver Population
Meaningfulness	Warning Messaging	N/A	Long Messaging	N/A
Annoyance	Action Messaging	Long Messaging	Action Messaging	Novice Population
Distraction	Action Messaging	Long Messaging	Action Messaging	N/A
Urgency	N/A	N/A	N/A	N/A
Desire to Turn Off	Action Messaging	Long Messaging	Action Messaging	Novice Population
Use in Unfamiliar Situations	Warning Messaging	Long Messaging	Warning Messaging	N/A
Use in Familiar Situations	Warning Messaging	N/A	N/A	Experienced Population
Use in Rural	Warning Messaging	N/A	N/A	Experienced Population
Use in Urban	Warning Messaging	Short Messaging	Warning Messaging	N/A
Appropriateness of Content	Warning Messaging	Long Messaging	Long Messaging	N/A
Appropriateness of Length	Warning Messaging	Short Messaging	Action Messaging	N/A

Table 16
Overview of Ratings Results for the Active Crossing Warning Violation Condition

	Message Content	Message Length	Content x Length Interaction	Driver Population
Meaningfulness	Action Messaging	Long Messaging	Short Messaging	N/A
Annoyance	N/A	Long Messaging	N/A	N/A
Distraction	N/A	Long Messaging	N/A	Novice Population
Urgency	Action Messaging	Long Messaging	Short Messaging	N/A
Desire to Turn Off	N/A	Long Messaging	N/A	Novice Population
Use in Unfamiliar Situations	Action Messaging	N/A	Short Messaging	N/A
Use in Familiar Situations	N/A	N/A	Short Messaging	Novice Population
Use in Rural	Action Messaging	N/A	Short Messaging	Experienced Population
Use in Urban	Action Messaging	N/A	Short Messaging	N/A
Appropriateness of Content	Action Messaging	N/A	Short Messaging	N/A
Appropriateness of Length	N/A	Short Messaging	Long Messaging	N/A

5.1 Contribution to Audiovisual Warning Research

This study made many contributions to the literature around intelligent in-vehicle audiovisual warnings, especially in the rail crossing context. This study evaluated variations in intelligent in-vehicle audiovisual warnings that may affect driver preferences for in-vehicle warnings, which is similar to what Nadri et al. (2021) studied. While they examined variables such as speech gender and pitch, this study manipulated message length and message content using speech warnings. This study also provided systematic and consistent evidence comparing message content (warning vs. action), which has not been done in the connected vehicle research or autonomous vehicle research to date that we could find.

The current study extended some of the finding of similar studies regarding intelligent in-vehicle warnings. Nadri et al. (2021) found that hybrid alerts were preferred by drivers, but speech warnings were more preferred overall. The current study furthered these results by concluding that speech warnings are preferred, but the type of messaging, that being warning versus action, affects driver preferences. This same idea is also seen in the results found by Dam et al. (2024). These results showed that ratings for warnings differed for different HRGC scenarios, based on message length. This same result was found in the current study, however, the current results show that message content also impacts driver ratings and preferences. Finally, the results of this study align with the results of McCoy et al. (2023), which found that color and context of the warning affect driver perceptions of annoyance and urgency. The current results found that the active crossing ahead alert (yellow) was significantly less urgent, while the active crossing warning violation (red) was very urgent. It was also found that the message content should vary based on the context, such as the HRGC scenario. All three of these studies tested more audio warnings and conducted more ratings than the current study, while also having less participants, yet similar results were found.

Alert Condition. The active crossing ahead alert (alert condition) warns the driver when they are approaching an active and activated HRGC. This warning is activated regardless of the drivers behavior (Withers & Utterback, 2021). The active crossing ahead alert condition results showed that the short action was the most meaningful warning. Both the long warning and long action speech had the highest ratings of annoyance, distraction, and desire to turn off. The short warning was rated the lowest in annoyance, distraction, and desire to turn off, which may make it the most beneficial warning to implement in an intelligent in-vehicle system. In general, warning messaging may be the most beneficial to implement for this HRGC scenario, which aligns with the purpose of this warning. The active crossing ahead alert is meant to inform drivers of something coming up, so no action is needed from the driver when this warning is activated. This may be the reason why drivers found the warning messaging to be more meaningful, useful, and appropriate for this HRGC scenario. It also makes sense that there was no significance for urgency in this HRGC scenario, as the active crossing ahead alert is not inherently and urgent warning. Again, this warning is only meant to inform drivers of something ahead, not get them to change their behavior rapidly to improve safety, so it may not be an urgent warning.

In the use case ratings regarding unfamiliar and familiar situations, the long warning was rated the highest in usefulness, making it a strong choice to implement in the in-vehicle system. However, there are drawbacks to this warning as well, as the reaction ratings showed a high desire to turn it off. Future research could test these warnings on driver behavior in simulator study to see if the benefits of impacting driver behavior will outweigh the desire to turn the warning off.

The long warning was rated the most appropriate in message content, while the short warning was rated the most appropriate in message length. Warning messaging was considered the most suitable overall in this condition, which makes sense in the scenario where this warning would be activated. The active crossing ahead alert is meant to inform the driver that there is an active and activated HRGC ahead, not change their behavior, so warning messaging is more logical for this scenario.

The results of the open-ended questions indicated implementing warnings would be useful in this HRGC scenario. However, over half of participants indicated some annoyance or desire to turn the warning off. The primary reasons for finding the warnings to be annoying included finding this type of warning unnecessary or redundant for the situation, the amount of times the warning would play, and if the warning played in familiar areas. This is interesting to note, especially in terms of the design of the intelligent warning system, as the ability to alter the message or the frequency of the message depending on the driver's location or familiarity with the environment may be beneficial to implement in the system. Low visibility due to inclement weather and unfamiliarity with the surroundings were also prominent reasons for the need for in-vehicle warnings in this HRGC scenario, which also may be addressed with alterations to the intelligent warning messaging.

All of these results indicate that the long warning messaging was the most preferred warning for this HRGC scenario. This warning messaging says, "Active rail crossing ahead. Proceed with caution." (Figure 15). Despite the incorrect understanding of the term "active" in the rail terminology pretest, this warning still had meaning that informed the drivers about the situation ahead in a way that they understood.

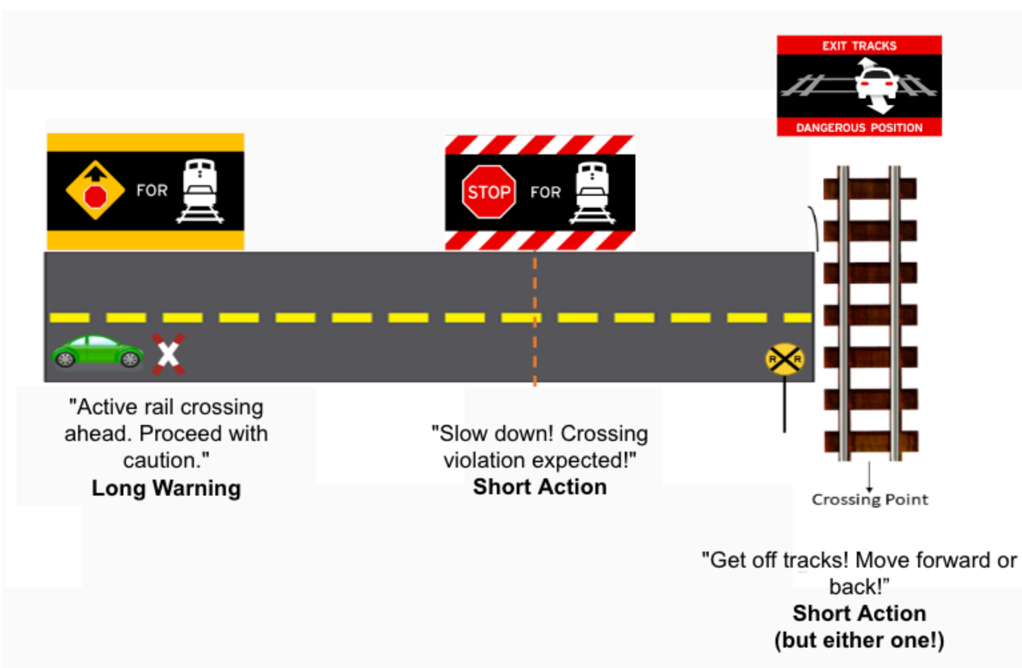

Figure 15. HRGC scenario with most preferred warning messages

Violation Condition. The active crossing warning violation (violation condition) is a warning that is activated if the driver is likely to commit a driving violation at the HRGC, such as speeding and not being able to slow down enough to safely stop at an activated rail crossing (Withers & Utterback, 2021). The active crossing warning violation condition results showed that the long warning was the most meaningful and the most urgent warning, but was also the most distracting, most annoying, and had the most desire to turn off. Generally, the long message length was rated higher than the short indicating that there are strong benefits and drawbacks of the long message length in this condition. While it may be perceived as the most meaningful and urgent warning, the high ratings of annoyance, distraction, and desire to turn off indicate there is a potential for the long message length warnings to be ineffective if they were to be implemented in an intelligent in-vehicle system.

The long warning was also one of the most useful across all use case ratings in the violation condition. The short action warning also was ranked as most useful in all use cases in the violation condition, indicating it may be another effective warning in this HRGC scenario. For appropriateness, the short action message was rated the most appropriate in message content and message length. Drivers found this message to be a suitable warning for the HRGC scenario.

The open-ended responses indicated that the warnings in this condition are perceived as useful, but there are many factors that influence how useful drivers find these warnings, including annoyance, distraction, and finding the warning to be too technical in the terminology used. The notion of annoyance and distraction impacting the usefulness of warnings in the violation condition is similar to the ratings results. The term "violation" was deemed too technical by many of the drivers leading to confusion about what the warning was trying to inform the driver of or how the driver should change their behavior. This is important to note in testing the effectiveness of these warnings in driving scenarios, as drivers may not behave in the correct way if they do not understand what the warning is telling them. Improving this warning messaging to make it simpler may be beneficial to the usefulness of the warning in this condition. In regard to inclement weather, many participants who found the warning to not be useful stated that it may be a distraction and put drivers in a more dangerous situation if they are trying to focus on the road or gain control of their vehicle. This was not considered when developing this question, but was a predominant response from participants, which is important to consider in the design of these warnings.

Because of these results, the most preferred choice for messaging for the active crossing warning violation is the short action messaging, which says, "Slow down! Crossing violation expected!" (Figure 15). However, due to the confusion around the term "violation" in the messaging, and alteration to this text may be necessary to make the speech more clear and easily understandable in order for the driver to behave appropriately, such as slowing down in time before reaching a crossing. While the text may be altered, it was clear that a short warning with messaging that informs the driver of what to do is the most preferred choice for this scenario.

On-Tracks Condition. The vehicle stopped on tracks warning is activated when the vehicle is stopped or stuck on the tracks, regardless of the activation status of the HRGC (Withers & Utterback, 2021). The vehicle stopped on tracks condition had no significant differences in message length and message content in the reaction ratings or message design ratings. This finding leads to a rejection of the hypothesis that there will be a driver preference for message length or message content. However, drivers rated the meaningfulness, urgency, and appropriateness of message length and message content high, and the annoyance, distraction, and desire to turn off low for both variations of messaging. This implies that both the warning and action messaging may be appropriate for implementation in an intelligent in-vehicle system. This HRGC scenario is the most dangerous situation at a rail crossing, so it makes sense that drivers may find any warning to be useful in the context of this scenario.

The open-ended responses were focused on usefulness in inclement weather, and the majority of participants determined that in-vehicle warnings would be useful in the situation that a car is stopped on the tracks in inclement weather. This situation is extremely dangerous, especially when visibility is low, so it is not surprising that drivers would see a need for a warning in this scenario. What was surprising, however, is the number of participants that indicated that the warning should repeat or increase in urgency in this scenario. Looming auditory warnings, or warnings that increase in intensity if ignored, have been proven to be effective in driving situations (Gray, 2011). However, this idea was not the focus of the current study, Despite that, knowing that drivers may prefer looming warnings or warnings that increase in intensity in more dangerous situations is beneficial in collecting more information on driver preferences of in altering the design of in-vehicle warnings.

Despite there being no significant difference between the warning versus action messaging in this HRGC scenario, it is assumed that the action messaging may be more effective in the event of being stopped on the railroad tracks, and thus is the recommended message for this scenario. This messaging says, “Get off tracks! Move forward or back!” (Fig 15). This messaging, as well as the potential increased intensity or repetition of messaging would need to be tested to confirm their effectiveness, however, it seems that based on this HRGC scenario, these may be effective changes.

5.2 Limitations

There are a few limitations in this study. First, drivers provided subjective ratings based on watching a video, and were not driving a vehicle and experiencing the warning. Therefore, participants were not interacting with the warnings or the system in a way that they were capable of fully experiencing the warning. Driver preferences and behaviors may differ when participants interact with the system outside in a more naturalistic manner (e.g., driving on the road or in a simulator). In this study, we used videos depicting real world demonstrations of the alerts and warnings for realism. Previous research has put drivers in simulators while the watch a simulated video, which may have improved physical fidelity of the experience because they were sitting in a driving simulator but does not seemingly change the cognitive fidelity because the drivers are not actually driving and experiencing the warnings and alters. Therefore, both approaches can be effective for giving the drivers an initial experience with the ratings. Next steps would be to take these warnings into a driving simulator. Second, sample size differences may have affected the likelihood to detect a driver population difference if one existed. The experienced population (n = 20) was smaller than the novice population (n = 58), which could have impacted the results to fit novice population n drivers' preferences more than older adults regarding these warnings. There were few statistically significant differences overall related to the driver population, suggesting that their preferences for warnings in different contexts were similar. Future research should replicate this study with a larger experienced population sample. Finally, the familiarity participants had with rail crossings and intelligent warning systems may impact how their ratings of perceived usefulness. Participants in this study crossed approximately 13 rail crossings a month in their hometowns, however, there was a range of HRGC types. Participants with little familiarity with rail crossings may have had different preferences for the warnings than participants with more familiarity.

5.3 Implications to Railroad Interventions

Based on the current study there are a couple recommendations for connected vehicle to HRGC interventions to improve safety. Implications from this study can be applied to research on driver behavior and driver safety, specifically in the highway-rail grade crossing contexts. First, determining what in-vehicle warning to use in real-world situations is not an easy task, which is why gathering information on driver preferences is so important. Driver preferences need to be considered in the design of intelligent in-vehicle warnings, as they may affect how drivers perceive the usefulness of warnings, and thus impact their effectiveness on the roads. If drivers have a negative perception of a warning, they are less likely to listen to it and respond to it appropriately. Secondly, no warning will be effective in all conditions and accepted by every driver. Therefore, research on the driver preferences and driver behavior in driving simulators and the field are critical. Drivers may find a warning meaningful, but still want to turn it off, as was seen in many of the ratings in the current study. Selecting an in-vehicle warning that will be used on the road with the goal of improving safety, will have benefits and drawbacks.

This study also found that certain conditions and situations are of concern to drivers across all scenarios that may be important to consider when designing and implementing these warnings. Across all three conditions, low visibility due to weather, infrastructure, the environment, etc. was a significant reason for desiring warnings in the vehicle. Unfamiliar and familiar situations also stood out as an important aspect of implementing intelligent warnings. Participants preferred warnings in unfamiliar situations and were more likely to find them annoying or turn them off in familiar situations. Due to the intelligent nature of the warning, it may be beneficial to have different warnings based on the GPS location of the driver, such as if they are in a short distance of their home versus in a new location.

5.4 Future Work

This study examined driver preferences for intelligent in-vehicle audiovisual warnings at highway-rail grade crossings. The current study was conducted online and highlighted potential use cases for in-vehicle warnings in many situations including unfamiliar and familiar situations, as well as rural and urban areas. The next steps are to evaluate these warnings and messages on driver behavior through driving simulators experiments under different driving conditions, as well as evaluate the ways in which the intelligent warning system can be used to further alter the warning to fit the needs of the driver.

Systematic differences in message length and message content variations in the speech were rated using reaction ratings, as well as the appropriateness of the length and content for different HRGC scenarios. Testing these warnings with the most appropriate content and length in the context of HRGC scenarios would be an effective tool to determine if driver preferences for these warnings impact driver behavior in future research. Using a driving simulator, the preferred audio selection from this study could be tested to determine if a driver's behavior and driving performance changes based on the implementation of the intelligent in-vehicle audiovisual warning.

The intelligent warning system itself can be further tested by expanding the messaging system to address some of the points made by participants in this study about why they would or would not use this system. First, it seems as though participants were more likely to use this system in unfamiliar situations, especially in situations of low visibility. Using the GPS system and weather information, the intelligent warning system could produce a different message to the driver that fits the situation going on in the environment and gives the driver information they find valuable. These intelligent warnings could also be altered to fit other aspects of the driver, such as making warnings more urgent if the driver is showing signs of fatigue due to the duration of the drive or playing multiple times if the driver is ignoring the warning. These ideas have not yet been tested but are interesting next steps into the future of the intelligent in-vehicle warning system at HRGCs.

6. Conclusion

Accidents and incidents at highway-rail grade crossings are common, and despite the added safety measures like physical warning devices that have been implemented at crossings, the rate of accidents remains steady (Federal Railroad Administration, n.d.). Driver noncompliance to road rules, poor driver decision making, and inattention are only a few of the factors that influence the number of accidents at HRGCs but play a significant role in understanding the role driver behavior plays in the accident rate in the rail crossing context (Beanland et. al., 2017; Linja et al., 2020; Veinott et al., 2020; Yeh & Multer, 2008).

Intelligent in-vehicle audiovisual warnings are an effective tool to combat issues in driver behavior at HRGCs, but only if the driver accepts the warning in their vehicle, which is why understanding what drivers prefer for in-vehicle warnings is so important. The current study evaluated driver preferences for intelligent in-vehicle audiovisual warnings for their reaction ratings, use case ratings, message design ratings, as well as open-ended responses. Our results indicate that message length and message content do impact driver preferences and perceptions of in-vehicle audiovisual warnings in systematic and meaningful ways. This work can be furthered by testing these warnings in a driving simulator to determine if driver preferences impact driver behavior at highway-rail grade crossings, as well as exploring the advancement of the messaging in the intelligent in-vehicle warning system.

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A. RCVW Training Information

An Introduction to Rail Crossing Violation Warning (RCVW) system

The Rail Crossing Violation Warning (RCVW) system has been developed in a Federal Railroad Administration (FRA)-funded research project to reduce the frequency and severity of crashes at Highway-Rail Grade Crossings (HRGCs). It uses Connected Vehicle (CV) technologies to improve the situational awareness of roadway drivers approaching an HRGC. It is to be deployed at any HRGC with active warning devices where there is a need to minimize safety-related incidents. It provides the means for roadway-vehicle drivers to be warned of violation or a predicted imminent violation of an HRGC protection system, which is critical in the prevention of avoidable incidents.

The following are the three conditions in which audio warnings will be tested in this study:

- **Violation Condition (Rail Crossing Violation Warning)**: When the vehicle is approaching an active HRGC, and the RCVW system determines the driver is not taking appropriate action to stop the vehicle this visual will appear alongside an audio warning. This warning will persist until adequate corrective action (e.g., braking) is taken to prevent the predicted imminent violation or until the HRGC status changes to be not active, while the vehicle continues its approach.

- **On-Tracks Condition (Clear HRGC Warning)**: When the vehicle is stopped on railroad tracks or is in a hazardous zone, this visual will be displayed alongside an audio warning. This warning aims to prevent a vehicle-train collision by encouraging the vehicle driver to exit the HRGC immediately and by any means necessary, prior to interception by a train.

- **Alert Condition (Approaching HRGC Information Message)**: Displayed alongside an audio message when the vehicle is approaching an active crossing but a violation is not predicted to happen. This message is to inform drivers of the approaching train.

Questions:

1. When would the violation warning occur?
   a. When the driver is speeding coming up to an active rail crossing
   b. When the car is stopped
   c. When the car is crossing over a rail crossing
2. When would the alert warning message be activated?
   a. When the driver is speeding
   b. When the driver is approaching a crossing where the dynamic warning devices (lights, gates) are in use
   c. When the driver is approaching a crossing and there is traffic at the crossing
3. When would the on-tracks message be activated?
   a. When the train is on the tracks
   b. When a car is stopped/stuck on the railroad tracks
   c. When the car approaches the tracks

B. Preference Questions

B.1 Ratings Questions

1. Using the scale, rather the audio you just heard on these dimensions (urgent, annoying, meaningful, distracting, desire to turn off)
2. How appropriate did you find the … (warning content, warning length)
3. How useful would you find this warning in … (an unfamiliar area, your hometown, an urban area, a rural area)

B.2 Open-Ended Questions

1. When would you find this warning useful? Under what conditions?
2. Are there any driving situations where this warning might be annoying? Or might result in you turning it off?
3. Please provide a brief explanation about your responses regarding rural and urban areas.
4. Imagine you are driving in inclement weather (heavy rain, heavy snow, etc.). Would you find this warning useful? If so, how?