Connected Motorcycle Crash Warning Interfaces

CONNECTED VEHICLE/INFRASTRUCTURE UNIVERSITY TRANSPORTATION CENTER (CVI-UTC)

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Connected Motorcycle Crash Warning Interfaces

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Connected Vehicles-Infrastructure UTC

The mission statement of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) is to conduct research that will advance surface transportation through the application of innovative research and using connected-vehicle and infrastructure technologies to improve safety, state of good repair, economic competitiveness, livable communities, and environmental sustainability.

The goals of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) are:

- Increased understanding and awareness of transportation issues
- Improved body of knowledge
- Improved processes, techniques and skills in addressing transportation issues
- Enlarged pool of trained transportation professionals
- Greater adoption of new technology

Abstract

Crash warning systems have been deployed in the high-end vehicle market segment for some time and are trickling down to additional motor vehicle industry segments each year. The motorcycle segment, however, has no deployed crash warning system to date. With the active development of next generation crash warning systems based on connected vehicle technologies, this study explored possible interface designs for motorcycle crash warning systems and evaluated their rider acceptance and effectiveness in a connected vehicle context. Four prototype warning interface displays covering three warning mode alternatives (auditory, visual, and haptic) were designed and developed for motorcycles. They were tested on-road with three connected vehicle safety applications - intersection movement assist, forward collision warning, and lane departure warning - which were selected according to the most impactful crash types identified for motorcycles. It showed that a combination of warning modalities was preferred to a single display by 87.2% of participants and combined auditory and haptic displays showed considerable promise for implementation. Auditory display is easily implemented given the adoption rate of in-helmet auditory systems. Its weakness of presenting directional information in this study may be remedied by using simple speech or with the help of haptic design, which performed well at providing such information and was also found to be attractive to riders. The findings revealed both opportunities and challenges of visual displays for motorcycle crash warning systems. More importantly, differences among riders of three major motorcycle types (cruiser, sport, and touring) in terms of riders' acceptance of a crash warning interface were revealed. Based on the results, recommendations were provided for an appropriate crash warning interface design for motorcycles and riders in a connected vehicle environment.

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Table of Contents

List of Figures

List of Tables

Introduction

A crash warning system (CWS) is an automobile safety system designed to reduce the frequency or severity of automobile crashes by detecting imminent crashes using various sensors and/or machine vision and delivering timely warnings to users. As a result of the warnings, users are able to respond quickly to potential threats, permitting sufficient time to execute evasive maneuvers and avoid crashes. There are various systems for mitigating different crash types: forward collision warning (FCW), lane change warning (LCW), intersection movement assist (IMA), etc. Built on a foundation of robust research and development conducted over the last couple of decades, CWSs are now deployed within the high-end vehicle market and are steadily spreading to additional motor vehicle industry segments each year. However, there is very little research on these systems for application to motorcycles and no systems have been released in the motorcycle market to date.

Traditional CWSs are based on relatively costly sensors such as RADAR and LIDAR to monitor objects on the roadway and, usually, multiple systems are needed to cover various directions for different crash types. Today, CWSs based on Connected Vehicle Technologies (CVT) are being actively developed. By utilizing dedicated short-range communications (DSRC), which are fast, secure, and reliable, connected vehicles, ranging from cars to trucks and buses to motorcycles, would be able to talk to each other (vehicle-to-vehicle [V2V]) and to different types of roadway infrastructure (vehicle-to-infrastructure [V2I]), continuously sharing important safety and mobility information [1]. CWSs will likely be among the first applications deployed that capitalize on the advantages of both V2V and V2I communications. By continuously monitoring and sharing information with surrounding traffic and infrastructure, one connected vehicle system could potentially prevent numerous types of crashes. CVTs provide expanded capabilities with 360-degree coverage, are small, lightweight, and inexpensive relative to traditional sensors, thus making them attractive for application to motorcycles.

As with any system, there are a number of objectives that must be met for successful implementation. A CWS interface must rapidly direct attention to the pertinent threat. The interface must also avoid unintended consequences, and be acceptable (if not desirable) to the target user. To balance these goals, it is important to conduct evaluations and collect responses and feedback from end users. By nature, CWS studies should aim to put participants in crash or near-crash situations. Indeed, researchers often develop safe protocols (e.g. passenger side brakes, soft targets, bailout procedures, etc.) for conducting CWS experiments in passenger vehicles. However, many of the traditional safety assurance techniques cannot be applied to motorcycles, and the rider is at a higher risk for injury should a crash inadvertently occur.

Thus, most previous CWS motorcycle studies were conducted in simulated environments where risk was well controlled. However, compared to other drivers, motorcycle riders are riding in a relatively exposed and dynamic environment where motorcycle noise, wind impacts, vibration, etc. are present, which increases the difficulties of reproducing a realistic riding environment in a simulator. This study was designed to evaluate a prototype motorcycle crash warning interface (CWI) and collect measures of user acceptance and input within realistic on-road riding scenarios in a connected vehicle environment.

Background

Motorcycle Crash Types

Motorcyclists are among the most vulnerable road-user groups. Per vehicle mile traveled in 2012, motorcyclists were over 26 times more likely than passenger car occupants to die in motor vehicle traffic crashes and 5 times more likely to be injured [2]. Although motorcycles made up only 3% of all registered vehicles in the U.S. in 2012, they accounted for 15% of all traffic fatalities and 18% of all occupant fatalities.

The most common motorcycle accidents are single-vehicle accidents, and crashes where another vehicle violates the motorcycle's right-of-way (ROW) at an intersection [3–5]. The motorcycle ROW violation crashes indicate a motorcycle conspicuity problem in both daytime and nighttime conditions [6] that leads to poor speed-spacing judgment and detection failure (also called "looked but failed to see" error [7,8]). This may be because motorists rely on visual cues to judge the speed and space of approaching traffic as part of their judgment in accepting gaps to cross the intersections, and due to the insufficient frontal surfaces of motorcycles, the visual cue for motorists is sometimes too weak to detect or use to adequately judge the speed and space-gap of motorcycles [9]. Rear-end and side-side crashes are the next most frequent crash types [4, 10]. The latter may be related to overtaking behaviors some riders are more likely to perform [10]. Among motorcyclist fatal crashes in which the motorcycle collided with other motor vehicles in transport, almost 90% are two-vehicle crashes, and in 75% of two-vehicle crashes, motorcycles collided with the vehicles in front of them [1].

It was found that in many cases, a rider did not have time to complete crash-avoidance maneuvers [11]. This suggests that warning riders of a potential threat ahead of time would help them complete evasive maneuvers and thus avoid crashes. Therefore, it is reasonable to believe that motorcyclists could benefit greatly from CWSs (or applications in a CVT based CWS) such as FCW, LCW, and IMA.

Warning Modalities on Motorcycles

Many CWS studies exist, but the majority pertain to the automotive domain [12–14]. Due to differences between four-wheel vehicles and motorcycles, and the lack of relevant studies for the latter, this study focused on the development and evaluation of a prototype CWI specifically for motorcycles and their riders.

A SAFERIDER project was recently implemented in the EU, and some traditional crash warning systems for motorcycles were studied [11, 15, 16]. The SAFERIDER project aims at introducing advanced driver assistance systems specifically designed for motorcycles, called Advanced Rider Assistance Systems (ARAS). The project schedule includes development of five rider assistance functions—Frontal Collision Warning, Intersection Support, Lane Change Support, Speed Alert, and Curve Warning—embedded in a unified hardware and software framework [11]. Its human-machine interface concepts and strategies were among the guidelines [17, 18] which were adopted when designing the motorcycle CWI for this study.

On motorcycles, there are fewer feasible locations where a CWI could be installed compared to four-wheel vehicles. Additionally, the interface between the system and the rider must function in an open environment with much noise and vibration. Motorcycle riding requires a lot of environment scanning, so CWI displays that provide visual cues should be located near current areas of visual focus, such as near mirrors or windshields. Not every motorcycle has a windshield or has a windshield high enough to reach riders' visual field [19, 20], but every street-legal motorcycle should have at least one mirror. Installation locations must also be carefully selected to reduce the environmental effects and integrate with current components. The inside of the helmet has also been identified as a good candidate for CWI displays. There are many auditory/communication devices for motorcyclists to install inside their helmets that could be used as auditory displays. Heads-up displays (HUDs) built into motorcycle helmets, or even motorcycle helmets that come with HUDs [21], are being developed and show potential for in-helmet visual displays.

Haptic technology is another CWI choice. Previous work has found that humans are most sensitive to vibration in the 100 to 300 Hz range [22]. Frequencies within this range are also unlikely to be masked by a vehicle's typically lower vibration frequency [23]. It has been widely established that hands and fingers are more sensitive to haptic stimuli than the abdominal region [24], so it is reasonable to expect riders would more easily perceive haptic stimuli presented to hands and fingers. In order not to interfere with the motorcycle's normal operation, the upper region of the hands or wrists could be selected for these stimuli.

Among several functions that crash warnings may serve, their main purpose is to alert the vehicle operator to a hazardous situation that requires immediate response. Ideally, a warning also provides information that allows a rapid determination of an appropriate response [25]. The information might include, for example, the direction of the potential threat (front, left, or right), and the level of the threat, with a high level requiring an immediate evasive maneuver and a lower level requiring only immediate attention.

Motorcycle Types

For the years 2005–2007, the top three types of new U.S. motorcycle sales were cruiser (33%), sport (18%), and touring (14%), which, totaled, accounts for more than 85% of street legal motorcycle sales [26]. Cruiser motorcycle design generally emphasizes appearance, style, and sound. These bikes have long profiles and low saddle height, and often the rider leans backwards with feet forward. Sport bike design follows road-racing design and emphasizes handling, acceleration, speed, braking, and cornering. Sport bike riders are in a forward leaning riding position. Touring bikes are designed for comfort over long rides. They are physically larger motorcycles with luggage and wind protection, and sometimes have amenities such as stereos, 2-

way communication, cruise control, heating, etc. Based on differences in bike design and purpose, it is believed that rider demographics and preferences will vary by motorcycle type, potentially including preference and acceptance of a CWI. However, none of the existing motorcycle CWS studies appear to consider these potential differences. As an important part of this study, the effect of motorcycle type was explored within the evaluation of a motorcycle CWI.

Method

Crash Warning Interface

Three warning mode alternatives were selected (visual, auditory, haptic) and based on that, four different motorcycle CWI displays were chosen for on road evaluation. Based on the literature review and a brainstorming session between researchers and hardware developers, one of the interface displays was located on the side mirror. This display consists of two 12-LED light strips attached to the top edge of the mirror on each side (Figure 1). Red LED lights were selected by default to present a warning signal.

During initial testing, it was determined that under direct sunlight, it was hard to detect warnings even when looking directly at the mirror-mounted strips. Their brightness was found comparable to some original equipment manufacturers' mirror blind spot indicators. Poor conspicuity might have been due to the fact that the strip angled up at the motorcyclist and sky, while the built-in car mirror warning light is partially shaded and faces horizontally, in-line with the driver's sight. As an alternative, two 3-LED light strips were mounted inside a motorcycle helmet on the visor as a wearable warning display (Figure 1). The LED strips were shorter, leveled with the rider's sight, and oriented vertically to avoid being obtrusive. With one on each side, they were approximately 60 degrees from the center, so that they were close to riders' peripheral vision (central binocular vision covers only 114 degrees [horizontally] of the field of vision in humans [27]; the remainder is peripheral vision). A pilot test was conducted among six participants riding mixed motorcycle types. It was found that the conspicuity issue was solved by moving the LED light strips into the shade of motorcycle helmets and close to riders' eyes with no major disadvantages. Therefore, visor-mounted LED light strips replaced the mirror strips as an individual test candidate. However, being mounted close to one of the visual focus points, mirror-mounted strips still showed potential effectiveness in certain scenarios (such as LCW) and, as a result, were retained in this study.

The third alternative was intended to integrate with riders' audio systems to capitalize on the sound attenuation provided by helmets. The auditory warning display was a Sena SMH10 Bluetooth headset (Figure 1), which can be easily installed on any full face or 3/4 helmet with two speakers close to the ears and a volume dial.

The final alternative was a haptic warning integrated into a wristband that was worn underneath riders' gloves and jacket sleeves. Each wristband contained two tactors placed on the top and bottom of participants' wrists, directly next to the skin (Figure 1). In a marketed system, the haptic warning could be integrated into a set of riding gloves or into the sleeves of a jacket.

Each of the designed interface displays was constructed and packaged in such a way that participants could experience the interface on any motorcycle. All displays had self-contained battery power sources and could be easily mounted and connected/controlled wirelessly.

Figure 1. A rider on a Yamaha V Star with a connected motorcycle CWS.

Along with the CWI, two motion cameras (capturing riders' torso and head, and forward roadway and hand(s) respectively) were mounted on the handlebar and a backpack (Figure 1) and deployed during the road test. Snapshots from the two cameras are shown in Figure 2.

Figure 2. Snapshots from cameras capturing rider (left) and forward roadway (right).

Warning Design

Crash warnings were capable of delivering two basic types of information: urgency and direction. Each display had two identical elements, generally oriented to the left and right of the rider, and so were designed to convey directional information to the rider. Activation of left element(s) indicated threats from the left-hand side, and vice versa. Activation of both sides warned riders of frontal hazards. The warnings were also designed to present two urgency levels (caution alert and warning alert). Characteristics of alerts for each warning interface display are summarized in Table 1.

Table 1. Characteristics of Caution and Warning Alerts for Each CWI Display

CWI Display	Caution alert	Warning alert
Visual (mirror/visor LED light strips)	Frequency – 2 Hz Duty Cycle – 20%	Frequency – 4 Hz Duty Cycle – 20%
Auditory (in-helmet headset)	Frequency – 800 Hz Pulse Rate – 1.5 Hz Duty Cycle – 12.5%	Frequency – 1250 Hz Pulse Rate – 6 Hz Duty Cycle – 33%
Haptic (wristbands)	Frequency – 150 Hz Pulse Rate – 1 Hz Duty Cycle – 20%	Frequency – 300 Hz Pulse Rate – 10 Hz Duty Cycle – 50%

Connected Vehicle System

Scenarios in this study required participants to ride a connected motorcycle, and experimenters to drive a four-wheel connected vehicle. The connected system used on the motorcycle (including a DSRC onboard unit and a microcomputer system communicating with CWI) was built into the backpack carried by riders. The system antenna and the forward view camera were mounted on top of the backpack (Figure 1). Weighing only a few pounds and containing its own power supply, this backpack design ensured portability so the evaluation could be performed on any motorcycle.

The four-wheel connected vehicle had its antenna attached on the top of the vehicle and its Savari DSRC onboard unit and data acquisition system (DAS) located in the trunk (see Figure 3).

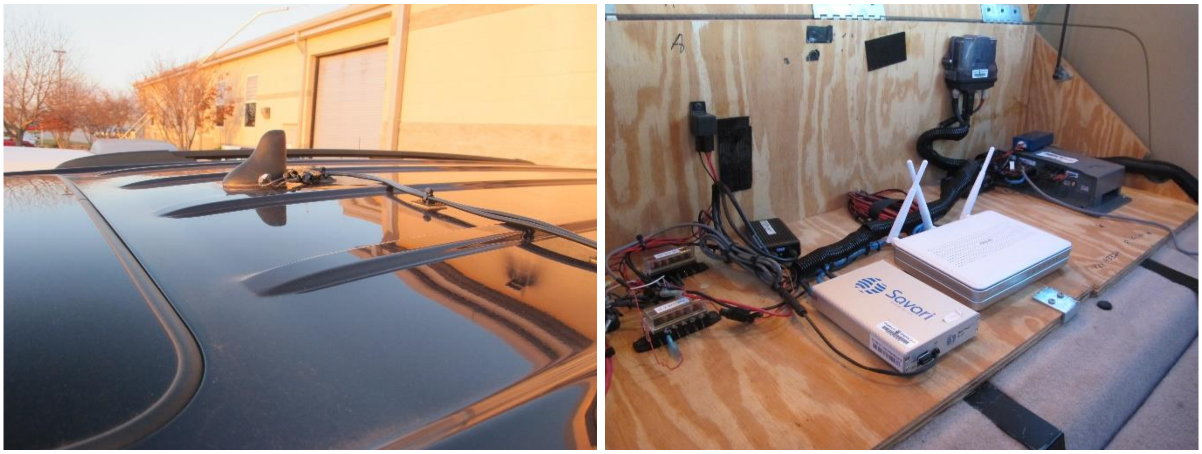

Figure 3. Connected vehicle system in a car, antenna (left), DSRC unit/DAS (right).

Since the study focused on the evaluation of CWI rather than the development of CWS application algorithms, warning capabilities were realized by manual control (i.e. Wizard of Oz technique) rather than using real-time algorithm calculations. This strategy considerably simplified the development requirements and ensured experimental focus remained on the interface itself. Experimenters rehearsed each of the test scenarios to provide precise and timely warnings so the actual presentation to participants was consistent and felt like an automatous process. The final connected vehicle system architecture is showed in Figure 4.

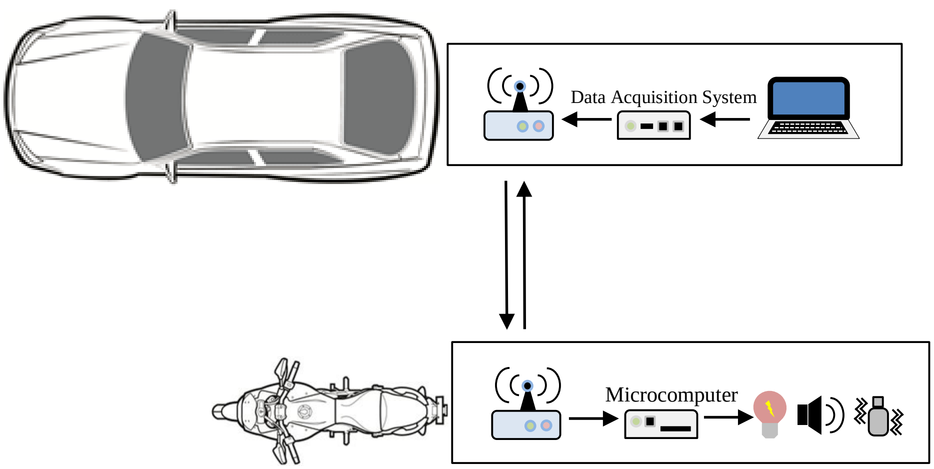

Figure 4. Architecture of the connected motorcycle system with warning capabilities.

Throughout the road test, the motorcycle and the car "talked" with each other continuously through their Savari DSRC onboard units. The in-vehicle computer system is showed in Figure 5. Through this computer and a VTTI-developed software program, any individual CWI display or a combination of displays could be triggered at any warning level.

Figure 5. The in-vehicle computer and its control interface.

At the appropriate time, based on landmarks on the road, an experimenter in the car entered a command using the in-vehicle laptop. This message was passed to the DAS, and then reached the motorcycle system through DSRC. After the control unit on the motorcycle received the command, it triggered the appropriate warning interface, which was connected either by wire or wirelessly, depending on the interface.

Experimental Vehicles

The motorcycle fleet included motorcycle types such as sport/dual-purpose (Kawasaki Versys, 649cc), cruiser (Honda Rebel, 250cc, Yamaha V Star, 950cc, and Road Star, 1670cc), and touring (Honda Gold Wing, 1832cc). Figure 6 shows all Virginia Tech Transportation Institute (VTTI) vehicles involved in this project. Each participant was provided with a motorcycle similar to the one they normally ride in terms of type and engine size, so focus would be on experiencing the CWI rather than adjusting to an unfamiliar bike. The confederate vehicle in this study was a Chevrolet Tahoe.

Figure 6. Research vehicles for this project.

Road Test Scenario

The road test took place on the Virginia Smart Road, a 2.2-mile test track in Blacksburg, Virginia. Exercising the warning interface was accomplished through the application of a carefully choreographed scenario for each CVT-based CWS application. Road test scenarios were conducted at speeds of 25 mph, and separations between vehicles were at least 2 seconds. Three scenarios were conducted on three consecutive sections of the Virginia Smart Road (see Figure 7).

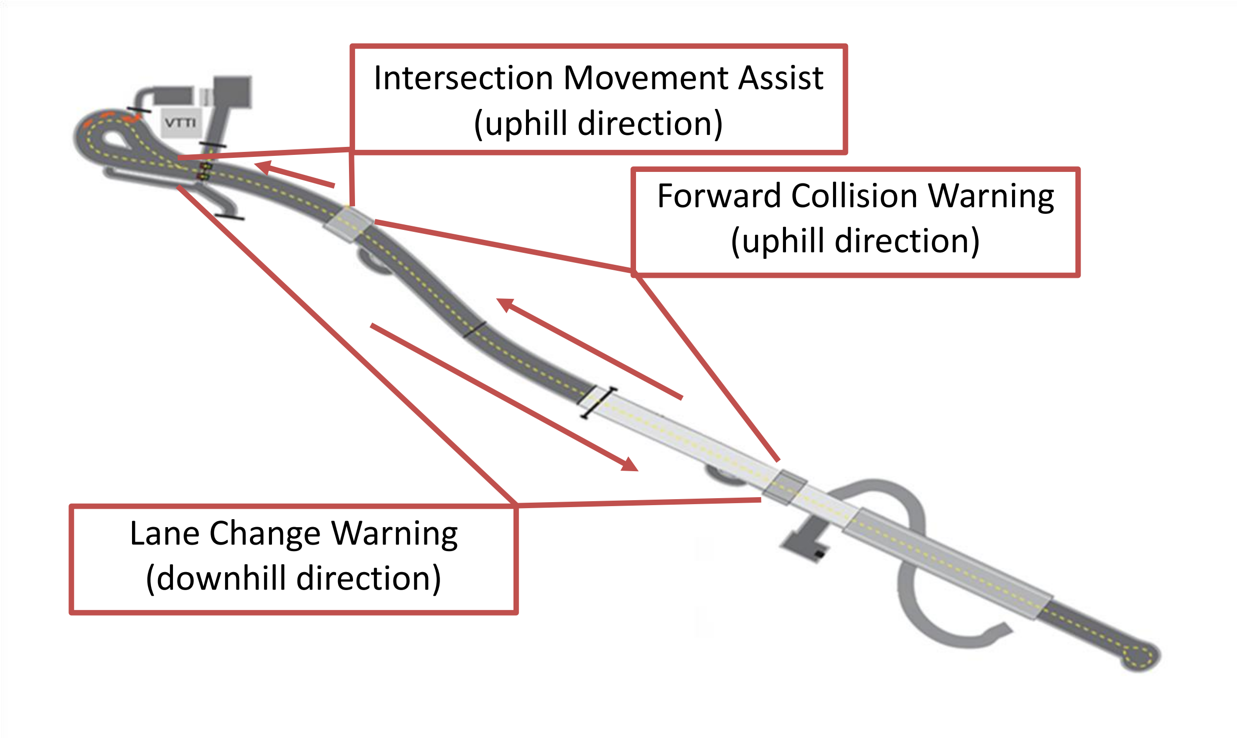

Figure 7. Sections on the Virginia Smart Road for CWS application scenarios.

The IMA application is intended to warn a rider that another vehicle is going to move through an intersection ahead, violating the rider's right-of-way in a manner that will require avoidance. The FCW is intended to warn a rider when they are approaching a lead vehicle too quickly and avoidance is required. The LCW is intended to warn a rider during a lane change attempt when the target lane is, or will soon be, occupied by another vehicle so that the attempt may be aborted. The characteristics of the three scenarios are summarized in Table 2 and illustrated in Figure 8.

Table 2. Scenario Characteristics of CVT-Based CWS Applications

Application	**Warning Direction**	**Warning Level**	
		Caution Alert	**Warning Alert**
IMA	Right*	Motorcycle is less than 5 seconds from the intersection	Motorcycle is less than 3 seconds from possible collision at an intersection
FCW	Forward	Lead vehicle is braking	Lead vehicle stops or headway less than 2 seconds
LCW	Left**	A vehicle is overtaking from left lane when rider turns on the left turn signal	A vehicle is in rider's blind spot when the left turn signal of the motorcycle is activated

* Only right side was selected to leave less space and increase the potential urgency level of this scenario.
** Assuming that vehicles often overtake from high-speed lane, the warning was from rider's left-hand side.

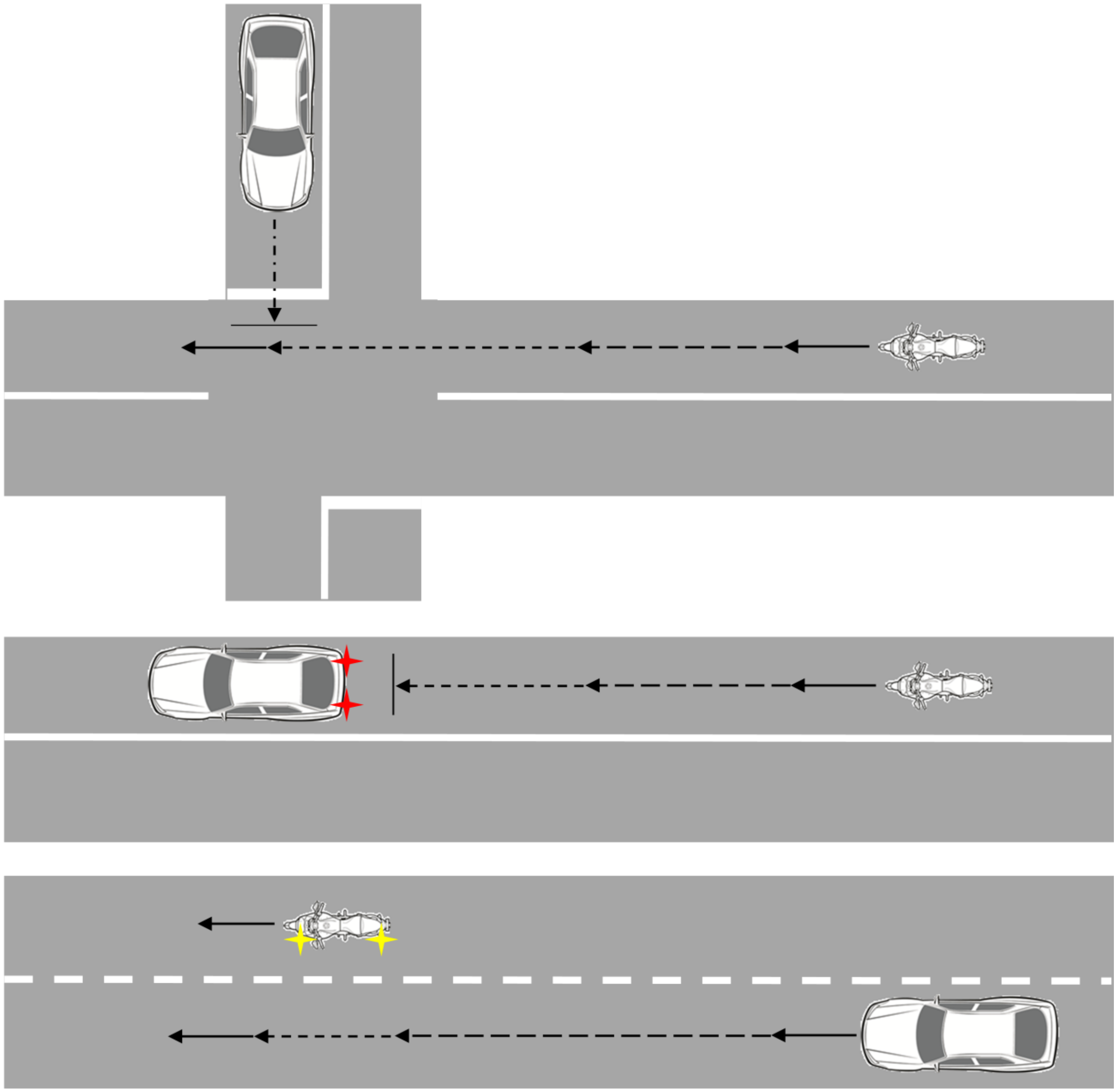

Figure 8. Application scenarios, IMA (top), FCW (middle), LCW (bottom).

Since high-risk scenarios were tested, a number of precautions were taken to ensure that participants rode comfortably, safely, kept focused and provided thoughtful feedback. Breaks were offered during road sessions, and pre- and post-ride portions of the study were conducted in a temperature-controlled room. Along with speed limit and vehicle headway precautions, thorough pre-ride instructions were provided to participants to prevent surprises during the scenarios. The only thing participants were not aware of was which display would be triggered.

Experimental Design

A mixed-factorial experimental design was used in this study so that participants experienced all application scenarios (three levels – IMA, FCW, and LCW) with each CWI display (four levels – visor-mounted LED strips, in-helmet headset, haptic wristbands, and a combination of all four displays [combo], including mirror-mounted LED strips) in a balanced order. (Although it was not feasible to evaluate all possible combinations in this study, by testing all displays in one combination, it was expected that we could get some flavor from rider acceptance and feedback about combining different warning modalities. The scope of this study was primarily focusing on evaluating each warning modality and making recommendations.) Some ratings were assessed both prior to and after the road test, so time (two levels – pre-ride and post-ride) was the third within-subject factor. Besides the three within-subject factors, motorcycle type (three levels - cruiser, sport, and touring) was included as a between-subject factor. During the road session, participants completed four trials with one CWI display evaluated in all three scenarios in each trial.

The experiment was designed to assess the performance of a CVT-based CWI primarily in terms of the metric of rider acceptance. Rider response, emphasizing measurement of riders' monitoring of surroundings and interface as captured by motion cameras, could have served as another set of performance assessing metrics. However, participants were generally aware of the purpose of a scenario and what was to be expected prior to execution. So participant response would either be fast, as they were prepared, or in some cases, slow, as they knew nothing needed to be done. Due to these limitations, rider response is only summarized very briefly in the results section and no statistical tests are applied.

Rider acceptance was assessed by collecting subjective data through a set of questionnaires that allowed the participants to reflect on their experiences to provide measures such as desirability, usefulness, and system limitations. These questionnaires consisted of rating questions (on a seven-point Likert scale), ranking questions, and open-ended questions and were administered at different stages of the study. With names corresponding to their phase of the study, these included a pre-ride questionnaire, post-scenario questionnaire, post-trial questionnaire, and post-ride questionnaire (See Appendix). A summary of questionnaires is provided in Table 3.

Table 3. Summary of Questionnaires Administered

Stage	Major Question Type		
	Rating (7-point Likert Scale)	Ranking	Open-Ended
Pre-ride	Benefit/comfort of having motorcycle CWS; Benefit of various CWS applications		
Post-scenario	Benefit for each display/application combo		
Post-trial	Performance of the CWI displays and alerts		
Post-ride	Benefit/comfort of having motorcycle CWS; Benefit of various CWS applications	CWI displays	Likes, dislikes, & improvements of each display

A pre-ride questionnaire was first administered to collect participants' riding experiences, experiences with CWS, benefit/comfort ratings of having CWSs on their motorcycles, and benefit ratings of various CWS applications. During the road session, participants were asked to give a single benefit rating for each display/scenario combination immediately after they experienced it. After completing one trial, a post-trial questionnaire was administered to collect comments on the performance ratings of the corresponding display and alerts, such as effectiveness of urgency level and directionality, directing attention, promoting a timely evasion, distraction of the display, etc. (Figure 9). After finishing the road session, a post-ride questionnaire was administered to collect open-ended comments on each of the displays (likes, dislikes, and recommended improvements), rankings of the displays, and, once again, benefit/comfort ratings of having CWSs on their motorcycles along with benefit rating of various CWS applications. Participants were also interviewed about their crash experiences and asked whether they thought the corresponding CWS applications could have helped in those scenarios.

Figure 9. A post-trial questionnaire survey being administered.

To control potential order effects, the question sequence followed the same display/scenario order that the participants followed in their road sessions. Statistical tools used in this study included ANOVA (analysis of variance), and the Friedman test/Wilcoxon signed-rank test (for ranking data). Rating data on Likert scales were considered ordinal and were processed with the Aligned Rank Transform [28] before the ANOVA procedures.

Participant Recruitment

In addition to identifying potential participants via VTTI's participant database, recruiting also took place via flyers (Appendix A1), news, VTTI website ads (Appendix A2), email, and social media ads (Appendix A3), such as VTTI Facebook posts. Participants were screened over the phone with a phone script to introduce and explain the study and to record basic information (demographics, motorcycle model, riding experience, medical history, etc.) in order to determine whether they met the study's participant criteria (Appendix B).

Participant recruitment and on-road tests were administered from early July to the end of August 2014. During the recruitment phase, a total of 132 riders were contacted for this study, and among them, 79 were screened and determined to be eligible. Owing to various factors, such as weather and system failure, of 46 recruited riders who showed up on site, 39 completed the study.

Research Procedure Overview

Upon arrival and initial contact at VTTI, participants were asked to show a motorcycle license to confirm their eligibility to participate. An experimenter reviewed the Informed Consent Form (Appendix C) with each participant and both the experimenter and participant signed the form.

Next, a pre-ride questionnaire (Appendix D) was administered. This was followed by a brief overview of the study during which participants were asked to watch video clips demonstrating the three safety applications for connected four-wheel vehicles.

Once the overview was completed and all participants' questions were answered, participants were directed to the preparation area where all the test equipment was demonstrated in preparation for the road test. Participants were provided with a Virginia Tech-owned motorcycle similar to what they normally rode, as indicated in the pre-screening. Participants put on all the safety riding gear, including the helmet with Bluetooth and LED displays, and the haptic wristbands. Participants were instructed to communicate with the experimenter verbally at any time if they decided to opt out and abort the test trial.

Participants were then escorted, while riding the instrumented motorcycle, onto the Smart Road by an experimenter-driven confederate vehicle. Prior to testing, participants were given the opportunity to get familiar with the motorcycle and the road by following the lead of the confederate vehicle for a practice lap.

The road test started with the conclusion of the practice. The organization of the road session as well as the administration of all questionnaire surveys are summarized in Table 4.

Table 4. Summary of Research Procedure

Pre-ride	Road Session							Post-ride
	Trial 1 (Display 1)			…	Trial 4 (Display 4)			
	Scenario 1 (App. 1)	Scenario 2 (App. 2)	Scenario 3 (App. 3)	…	Scenario 1 (App. 1)	Scenario 2 (App. 2)	Scenario 3 (App. 3)	
Pre-ride Survey	Post-scenario Survey	Post-scenario Survey	Post-scenario Survey	…	Post-scenario Survey	Post-scenario Survey	Post-scenario Survey	Post-ride Survey
	Post-trial Survey			…	Post-trial Survey			

During the on-road test, participants rode the motorcycle, interacted with the experimenter's confederate vehicle per the protocol, and experienced the safety applications. Participants experienced three safety applications on each different warning interface display. Prior to each run during the road test, test protocol (Appendix E1, E2, and E3) of each safety application was presented to participants in person. The presentation included a description of the application/scenario, instructions about speed and following distance, and the driving path to be followed. Experimenters answered any participant questions that arose during this presentation.

After exposure to each safety application, participants were asked to verbally provide a numeric rating of the safety application in the single-question questionnaire (Appendix F), which was administered by experimenters during the road test session. After exposure to all safety applications with one warning interface display, participants were asked to provide general feedback about the warning interface by completing the post-trial questionnaire (Appendix G). Then testing was repeated until all displays were tested.

Following completion of the on-road test, participants were escorted back to the preparation area where they were asked to complete a post-ride questionnaire (Appendix H). After completing the study, participants were thanked for their time and paid $70. In compliance with the Virginia Tech Controller's Office, participants were asked to complete a Virginia Tech W-9 tax form and provided with a receipt of payment. Total time for those participating in the study was around two and a half hours.

The experimenter Protocol is shown in Appendix I. This project's research plan was approved by the Virginia Tech Institutional Review Board (IRB) after a full board review.

Results

Participants

A total of 39 licensed riders were recruited for and finished this study. A control was applied over motorcycle type but not over age and gender. Of the 39 participants, 29 were male and 10 were female. The average age was 47.4, ranging from 18 to 69, with a standard deviation of 13.7. Participants fell evenly into three motorcycle types: cruiser, touring, and sport, with 13 participants in each group.

It is important to have a good understanding of the differences among participants owning different motorcycle types, as riding position, use case of the different types, or rider preferences could impact rider acceptance of a CWI. The different motorcycle types carried significant differences in participants' age ($p = 0.012$) as well as experience in terms of mileage per year ($p = 0.042$). Main effect plots are shown in Figure 10. Participants riding sport bikes were the youngest, while participants with touring bikes had ridden the longest time and distance.

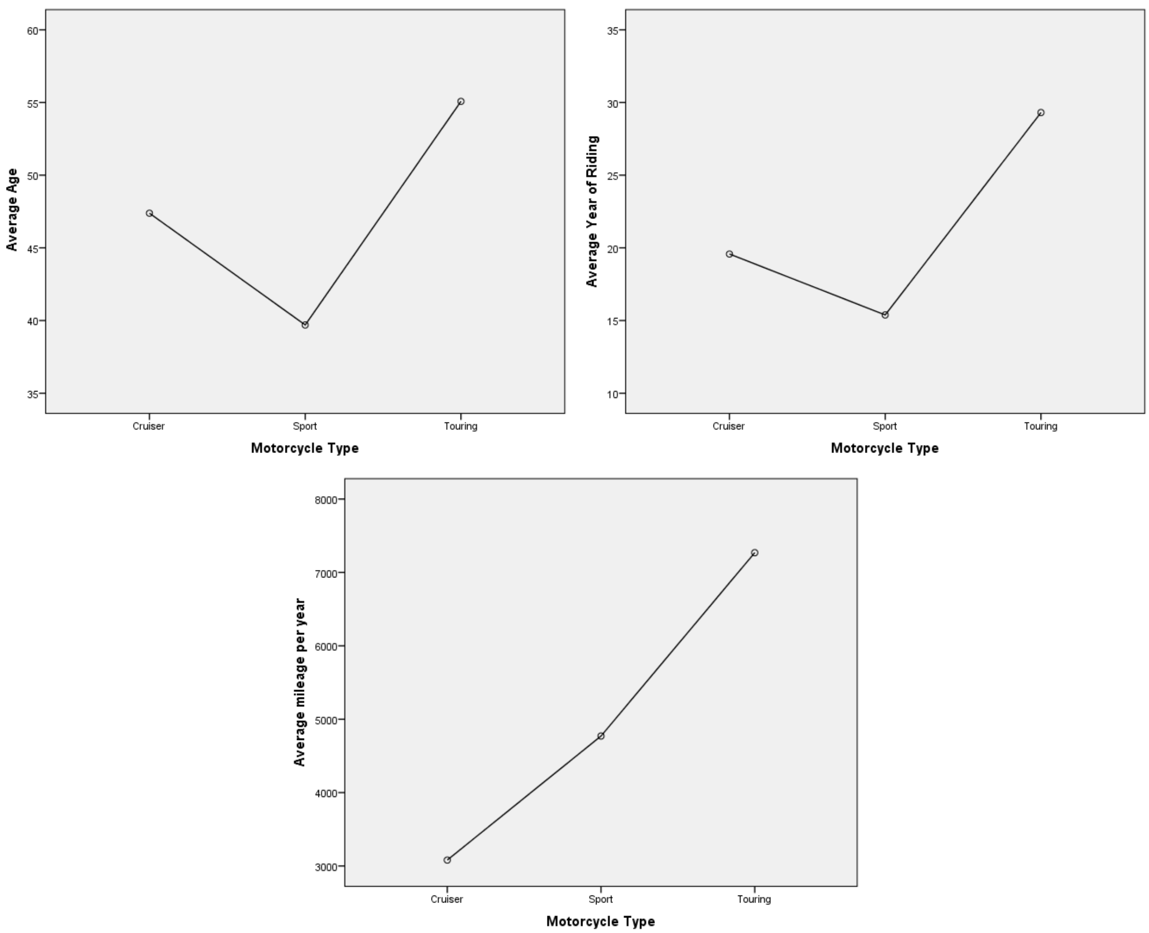

Figure 10. Age and experience (time and mileage) among three motorcycle groups.

Rider Acceptance

In both pre-ride and post-ride questionnaires, participants were asked to rate the benefit of various CWS applications. Benefit rating data were pre-processed and then analyzed using ANOVA, with time (pre-ride and post-ride) and scenario (IMA, FCW, and LCW) being within-subjects factors, and motorcycle type (cruiser, sport, and touring) being between-subjects factor.

Scenario ($p = 0.033$) and the interaction between time and scenario ($p < 0.001$) were found to be significant. Figure 11 shows the interaction between time and scenario. Benefit ratings of both FCW and LCW increased after the road test. In IMA, participants had a good view of the crossing vehicle and could estimate well when to make evasive maneuvers without the assist of CWS. This might be the reason why its benefit rating decreased after the road test (from 6.37 to 5.87). Still, all the post-ride benefit ratings were very close to extremely beneficial (rating of seven), suggesting that all scenarios were considered very beneficial.

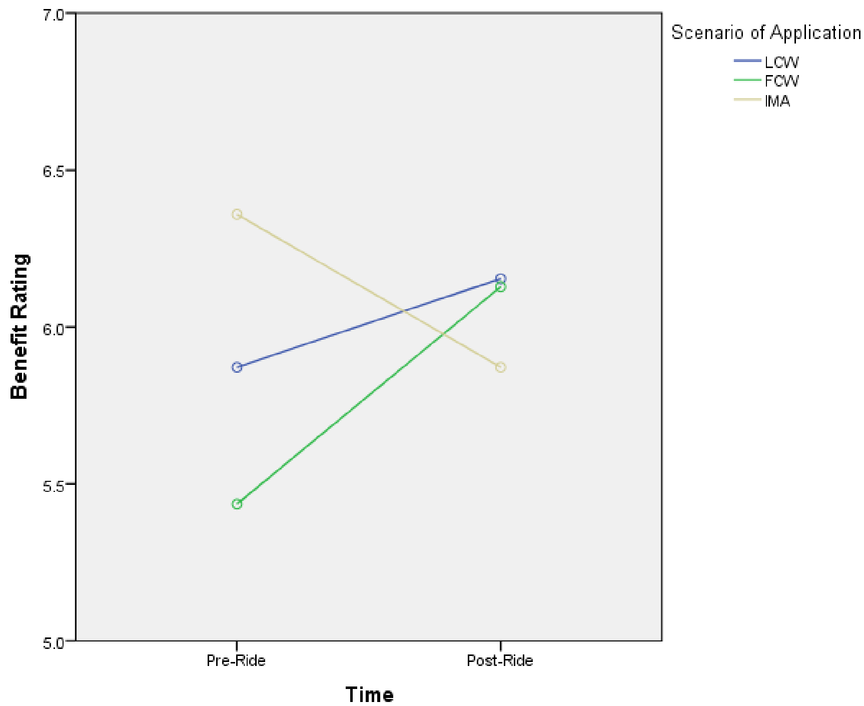

Figure 11. Interaction plot between time and scenario of application.

Although there was no significant difference in motorcycle type, cruiser and touring riders gave higher benefit ratings (averages are 6.23 and 6.37, respectively) to CWS applications than sport riders (average 5.31). Benefit ratings showed no difference between cruiser riders and touring riders. That means, on a scale of 1 to 7, cruiser and touring riders thought that a system capable of providing warnings in these situations was close to extremely beneficial (rating of 7). Sport riders still thought similarly, but placed ratings between somewhat beneficial (rating of 4) and extremely beneficial.

Other questions that were asked both during the pre- and post-ride phase involved comfort and benefit ratings of CWS. Analysis with ANOVA shows that participants' benefit ratings increased from 5.41 to 6.31 ($p < 0.001$) and comfort ratings increased from 5.03 to 6.00 ($p < 0.001$). These changes didn't differ among three motorcycle types ($p = 0.194$ and 0.743). This finding suggests that riders became more comfortable with CWS after exposure to the alerts.

ANOVA was performed again on participants' post-scenario benefit ratings, with CWI display and scenario being the within-subjects factors, and motorcycle type being the between-subjects factor. CWI display was significant ($p = 0.005$) and motorcycle type was significant ($p = 0.012$). No other significant factor or interaction was identified. Main effect plots are shown in Figure 12.

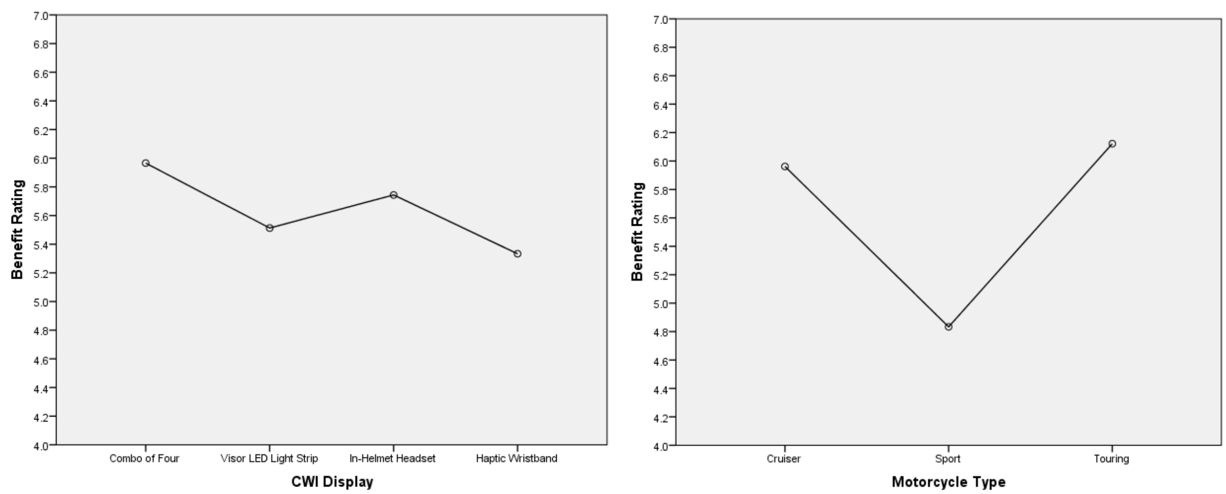

Figure 12. Post-Scenario benefit rating by CWI display and motorcycle type.

Tukey's test shows that the average benefit rating of the combination of all four displays (5.97) was significantly higher than the visor strips (5.51) and haptic wristbands (5.33) (both $p < 0.001$). No significant difference was found in other pairs. Average post-scenario benefit rating from sport riders (4.83) is significantly lower than that from cruiser (5.96) and touring riders (6.12) ($p = 0.031$ and 0.012, respectively). No significant difference was found between cruiser riders and touring riders.

No significant result was identified in any post-trial questionnaire question.

In the post-ride questionnaire, a few participants indicated that they had real-life crash experience in situations similar to the three scenarios tested (three cases similar to an IMA scenario, two to FCW, and three to LCW). All participants agreed that having a motorcycle CWS would somewhat benefit them in these situations.

Participants were then asked to rank order all four CWI displays they experienced during the on-road session, within each scenario and overall. The Friedman test was used to analyze ranking data. Significant difference (p = 0.003) was identified among displays only with the overall ranking. The analysis of crash warning interface ranking data (overall) is shown in Table 5.

Table 5. Mean Ranks and Test Statistics for Crash Warning Interface Displays – Overall

Display	Mean Rank
In-helmet Headset	1.86
Haptic Wristbands	2.59
Visor-mounted LED Strips	2.71
Combo	2.85

N	39
Chi-Square	13.805
df	3
Asymp. Sig.	**0.003***

* Significant @ α = 0.05

Wilcoxon signed-rank tests were then used to compare each of the displays against each other to examine where the differences actually occur. The results are showed in Table 6. Tests showed that the in-helmet headset, with a mean rank of 1.86, was ranked significantly higher than the other three displays (p = 0.008 against wristband, p = 0.004 against visor LED, and p = 0.001 against combo). The ranks for the wristband (2.59), visor LED (2.71), and combo (2.85) were not significantly different from each other.

Table 6. Wilcoxon Signed-Rank Test Significance for Display Ranks – Overall

	Headset	Wristbands	Visor LED	Combo
Headset		**0.008***	**0.004***	**0.001***
Wristbands	**0.008***		0.632	0.310
Visor LED	**0.004***	0.632		0.522
Combo	**0.001***	0.310	0.522	

* Significant @ α = 0.05

Open-ended comments were collected from participants on what they liked, disliked, and would like to change about each display. The top four things participants liked about visor-mounted LED light strips were “location in field of vision" so warnings can’t be missed no matter where the user is looking (46.2%); “get user's attention fast” (33.3%); “install location/size being unobtrusive” (30.8%); and “bidirectionality that is easy to interpret” (28.2%) (Figure 13). Although some participants liked this display because it was in the field of vision, more participants (61.5%) thought warnings were "obtrusive and distracting being in field of vision." Some mentioned that they tended to focus on the warnings and thus ignored anything further ahead on the road. Other dislikes included the visor-mounted display not working in extreme lighting conditions such as direct sunlight (28.2%) and confusion with other red light sources, such as taillights or stoplights (25.6%). The top two proposed changes included, "relocate and make them less obtrusive" (53.8%) and "change color"(28.2%) (Figure 14). Since currently the light strips are located in an area between binocular vision and peripheral vision, they could be moved further into the peripheral vision field. Automatically adjusting brightness would be useful to remedy extreme lighting conditions.

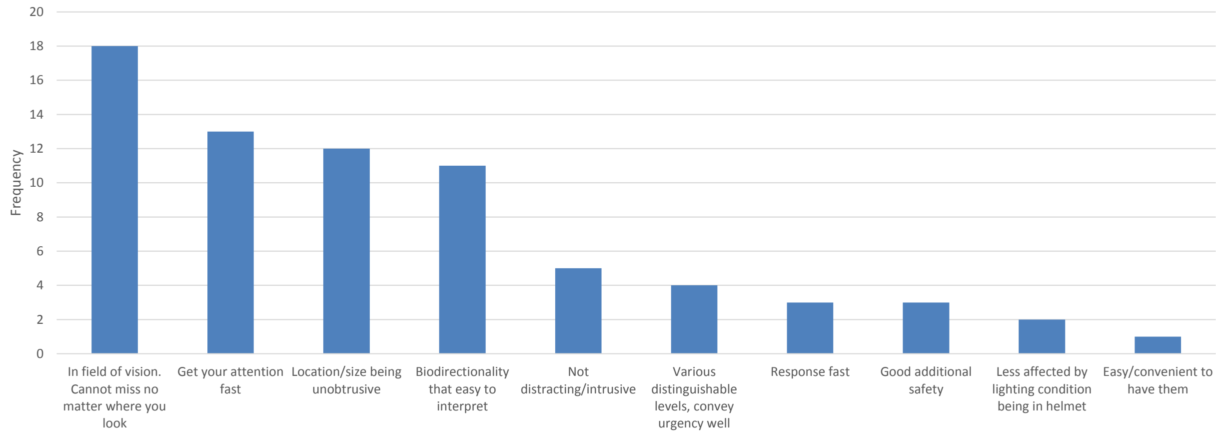

Figure 13. Visor-mounted LED light strips likes.

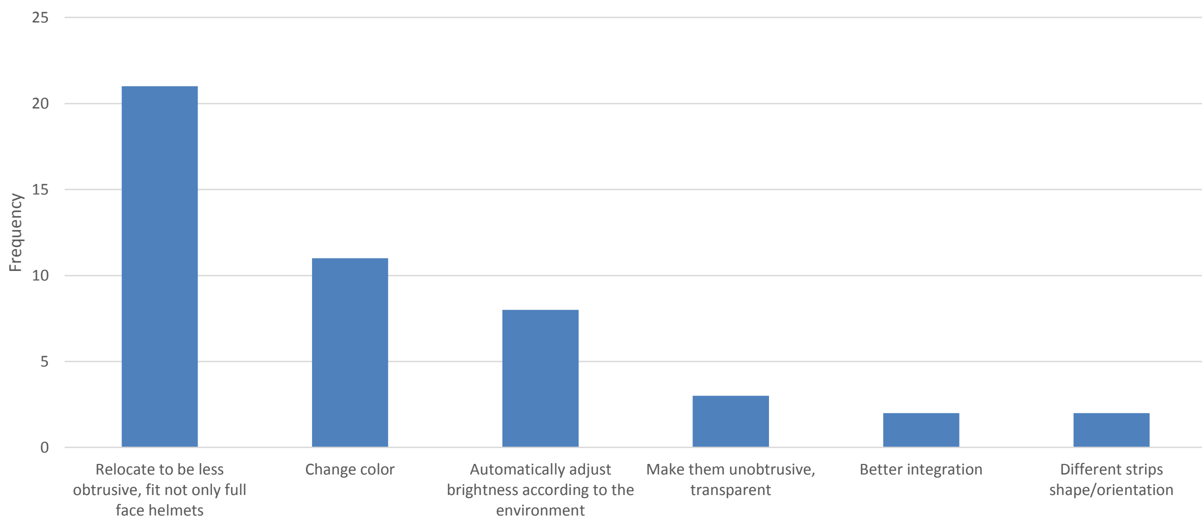

Figure 14. Suggested changes to visor-mounted LED light strips.

The most frequent participant likes of the in-helmet headset can be summarized as "not interfering with vision" (41.0%); "cannot miss no matter where user looks"(41.0%); "get attention fast"(35.9%); and "alert levels conveyed urgency well"(35.9%). The most frequent dislikes were “affected by environment noise” (15.4%) and “alerts (direction) are confusing” (12.8%). The top two changes suggested were “use speech/unique tone” (23.1%) and “automatically adjust volume”(17.9%). Both could improve the auditory alerts’ directionality problem.

"Using new sensation and location" turned out to be the leading advantage of the haptic display (46.1%). Physical stimuli "gets riders’ attention fast" (43.6%), and "cannot be missed no matter where they look"(38.5%). Haptic warning was also considered "good at presenting direction information" (33.3%). The dominant two dislikes were “bulky and interfering design” (41.0%), which is not surpsing for a prototype design, and "maybe hard to distinguish from environment" (38.5%) (Figure 15). The latter dislike was due to participants' concerns about motorcycle vibration. However, participants confirmed that caution alerts with a 1 Hz pulse rate easily grabbed their attention. A 10 Hz pulse rate with 50% duty cycle for warning alerts was found to be too high, and could be confused with motorcycle vibration. By carefully designing the vibrating pattern (low pulse rate and duty cycle), it is expected that distinguishing between haptic alerts and motorcycle vibration would not be a concern. The two dominant haptic display changes participants suggested were targeted at its bulky design (Figure 16). They were "integration into bike, jacket or gloves" (28.2%) or "making them slimmer" (23.1%).

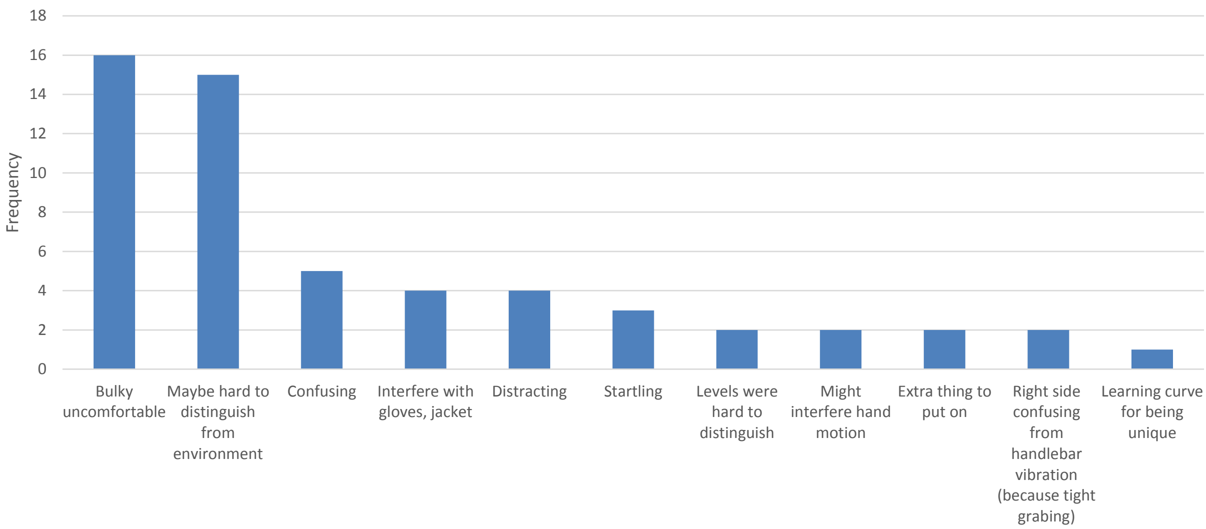

Figure 15. Haptic wristband dislikes.

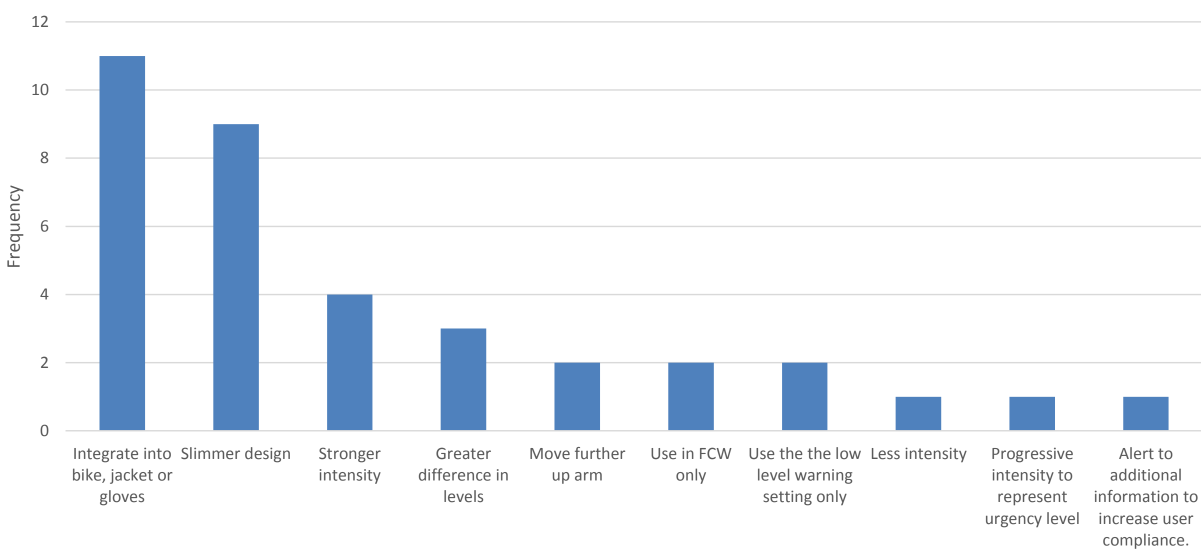

Figure 16. Suggested changes for haptic wristband.

Since the combo triggered all displays covering all warning modalities, its dominant advantage was attracting attention. Almost half (46.2%) of participants said, "impossible to miss or ignore" and 43.6% thought the combo would "get user's attention fast" (Figure 17). However, for the same reason, an even greater percentage of participants (56.4%) disliked the combo for being" too much and distracting" (Figure 18). Some displays might not be appropriate for low urgency situations and situations where stopping is dangerous. As a result, reasonable changes might include "reduc[ing] the number of displays" (41.0%) to a balanced level or, making it "a dynamic combo" (15.4%) based on urgency level.

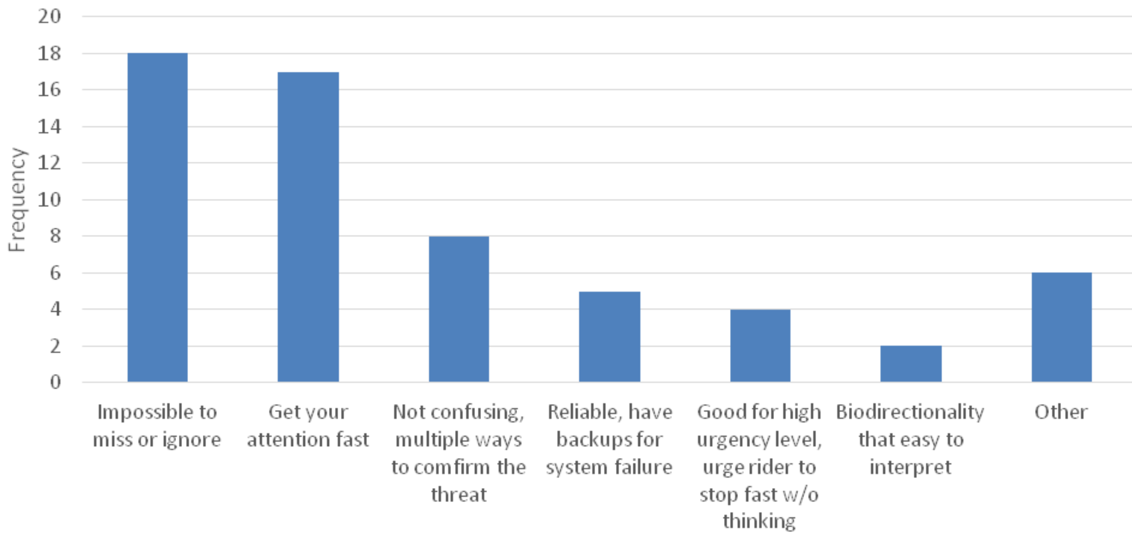

Figure 17. Combo of four displays likes.

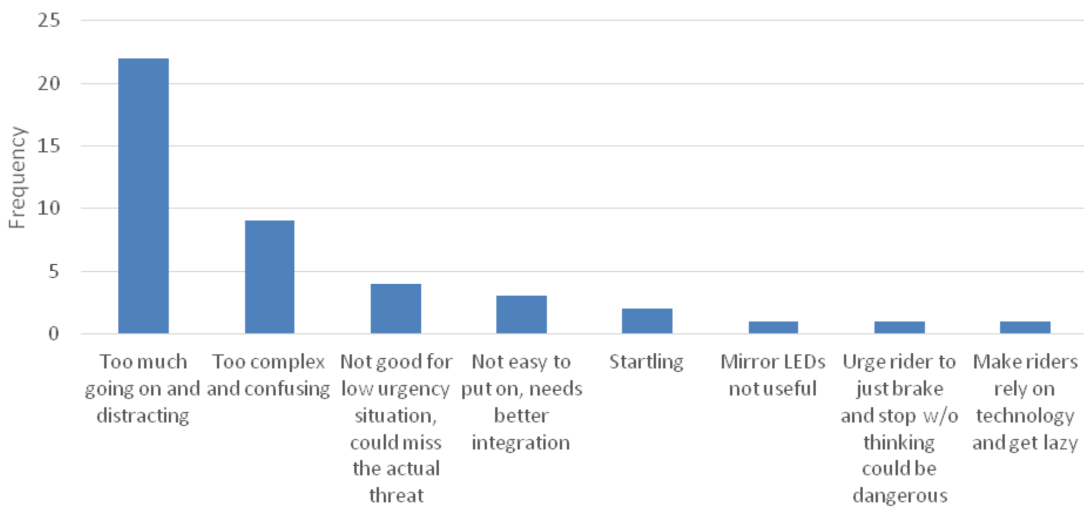

Figure 18. Combo of four displays dislikes.

An extra question formulated specifically for the combo asked participants to customize a combination with available displays. Although it was not feasible in this study to test every possible combinations of displays, it was expected through this question that some initial insights of the most effective combination could be gained. Nearly all (92.3%) participants chose to have fewer than four displays in their ideal CWI. Participants' favorite combination was two displays (56.4%), possibly so a backup would prevent missed alerts, with distraction still kept to a minimum. A combination of three displays was the preference of 23.1% of participants and 12.8% preferred a single-display interface (Figure 19). A summary of individual displays in participants' customized combinations is shown in Figure 20. The most frequently chosen display was the in-helmet headset (74.4%). This might be due to the fact that auditory alerts are very common and the in-helmet headset is a well-integrated display. Although still a prototype, the haptic wristband was the second most frequent pick (56.4%) in participants' ideal combo. The top two preferences may suggest that since riding is a task requiring a lot of scanning, most riders would prefer non-visual sensations to prevent visual distraction. Only 27.6% of participants had both visual displays in their combo. This might be due to most participants finding it redundant or distracting to have both visual displays.

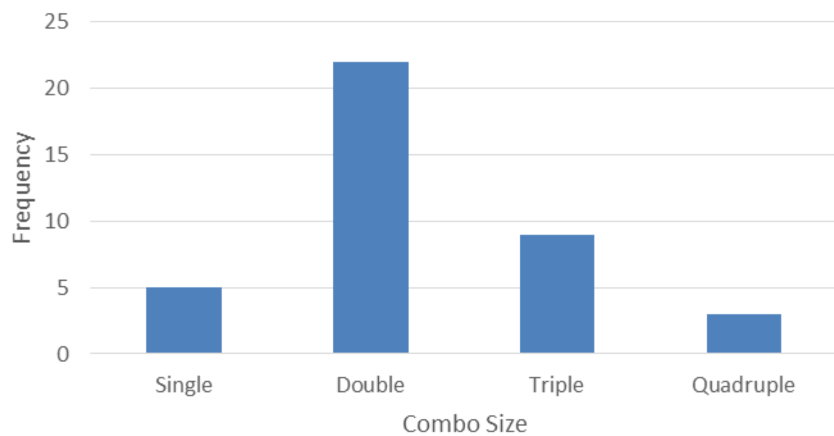

Figure 19. A summary of participants' preferred combination sizes.

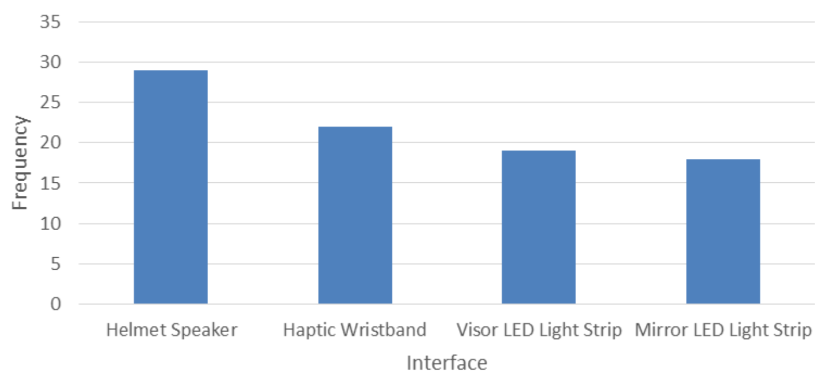

Figure 20. Counts of individual display in participants' preferred combinations.

The results were broken down by motorcycle type (Figure 21). Cruiser and touring riders, who might use in-helmet headsets more often when riding, preferred it over other displays (both with 84.6%), while sport riders showed no preference among the four displays. Touring riders tended to have fewer displays in a combo (average size: 2.1) but the difference is not significant (2.3 for both cruiser and sport).

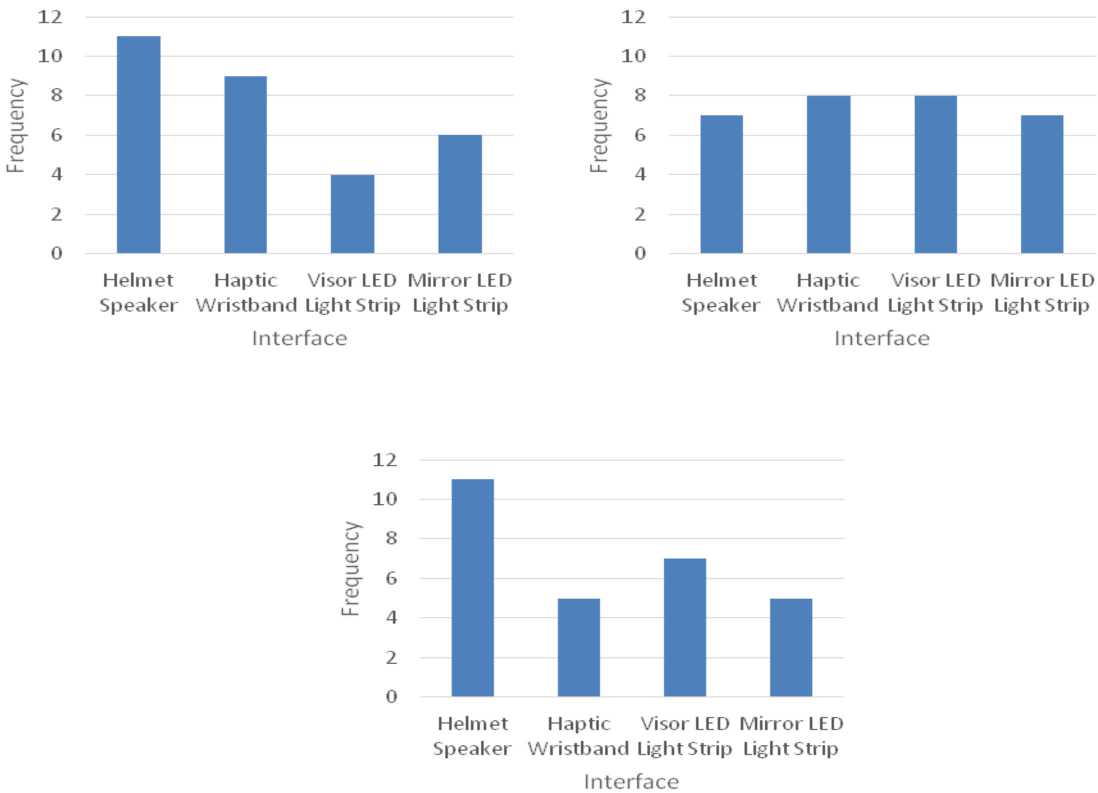

Figure 21. Counts of individual displays in preferred combination by motorcycle type: top left – cruiser, top right – sport, bottom – touring.

The majority of participants indicated that they did not notice mirror-mounted LED strips at all. Direct sunlight was a possible reason. Mirror LED strips would be good for left/right threats but not front threats, both because they would distract from forward view and because it is difficult to look at two mirrors at the same time. Possible changes include relocating the strips to the center area and increasing contrast with higher intensity LEDs and/or more extensive shading from the ambient lighting. Mirror LED strips might be still useful for scenarios like LCW.

Rider Response

Participants' responses following the presentation of alerts from CWS displays were recorded using video. These videos were then used to isolate times when events occurred and were then followed by some rider action or response. Common responses included glancing at the other vehicle/mirror/displays and applying clutch/brake to slow down. In general, approximate times at which a response was observed in these scenarios were 2.58 seconds for the LCW scenario, 0.79 seconds for the FCW scenario and 0.74 seconds for the IMA scenario. Overall, no evidence of distraction (glance of 2 seconds or longer at displays) was identified from the videos when alerts were presented.

As mentioned noted in the Experimental Design section, measurement of rider response to these applications has limitations - no response was necessary in LCW (i.e. the rider needed only to decide not to change lanes), and as a result, most participants took their time to check the left mirror briefly or turn their heads; in the FCW scenario, safety was retained by targeting a 2-second headway prior to the warning, a headway that would generally be considered too early for a FCW alert and indeed may be longer than what most drivers normally maintain (2931) - but the measurement of rider response may still provide an initial reference point of value to some readers; particularly those who need preliminary information for protocol development in future motorcycle CVT algorithm and timing research.

Discussion

Although general guidelines for CWIs exist in the automotive domain, due to the distinct characteristics of motorcycles, further exploration and evaluation were needed for motorcycle-specific CWIs, especially in a real-world environment. In this study, prototype CWI displays for CVT-based motorcycle CWSs were designed and developed. These displays covered three warning modalities (visual, auditory, and haptic) and can be classified into on-vehicle display or wearable display based on their installation locations. An on-road evaluation was performed by cruiser, sport, and touring riders in realistic scenarios targeted at major motorcycle crash types.

Rider acceptance and feedback towards a motorcycle CWS and its prototype CWI were collected through a series of questionnaires before, during, and after a road test. It was found that participants of all motorcycle groups had overwhelmingly positive views of a potential CVT-based motorcycle CWS, through its prototype CWI and applications.

It was theorized that the auditory warning mode might be difficult to implement on motorcycles due to environmental noise, and that haptic warnings would potentially be difficult to detect due to vibration. However, participants' input on preferred modalities showed that auditory combined with haptic warnings were preferred among the presented displays.

Lessons learned about each presented CWI display are summarized as follows.

- Auditory display presented through an in-helmet headset system was successful in presenting warnings. The presentation of directional information turned out to be a weak point for simple tones on different channels. Although riders may need slightly more time to interpret the message, using simple speech such as "left," "front," and "intersection" in addition to various channels may be a good solution for warnings with a longer required response time. It is worth noting that hearing tests are not required for legally operating a motorcycle; this might pose some problems for auditory alerts.
- Although the bulky haptic design requires further improvement, the concept is promising. Riders could easily distinguish between the haptic warnings and handlebar vibration. As with visual displays, the haptic design performed well at presenting directional information.
- Visual display alternatives were less favored than the auditory and haptic modes. Visor-mounted LED light strips were level with eyes on the visual scanning path and test suggested that naïve users might look directly at them when they are triggered. Such behavior would cause the loss of tracking on roadway further ahead. Moving the strips further apart, deep into the peripheral vision or up to the edge of the visor, might discourage riders from looking directly at them and minimize the resulting distraction. Although commonly used for warnings, red visual alerts in traffic with numerous red taillights and stoplights could lead to confusion for certain scenarios. Mirror-mounted LED light strips were not believed to be effective in quickly directing riders' attention to threats. However, mirror mounting was advantageous for situations like lane changes when mirrors are more likely to be checked.

Integrating the light strips into mirrors, increasing sun shading, and clustering strips in tight concentration would help improve their conspicuity.

- The combo of all of the modalities was rated the most beneficial during road testing. However, its ratings fell following the post-ride pros and cons discussion. This is likely due to the fact that when asked on the road, participants tended to consider the displays as-is and favored the one that most quickly grabbed their attention. In that aspect, the combo exceeded every individual display. In the post-ride session, participants instead considered each display thoroughly, including its potential as a prototype. The combo's leading benefit, noticeability, became its biggest drawback, as noticeability translated into being overwhelming and distracting upon further consideration. The combo demanded so much attention that participants worried their normal riding behavior would be impaired. Participants indicated that they would prefer a combination to a single display, but that the number of displays needs to be reduced from the four included in the study's combo design. Double-stimulus is hard to miss, but not too overwhelming, and was the most frequent choice for number of displays in a combination. For a combination, having various warning levels for all displays was not always the best way to present urgency levels; varying the number of displays activated should be considered as well. For example, there could be fewer active displays for caution alerts and more for warning alerts. Instead of having limited levels of warning for urgency, a gradual warning intensity build-up based on urgency may also be helpful in warning riders about potential threats.

As pilot test shows, the environment could influence the performance of warning interface. Therefore, one general recommendation based on this study is to develop a smarter CWI by adjusting alerts based on environmental measures that have potential impacts on CWI's performance. For example, self-adjusted brightness of visual alerts based on lighting conditions, and self-adjusted volume of auditory alerts based on travel speed or other indicators of ambient noise level.

Many riders put the emphasis on appearance and style of their bikes and riding gear. This holds true for add-ons such as motorcycle CWSs, including their interface. Another general recommendation is style and better integration, which would help provide comfort and convenience to riders and thus improve CWS acceptance. Rather than being separate equipment, it would be better to integrate CWIs into common riding gear or motorcycles, while the latter option also has the advantage of CWI always being present and available (wearable solutions will likely require specialized attire and a changed battery). Mirror-mounted LED light strips could be built into mirrors much like OEM's mirror warning lights or turn signals. Visor-mounted LED light strips could be moved off the visor and built into the helmet and offer warning lights that reflect into rider's eyes. Motorcycle jackets are a potential location to integrate haptic warnings, similar to Ducati's riding jacket with integrated airbag [*30*]. Though not tested here, haptic displays in helmets are also being considered [*31*]. Whether with integrated auditory displays or other, incorporating additional capabilities into protective gear and helmets will likely promote adoption by riders.

When it comes to motorcycle CWSs, an important aspect that was rarely considered is the effect of motorcycle type on system needs and acceptance. Variance in riding position, rider characteristics (such as age, skill level, habits, and experience), and even riding gear all affect acceptance of a CWS. CWS applications overall received slightly lower scores from sport bike riders than cruiser and touring riders. Though further understanding of this relationship is not available in the survey responses, it could be related to the older average age of the cruiser and touring bike riders within this sample. The older age groups would be expected to place more emphasis on riding comfort and safety than younger groups.

More riding experience and experience with CWSs would also affect riders' acceptance and preference of a CWI. Although we believed that most participants would be unfamiliar with a motorcycle CWS, there was a general level of acceptance. Cruiser and touring riders preferred the headset over other displays, while sport riders showed no preference.

Due to the novel nature of CWIs on motorcycles and the associated safety concerns of a two-wheeled vehicle, a number of precautions were taken during the on-road portion of this study, but naturally led to some study limitations. First, all sessions were conducted at low speeds, and while the confederate vehicle created a realistic scenario, the timing was presented conservatively without the extreme urgency of a real imminent crash situation. In addition, “surprise” events were eliminated in order to maintain the safety of the participants. Therefore, the focus of the study remained on objective measures rather than subjective measures. Second, road tests were conducted during the daytime because previous studies showed that more than 70% of motorcycle crashes occur during the daytime (3). Although the study covered mixed weather conditions (ranging from clear to overcast) as well as various daylight hours (6AM till 6PM), poor visibility and low lighting conditions encountered during the nighttime hours were not tested. It is expected that a similar study conducted during evening hours would create different impacts on rider acceptance and feedback towards current CWI design, especially visual displays.

With refined CWI displays based on this study, a future study would be valuable in order to evaluate individual displays as well as selected combinations in more sophisticated scenarios (at normal speeds and with “surprise” events). Any future data collection should include both objective measures (rider acceptance and feedback) and subjective measures (rider response) while the latter would be the primary indicator of CWI effectiveness.

Conclusions and Recommendations

Prototype CWI displays for CVT-based motorcycle CWS were designed, developed and evaluated in this study. Through an on-road evaluation, combined auditory and haptic displays showed considerable promise for implementation. They were found here to be appealing to riders when presented with representative scenarios and working prototypes. Auditory display, in particular, is easily implemented given the adoption rate of in-helmet auditory systems. Its weakness of presenting directional information may be remedied by using simple speech or with the help of haptic design, which performed well at providing such information. A basic haptic display design, resulting in a somewhat bulky working prototype was also found to be attractive to riders. Migration of this haptic display into gloves or a jacket would be inconspicuous, and provide warning benefits along with encouraging the use of riding gear. The findings related to visual displays revealed both opportunities and challenges for visual displays in motorcycle CWSs, and indicated areas where further testing is needed to obtain visual displays that elicit desired responses without being distracting. The effect of motorcycle type on riders' acceptance of a CWI was revealed in this study and has to be considered when designing motorcycle CWSs. It is expected that findings from this study would not only benefit CVT-based motorcycle CWS design, but also traditional CWS design for motorcycles.

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Appendices

Appendix A1. Recruitment Flyer

PARTICIPANTS NEEDED FOR MOTORCYCLE TECHNOLOGY STUDY

Are you 18 years old or older?

Do you have a valid U.S. motorcycle license?

Do you currently ride a motorcycle?

If yes to all of these questions, please

call VTTI @ 540-231-XXXX or

e-mail: drivers@vtti.vt.edu

- Mention the study's name **"Yellow Flag"** as the subject of your message
- Study involves 1 visit, lasting about 2.5 hours
- You will ride a Virginia Tech motorcycle on the Smart Road
- Compensation is $70

Appendix A2. Recruitment VTTI website Ads

UTC Study Overview

The intent of this project is to evaluate various designs of motorcycle crash warnings through feedback collected from motorcyclists in a simulated riding environment. Three types of crash warning interfaces (auditory, visual, and tactile) will be experienced within three safety riding applications (forward collision warning, lane change/blind spot warning, and intersection movement assist). These crash warning designs could potentially be used in combination with wireless vehicle-to-vehicle or vehicle-to-roadway communications to convey potential threat information to motorcyclists and reduce fatalities and injuries. Your input will help us understand and improve the design of these systems.

The Who, What, Where, etc. for this study is below. Links to the right provide more detail.

Please don't hesitate to contact us to talk to a real person!

Who
Riders who currently ride a motorcycle at least once a month.

Where
The Smart Road in Blacksburg, Virginia

What
Experience various crash warning designs while riding on the Smart Road and provide feedback.

Why
You will be contributing to important research for enhancing motorcyclist safety. It also pays $70 for one visit up to 2.5 hours.
Participation in this study will contribute to the improvement of crash warning systems which could increase the safety of motorcycle transportation.

When
Now!

How
Contact us at: 1-540-231-xxxx or motorcycle@vtti.vt.edu. Please include a call-back number.

Appendix A3. Recruitment Social Media Ads

Wanted for Research Study

The Virginia Tech Transportation Institute (VTTI) is seeking individuals who:

- are 18 years old and older
- have a valid U.S. Motorcycle driver's license
- currently ride a motorcycle

- Total participation time: 1 visit, lasting about 2.5 hours
- You will ride a Virginia Tech motorcycle on the Smart Road
- This project pays $70
- Your data will be kept strictly confidential

If you are interested in learning more,

Please contact us at: 540-231-XXXX or email, drivers@vtti.vt.edu
Reference "the Yellow Flag Project" in your message

All inquiries welcome!

Virginia Tech Transportation Institute

www.vtti.vt.edu

Appendix B. Phone Screening Script

Note to Researcher:
Initial contact between participants and researchers may take place over the phone. If this is the case, read the following Introductory Statement, followed by the questionnaire. Regardless of how contact is made, this questionnaire must be administered verbally before a decision is made regarding suitability for this study.

Introductory Statement:
After prospective participant calls or you call them, use the following script as a guideline in the screening interview.

Hello. My name is _____ and I'm with the Virginia Tech Transportation Institute, located in Blacksburg, VA. We are currently recruiting motorcycle riders to participate in a research study. This study involves participating in one road session during daylight hours.

We will ask for your help to evaluate a variety of warning displays on motorcycles. These displays may be used to warn riders of a potential threat. Your input will help us understand the needs of riders and improve the design of these systems.

For this study, we would need you to ride our motorcycle here on the Smart Road with an accompanying vehicle operated by trained research staff. The motorcycle is equipped with two mirror LED light strips and a digital video camera.

You will be asked to ride wearing jacket, gloves, long pants and boots. You will also be asked to wear a Bluetooth headset and two LED light strips mounted on helmet, two tactile wristbands, and a backpack instrumented with another digital video camera. Both video cameras will record you while you are riding.

This project pays $70 for full participation, and it should take about 2.5 hours. Should the session end early for any reason, you will be paid $30 per hour with a minimum of $30. Does this sound interesting to you?

If you are interested in possibly participating, I need to go over some screening questions to see if you meet all the eligibility requirements of this study. Any information given to us will be kept secure and confidential.

Do I have your consent to ask the screening questions?
If yes, continue with the questions. If no, then thank him/her for their time and end the call.

1. Do you have a valid U.S. motorcycle license?
   - Yes
   - No

2. What is your age? _______________ (Stop if not 18 or older)

3. Are you a U.S. Citizen?

- Yes
- No

  If No, do you hold a green card? Yes _____ No _____

4. Are you willing to provide your Social Security # should you participate, as required by the University? (explain they will be asked to complete a W-9 if they ask why)

- Yes
- No

Please note that for tax recording purposes, the fiscal and accounting services office at Virginia Tech (also known as the Controller's Office) requires that all participants provide their social security number to receive payment for participation in our studies. Or if a VT employee they may provide their VT employee #.

5. What type of motorcycle do you normally ride?

- Cruiser if cruiser, identify a model(s)____________________________________
- Touring if touring, identify a model(s)____________________________________
- Sport if sport, identify a model(s)_______________________________________
- Scooter
- Trike

Please note that you may not be selected for participation if sufficient numbers of participants for your motorcycle type have already been enrolled.

6. For this study, we would like you to wear your own helmet. Do you own a full face helmet or a ¾ helmet with untinted visor that you can bring to the study?

- Yes
- No

  If no and you have no helmet to bring to the study, we could provide a helmet to you if you don't mind wearing it. Helmet type and size _____________________

  It will either be new or sanitized between participants.

7. Do you need prescription glasses for riding?

- Yes
- If yes, please bring untinted ones. No

8. For this study, we will need you to ride wearing long sleeve jacket, gloves, long pants and boots. Can you bring those items with you to wear?

- Yes
- No if no jacket or gloves, do you mind wearing what we provide? It will either be new or sanitized between participants. Jacket size _______ Glove size ______

9. On average, how often do you ride your own motorcycle during riding season? Check the one that best describes your answer.

- Almost once a day
- At least once a week
- At least once a month

- Less than once a month
- Not at all

10. Have you had any moving violations in the past 3 years? If so, please explain.

- Yes ____
- No

11. Have you been involved in any automobile accidents in the past 3 years, either driving a car or riding a motorcycle? If so, please explain.

- Yes ____
- No

We need to ask a few questions about your medical history…

12. Do you have a history of any of the following medical conditions? If yes, please explain.

a. Neck or back pain or injury No____
Yes____________________________________
b. Head Injury, Stroke, or illness or disease affecting the Brain
No____ Yes______________________________________
c. Current Heart Condition
No____ Yes______________________________________
d. Current uncontrolled Respiratory disorder or conditions which require oxygen
No____ Yes______________________________________
e. Epileptic seizures or lapses of consciousness
No____ Yes______________________________________
f. Chronic Migraines or tension headaches
No____ Yes______________________________________
g. Inner ear problems, Dizziness, Vertigo, or Any Balance problems (current)
No____ Yes______________________________________
h. Uncontrolled Diabetes
No____ Yes______________________________________
i. Have you had major surgery in the past 6 months?
No____ Yes______________________________________
j. Are you taking any substances on a regular basis which could impair your motor skills or your ability to ride? No_____
Yes____

13. (*Females only*) Are you currently pregnant? (if "yes," politely inform the participant: *while being pregnant does not disqualify you from participating in this study, you are encouraged to talk to your physician about your participation to make sure that you both feel it is safe. If you like, we can send you a copy of the consent form to discuss with your physician.* Answer any questions)

- Yes
- No

14. Do you have normal or corrected-to-normal hearing and vision in *both* ears and *both* eyes? If no, please explain.

- Yes ________
- No ____

15. Are you comfortable reading and writing English?

- Yes
- No

If Eligible:

Scheduled on (date & time):____

Email for directions and consent form: ____

Criteria for Participation:

1. *Must hold and able to present a valid U.S. motorcycle license at time of participation*
2. *Must be 18 or older.*
3. *Must be a U.S. citizen or permanent resident (green card holder)*
4. *Must be willing to provide SSN or VT ID number for payment.*
5. *Must currently ride one of the first three motorcycle types listed; scooter and trike riders are not eligible*
6. *Must have balanced participant number among these three motorcycle types. For any motorcycle type, no more individuals will be recruited if sufficient numbers are enrolled for this type.*
7. *Must be able to bring a full face helmet or a ¾ helmet; or willing to wear a helmet we provide;*
8. *Must bring untinted prescription glasses if the participant needs a pair when riding. No prescription sunglasses (including photochromatic ones).*
9. *Must be able to bring long pants and boots; must be able to bring long sleeve jacket and gloves or willing to wear jacket and gloves we provide*
10. *Must ride at least once a month on average during riding season*
11. *Must not have more than two moving violations in the past 3 years.*
12. *Must not have caused an injurious accident within the past 3 years*
13. *Health Questions:*
    a. *Cannot have a history of neck or back conditions which still limit their ability to participate in certain activities. No current conditions. No current pain or injuries.*
    b. *Cannot have a history of brain damage from stroke, tumor, head injury, recent concussion, or disease or infection of the brain*
    c. *Cannot have a current heart condition which limits their ability to participate in certain activities*
    d. *Cannot have current respiratory disorders or disorders requiring oxygen*
    e. *Cannot have had epileptic seizures or lapses of consciousness within the last 12 months*

f. Cannot have chronic migraines or tension headaches (no more than one per month).
g. Cannot have current problems with motion sickness, inner ear problems, dizziness, vertigo, or balance problems
h. Cannot have uncontrolled diabetes (have they been recently diagnosed or have they been hospitalized for this condition, or any changes in their insulin prescription during the past 3 months)
i. Must not have had any major surgery within the past 6 months (including eye procedures).
j. Cannot currently be taking any substances that may interfere with riding ability (cause drowsiness or impair motor abilities)

***14.** If pregnant, encourage them to speak with their doctor first (sharing the informed consent)*

***15.** Must have normal (or corrected-to-normal) hearing in both ears and vision in both eyes. Must be able to read and write English well.*

Appendix C. Information Consent Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants
In Research Projects Involving Human Subjects

Title of Project: Connected Motorcycle Crash Warning Interfaces

Investigators:	Dr. Zac Doerzaph	zdoerzaph@vtti.vt.edu/ (540) 231-1046
	Dr. Shane McLaughlin	smclaughlin@vtti.vt.edu/ (540) 231-1077
	Dr. Miao Song	msong@vtti.vt.edu/ (540) 231-0280

I. PURPOSE OF THIS RESEARCH PROJECT

The purpose of this project is to collect guidance from riders regarding the design of different crash warning displays. Three different types of crash warnings will be tested. One warning is an audio alert that the driver receives through a helmet-mounted Bluetooth headset. The second warning is a visual warning that is displayed to the rider on the motorcycle mirrors or on the helmet visor. The third warning uses two wrists bands that warn the rider by vibrating when there is a potential threat. These different warnings will be tested in three different scenarios: forward collision warning, lane change/blind spot warning, and intersection movement assist. These crash warning designs could potentially be used in combination with wireless vehicle-to-vehicle or vehicle-to-roadway communications to convey potential threat information to motorcyclists and reduce fatalities and injuries. Your input will help us understand and improve the design of these systems. Up to 50 other riders will be participating in this study.

II. PROCEDURES

During the course of this experiment, you will be asked to perform the following tasks:

1. Show a motorcycle license to confirm your eligibility to participate.
2. Review the Informed Consent with an experimenter. Ask any questions you may have, sign the Informed Consent Forms with the experimenter if you wish to proceed.
3. Complete a Virginia Tech W9 tax form. This is required by Virginia Tech in order to process payment.
4. Complete a pre-ride questionnaire, followed by a brief overview of the study.
5. Watch video demonstrations of three safety applications which include:
   - Intersection Movement Assist (IMA), defined as follows:
     The IMA application is intended to warn the rider when it is not safe to enter an intersection due to high collision probability with other upcoming vehicles. Initially, IMA is intended to help riders avoid or mitigate vehicle collisions at stop sign-controlled and uncontrolled intersections.
   - Blind Spot Warning / Lane Change Warning (BSW / LCW), defined as follows:
     The BSW / LCW application is intended to warn the rider during a lane change attempt if the blind-spot zone into which the motorcycle intends to switch is, or will soon be,

occupied by another vehicle traveling in the same direction. The application is intended to help riders in avoiding lane change / blind spot collisions.

- Forward Collision Warning (FCW), defined as follows:
  The FCW application is intended to warn the rider in case of an impending rear-end collision with a vehicle ahead in traffic in the same lane and direction of travel. FCW is intended to help riders in avoiding or mitigating rear-end collisions in the forward path of travel.

6. Review all the test equipment in the preparation area. You will be provided with a Virginia Tech-owned motorcycle similar to what you normally ride as indicated in the pre-screening. The motorcycle is instrumented with two mirror LED warning stripes and a camera that captures the view of the rider's upper body. Then you will be asked to put on all the safety riding gear as well as two tactile wrist bands, a backpack with a front camera, Bluetooth headset and two helmet visor LED warning lights. The Bluetooth headsets enable uninterrupted two-way communication between participant and experimenter throughout the study. You can also use that to communicate with experimenter verbally at any time if you decide to opt out and abort the test trial.
7. You will ride VTTI's instrumented bike out onto the Smart Road, following a lead vehicle, driven by a VTTI experimenter. The Smart Road test track will be closed to traffic not involved in this study. First, you will be given the opportunity to get familiar with the motorcycle and the road. You will follow the lead vehicle on the Smart Road for a practice lap. The speed limit will be 25 mph.
8. During the experiment, you will experience three different scenarios with each type of warning. Before you are asked to ride the motorcycle through a given scenario, the experimenter will explain the scenario and give you instructions. The instructions will include information about the speed you will travel, the following distance, and the driving path.
9. After exposure to each scenario, you will be asked to provide a numeric rating of the scenario in a single-question questionnaire verbally
10. After you have experienced all the scenarios with one of the warnings, you will be asked to complete a questionnaire. This will repeat until you have experienced all of the warnings. The riding portion of the experiment is expected to last approximately 90 minutes.
11. At the end of the study, you will be asked to complete a post-ride questionnaire. It is important that you understand that we are not evaluating you or your performance in any way. You are helping us evaluate only the effectiveness of various crash warning interfaces.
12. Following completion of all tasks, you will be escorted back to the preparation area where all the equipment will be removed and you will be compensated for your time. Total time for participating in this study is expected to be around two and a half hours.

III. RISKS

Caution should be exercised when riding the motorcycle. Be aware that accidents can happen at any time while riding. As a participant, you may be exposed to the following risks or discomforts by volunteering for this research. These risks are no more than those involved in daily life.

1. The risk of an accident normally present while riding at speeds of 25mph or less on a closed test track in daytime under fair weather conditions.
2. The risk of riding an unfamiliar motorcycle.
3. Any risk present when riding a motorcycle while using new and unfamiliar technology. The system that will be mounted on motorcycles and helmets are designed to provide warning about certain risky driving situations; however, risks are not completely eliminated and system malfunctions may occur.
4. While the risk of participation in this study is considered to be no more than that encountered in everyday riding, if you are pregnant you should talk to your physician and discuss this consent form with them before making a decision about participation.
5. Please be aware that events such as equipment failure, changes in the test track, stray or wild animals entering the road, and weather changes may require you to respond accordingly. If at any point in the session the experimenter believes that continuing the session would endanger you or the equipment, he/she will stop the testing.

The following precautions will be taken to ensure minimal risk to you:

1. You may decide not to participate at any time without penalty.
2. Breaks will be offered at the end of each trial (approximately every 20 minutes).
3. You will be required to wear all the safety riding gear including helmet, jacket, gloves, long pants and appropriate boots while riding on the Smart Road during the study.
4. You should not ride the vehicle while impaired by any substances.
5. You should ride in a defensive manner, anticipating situations where incidents are likely to occur.
6. Experimenters will be on the road with you at all times and may stop the study at any time if they feel that your safety is in danger. They are the only traffic allowed on the road during the experiment.
7. All the experimenters who will be running the study have been well-trained and rehearsed on the scenarios and in how to conduct the research in a manner that minimizes risks to the participants.
8. A pair of Bluetooth headsets will be used to make sure you receive and follow the experimenter’s instructions at all times regarding items such as the driving speed, following distance, driving path, and when to start riding or pull over.
9. The study will only be conducted when the road surface is dry.
10. Specific participant protocols have been developed for each scenario, providing the exact choreography to be followed, and addressing issues such as instructed driving speed, following distance, etc. The study is not intended to simulate the risk level of any real life situations but rather to let you experience how these safety applications work. As a result, slower speed and more than sufficient following distance are adopted to minimize risk.

11. Roadway areas for scenarios are selected to minimize risk. No task will be conducted where there are hazards such as narrow shoulders, sharp curves, etc.
12. You will be assigned a motorcycle which is which is similar in style/model to what you normally ride and at the beginning of the road test, you have a practice ride to become familiar with the motorcycle and with the test track at slow speed (25 mph) following the lead of experimenters' vehicle.
13. In the rare event that Bluetooth communication is lost between you and the experimenter, a visual signal (hand gesture) will be used by either side to communicate and stop the current road test.
14. You do not have any medical condition that would put you at a greater risk, including but not restricted to history of neck/spine injury, epilepsy, balance disorders, or lingering effects of head injuries and stroke.
15. In the event of a medical emergency, or at your request, VTTI staff will arrange medical transportation to a nearby hospital emergency room. You may elect to undergo examination by medical personnel in the emergency room.

In the event of an accident or injury while driving a motorcycle owned or leased by Virginia Tech, the vehicle liability coverage for property damage and personal injury is provided. The total policy amount per occurrence is $2,000,000. This coverage would apply in case of an accident for all volunteers and would cover medical expenses up to the policy limit. For example, if you were injured in an automobile owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by this policy.

Participants in a study are considered volunteers, regardless of whether they receive payment for their participation; under Commonwealth of Virginia law, workers compensation does not apply to volunteers; therefore, the participants are responsible for their own medical insurance for bodily injury. Appropriate health insurance is strongly recommended to cover these types of expenses.

IV. BENEFITS

While there are no direct benefits to you from this research, you may find the experiment interesting and gain satisfaction as a result of contributing to further advancement of automotive safety. No promise or guarantee of benefits is made to encourage you to participate. Participation in this study will contribute to the improvement of communication-based motorcycle safety applications.

V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

Data gathered in this experiment will be treated with confidentiality, and will be used for research purposes only. Shortly after participation, information that identifies you, such as your name, will be separated from your data. A coding scheme will be employed to identify the data by participant number only (for example, Participant No. 3).
The data from this study will be stored on a secure server for a period of three years at Virginia Tech Transportation Institute. Access to the data will be under the supervision of Dr. Zac Doerzaph and Dr. Shane McLaughlin. The data collected in this study may be used in future IRB approved research projects by VTTI staff. Clips of video data containing your image may be

used by VTTI personnel for research-related presentations (such as conferences). All identifiable data will remain in the possession of VTTI.
The Virginia Tech (VT) Institutional Review Board (IRB) may view the study's data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

VI. COMPENSATION

You will be paid $70 for full participation. If the session ends early for any reason, you will be paid at a rate of $30.00 per hour and a minimum of $30. You will be paid at the end of the session in cash. If payments for this and other studies are in excess of $600 dollars in any one calendar year, then by law, Virginia Tech is required to file Form 1099 with the IRS. For any amount less than $600, it is up to you as the participant to report the income as Virginia Tech will not file Form 1099 with the IRS.

VII. FREEDOM TO WITHDRAW

It is important for you to know that you are free to withdraw from this study at any time without penalty. You are free not to answer any questions that you choose or respond to what is being asked of you without penalty. If you choose to withdraw during the study session, please inform the experimenter of this decision and he/she will drive you back to the building.

Please note that there may be circumstances under which the investigator may determine that a subject should not continue as a subject.

Should you withdraw or otherwise discontinue participation, you will be compensated for the portion of the project completed in accordance with the Compensation section of this document.

VIII. VII. APPROVAL OF RESEARCH

Before data can be collected, this research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Tech and by the Virginia Tech Transportation Institute. You should know that this approval has been obtained. This form is valid for the period listed at the bottom of this page.

VIII. PARTICIPANT'S RESPONSIBILITIES

If you voluntarily agree to participate in this study, you will have the following responsibilities:

1. To follow the experimenter's instructions at all times regarding items such as the safe driving speed, following distance, and driving path.
2. To ride within sight of the experimenters.
3. To inform the experimenter if you are not comfortable or have difficulties of any kind.
4. To wear all required safe riding gear while on the motorcycle.
5. To abstain from any substances that will impair your ability to ride.
6. To avoid personal cell phone use while participating.
7. To obey traffic regulations and ride in a safe and defensive manner at all times.

8. To never rely on the crash warning interfaces, but to exercise normal caution when operating the motorcycle.

IX. PARTICIPANT'S ACKNOWLEDGMENTS

Please confirm the statement below by checking the box:
Check all that apply:

- ☐ I am not under the influence of any substances or taking any medications that may impair my ability to participate safely in this experiment.
- ☐ I am in good health and not aware of any health conditions that would increase my risk including, but not limited to lingering effects of a heart condition.
- ☐ I have informed the experimenter of any concerns/questions I have about this study.
- ☐ I understand that digital video including my image will be collected as part of this experiment.

- ☐ If I am pregnant, I acknowledge that I have either discussed my participation with my physician, or that I accept any additional risks due to pregnancy.

X. SUBJECT'S CONSENT

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. **If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.**

____

Participant Signature Date

____

Participant Printed Name

____

Experimenter Signature Date

XII. QUESTIONS OR CONCERNS

Should you have any questions about this study, you may contact one of the research investigators whose contact information is included at the beginning of this document.

Should you have any questions or concerns about the study's conduct or your rights as a research subject, or need to report a research-related injury or event, you may contact the VT IRB Chair, Dr. David M. Moore at moored@vt.edu or (540) 231-4991.

The Participant must be provided with a copy of this Informed Consent document.

Appendix D. Pre-Ride Questionnaire

Connected Motorcycle Crash Warning Interfaces
Pre Ride Questionnaire

1. How many years have been riding a motorcycle? ________

2. On average, how many miles did you ride per year for the past three years? ________

3. How much do you rely on technologies in your daily life?

1	2	3	4	5	6	7
I am an anti-tech person.			Neutral			Use hi-tech products in every aspect of my life

4. I tend to have hands-on experience with newly released technologies.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

5. Crash Warning Systems on vehicles convey threat information to the motorists in the seconds leading up to a predicted crash to elicit an appropriate crash avoidance response. Have you heard of Crash Warning System?
   - ☐ Yes
   - ☐ No, skip to Question 8.

6. Do you have any hands-on experience with Crash Warning System?
   - ☐ Yes (Describe: ____)
   - ☐ No

7. Have you participated in any studies about Crash Warning System?
   - ☐ Yes (Describe: ____)
   - ☐ No

8. I would be comfortable having a Crash Warning System on my motorcycle for daily riding?

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

9. Motorcycle riders would benefit from this technology.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

10. If you could have a motorcycle that could alert you to…... for your daily riding, how beneficial do you think that would be (please check the appropriate box to the right of each option using the scale at the top of the table)?

	1: Not at all Beneficial	**2**	**3**	**4: Somewhat Beneficial**	**5**	**6**	**7: Extremely Beneficial**
A rapidly decelerating/stopped lead vehicle ahead of you							
A rapidly decelerating/stopped lead vehicle ahead of the vehicle you are following (out of sight)							
Cross Traffic about to run a red light/stop sign through an intersection you are approaching							
Oncoming traffic when you are attempting to pass a slower moving vehicle on a 2-lane roadway							
Vehicles in your blind spot when you are attempting to make a lane change							

Appendix E1. Test Protocol – LCW

Lane Change Warning (LCW)

Now we are ready to demonstrate a Lane Change Warning (LCW) application. LCW is intended to warn a rider during a lane change attempt if his or her blind spot is, or will soon be, occupied by another vehicle.

In this demonstration, LCW will be issued for a vehicle driving through your blind spot when you are attempting to make a lane change. [Show video]

Do you have any questions?

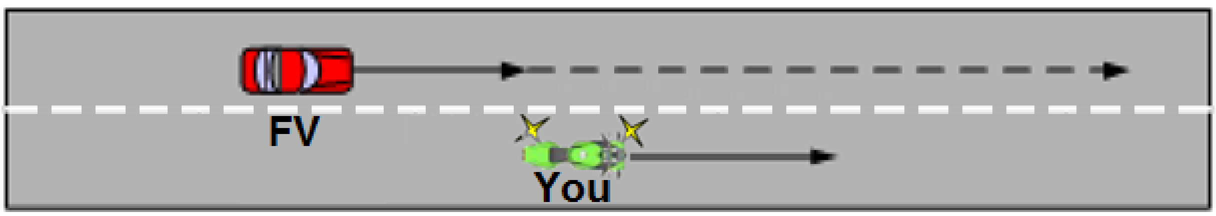
*****Next Page is for Road Test Session****

1. **Orientation to LCW Scenario**

During this Lane Change Warning demonstration, we would like you to get up to [instructed speed no greater than 25mph] in this lane (direct participant to appropriate lane) *with a following vehicle (FV) in the left lane.*

In this demonstration, you will receive the warning [through your helmet, from these lights, on your wrists].

Try to maintain your speed as you drive within your designated lane. Turn on the left-turn signal when you are asked to do so. As soon as you receive the warning, you should keep driving within your designated lane and maintain your speed. Though conducted at lower speeds for demonstration, this scenario is intended to demonstrate a situation where lane change warnings would be provided. Remember that your first priority is safety.



Do you have any questions before we get started?

2. **Execution of LCW Scenario**
    - Provide basic guidance to participant when needed
        - Vehicle speed
        - Appropriate travel lane
    - Communicate with participant the start of the scenario
        - Motorcycle starts in the right lane and accelerates to 25 mph
        - Simultaneously, the confederate vehicle accelerates to 25 mph in the left lane but hangs back approximately 20m/65ft
    - Communicate with participant the start of lane change around half way
        - Motorcycle activates the left turn signal
        - Experimenter sends alerting warning to participants when the confederate vehicle is hanging back.
        - After the motorcycle activates the signal, the confederate vehicle accelerates to around 30 mph and slowly overtakes the motorcycle
        - Experimenter sends imminent warning as soon as the confederate vehicle enters motorcycle’s blind spot (starting from that front bumper of the confederate vehicle is in line with rear bumper of the motorcycle) and terminates warning when completely overtakes the motorcycle.

- Communicate with participant the end of the scenario after FV completely overtakes motorcycle and leads with a following distance of at least 20m/65 ft. (2 seconds at 25mph)
- Lead the participant and pull over at the starting location of the next scenario

3. Administer Post-Interface Questionnaire (if this is the last scenario for an interface) Move on to next Safety Application based on Participant order (if this is not the last one)

Appendix E2. Test Protocol – FCW

<u>Forward Collision Warning (FCW)</u>

Now we are ready to demonstrate a Forward Collision Warning (FCW) application. FCW is intended to warn a rider if he or she is approaching a lead vehicle too quickly. This could be a situation where a car ahead is braking quickly, or has stopped.

In this demonstration, FCW will be issued for a slowing or stopped vehicle in your path of travel. [Show video]

Do you have any questions?

*****Next Page is for Road Test Session****

4. Orientation to FCW Scenario

During this Forward Collision Warning demonstration, we would like you to follow a lead vehicle (LV) and get up to [instructed speed no greater than 25mph] in this lane (direct participant to appropriate lane).

In this demonstration, you will receive the warning [through your helmet, from these lights, on your wrists].

Try to maintain [instructed following distance no less than 100 ft. (30m, or 3 seconds at 25mph), as indicated by the distance between you and LV now] as you ride within your travel lane. As soon as you receive the warning, you should brake to keep the distance. Bring the motorcycle to a complete stop if you keep receiving warning. Though conducted at lower speeds for demonstration, this scenario is intended to demonstrate a situation where forward collision warnings would be provided. Remember that your first priority is safety.

Do you have any questions before we get started?

5. Execution of FCW Scenario

- Provide basic guidance to participant when needed
    - Vehicle speed
    - Following distance
    - Appropriate travel lane
- Communicate with participant the start of the scenario
    - The confederate vehicle starts in the right lane 30 m (~100ft) ahead of the motorcycle at speed of 25 mph.
    - The motorcycle follows and maintains the following distance of 30m (~100ft).
    - After driving at least 0.5 miles, the confederate vehicle driver taps brake briefly, and then looses brake and reestablishes the 25 mph speed.
    - At the end of the scenario, the confederate vehicle brakes, gradually slows down and stops when the motorcycle is in a safe stopping distance.
    - The motorcycle stops behind the confederate vehicle.
    - The experimenter will send alerting warning to the participant as soon as the confederate vehicle is braking. Imminent warning will be sent when the

confederate vehicle stops or motorcycle is less than 20m/65ft away from the confederate vehicle.

- Communicate with participant the end of the scenario after he/she stops to avoid collision
- Lead the participant and pull over at the starting location of the next scenario

6. Administer Post-Trial Questionnaire (if this is the last scenario for an interface) Move on to next Safety Application based on Participant order (if this is not the last one)

Appendix E3. Test Protocol – IMA

Intersection Movement Assist (IMA)

Now we are ready to demonstrate an Intersection Movement Assist (IMA) application. IMA is intended to warn a rider when it looks like another vehicle is going to enter an intersection at the same time. This could be a situation where a vehicle crossing your path is about to run a red light or stop sign.

In this demonstration, IMA will be issued for a vehicle that is going to cross your path of travel at the intersection. [Show video]

Do you have any questions?

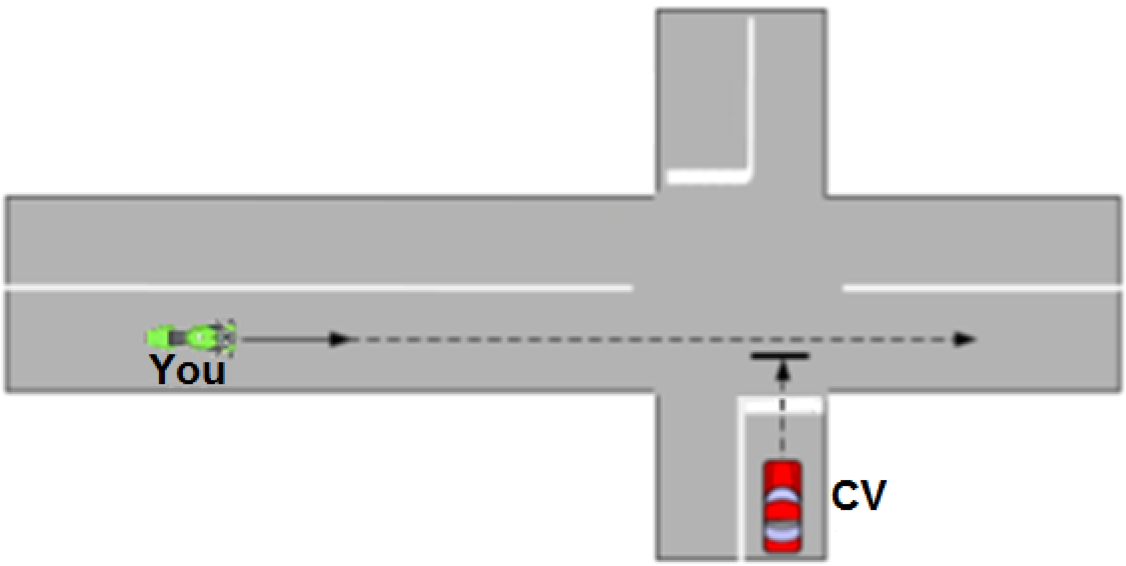
*****Next Page is for Road Test Session****

7. **Orientation to IMA Scenario**

During the Intersection Movement Assist demonstration, we would like you to get up to [instructed speed no greater than 25mph] in this lane (direct participant to appropriate lane).

In this demonstration, you will receive the warning [through your helmet, from these lights, on your wrists].

Try to maintain [instructed speed no greater than 25mph] as you approach an intersection. As soon as you receive the warning, you should brake and watch for a cross vehicle (CV) in the farthest lane. Bring the motorcycle to a complete stop in case of an impending collision. Though conducted at lower speeds for demonstration, this scenario is intended to demonstrate a situation where IMA would be provided. Remember that your first priority is safety.



Do you have any questions before we get started?

8. **Execution of IMA Scenario**
   - Provide basic guidance to participant when needed
     - Vehicle speed
     - Appropriate travel lane
   - Communicate with participant the start of the scenario when CV at intersection and motorcycle at Turn 2
     - The participant rides the motorcycle and approaches the intersection.
     - When the motorcycle is 100m/320ft away from the intersection, the confederate vehicle waiting at the crossroad starts.
     - As motorcycle approaches the intersection, the confederate vehicle drives slowly (@ 5 mph) towards the intersection.

    - Meanwhile, experimenter in the confederate vehicle sends warnings to participant (alerting warning when the motorcycle is 30m/100ft away from the intersection and imminent warning when 20m/65ft away) reminding him/her of the approaching confederate vehicle.
    - The confederate vehicle stops at the stop line at the intersection and lets the motorcycle to pass.
    - If the motorcycle stops before the intersection after receiving the warning, the confederate vehicle clears the intersection without a stop.
- Communicate with participant the end of the scenario when he/she passes the intersection or stops before the intersection
- Lead the participant and pull over at the starting location of the next scenario

9. **Administer Post-Interface Questionnaire (if this is the last scenario for an interface) Move on to next Safety Application based on Participant order (if this is not the last one)**

Appendix F. Post-Scenario Questionnaire

Connected Motorcycle Crash Warning Interfaces

Post Scenario Rating Scale

If you could have this type of warning on your motorcycle that alerts you in this situation for your daily riding, how beneficial do you think that would be?

1 2 3 4 5 6 7

Not at all Beneficial | Somewhat Beneficial | Extremely Beneficial

Overall Data Sheet

INTERFACE	**<u>VISOR</u> LED Strips**			**Helmet Speakers**			**Haptic Wristbands**			**Combination of FOUR**		
SCENARIO	LCW	FCW	IMA	LCW	FCW	IMA	LCW	FCW	IMA	LCW	FCW	IMA
RATING												

Appendix G. Post-Trial Questionnaire

Yellow Flag Post-Trial Questionnaire

1. Overall I felt this warning interface performed…..

1	2	3	4	5	6	7
Very Poorly			Neutral			Very Well

2. I felt this warning interface easily attracted my attention.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

3. The warnings issued were easy to understand.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

If your answer was 1, 2, or 3 above, what did you find confusing about this warning?

4. This warning interface effectively directed my attention to <u>a vehicle in your blind spot</u>.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

5. To what extent do you feel the warning provided you with enough time to avoid the vehicle in your blind spot?

1	2	3	4	5	6	7
Provided insufficient notice			Neutral			Provided sufficient advanced notice

6. This warning interface effectively directed my attention to a vehicle approaching the intersection and not slowing down to stop.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

7. To what extent do you feel the warning provided you with enough time to avoid the vehicle approaching the intersection and not slowing down to stop?

1	2	3	4	5	6	7
Provided insufficient notice			Neutral			Provided sufficient advanced notice

8. This warning interface effectively directed my attention to a slowing/stopped vehicle ahead.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

9. To what extent do you feel the warning provided you with <u>enough time to avoid</u> the slowing/stopped vehicle ahead?

1	2	3	4	5	6	7
Provided insufficient notice			Neutral			Provided sufficient advanced notice

10. The installation location of the warning interface would not interfere with my current riding behavior.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

11. The warnings startled me in a way that was not helpful.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

12. I would want this warning interface to indicate the direction of specific threat.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

13. This warning interface was effective at communicating the direction of specific threat.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

14. The warnings were effective at communicating the urgency of specific threat.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

15. Rate the overall safety impact this warning system is likely to have on your daily riding.

1	2	3	4	5	6	7
Significantly decrease			Neutral			Significantly increase safety

16. I would like to have this warning system on my personal vehicle.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

If you answered 1, 2, or 3, please explain why.

Appendix H. Post-Ride Questionnaire

Yellow Flag Post-Ride Questionnaire

Thank you for taking time out of your busy schedule to experience a range of vehicle-to-vehicle safety applications and crash warning displays.

This is the final questionnaire, in which we would like to collect your impressions of the displays as a group.

Thanks again for your feedback.

Questions related to each crash warning interfaces you experienced today

Helmet Speakers

1. What did you like about the helmet speakers? What do you feel is the most beneficial aspect of the helmet speakers?

2. What did you dislike about the helmet speakers?

3. What, if anything, would you change about the helmet speakers?

Tactile Wristbands

4. What did you like about the tactile wristbands? What do you feel is the most beneficial aspect of the tactile wristbands?

5. What did you dislike about the tactile wristbands?

6. What, if anything, would you change about the tactile wristbands?

Visor LED Strips

7. What did you like about the visor LED strips? What do you feel is the most beneficial aspect of this combination?

8. What did you dislike about the visor LED strips?

9. What, if anything, would you change about the visor LED strips?

10. The combination of all interfaces including mirror LED strips What did you like about the combination? What do you feel is the most beneficial aspect of this combination?

11. What did you dislike about this combination?

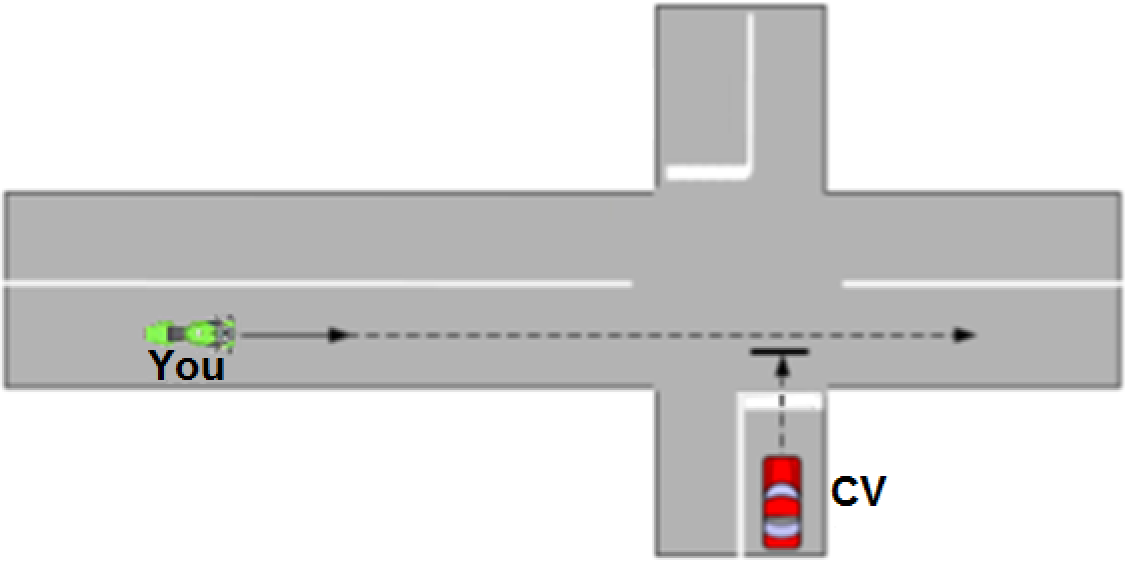
12. What, if anything, would you change about this combination?

13. What combination would you choose to have on your motorcycle for daily riding? Mark all that apply.
    ___ Mirror LED Strips ___ Visor LED Strips___Helmet Speakers ___ Tactile Wristbands

Questions related to each scenario you experienced today

Intersection Movement Assist (IMA)

In the IMA scenario, the rider is warned when it looks like another vehicle is going to enter an intersection at the same time.



14. How beneficial do you feel it would be to have an IMA warning application on your motorcycle for your daily riding?

1	2	3	4	5	6	7
Not at all beneficial			Somewhat beneficial			Extremely beneficial

15. Have you ever been involved in a crash similar to what could have occurred during this scenario you experienced?
    - ☐ Yes
    - ☐ No

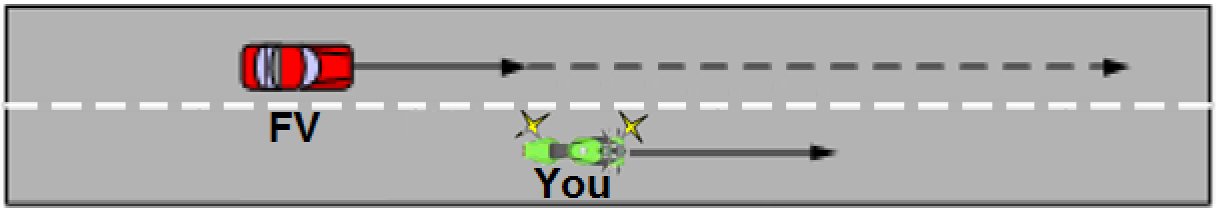
    If Yes, could the warnings issued by this interface have assisted you in the previous real-life riding experience?
    - ☐ Yes; please explain below
    - ☐ No

16. Which of the following crash warning interfaces performed well in an IMA scenario? Rank them from 1 (best) to 5 (worst)

    ___ Visor LED Strips
    ___ Helmet Speakers
    ___ Tactile Wristbands
    ___ Combination of ALL including Mirror LED Strips

Lane Change Warning (LCW)

In the LCW scenario, the rider is warned during a lane change if another vehicle is, or soon will be, in his or her blind spot.



17. How beneficial do you feel it would be to have an LCW application on your motorcycle for your daily riding?

1	2	3	4	5	6	7
Not at all beneficial			Somewhat beneficial			Extremely beneficial

18. Have you ever been involved in a crash similar to what could have occurred during this scenario you experienced?
    - ☐ Yes
    - ☐ No

    If Yes, could the warnings issued by this interface have assisted you in the previous real-life riding experience?
    - ☐ Yes; please explain below
    - ☐ No

19. Which of the following crash warning interfaces performed well in a LCW scenario? Rank them from 1 (best) to 5 (worst)

___ Visor LED Strips
___ Helmet Speakers
___ Tactile Wristbands
___ Combination of ALL including Mirror LED Strips

Forward Collision Warning (FCW)
In the FCW scenario, the rider is warned if he or she is approaching a slower moving or stopped vehicle ahead.

20. How beneficial do you feel it would be to have an FCW application on your motorcycle for your daily riding?

1	2	3	4	5	6	7
Not at all beneficial			Somewhat beneficial			Extremely beneficial

21. Have you ever been involved in a crash similar to what could have occurred during this scenario you experienced?
☐ Yes
☐ No

If Yes, could the warnings issued by this interface have assisted you in the previous real-life riding experience?
☐ Yes; please explain below
☐ No

22. Which of the following crash warning interfaces performed well in a FCW scenario? Rank them from 1 (best) to 5 (worst)

___ Visor LED Strips
___ Helmet Speakers
___ Tactile Wristbands
___ Combination of ALL including Mirror LED Strips

Questions related to all crash warning interfaces you experienced today

23. I would be comfortable having a Crash Warning System on my motorcycle for daily riding.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

24. Motorcycle riders would benefit from this technology.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

25. Overall, I would like to have this crash warning interface on my motorcycle for daily riding. Rank them from 1 (most likely) to 5 (least likely)

___ Visor LED Strips
___ Helmet Speakers
___ Tactile Wristbands
___ Combination of ALL including Mirror LED Strips

For interface ranked No.1,
26. Having this interface would distract me in my daily riding.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

For interface ranked No.1,
27. Having this interface would cause me to pay less attention to the environment in my daily riding.

1	2	3	4	5	6	7
Strongly Disagree			Neither Agree nor Disagree			Strongly Agree

28. Any final thoughts or comments you would like to provide?

Appendix I. Experimenter Protocol

<u>Lead Experimenter Protocol</u>

1. **Make sure the following items are ready**

   From office area

   a. **One radio (check out from Control Room)**
      (Participant will need to wear Bluetooth headset as one of the warning interfaces and will keep in contact with the experimenter with it so won't need another radio)
   b. **Laptop**
      i. **Safety application video demos are ready**
      ii. **Power cable (connect to the lighter power outlet)**
   c. **Participant packet include the following:**
      On the cover of the packet, write down participant number, interface sequence number, and scenario order number. Riding gears needed and their sizes.
      i. **2x Informed consent**
      ii. **Pre-ride questionnaire**
      iii. **Briefing documents (LCW, FCW, IMA)**
      iv. **Post-scenario rating sheet**
      v. **Post-trial questionnaire**
      vi. **Post-ride questionnaire**
      vii. **Tax form W-9**
      viii. **Checkbook/Cash**
      ix. **Debrief-payment form and payment acknowledgement**
      x. **Clipboards and pens for questionnaires**
      xi. **Color blind test packet**

   d. **2x Headsets (Sena)**
      i. **Charged**
   e. **Notepad to show participant # and interface # in the camera**
   f. **Interface test order sheet/scenario test order sheet**
   g. **Experimenter's Smartphone**
      i. **App to check camera angle**
      ii. **Charged**
   h. **Cameras**
      i. **Charged**
      ii. **Enough space on memory cards** (export existing contents to project laptop)
   i. **Warning Interfaces**
      i. **9v battery charged**

ii. **Installation instructions**

j. **Bottled water for participant**

k. **Other supplies**

i. **Tapes (two types)**

ii. **Adhesive dots**

iii. **Hand wipes**

l. **Confederate vehicle/motorcycle**

i. **Get keys**

Out of office area

m. **Confederate vehicle/motorcycle**

i. **Get Car -- Hard drive in NextGen and switch is on**

ii. **Drive the car to the staging parking lot**

iii. **Move all the equipment to the car**

iv. **Park the car outside Bay 4 facing the gate. Engine off, key in ignition**

v. **Motorcycle key in ignition**

vi. **Check the following**

1. **Motorcycle's Headlight**
2. **Turn signals of both**
3. **Brake light of both**

vii. **Mirror LED strips and face camera pre-installed**

1. **Attach the nylon strings to the back of the mirror bars with tape in case of participant's hands get tangled.**
2. **Check the face camera angle with smartphone app**

n. **Helmet if participant indicated that he/she will not bring one**

o. **Jacket and gloves for participant if he/she needs**

i. **Sanitized with wipes**

2. **With participant packet, laptop, participant headset, helmet installation instruction (and helmet if participant needs ours), experimenters greet participant and lead to subject prep room**

a. **Record the time that the participant arrived**

On debrief-payment form

b. **Show motorcycle license**

i. **Must be a valid motorcycle license. Out of state is fine**

ii. **Make sure it has not expired**

c. **Check participant's safe riding gear**

i. **Helmet (if they bring their own, must be full or ¾ with clear visor)**

ii. **Jacket (if they bring their own)**

iii. **Gloves (if they bring their own)**
iv. **Long pants**
v. **Boots**
vi. **Untinted prescription glasses if participant wears one when riding**

3. **Informed consent**
    a. **Present participant with the form – Encourage them to read it before signing it.**
    b. **Answer questions**
    c. **Have participant sign and date the form**
    d. **Give participant a copy of the informed consent**

4. **If participant brings his/her own helmet, show him/her what will be installed on the helmet and ask for permission to install the visor LED and headset. Upon approval, the second experimenter takes participant's helmet to Bay 4 and starts installation (follow the printed instructions, headset on the left and visor LED console on the right). Otherwise, try VTTI helmet and see if it fits. Then go to Bay 4 and start installation.**

5. **Tax forms**
   To complete the W-9, the participant must fill out the following:
    a. **Name.**
    b. **Address**
    c. **Tax ID number (SSN)**
    d. **Sign and date at the bottom**

   If the participant makes more than $600.00 doing studies from Jan 1 to Dec 31, this will be reported to the IRS as income.

6. **Administer pre-ride questionnaire**

7. **Training/Protocol/Video**

During today's experiment, you will be riding a motorcycle on the Smart Road. During this time you will experience various scenarios and warning interfaces. Your job will be to experience, and evaluate these warning interfaces in different scenarios and provide your feedback later in questionnaires. I will be driving another vehicle during the experiment. All together, the study will take about 2 hours and there will be breaks during driving. If at any time you have any questions please let me know.

You will experience three different riding scenarios during today's experiment. In one, you will try to make a lane change. In another, you will be following a lead vehicle. In the third scenario, you will approach and ride through an intersection. Our goal is for these scenarios to be as

realistic as possible so please try and ride as if you were on a real road with actual traffic. However, for your safety, we have taken a number of precautions as previously mentioned in the informed consent form.
To give you a better idea of the three scenarios you will experience, I am going to show you a short video demonstration. [Use each scenario info sheet to provide more details and then play video]

Each scenario will be explained in greater detail after we enter the Smart Road. Do you have any questions so far?

Before we go to the preparation area, would you like to use the restroom? There is no restroom once we enter the Smart Road.

8. Ask participant to turn off cellphone (or airplane mode)
If you have a cellphone with you, we need to ask you to turn it off or put it in airplane mode so you will not be distracted during the test.

9. Direct participant to the preparation area (Bay 4)

10. Second experimenter puts the notepad and interface test order sheet near driver's seat. Hooks laptop with DAS in car, starts the car, opens SolEye and connects to Sol.

11. Show and explain equipment

a. **LED strips on mirrors**
These LED strips will provide visual warnings by flashing red light in either low or high frequency. At times either or both may be illuminated.

b. **Face camera on handlebar**
This camera will capture the view of your upper body

c. **Headset/microphone kit and visor LED strips on a helmet**
We will use this Bluetooth headset to communicate with you throughout the experiment. It will also provide audio warnings which are simple warning tones in either low or high rate. The warnings could be on one or both sides.
These short visor LED strips will provide the same visual warnings as the mirror ones expect for the strip length and location.

d. **Wristbands**
These are haptic wristbands that you will be asked to wear during the experiment. It will provide haptic/vibrating warnings in either low or high frequency. Again, the warnings could be on one single or both sides.

e. **Backpack with a LED light and video camera**

We will also ask you to wear this backpack during the road test. All these warning interfaces are wirelessly connected with equipment in this backpack. This camera on the backpack will capture the view of the handlebar and roadway in front of you.

Now make sure the two batteries inside the backpack are connected and both the Savari box and the black RaspberryPi box have led lights illuminated.

Any questions before you put everything on?

12. Start installation

a. **Put on jacket (offer our summer mesh jacket which should be much cooler)**
b. **Ask participant to clean hands and wrists with wipe and put on wristbands**
    - **The wristbands should be worn directly against skin on participants' wrists.**
    - **Check the letters "L" and "R" marked inside the wristbands to make sure each goes to the correct side; the side with wires should face upwards. Make sure one tactor on the top of the wrist and one on the bottom.**
    - **If participant wears a watch, encourage them to take off the watch before wearing wristbands.**
c. **Put on backpack and then the helmet.**
   Plug in audio cable and turn on the headset.
   In order to make sure you see the visor LED properly, you have to keep your visor down at all times when running the test. You may open your visor or take the helmet off during breaks but please ask the experimenter to do this for you because of the wires.
d. **Put on gloves**
e. **Adjust camera angle**
   We are adjusting the backpack camera with a smartphone app to make sure the camera angle are right.
f. **Test headset – Turn on experimenter's headset and talk with the participant over the headset**
   I am now going to quickly check that the headset is working…..
   Do you copy? Can you hear my clearly?
g. **Ask participant to move the motorcycle out of Bay 4 and park in front of the confederate vehicle. Shut off the engine. Close Bay 4.**
h. **Experimenters get into the car**
i. **Test interface connections with laptop/informal sense test**
   Through the headset: *Now I am going to quickly check the warning interfaces to make sure they are working correctly, please raise your left hand if you detect a*

warning from the left side and vice versa. Raise both your hands if warnings come from both sides.

i. **Trigger all interfaces (both levels) by pressing the buttons one by one on the SolEye interface**
Please note, audio warning can only be triggered when headset communication is shut down.
Press space to terminate one audio level prior to triggering another.

ii. **Let participant raise left/right hand (or both) to confirm if they receive warnings from any of the interfaces on the left/right (or both sides)**

13. Final check out – second experimenter leaves the car and check out

Now we are coming to you to do a final check before heading to the Smart Road

a. **Headset solidly mounted**
b. **Helmet buckled**
c. **Mirrors adjusted**
d. **Backpack secure – chest/waist straps bucked up**
e. **Participant tried turn signal and is familiar with it**
f. **Researchers – Cellphone in silent**

14. Ask participant to start the motorcycle

Now we are going to enter the Smart Road. Please ride your motorcycle and follow my vehicle's lead. Throughout the experiment, our headsets will be connected. I will give you instructions over the headset and you are free to ask questions if you have any concerns. The communication will only be interrupted when audio warnings are activated. In the rare event that the communication is lost due to another reason, such as if something seems to not be working, wave your hand and gradually pull to the side of the road and stop. I'll do the same if something isn't working for me or I have a concern. Do you have any questions so far?

We would like you to follow a couple rules while we are on the Smart Road. First, follow the experimenter's instructions at all times. And, second, the maximum speed limit is 25mph unless instructed otherwise.

As you are riding today we would like you to drive as if you were on a real road with actual traffic. Please keep this in mind during each scenario and try to react as you would in a similar situation on a real road. The information about your riding will help us understand and improve the design of these systems. Please remember that the <u>system</u> is being evaluated, not you or your performance.

15. Lead the way and enter the Smart Road

Do not rush. Yield to all upcoming traffic at stop signs to make sure that motorcycle is staying together with you.

Please follow my lead when we are heading to the Smart Road. Once we arrive at the Smart Road we will need to wait outside of the gate while we talk to the Smart Road Control Room and request for the gate to be open. After we enter the road we will stop and wait for the gate to be completely closed. Please be patient while we talk to the Control Room and follow our lead once the gate is open.

The second experimenter talks to the Smart Road Control Room with radio while the lead experimenter on the passenger seat keeps talking to the participant over the headset and make him/her informed what is currently happening.

16. Lead the participant to do an one-loop test ride

We will start with a practice lap, driving down and back up the Smart Road, to help familiarize you with the portion of the road we will be using during the experiment. Additionally, you should get familiar with the motorcycle. Remember that the speed limit is 25 mph. Please follow our lead, maintain a safe following distance, and use caution like you would if you were driving on a real road with actual traffic. Do you have any questions before we begin?

When approaching Turn 4

We are approaching the end of Smart Road, be prepared to slow down and we will turn around and head back. Are you comfortable with this motorcycle? Do you have any questions?

Now we will start with the scenarios. There will be five loops with three different scenarios each. In each loop, you will receive a different warning interface.

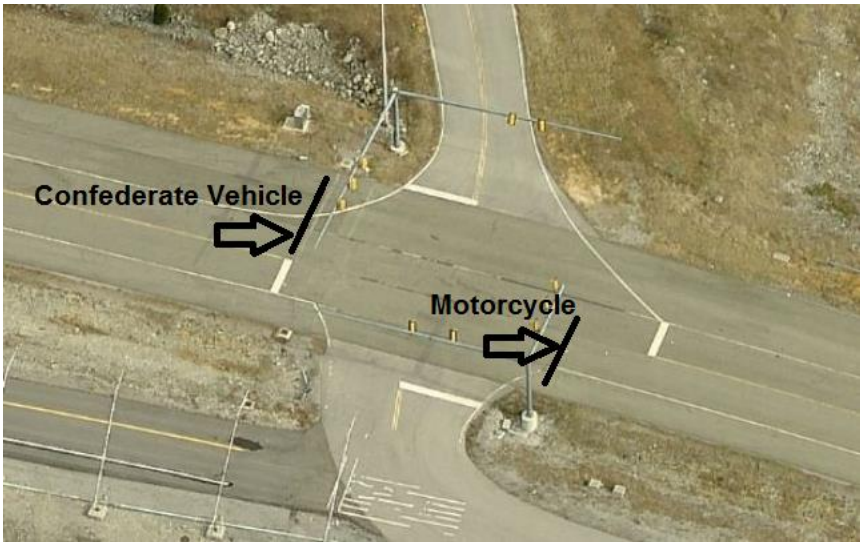
Don't need to complete a whole loop, lead the motorcycle to the starting location of the first scenario when you are on way back from Turn 4.

17. Orient the participant to one of the scenarios following the order sheet

Lead experimenter instructs the participant/second experimenter to their starting locations follow the instructions of the three scenarios below.

a. **LCW**
    i. **Lead the participant to ride to the starting location at the intersection towards Turn 3 (in right lane flush with the traffic pole on the right side)**
    ii. **Ask the participant to shut off the motorcycle**

iii. Second experimenter drives forward and change to the left lane towards the same direction and back off to flush with the white line in the right lane behind the motorcycle.

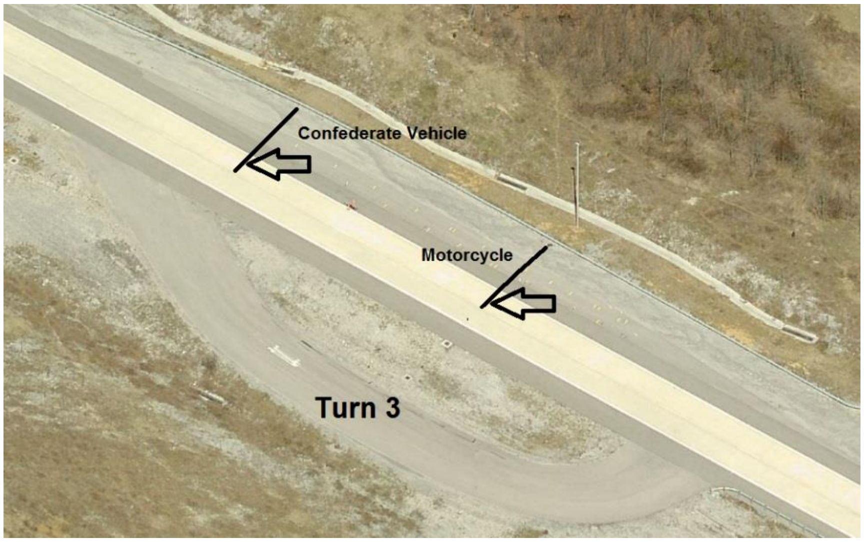


b. FCW

i. Lead the motorcycle to the starting location at Turn 3 (in the right lane flush with the first light pole towards uphill)

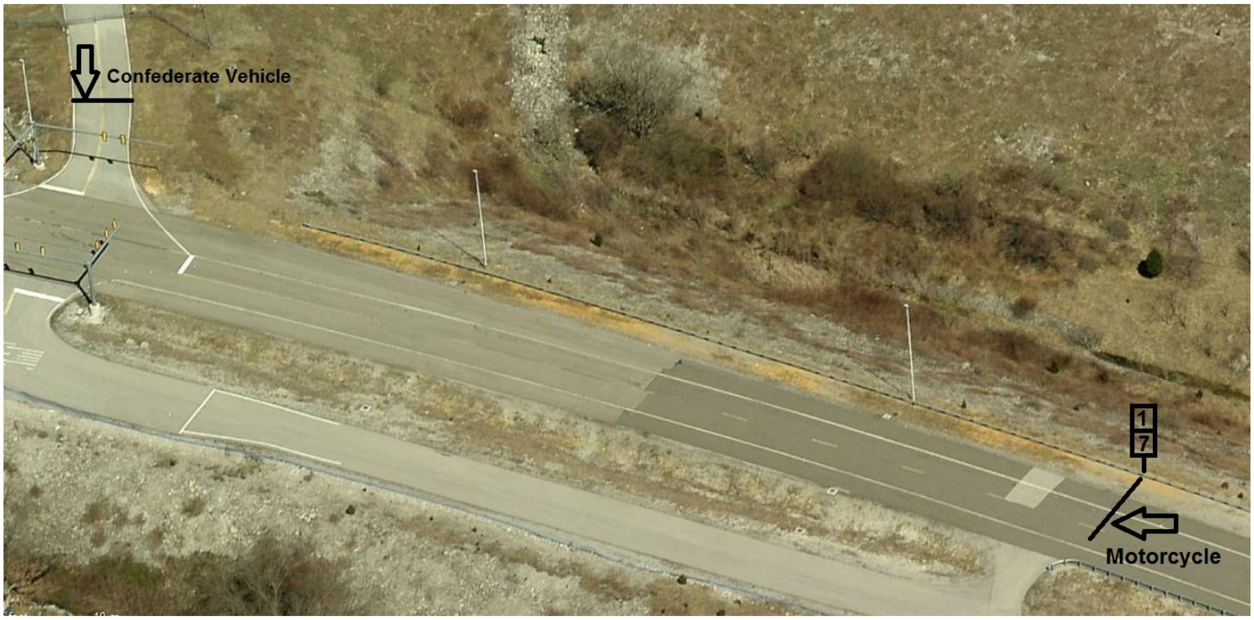
ii. Ask the participant to shut off the motorcycle

iii. Second experimenter drives the confederate vehicle forward in the right lane 100ft ahead of the motorcycle (car's FRONT bumper flush with a reference mark).



c. IMA

i. **Lead the motorcycle to the starting location towards intersection (flush with a green 17 sign between the 2nd and the 3rd light poles away from the intersection)**
ii. **Ask the participant to shut off the motorcycle**
iii. **Second experimenter drives the confederate vehicle onto the crossroad towards intersection, half way from the gate to the while line in the right lane.**



<u>If it is the beginning of one trial (first scenario of each interface test)</u>
In a few seconds, we are going to walk to you and turn on the cameras
The second experimenter will prepare a paper with participant # and interface # and prepares SolEye to be able to trigger the corresponding interface according to the interface order sheet (need to change side to be triggered at the beginning of each scenario, LCW-left, FCW-both, IMA-right)
Then the second experimenter leave vehicle to turn on cameras.
i. **Make sure the GPS sensor is ready (solid green)**
ii. **Check camera angle**
iii. **Turn on both cameras**
iv. **Flash the paper with participant # and interface # in front of cameras**

Lead experimenter keeps talking with participant about the scenario:

a. LCW
During this Lane Change Warning scenario, we would like you to get up to 25mph in the right lane with a following vehicle which is us in the left lane.

Try to maintain your speed as you drive within your designated lane. Turn on the left-turn signal when you are asked to do so. You will receive lance change warnings in this demonstration. As soon as you receive the warning, you should keep driving within your *designated lane and maintain your speed. Though conducted at lower speeds for demonstration, this scenario is intended to demonstrate a situation where lane change warnings would be provided. Remember that your first priority is safety.*

Now please adjust your mirrors again to make sure you can see our car.
Please find and turn on your left turn signal… OK, turn it off now.
Do you have any questions before we start?

Meanwhile, second experimenter prepares SolEye to trigger the LEFT side of the interface only.

Lead experimenter double checks.

b. FCW

During this Forward Collision Warning demonstration, we would like you to follow a lead vehicle and get up to 25mph in the right lane.

Notice that there are three paint lines between us right now. Try to maintain this distance between you and our car right now as you follow us within your travel lane. You don't have to hold this distance precisely, but this is a helpful way to know you're at about the safe distance we're shooting for.

You will receive forward collision warnings in this demonstration. As soon as you receive the warning, you should be prepared to brake to maintain the following distance. Bring the motorcycle to a complete stop if you keep receiving warning. Though conducted at lower speeds for demonstration, this scenario is intended to demonstrate a situation where forward collision warnings would be provided. Remember that your first priority is safety.

Do you have any questions before we start?

Meanwhile, second experimenter prepares SolEye to trigger BOTH sides of the interface.

Lead experimenter double checks.

c. IMA

During the Intersection Movement Assist scenario, we would like you to get up to 25mph in the right lane.

Try to maintain 25mph as you approach the intersection. You will receive warnings in this demonstration. As soon as you receive the warning, you should brake and watch for a cross vehicle. Bring the motorcycle to a complete stop in case of an impending collision. Though conducted at lower speeds for demonstration, this scenario is intended to demonstrate a situation where IMA warning would be provided. Remember that your first priority is safety.

If traffic light is not on, (*Please ignore the traffic light, and you have the right of way.*) *We are now ready to start the scenario. Do you have any questions before we start?*

Meanwhile, second experimenter prepares SolEye to trigger the RIGHT sides of the interface only.

Lead experimenter double checks.

18. Execute the scenario

a. **LCW:**
   i. **Communicate with participant the start of the scenario**
      You may start your motorcycle and ride whenever you are ready. Again your speed limit is 25 mph. Follow our instruction to turn on your left turn signal. But please keep riding in this lane and do not change lane.
   ii. **Following motorcycle, accelerate to 25mph and keep the same following distance**
   iii. **After around 0.5 mile driving, give instruction via headset:**
      Do you copy? **If yes**
      "*In 5 seconds, turn on your left turn signal***"**
   iv. **Upon motorcycle turning on left blinker, trigger alerting warning and accelerate to around 30 mph to slowly overtake the motorcycle on the left**
   v. **Trigger imminent warning when getting into its blind spot.**
   vi. **Terminate warnings after completely passing the motorcycle**
   vii. **Communicate with participant the end of the scenario**
      That is the end of this scenario. Please turn off the left turn signal. Now the car is going to change to the right lane and lead you to make a U-turn at the turnaround ahead. Please maintain safe following distance.
   viii. **Stop after making a U-turn at T3**
   ix. **Administrate post-scenario rating**
   x. **Lead motorcycle to the next scenario if the trial has not ended yet.**

b. **FCW:**
   i. **Communicate with participant the start of the scenario**

Please follow our car and slowly get to 25mph. Maintain the current distance. You may start your motorcycle now.
Are you ready? **If Yes**
We will be going in 3 seconds, 3…2…1…go

ii. **Slowly accelerate to 25mph, wait till motorcycle is following with designated distance. Ask him/her to get closer if distance is too long.**
iii. **Brake and trigger alerting warning.**
iv. **Release brake, re-establish speed, and terminate warning.**
v. **Brake (trigger alerting warning) and get into a full stop, trigger imminent warning, and observe motorcycle's position.**
vi. **Terminate warning when the motorcycle stops.**
vii. **Communicate with participant the end of the scenario**
viii. **Administrate post-scenario rating**
ix. **Lead motorcycle to the next scenario if the trial has not ended yet.**

c. IMA:

i. **Communicate with participant the start of the scenario**
You may start your motorcycle and ride whenever you are ready. Again your speed limit is 25 mph. Please ignore the traffic light because you have the right of way.
ii. **Approach the intersection at low speed (5mph, no throttle, just loose brake and let the car slide)**
iii. **Observe motorcycle's position and trigger warnings**
   1. **Alerting warning - when motorcycle is 30m away**
   2. **Imminent warning - when motorcycle is 20m away**
iv. **Terminate warning as soon as the motorcycle passes the intersection**
OR if the motorcycle stops before entering the intersection
   1. **Clear the intersection if participant stops before entering**
   2. **Terminate warning after passing the motorcycle**
v. **Communicate with participant the end of the scenario and pull over on the right side of the road.**
vi. **Administrate post-scenario rating**
vii. **Ask participant to make a U-turn ride back to the intersection.**
viii. **Lead motorcycle to the next scenario if the trial has not ended yet.**

19. Repeat 18-19 until all three scenarios of a trial are done.

20. After a trial ends, pull over at the following locations

LCW – Turn3
FCW – where both stop at the end of the scenario
IMA – Ask participant to pull over and

Ask participant to shut off the motorcycle.
Experimenters leave the confederate vehicle and approach the participant.

- **a. Shut down cameras**
- **b. Offer break**
  - **i. Offer water.**
  - **ii. Help participant open visor or take off helmet if he/she wants to. Be careful about the visor led wires and audio cable connects the headset and backpack. Disconnect the audio cable if participant want to take off the helmet.**
- **c. Administer post-trial questionnaire**

Meanwhile, the second experimenter goes back to the car and prepares SolEye to be able to trigger the next interface according to the interface order sheet.

When break ends, help participant put helmet on, connect audio cable and close visor

21. Repeat previous Step 18-21 until all the trials are done

That is the end of our riding session. Now we are going to exit the Smart Road. Please follow our lead back to the garage where you will fill out a post-drive questionnaire and get paid.

22. Radio Dispatch that you are on your way back

We need to wait in front of the gate while I ask the Smart Road Control Room to open the gate. After we exit, we have to wait still the gate is completely closed behind us. So please be patient and follow our lead.

23. Lead participant back to Bay 4

24. Second experimenter shuts down the car and leads motorcycle into Bay 4

25. Second experimenter uninstalls equipment

- **a. Take off helmet, backpack, wristbands, and gloves**
- **b. Offer hand wipes to participants**
- **c. Uninstall all interfaces and the camera from the motorcycle (if the next scheduled participant is not going to use the same motorcycle) and from the helmet (if the next scheduled participant is not going to use the same helmet).**
- **d. Disconnect all batteries (interfaces and backpack) and shut down headset**

26. Lead experimenter shut down headset, leaves the car with participant packet and offers participant a few minutes' break and water.

27. **Lead experimenter administers post-ride questionnaire**
    This is the last questionnaire today. First I will ask you some questions.
    Experimenter asks all the open questions and writes down participant's answers. Then leave the rest questions to the participant.

28. **Record the ending time**

29. **Pay the participant**
    a. **Ask participant to sign the payment acknowledgment form (for us to keep)**
    b. **Fill and sign debrief-payment form and give to participant**
    c. **Pay participant with check or cash**

    Please give me a few seconds while I am checking if the paperwork is complete.

30. **Verify that the participant's file is complete.**
    a. **Informed Consent**
    b. **W-9 tax form**
    c. **Payment acknowledgment**
    d. **Pre-ride questionnaire**
    e. **Post-scenario rating scale**
    f. **5x post-trial questionnaire**
    g. **Post-ride questionnaire**

31. **Thank and dismiss the participant**
    You are all set. Thanks for your time today. We really appreciate it.
    Let me lead you the way to the parking lot. If you want to take a rest or use the restroom, please follow my lead. **Lead the participant to the lobby/restroom. Wait or ask the front desk to show him/her the way to the parking lot.**

32. **Copy video files to the laptop and empty memory cards**

33. **Charge cameras, headsets, backpack batteries, 9v batteries**

34. **If end of the day**
    a. **Return radio**
    b. **Check fuel of the confederate vehicle and all VTTI motorcycles. Refuel if fuel level is low (cannot run for a whole day).**