AN ON-ROAD EVALUATION OF CONNECTED MOTORCYCLE CRASH WARNING INTERFACE

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ABSTRACT

Crash warning systems (CWS) have been deployed in the high-end vehicle market segment and are trickling down to additional segments each year. The motorcycle segment, however, has very little corresponding research and has not deployed a CWS. Today, next generation CWSs based on Connected Vehicle Technologies (CVT) are being actively developed and will likely be among the first applications deployed that capitalize on the advantages of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. Recognizing CVT application on motorcycles as feasible, this study explored possible interface designs for motorcycle CWSs and evaluated their rider acceptance and effectiveness in a CVT 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 that were selected according to the most impactful crash types identified for motorcycles: intersection movement assist (IMA), forward collision warning (FCW), and lane departure warning (LCW). Rider acceptance and response were collected and analyzed. Differences among riders of three major motorcycle types (cruiser, sport, and touring) were explored. Based on the results, recommendations were provided for an appropriate crash warning interface design for motorcycles and riders in a connected vehicle environment.

Keywords: crash warning system, crash warning interface, connected vehicle, V2V, connected motorcycle
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 warning, 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 segments each year. However, there is very little research on these systems for application to motorcycles and nothing has 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 (V2V) and to different types of roadway infrastructure (V2I), continuously sharing important safety and mobility information (1). CWS will likely be among the first applications deployed that capitalize on the advantages of 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 are 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 then 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 (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 (2).

It was found that in many cases, a rider did not have time to complete crash-avoidance maneuver (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 apply to the automotive domain (12-14). Due to differences between four-wheel vehicles and motorcycles, this study focused on the development and evaluation of a prototype CWI specifically for motorcycles and 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) we adopted when designing the motorcycle CWI.

On motorcycles, there are fewer feasible locations where 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 mirror(s). 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. There are many auditory/communication
devices for motorcyclists to install inside their helmets that could be used as auditory displays.
Heads-up displays (HUD) built into motorcycle helmets or even motorcycle helmets that come
with HUD (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 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, the 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). For
example, information about direction of the potential threat (front, left, or right), and 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. They 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

Apparatus

Crash Warning Interface

Three warning mode alternatives were selected (visual, auditory, haptic) and based on that, four
different motorcycle CWI displays were retained for on road evaluation. Based on literature
review and brainstorming, 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 OEM’s mirror blind spot indicators. Poor conspicuity might be due to the fact that the strip angles 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 three-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 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 showed potential effectiveness in certain scenarios (LCW etc.) and, as a result, were retained in the study.

Figure 1. A rider on a Yamaha V Star with a connected motorcycle CWS
Along with the CWI, two motion cameras (capturing rider torso and head, and forward roadway and hand(s) respectively) were mounted on the handlebar and the backpack (Figure 1) and deployed during the road test.

**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

<table>
<thead>
<tr>
<th>CWI Display</th>
<th>Caution alert</th>
<th>Warning alert</th>
</tr>
</thead>
</table>
| 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 was built into a backpack carried by riders. 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.

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.

**Experimental Vehicles**
Our motorcycle fleet includes 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). Each participant was provided with a motorcycle similar to
his/her own (in terms of type and engine size) so focus would be on experiencing the CWI. The confederate vehicle in this study was a Chevrolet Tahoe.

**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 vehicle-to-vehicle separations were at least 2 seconds.

The IMA application is intended to warn a rider that another vehicle is going to move through an interaction ahead, violating the rider’s right-of-way, in a way that will require avoidance. The FCW is intended to warn a rider when 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 2.

<table>
<thead>
<tr>
<th>Application</th>
<th>Warning Direction</th>
<th>Caution Alert</th>
<th>Warning Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMA</td>
<td>Right</td>
<td>Motorcycle is less than 5 seconds from the intersection</td>
<td>Motorcycle is less than 3 seconds from the intersection</td>
</tr>
<tr>
<td>FCW</td>
<td>Forward</td>
<td>Lead vehicle is braking</td>
<td>Lead vehicle stops or headway less than 2 seconds</td>
</tr>
<tr>
<td>LCW</td>
<td>Left</td>
<td>A vehicle is overtaking from left lane when rider turns on the left turn signal</td>
<td>A vehicle is in rider’s blind spot when the left turn signal of the motorcycle is activated</td>
</tr>
</tbody>
</table>

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 session and pre- and post-ride portions of the study were conducted in an air-conditioned 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.
A mixed-factorial experimental design was used in this study where 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 (combo), including mirror-mounted LED strips) in a balanced order. 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, a participant 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 along the metric of rider acceptance. Rider response, emphasizing measurement of rider monitoring of surroundings and interface and captured by motion cameras, could have served as another set of performance assessing metrics. However, through pre-scenario training, 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 were administered at different stages of the study and consisted of rating questions (on a seven-point Likert scale), ranking questions, and open-ended questions. 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 they just experienced. After completing one trial, a post-ride 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. After finishing the road session, a post-ride questionnaire was administered to collect open-ended comments on each of the displays (likes, dislikes, and improvements), rankings of the displays, and again benefit/comfort ratings of having CWSs on their motorcycles and benefit rating of various CWS applications. Participants were also interviewed about their crash experiences and asked whether the corresponding CWS applications could help.

The question sequence followed the display/scenario order the participants received in their road session to control potential order effects. 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.

RESULTS

Participants

A total of 39 licensed riders were recruited and finished this study. A control was applied over motorcycle type but not over age and gender. The 39 participants fell evenly into three motorcycle types (cruiser, touring, and sport). Among them, 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.

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 the age (p = 0.01) of participants as well as experience in terms of mileage per
year (p = 0.04). Main effect plots are shown in Figure 3. Participants riding sport bikes were the youngest, while participants with touring bikes had ridden the longest time and distance.

**Figure 3.** 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.

It is found that scenario (p = 0.03) and the interaction between time and scenario (p = 0.00) are significant. Benefit rating 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.

Although 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 a system capable of providing warnings in these situations was close to extremely beneficial (scale 7). Sport riders still thought similarly, but between somewhat beneficial (scale 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 = 0.00) and comfort rating from 5.03 to 6.00 (p = 0.00). These changes didn’t differ among three motorcycle types (p = 0.19 and 0.74). This finding suggests that riders became more comfortable with CWS with exposure to the alerts.

ANOVA was performed again on participants’ post-scenario benefit ratings, with CWI display and scenario being within-subjects factors, and motorcycle type being between-subjects factor. It was found that CWI display was significant (p = 0.01) and motorcycle type was significant (p = 0.01). No other significant factor or interaction was identified.

Given’s test shows that the average benefit rating of the combination of all four displays (5.97) was significantly higher than the visor strip (5.51) and haptic wristband (5.33) (p = 0.03 and 0.00, respectively). 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 = 0.05 and 0.01, 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 a situation 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 = 0.00) was identified among displays only with the overall ranking. Wilcoxon signed-rank tests were then used to compare each of the displays against each other to examine where the differences actually occur. Test showed that in-helmet headset, with a mean rank of 1.86, was ranked significantly higher than the other three (p = 0.01 against wristband, p = 0.00 against visor LED, and p = 0.00 against combo). The ranks for wristband (2.59), visor LED (2.71), and combo (2.85) were not significantly different from each other.

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%). 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 them and thus ignored anything further ahead on the road. Other dislikes including 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 proposed changes included "relocate and make them less obtrusive" (53.8%) and "change color" (28.2%). Since currently they are located in an area between binocular vision and peripheral vision, they
could be moved further into the peripheral vision field. Automatically adjusted brightness would be useful to remedy extreme lighting conditions.

The most frequent participant likes of 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 directionality problem of auditory alerts.

"Using new sensation and location" turned out to be the leading advantage of 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 surprising for a prototype design and "maybe hard to distinguish from environment" (38.5%). The latter dislike was due to some participants’ concern about motorcycle vibration. However, participants confirmed that caution alert with a 1 Hz pulse rate easily grabbed their attention. A 10 Hz pulse rate with 50% duty circle for warning alerts found to be too high, and may 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. They were "integration into bike, jacket or gloves" (28.2%) or "making them slimmer" (23.1%).

Since the combo triggered all displays covering all warning modalities, its dominant advantage is attracting attention. 46.2% of participants said, "impossible to miss or ignore" and 43.6% mentioned, "get user’s attention fast." However, for the same reason, they disliked the combo for being "too much and distracting" (56.4%). It might not be appropriate for low urgency situations and situations where stopping is dangerous. As a result, "reduce the number of displays" (41.0%) to a balanced level or, making it "a dynamic combo" (15.4%) based on urgency level would be reasonable changes.

An extra question specifically for the combo asked participants to customize a combination with available displays. 92.3% of them chose to have fewer displays in their ideal CWI. Participants’ favorite combination was two displays (56.4%), possibly so a backup would prevent missed alerts, with distraction still minimal. 23.1% chose three displays and 12.8% preferred a single-display interface. The most frequent 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, 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.

The results were broken down by motorcycle type. Cruiser and touring riders, who might use in-helmet headsets more often when riding, preferred it over others (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).

The majority of participants indicated that they did not notice mirror-mounted LED strips at all. Direct sunlight was the possible reason. Mirror LED strips would be good for left/right threats but not front threats, as 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

As mentioned in the Experimental Design section, measurement of rider response within these scenarios has limitations, but may 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. 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.

In addition to the aforementioned limitations, it should be noted that, in LCW, no response was necessary (i.e. the rider need only decide not to change lanes). As a result, most participants took their time to check the left mirror briefly or turn their heads. Also, in the FCW scenario, safety was retained in this experiment 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 (29). In addition, the trials were conducted at a low speeds, and while the confederate vehicle created a realistic scenario, the timing was presented without the extreme urgency of a real imminent crash situation. Overall, no evidence of distraction (glance of 2 seconds or longer at displays) was identified from the videos when alerts were presented.

DISCUSSION

Although general guidelines for CWIs exist in the automotive domain, due to the distinct characteristics of motorcycles, further exploration and evaluation was needed. 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. It should be noted that due to the novel nature of CWI on motorcycles and the associated safety concerns of a two-wheeled vehicle, all warnings were timed conservatively and the focus of the study remained on rider acceptance.
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 sport, cruisers, and touring motorcycles had overwhelmingly positive views of potential CVT based motorcycle CWS, through its prototype CWI and applications.

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

Auditory display presented through 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 found less favored than the auditory and haptic modes. Visor-mounted LED light strips were level with eyes on the visual scanning path which make them hard to be ignored. However, the test suggested that naïve users may look at them when triggered. Looking at something close to the face will cause the loss of tracking on everything further ahead on the road. 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 the color red is commonly used for warnings, having red visual alerts in traffic with numerous red taillights and stoplights could lead to confusion for certain scenarios.

The combo of all of the modalities was rated the most beneficial during road test. However, its rank lowered following the post-ride brainstorming 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 for being overwhelming and distracting. It 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. Double-stimulus is hard to miss but not too
overwhelming, and was the most frequent choice. 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, fewer active displays for
calculations 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, environment could influence the performance of warning interfaces, so it
would make sense to develop a smarter CWI by adjusting alerts based on environmental
measures. 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 emphasis on appearance and style of their bikes as well as riding gear. This
holds true for add-ons such as motorcycle CWSs, including their interface. Style and better
integration would help provide comfort and convenience to riders and thus improve their
acceptance. Rather than being separate equipment, it would be better to integrate CWIs into
motorcycles or common riding gear. 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 is rarely considered is the effect of
motorcycle type on system needs and acceptance. Variance in riding position, skill level, habits,
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
expected to 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 affect riders' acceptance and
preference of a CWI. Although we believed that most participants would be unfamiliar of 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.
CONCLUSIONS

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 show considerable promise for implementation. They were found here to be appealing to riders when presented with representative scenarios and working prototypes. Auditory, 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 this. After basic design of the haptic display, a somewhat bulky working prototype was also found to be attractive to riders. Migration of this into gloves or a jacket would be inconspicuous, but provide warning benefits and encourage the use of riding gear. The findings related to visual displays revealed both opportunities and challenges of visual displays in general for 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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REFERENCES


