Human Factors in Transportation, Vol. 95, 2023, 292–303
https://doi.org/10.54941/ahfe1003814

Human Factors Issues of Advanced Rider Assistance Systems (ARAS)

Chason J. Coelho[1], Stephen B. Garets[2], Jordan D. Bailey[1], Todd A. Frank[3], Iiona D. Scully[4], and David M. Cades[4]

[1]Exponent, Bellevue, WA 98007, USA
[2]Garets Consulting, Corvallis, OR 97339, USA
[3]Exponent, Austin, TX 78746, USA
[4]Exponent, Chicago, IL 60661, USA

ABSTRACT

Advanced driver assistance systems (ADAS), such as adaptive cruise control (ACC), forward collision warning (FCW), automatic emergency braking (AEB), and blind-spot monitoring (BSM) for passenger vehicles are becoming ubiquitous, with some features being standard on vehicles. The same is not true for motorcycles. However, limited analogous advanced rider assistance systems (ARAS) have been introduced, and the ARAS market is expected to grow significantly in the coming years. Some reasons for the development and implementation lags of ARAS include functional differences between passenger vehicles and motorcycles, such as lack of passenger restraints, more pronounced vehicle dynamics, greater operator physical involvement in achieving vehicle control, and more constrained means of presenting information for motorcycles. In turn, these differences highlight notable human factors issues, especially because ARAS may produce unique or unexpected riding situations that may impact the performance of the motorcycle operator. For example, abrupt, unexpected changes in the orientation and/or dynamics of the motorcycle, such as through application of AEB, could result in loss of control problems, operator or passenger separation from the motorcycle, or both, even while still mitigating collision involvement. In this paper, we review relevant scientific and technical literature and discuss how unique demands of ARAS applications can shape the ways research can be translated into practical innovation, development, and implementation of ARAS features. Relevant scientific topics include feedback modalities, perceptual-motor behavior and control, perception-reaction time, user acceptance and trust, learning, and attention, with a focus on safety-critical issues spanning multiple scientific topics. For example, operator visual behavior, and in particular, operator sight distance (i.e., how far the operator is looking down the road at a given time), have been identified as critical variables that can affect rider safety. An operator can be said to override the sight distance when they travel above a speed that would allow them to safely stop the motorcycle after detecting a hazard. In this situation, ARAS may be able to alert the operator via forward collision warnings and/or intervene more directly via AEB. Important questions exist about whether and how to present warning information through vision, audition, or touch modalities, and with what physical features (e.g., frequency, duration, and intensity). Regarding the latter possibility, using more direct ARAS intervention with assistive control inputs to the motorcycle raises safety-critical questions about the degrees to which the ARAS technology can predict and/or detect the state of the operator and the degrees to which the operator can predict and/or detect and respond to the assistive actions on the motorcycle. We discuss these topics in the context of relevant literature with the overarching goal of informing future research, development, and adoption of ARAS, in addition to the development of evaluative test criteria and standards.

Keywords: Aras, Motorcycle safety, Vehicle assistive technology

INTRODUCTION

Advanced rider assistance systems (ARAS)[1] are equipment that support and assist the motorcycle operator and may also reduce stress and strain; ARAS are intended as means of supporting accident mitigation and may help reduce harmful energy involved during pre-crash phases (Kuschefski et al., 2010). The main purpose of ARAS is to increase motorcyclist safety (Bekiaris et al., 2009). Indeed, ARAS are motivated, in part, by reports that motorcycle accidents and fatalities remain at elevated levels in the United States and abroad (NHTSA, 2022).

The physical characteristics and dynamics of motorcycles are sufficiently different from passenger vehicles to warrant focused study of ARAS issues independent of existing advanced driver assistance systems (ADAS) for passenger vehicles. However, ARAS and ADAS share some similarities, and ADAS-related literature can inform the study of ARAS. Initial ARAS research efforts have provided useful information, but there is a general consensus that a significant amount of research is still needed to inform and promote ARAS to increase safety, reliability, and acceptability for motorcycle operators. This paper reviews some of the unique issues presented by ARAS, and it discusses how applications of human factors principles to ARAS can shape the ways that research is translated into practical innovation, development, implementation, and ARAS adoption.

ADAS ACHIEVEMENT AND CURRENT STATE

Given similarities between ADAS and ARAS, the former is briefly reviewed here ahead of a deeper treatment of the latter. ADAS are not fully automated; instead, they are designed to assist the driver – they require driver supervision and responsibility (IIHS, 2022). SAE International (SAE) distinguishes levels of automation, stating that systems that require driver supervision, steering, and braking to maintain safety are "support" systems rather than "automated driving features" (NHTSA, n.d.; SAE, 2021).

ADAS features, such as forward collision warning (FCW) and automatic emergency braking (AEB) provide warnings and/or assistance to help the driver with driving tasks, especially with detecting and responding to in-path hazards (IIHS, 2022). Research suggests that ADAS have potential to reduce or mitigate the severities of some crashes (e.g., Grover et al., 2008; IIHS, 2022); estimates suggest that these technologies have the potential to reduce the severities of 1.2 to 3.6 million crashes per year (e.g., Jermakian, 2011; Wang, 2019). In addition to the potential safety impacts of these technologies, research has found that equipping vehicles with some ADAS features reduced the frequency of insurance claims related to property damage and collision liability (HLDI, 2018), further suggesting that this technology leads to reductions in collisions. These findings point to possible benefits of similar technologies for motorcycles via ARAS.

[1]The acronym "ARAS" includes the term "rider," but this paper uses the term "operator" to refer to an individual actively operating a motorcycle as opposed to riding as a passenger.

For ADAS warning stimuli, the perceptual modality (e.g., visual, auditory, haptic), number, presentation, latency, duration, magnitude, and periodicity have been evaluated in scientific and technical literature. Campbell et al. (2016) provides guidance for designing driver-vehicle interfaces based on such research. However, similar guidance does not yet exist for motorcycles or ARAS. Therefore, a review of some fundamental vehicle operator perceptual motor behavior principles and their potential interaction with existing and proposed ARAS features is helpful to promote the successful development, implementation, and adoption of ARAS.

HUMAN FACTORS AND ENGINEERING CHALLENGES FOR ARAS

Perceptual-motor behavior of motorcycle operators is likely to garner high interest from human factors scientists as ARAS features proliferate. There are interesting and impactful questions arising from substantial differences between physical dynamics and characteristics of motorcycles and passenger vehicles. These differences highlight needs to understand and apply behavioral principles in the specific context of motorcycling and to take care in generalizing findings from the ADAS literature to ARAS applications. ARAS developers and manufacturers must also contend with the fact that motorcycles offer fewer places where sensors and displays can be mounted (Biral et al., 2010b). Still, some research has been conducted that informs ARAS feature development.

Compared to ADAS, which operate on a passenger vehicle that maintains a generally consistent orientation within its environment, ARAS systems must operate with a constantly changing orientation. For instance, motorcycles achieve manuevering through a combination of leaning and countersteering. As a result, the motorcycle constantly navigates transient phases from an upright position until the motorcycle reaches the appropriate lean angle for the radius of curvature and speed of the vehicle. The motorcycle will then become upright as it exits the curve. Depending on the roadway, this can be a constantly changing lean angle. Even the path a motorcycle operator takes while negotiating a curve can change depending on if the operator wants to "apex" the curve, which effectively changes the radius of curvature of the roadway. Thus, motorcycles tend to have more pronounced movements of pitch (forward/backward), roll (lean left/right), and yaw (clockwise/counterclockwise) than passenger vehicles (SAE, 2020). The body of a motorcycle operator is also typically more involved in achieving these vehicle dynamics (SAE, 2021).

One of the most salient challenges with respect to ARAS is that motorcycles are intrinsically unstable because they have two wheels rather than four and are single-track vehicles (Biral et al., 2010b). Any assistive system that directly intervenes with assistive control inputs may result in an adverse event for the operator and/or passenger. Because the operator is an integral part of the motorcycle-operator system, successful motorcycle operation requires controlling throttle application, clutch usage, gear selection, and front and rear brake application, all while balancing, leaning, and steering (Frank et al., 2020; Garman et al., 2018). Consideration of both operator and passenger influence on the motorcycle should therefore be figured into ARAS systems. Operators must also manage a number of physical variables that passenger vehicle drivers do not, including, but not limited to, vibration from being near the motor, potential noise interference, exposure to the airstream and weather, potential field of vision limitations imposed by motorcycle helmets, and sensory limitations that may be associated with various other protective motorcycling gear (Kuschefski et al., 2010; Pieve et al., 2009). Moreover, these variables may compete or interfere with extrinsic stimuli that can inform an operator on how to behave in a given context.

Specific ARAS Features

A recent literature review identifies 15 specific ARAS features considered in scientific literature to date (Fowler et al., 2022). This list includes intelligent speed assist (ISA), anti-lock braking systems (ABS), combined braking system (CBS), motorcycle AEB (MAEB), adaptive cruise control (ACC), traction control, stability control, BSM, adaptive headlights, FCW, curve warning (CW), emergency notification, lane-keep assist (LKA), GPS navigation, and tire pressure monitoring (Fowler et al., 2022).

Here, we focus on the following: MAEB, ISA, FCW, CW, LDW, and LKA, because these systems may pose the strongest operator resistance to widespread adoption. Research suggests that motorcycle operator acceptability is highest for systems that (a) are primarily for emergency situations, (b) do not interfere with the operating tasks, and (c) are familiar to the operator (Beanland et al., 2013). For simplicity, we discuss these features by forming two groups: ARAS that only provide warning stimuli to motorcycle operators and ARAS that directly intervene with assistive motorcycle control.

Acceptability and Trust

In general, motorcycle operator acceptability can be defined as the actual use of a system, or, in the event that a system is under development, behavior that signals the degree to which a given user would use the system (Huth & Gelau, 2013). Acceptability is likely a moderating variable that impacts both whether and how ARAS are adopted.

Trust has not been readily defined in ARAS literature, however, in the ADAS literature, trust has been defined as operator attitude that an assistive system will help achieve goals in contexts with uncertainty about safety (Zahabi et al., 2021). Based on this definition, it is evident that acceptability and trust are related, and both may be impacted by whether and how the ARAS feature is effective.

Acceptability and Trust of ARAS Features That Warn the Operator

Warning presentation method has been identified as a significant predictor of operator acceptability (Huth & Gelau, 2013). Researchers can examine multiple issues, such as the perceptual modality (e.g., vision, auditory, haptic), number, latency, magnitude, and the periodicity of stimuli presented by the assistive system, just as has been done in the ADAS literature. There, latency has been identified as a variable that affects operator trust. For example, ADAS FCW that require lower deceleration forces (i.e., they provide warnings earlier) are correlated with greater levels of operator trust (Campbell et al., 2016). However, providing warnings too early can lead to a perception of the alerts as a nuisance (e.g., Fisher et al., 2020). The same relation could exist for motorcycling; however, the nature of the relation may be relatively exaggerated given the greater physical instability and slimmer margins of controllability for motorcycles.

Single stimulus ARAS warnings have been studied, but in a limited capacity. Two methods of haptic delivery have been tested as an example of a single-stimulus presentation method. For CW, research suggests that operators may prefer haptic warnings delivered with a glove as opposed to the throttle (Huth et al., 2012). The preference for the glove observed by Huth and colleagues (2012) may have been due to intrusiveness of haptic warnings delivered through the throttle because they directly increased the resistance of the throttle. The authors suggested that intrusiveness in this case was a helpful ergonomic quality of the warning, also noting that operators reported needing to increase levels of attention when receiving warnings through the throttle. However, it seems likely that overall acceptability of the throttle-based warning was low due to the aversive and persistent nature of such resistance. Note that the haptic stimulation from the glove-based warning did not influence the vehicle controls and did not vary with speed (Huth et al., 2012).

Although effectiveness and safety of multimodal warnings has received significant attention, motorcycle operator preference for different warning modalities has not. Savino and colleagues (2020) reported that multimodal warnings have the highest acceptance, but they did not measure acceptance – only effectiveness. Valtolina and colleagues (2011) showed greater effectiveness of multimodal warnings compared to single and dual stimulus, and while effectiveness and acceptability are likely correlated, a high degree of effectiveness does not necessarily translate to a high degree of acceptability. More research is needed to clarify these links.

In general, discrimination history is one variable that may cause humans to prefer certain stimuli to others. Humans learn to form concepts as relations between the environment and their behavior through the process of stimulus discrimination (Donahoe & Palmer, 2004). For example, in providing ARAS FCW, operators may prefer an icon that shows a motorcycle in close proximity to another vehicle with a star shape to depict collision energy transfer. Humans constantly make discriminations, and new environment-behavior relations form as a result of experience. For these reasons, ARAS warnings that do not accurately and/or clearly map onto the sensation and perception of operators may come with low levels of acceptability. An example is over-warning, where a high number of false alarms (e.g., a FCW is provided, but nothing is in front of the operator) may be annoying to drivers and may lead to low acceptability and non-use of the assistive system (Campbell et al. 2016).

That operators may prefer multimodal warnings raises interesting possibilities. One hypothesis is that there is some basic intrinsic preference for richer stimuli. The more interesting hypothesis is that this preference is related to perceived and/or actual performance facilitation. Support for the latter hypothesis comes from literature on stimulus control, which suggests that the influence of stimuli on behavior is not limited to single stimulus-response relations. In fact, multiple stimuli in close temporal proximity often occasion or guide a single response (Donahoe & Palmer, 2004). When multiple stimuli acquire influence over a response, the response strength (i.e., performance) may be greater than it would be with just one of the stimuli (Palmer, 2009). Future research can address these issues specifically for motorcycling, which may be especially useful because this environment may require unique methods of ARAS warnings presentation.

Acceptability and Trust of Assistive ARAS Motorcycle Control

Given the greater physical instability and slimmer margins of controllability for motorcycles, it is reasonable to predict generally low operator acceptability, at least initially, of ARAS features that directly intervene on the motorcycle. Indeed, methods of increasing acceptability for ARAS that provide assistive control are important to consider because these types of ARAS have indeed generally been shown to have low levels of acceptability. For example, ISA systems that directly intervene by counteracting operator throttle responses have been shown to have relatively low levels of acceptability (Beanland et al., 2013). However, research has indicated that acceptability of ARAS elements that provide assistive control inputs to the motorcycle can increase when those inputs are preceded by warning stimuli. Interestingly, anti-lock braking provides assistive control inputs, but this ARAS feature received the second highest acceptability rating in one study (Beanland et al., 2013). One explanation for this finding is that the operators canvassed were already familiar with anti-lock braking. If correct, one might predict that as ARAS become more common, they may become more acceptable to operators due to mere exposure (Bornstein & D'Agostino, 1992) and/or to other factors, such as increase in trust due to positive experiences with the feature (Campbell et al., 2016).

Research indicates that there is a positive correlation between human preferences and information that is useful for human performance; in particular, evidence suggests that information containing predictive value is perceived as intrinsically valuable (see Trapp et al., 2015 for review). This body of research informs the issue of acceptability of ARAS features that provide assistive control inputs because acceptability can be expected to increase when operators believe that the assistance predicts positive outcomes on the road. But this type of prediction is not the only one at play for ARAS. Indeed, there is substantial evidence that the central nervous system uses prediction to help interpret sensory input (e.g., Trapp et al., 2015). In turn, this observation highlights a fundamental open human factors question about ARAS – the degree to which the operator can predict and/or detect and respond to assistive control inputs. It is possible that issues of prediction are at the base of the above-mentioned finding that operators find more familiar ARAS features more acceptable. As a result, future research should not focus on acceptability alone, but instead should investigate the link between acceptability of directly intervening ARAS features and the performance of operators interacting with them. This suggestion connects to issues of safety and effectiveness of ARAS features that provide assistive inputs. Strong preferences and high acceptability do not necessarily translate to better performance, and high acceptability of an ARAS feature is meaningless if that feature fails to increase safety or worse, impairs it.

Safety and Effectiveness

This section addresses safety and effectiveness with a focus on how ARAS features interact with the operator to potentially produce safer outcomes. Indeed, a general premise of ARAS is they may reduce accidents or fatalities.

Safety and Effectiveness of ARAS That Only Warn the Operator

Effectiveness of ARAS that only provide warning stimuli to the operator may be constrained for motorcycles due to the exposure of the operator to the environment, limited space to present stimuli, and noise and vibration. However, systems that provide multimodal stimuli may be more effective than systems that deliver stimulation within a single perceptual channel, or no system. Multimodal warnings may be more effective because they are more detectable and offer an alternative means of providing stimuli if attention drifts, or if a given perceptual modality is blocked (e.g., Campbell et al., 2016). Valtolina et al. (2011) found that operator reaction times were shortest when three stimuli were used compared to two or one.

Research suggests that when using haptic stimuli, perceptibility may be greatest with pressure rather than vibration (Baldanzini et al., 2011). It may make sense to deliver pressure rather than vibration given the competing vibration from the environment. Auditory stimuli may be best delivered through a single earphone so as to not interfere with critical information coming from the external environment, and visual stimulation may be effectively provided through a helmet-integrated HUD (Baldanzini et al., 2011).

Another relevant factor is the ratio of sight distance (i.e., how far away the operator is looking along the path of travel) to stopping distance (i.e., operator perception-reaction time plus braking distance). This ratio has been identified as a critical variable for motorcycle operator safety because operators can override their sight distance, especially when attention drifts (Smith et al., 2013). When attention drifts, for example, operators may not attend to upcoming curves or hazards in front of them. ARAS such as CW systems may help bring attention back to the task, and CW systems have been shown to help some operators adapt to curves earlier than other riders (Huth et al., 2012). In general, ARAS holds promise for not only alerting operators to such overriding in the moment but also for helping them better understand and predict the limitations of their vehicles and of themselves.

Although the specific application of multimodal presentation may be different for ARAS than ADAS, providing multimodal stimuli is an approach that could remain effective. This idea comports with human performance literature on attention and multiple control. Regarding attention, there are at least four reasons a behavior may not occur despite motivation to engage in it: (1) failure to sense a stimulus; (2) lack of discrimination history with the stimulus/stimuli presented; (3) stimulus/stimuli presentation in an unfamiliar context; and (4) concurrent stimulus competition (Donahoe & Palmer, 2004). Research focused on the last two reasons may be especially useful for ARAS. Operators in an unfamiliar context may sense a unimodal warning but fail to respond because the response is not at sufficient strength due to the relatively novel context. In this case, providing multimodal stimuli may result in greater response likelihood. Discriminative stimuli can also compete with one another, for example, when observing a road hazard in temporal proximity to an unrelated warning may cause the operator to engage in a response to the warning, response to the road hazard, successive responses to both, or an otherwise incompatible combination thereof.

Safety and Effectiveness of Systems That Directly Intervene

MAEB has been identified as an ARAS feature that could prevent rear-end crashes (Savino et al., 2013). One concern related to MAEB is operator expectations and preparedness for braking performed by the ARAS feature rather than by the operator (Merkel & Winner, 2020). When braking occurs, operators must assume a position that allows them to support their upper body and maintain control over the motorcycle (Merkel et al., 2019). In an unexpected braking event, a stimulus-response relation exists whereby the operator senses inertial forces and prepares their body to respond. Researchers have found that with unexpected automatic braking on motorcycles, operators engage in a relatively homogenous pattern of behavior in which their upper body pitches forward – at least when braking in a straight line – and the operator counteracts the movement, typically within 0.5 s at 70 km/h (Merkel et al., 2019). For unexpected braking events, decelerations up to 5 m/s^2 (0.5 g) allow the operator to maintain control over their motorcycle (Cassesse et al., 2022; Merkel & Winner, 2020). MAEB studies that explore the limits of operator preparation during unexpected braking have not investigated a range of vehicle types, initial velocities of travel, and effects of braking while cornering, so much research remains (Merkel et al., 2019).

Other ARAS have received less focus. ADAS LKA is common, but a recent ARAS review found no studies on safety and efficacy of LKA (Fowler et al., 2022). Although LKA for ADAS may include assistive control, two reviews discussed ARAS LKA as a warning (Beanland et al., 2013; Fowler et al., 2022). ISA systems that counteract operator throttle responses may not be as safe as desired due to lack of rider control over their speed in certain situations (Beanland, et al., 2013).

Perception reaction time (PRT) describes the interval between when it becomes possible for a driver or operator to perceive/detect a stimulus (e.g., a hazard) and when the operator initiates a response (e.g., braking or swerving; Krauss, 2015). Although this issue has not been investigated thoroughly with respect to ARAS, initial findings suggest that motorcycle operators may have shorter PRTs on average than passenger vehicle drivers (Wong & Wong, 2022). Given the greater acceptability of MAEB systems that provide warnings to the operator before initiating braking, and the potentially shorter PRT of motorcycle operators, it will be important for researchers to further characterize these initial findings and for manufacturers to design systems that consider that research.

CONCLUSION

This paper has reviewed scientific and technical literature bearing on ARAS, and it has identified some ways that unique demands of ARAS applications can shape how basic research can be translated into practical innovation, development, and implementation of ARAS features. The topics addressed here are certainly in need of further scientific inquiry, and full reviews of each remain beyond the scope of this paper. However, this paper provides a synthesis that should be valuable for future empirical studies aimed at fostering the development, implementation, and adoption of ARAS in addition to the enhancement of safe motorcycling.

Of all the issues addressed, one stands out as a promising area for ARAS-related research: hazard detection. The potential for ARAS to assist the operator in on-road hazard detection and reduction of instances of sight-distance overriding is an exciting advance in assistive motorcycle technologies. A likely path for this benefit, at least initially, is through effective multimodal ARAS warnings.

In conjunction with empirical research, it should also be a goal to develop evaluative test criteria and standards for ARAS. SAE J3016 presents and explains six levels of driver assistance and automation for ADAS; however, the standard does not consider ARAS (Fowler et al., 2022). As noted above, ARAS may be sufficiently different from ADAS that a distinct classification system and standard set may be necessary, or at least some additional clarification or classification for motorcycles. The current state of ARAS research may not yet permit such a classification system, because such investigation is relatively underdeveloped. However, it should be possible to translate research of the kind discussed here to assist in the innovation, development, and implementation of ARAS.

REFERENCES

Baldanzini, N., Bencini, G., & Pierini, M., 2011. Design and preliminary testing of an haptic handle for powered two wheelers. *European Transport Research Review*, *3*(1), 1–9. https://doi.org/10.1007/s12544-010-0044-z

Beanland, V., Lenné, M. G., Fuessl, E., Oberlader, M., Joshi, S., Bellet, T., Banet, A., Rößger, L., Leden, L., Spyropoulou, I., Yannis, G., Roebroeck, H., Carvalhais, J., & Underwood, G., 2013. Acceptability of rider assistive systems for powered two-wheelers. *Transportation Research Part F: Traffic Psychology and Behaviour*, *19*, 63–76.

Bekiaris, E. D., Spadoni, A., & Nikolaou, S. I., 2009. SAFERIDER Project: new safety and comfort in Powered Two Wheelers. In *2009 2nd Conference on Human System Interactions* (pp.600–602). IEEE.

Biral, F., Lot, R., Sartori, R., Borin, A., & Roessler, B. (2010, October). An intelligent frontal collision warning system for motorcycles. In *Proceedings of the bicycle and motorcycle dynamics 2010 symposium. Delft*. https://www.bicycle.tudelft.nl/ProceedingsBMD2010/papers/biral2010intelligent.pdf

Biral, F., Da Lio, M., Lot, R., & Sartori, R., 2010. An intelligent curve warning system for powered two wheel vehicles. *European transport research review*, *2*(3), 147–156. https://doi.org/10.1007/s12544-010-0033-2

Bornstein, R. F., & D'agostino, P. R., 1992. Stimulus recognition and the mere exposure effect. Journal of personality and social psychology, 63(4), 545.

Campbell, J. L., Brown. J. L., Graving, J. S., Richard, C. M., Lichty, M. G., Sanquist, T., … & Morgan, J. L., 2016. *Human factors design guidance for driver-vehicle interfaces* (Report No. DOT HS 812 360). Washington, DC: National Highway Traffic Safety Administration.

Cassese, G., Lucci, C., Savino, G. and Baldanzini, N., 2022. Analysis of the rider's body movement during the intervention of the Autonomous Emergency Braking system for Motorcycles (MAEB). In *IOP Conference Series: Materials Science and Engineering* (Vol. 1214, No. 1, p. 012047). IOP Publishing.

Donahoe, J. W., & Palmer, D. C., 2004. *Learning and complex behavior*. Ledgetop Pub.

Fisher, D. L., Horrey, W. J., Lee, J. D., & Regan, M. A. (Eds.)., 2020. *Handbook of Human Factors for Automated, Connected, and Intelligent Vehicles* (1st ed.). CRC Press.

Fowler, M., Geiselbrecht, T., Brydia, R., Geary, M., & Manser, M., 2022. *Addressing the Motorcyclist Advisory Council Recommendations: Synthesis on Intelligent Transportation System Applications and Automated Technologies for Motorcyclists* (No. FHWA-SA-22-033). United States. Federal Highway Administration. Office of Safety.

Frank T. A., Fowler G. F., Garman C. M. R., Sharpe S. S, 2020. Motorcycle Rider Inputs During Typical Maneuvers. SAE Technical Paper.

Garman C. M. R., Sharpe S. S., Frank T. A., Fowler G. F., 2018. Motorcycle Rider Kinematics during Low and High Speed Turning Maneuvers. SAE Technical Paper.

Grover, C., Knight, I., Okoro, F., Simmons, I., Couper, G., Massie, P., & Smith. B., 2008. *Automated emergency brake systems: Technical requirements costs and benefits* (PPR 227). TRL Limited.

Highway Loss Data Institute., HLDI; 2018. Compendium of HLDI collision avoidance research. *HLDI Bulletin, 35* (34). Arlington, VA.

Huth, V., Biral, F., Martín, Ó., & Lot, R., 2012. Comparison of two warning concepts of an intelligent Curve Warning system for motorcyclists in a simulator study. *Accident Analysis & Prevention*, *44*(1), 118–125. https://doi.org/10.1016/j.aap.2011.04.023

Huth, V., & Gelau, C., 2013. Predicting the acceptance of Advanced Rider Assistance Systems. *Accident Analysis & Prevention*, *50*, 51–58. https://doi.org/10.1016/j.aap.2012.03.010

Insurance Institute for Highway Safety., IIHS; 2022. Advanced Driver Assistance. Retrieved from: https://www.iihs.org/topics/advanced-driver-assistance.

Insurance Institute for Highway Safety., IIHS; 2016. U. S. DOT and IIHS announce historic commitment of 20 automakers to make automatic emergency braking standard on new vehicles. Retrieved from: U. S. DOT and IIHS announce historic commitment of 20 automakers to make automatic emergency braking standard on new vehicles.

Jermakian, J. S., 2011. Crash avoidance potential of four passenger vehicle technologies. *Accident Analysis & Prevention*, *43*(3), 732–740.
Krauss, D. A. (2015). *Forensic aspects of driver perception and response*. Lawyers & Judges Publishing Company.
Kuschefski, A., Haasper, M., & Vallese, A., 2009. Advanced rider assistance systems for powered two-wheelers (ARAS-PTW). https://www-esv.nhtsa.dot.gov/Proceedings/22/files/22ESV-000123.pdf
Merkel, N. L., Pleß, R., Winner, H., Hammer, T., Schneider, N., & Will, S., 2019, June. Tolerability of Unexpected Autonomous Emergency Braking Maneuvers on Motorcycles-a Methodology for Experimental Investigation. In *National Highway Traffic Safety Administration (Ed.), The 26th ESV Conference Proceedings. International Technical Conference on the Enhanced Safety of Vehicles (ESV), Eindhoven, The Netherlands*.
Merkel, N. L., & Winner, H., 2020, May. Measures for the Evaluation of Riders' Adaption to the Changing Vehicle State during Autonomous Emergency Braking Maneuvers on Motorcycles. Symposium on the Dynamics and Control of Single Track Vehicles.
National Highway Traffic Safety Administration, NHTSA; n.d. Automated Vehicles for Safety. https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety
NHTSA, 2022. Traffic Safety Facts. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813306
Palmer, D. C. (2009). Response strength and the concept of the repertoire. *European Journal of Behavior Analysis*, *10*(1), 49–60. https://doi.org/10.1080/15021149.2009.11434308
Pieve, M., Tesauri, F., & Spadoni, A., 2009. Mitigation accident risk in powered two wheelers domain: Improving effectiveness of human machine interface collision avoidance system in two wheelers. In *2009 2nd Conference on Human System Interactions* (pp.603–607). IEEE.
Savino, G., Giovannini, F., Baldanzini, N., Pierini, M., & Rizzi, M., 2013. Assessing the potential benefits of the motorcycle autonomous emergency braking using detailed crash reconstructions. *Traffic injury prevention*, *14*(sup1), S40-S49. https://doi.org/10.1080/15389588.2013.803280
Savino, Lot, R., Massaro, M., Rizzi, M., Symeonidis, I., Will, S., & Brown, J., 2020. Active safety systems for powered two-wheelers: A systematic review. Traffic Injury Prevention, 21(1), 78–86. https://doi.org/10.1080/15389588.2019.1700408
Smith, T., Garets, S., & Cicchino, J., 2013. The effect of sight distance training on the visual scanning of motorcycle riders: A preliminary look. (Report No. DOT HS 811 689). Washington, DC: National Highway Traffic Safety Administration.
Society of Automotive Engineers. (2021). *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles*. (SAE J3016-2021). SAE. https://www.sae.org/standards/content/j3016_202104/
Trapp, S., Shenhav, A., Bitzer, S. and Bar, M., 2015. Human preferences are biased towards associative information. *Cognition and Emotion*, *29*(6), pp. 1054–1068.
Valtolina, S., Vanzi, S., Montanari, R., Minin, L., & Marzani, S., 2011. Design of warning delivery strategies in advanced rider assistance systems. In *World Conference on Innovative Virtual Reality* (Vol. 44328, pp. 41–50).
Wang, J. S., 2019. *Target Crash Population For Crash Avoidance Technologies in Passenger Vehicles* (No. DOT HS 812 653).

Wong, G., & Wong, Y. D., 2022. Young male motorcycle rider perception response times to abrupt- and gradual-onset hazards. *Accident Analysis & Prevention*, *165*, 106519. https://doi.org/10.1016/j.aap.2021.106519

Zahabi, M., Razak, A. M., Mehta, R. K., & Manser, M., 2021. Effect of advanced driver-assistance system trainings on driver workload, knowledge, and Trust. *Transportation Research Part F: Traffic Psychology and Behaviour*, *76*, 309–320. https://doi.org/10.1016/j.trf.2020.12.003