Novel Highway Signs Study to Support Infrastructure-Based Motorcycle Crash Countermeasures—Phase II

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FOREWORD

Motorcycle crashes make up a disproportionately high number of crashes on the Nation's roadways. Highway signs designed for motorcyclists have the potential to reduce motorcycle crashes by drawing the attention of road users to situations that may be particularly hazardous for motorcyclists. This study examined the potential for novel signs to be used as motorcycle-crash countermeasures. Based on research conducted as part of an earlier project entitled New/Novel Highway Signs to Support Infrastructure-Based Motorcycle-Crash Countermeasures: Phase I Project and a review of the relevant literature, the research team selected signs within four categories to study: motorcycle awareness, advance curve warning, pavement change, and limited sight distance.(1)

The research team generated a preliminary set of novel signs designed specifically to target the needs of motorcyclists. Feedback on this preliminary sign set was solicited from motorcyclists via an online questionnaire. Results from the questionnaire were used to narrow and refine the stimulus set. Finally, a human factor–based experimental assessment of novel sign comprehension and legibility was conducted using both motorcyclists and nonmotorcyclists. The result is a prioritized list of five novel signs that may serve as effective motorcycle-crash countermeasures. This report may be of interest to engineers, academics, researchers, industry partners, and motorcycle riders involved in the design, construction, installation, and testing of infrastructure-based countermeasures to address motorcycle crashes.

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Director, Office of Safety and Operations
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Motorcycle crashes make up a disproportionately high number of crashes on the Nation's roadways. Warning signs have the potential to reduce motorcycle crashes by drawing the attention of road users to situations that may be particularly hazardous for motorcyclists. The current study examined the potential for novel signs to be used as motorcycle-crash countermeasures. Based on research conducted as part of an initial project entitled New/Novel Highway Signs to Support Infrastructure-Based Motorcycle-Crash Countermeasures: Phase I Project and a review of the relevant literature, four categories of potential signs were selected: motorcycle awareness, advance curve warning, pavement condition, and limited sight distance signs.[(1)] Next, the research team generated a preliminary set of novel signs designed specifically to target the needs of motorcyclists. Feedback on this preliminarily sign set was solicited from motorcyclists via an online questionnaire. The research team used results from the questionnaire to narrow and refine the stimulus set. Finally, an experimental assessment of sign comprehension and legibility of the novel signs was conducted using both motorcyclists and nonmotorcyclists. The result is a prioritized list of five novel signs that may serve as effective motorcycle-crash countermeasures.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS

DOT	department of transportation
FHWA	Federal Highway Administration
FDOT	Florida Department of Transportation
MnDOT	Minnesota Department of Transportation
MUTCD	*Manual on Uniform Traffic Control Devices for Streets and Highways*
VDOT	Virginia Department of Transportation
V2V	vehicle-to-vehicle

CHAPTER 1. INTRODUCTION

After reaching a modern-day low in the 1990s, motorcyclist fatalities have increased both in their overall number and with respect to their proportion of all crash fatalities in the United States. Since 1994, the number of motorcycle-related crash fatalities has more than doubled, rising from 2,320 to 5,286 in 2016, an increase of 127 percent.[(2)] This increase has occurred concurrently with a generally consistent decline in fatalities among other (i.e., nonmotorcycle) crashes over this same period. Motorcycle crashes account for more than 14 percent of all traffic fatalities in the United States while only representing 0.6 percent of vehicle miles traveled nationally. There is a clear need to develop effective countermeasures, policies, and programs to address the increase in motorcycle-related crash fatalities.

Warning signs have the potential to reduce motorcycle crashes by drawing riders' attention to specific areas of the roadway, such as irregular surfaces that may reduce traction or horizontal curves with high degrees of curvature. Signing is also a potential crash countermeasure for all road users at locations with limited sight distance or intersections experiencing higher-than-expected crash frequencies where vehicular movements may need to be prohibited, both of which are concerns for motorcyclists. However, warning signs will only be effective crash countermeasures if motorcyclists and other road users can see, understand, and respond to them appropriately. Research conducted as part of a project entitled New/Novel Highway Signs to Support Infrastructure-Based Motorcycle-Crash Countermeasures: Phase I Project identified four types of signs with the potential to serve as effective motorcycle-crash countermeasures: movement prohibition, advance curve warning, pavement condition, and limited sight distance.[(1)]

The *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) is the national standard for all traffic control devices installed on any street, highway, bikeway, or private road open to public travel.[(3)] To become part of this national standard, new signs (with the exception of signs with word-only messages not otherwise provided for in the manual) must undergo experimentation in accordance with the provisions of the manual and must be approved by the Federal Highway Administration (FHWA). This rigorous process promotes roadway safety by helping to ensure that road users are able to understand signs on U.S. roadways correctly and signs are both legible from an appropriate distance and standardized across the country.

Movement-prohibition, pavement-surface-warning, advance curve-warning, and limited-sight-distance signs already exist in the MUTCD. Design of these signs has typically been motivated by their potential value to drivers of passenger vehicles and trucks. Do these same signs serve as adequate warnings for motorcyclists, or would this population be better served by novel sign designs, including signs that specifically target motorcycle operators? The current study sought to address this important research question by determining and developing various novel highway sign alternatives, conducting comprehension and legibility testing of these highway signs, and developing a prioritized list of highway sign alternatives that may serve as effective motorcycle-crash countermeasures. Prior to novel-sign development, the research team conducted a review of the literature on the value of signs as motorcycle-crash countermeasures. The literature review identified potential gaps that novel motorcycle signs could help fill.

LITERATURE REVIEW

Motorcycle safety literature has identified a broad list of risk factors that are associated with motorcycle-crash occurrence and crash severity.(4–7) Research has shown that crash risks vary significantly across motorcyclists. Crash risk is influenced by age, marital status, riding experience, history of motorcycle training, and proclivity for helmet use and alcohol consumption.(8) Crash risk among motorcyclists is also related to the individual rider's amount of riding exposure (i.e., ride frequency) and whether the rider is appropriately licensed.(9–12) Crash risks tend to be exacerbated among a subset of higher-risk riders; research has shown that unlicensed riders are both less likely to report using daytime headlights or wearing body protection and more likely to report driving after consuming alcohol.(13,14)

In addition to factors related to individual motorcyclists, crash risk is influenced by the characteristics of the roadway or infrastructure.(15–17) In an analysis of the causes of the crashes documented in the *Motorcycle Crash Causation Study*, Bents et al. reported that infrastructure countermeasures had the potential to prevent up to 66 percent of reported crashes.(17) Among the suggested infrastructure countermeasures were four types of warning signs: movement-prohibition, advance curve-warning, pavement-condition, and limited-sight-distance signs. The sections that follow provide a summary of research on each of these four types of warning signs as they relate to motorcycle safety.(1)

Movement-Prohibition Signs

A longstanding safety concern is the overrepresentation of motorcycle crashes involving moving violations by drivers of other vehicles. Hurt et al. found that the primary cause of motorcycle crashes was other vehicles, such as collisions into motorcycles due to right-of-way violations at intersections.(11) Subsequent research in Australia, Europe, and the United States confirm the ongoing and wide-reaching nature of these types of crashes.(8,18)

Multiple factors influence the occurrence of motorcycle crashes involving other vehicles. de Craen et al. sought to determine whether the failure of cars to yield to motorcycles is simply a product of the number of cars on the roadway.(18) The authors used police reports to gather data on serious crashes involving two vehicles over a 9-yr period in the Netherlands. They found that the most common cause of crashes was cars failing to give priority or a crash that occurs because a car fails to yield to a vehicle traveling on an intersecting road. When the total number of crashes was accounted for, the proportion of crashes in which a car failed to give priority to a motorcycle (56 percent) was no greater than the proportion of crashes in which a car failed to give priority to another car (56 percent), indicating that failing to give priority is not a motorcycle-specific problem. In contrast, motorcyclists were found to be at greater risk for the second most common crash type, failing to give way, or a crash that occurs because a car attempting to make a left turn (or U-turn) fails to yield to a vehicle traveling toward them on the same roadway. The proportion of crashes in which a vehicle failed to give way to a motorcycle (32 percent) was over twice as high as the proportion of crashes in which a car failed to give way to another car (13 percent). The results suggest that motorcyclists are at particular risk from drivers who are attempting to make left turns and U-turns.

In many instances, when a vehicle collides with a motorcycle, the driver of the vehicle reports failing to see the motorcycle despite looking in the motorcycle's direction prior to the crash. This phenomenon is known as the looked-but-failed-to-see error.[15,16] One potential source of this error is the low conspicuity of motorcycles relative to other types of vehicles. Motorcycles are smaller than passenger vehicles, and the front of a motorcycle is particularly small, frequently with a visual footprint less than half the size of the front of a passenger vehicle. The small physical size of the front of a motorcycle could explain why the looked-but-failed-to-see error is more likely to occur for motorcycles headed directly toward a vehicle than for those traveling perpendicular to the vehicle.[18] Research on motorcycle conspicuity has found that helmet color, reflective or fluorescent clothing, and daytime headlights can all significantly reduce motorcycle crash risk.[19]

In addition to the physical size of the motorcycle itself, the looked-but-failed-to-see error is likely to be affected by drivers' mental models, or their mental representation of traffic. For any given roadway, the number of vehicles with four wheels will greatly outnumber those with two. As a result, drivers scanning the roadway for other vehicles are more likely to look for nonmotorcycle vehicles than to look specifically for motorcycles. A wealth of research indicates that expectations and mental models have a significant influence on perception.[20–23] People are more likely to perceive and are able to respond more quickly to stimuli that they are expecting to see, which explains why drivers who hold motorcycle licenses and drivers who regularly interact with motorcyclists are less likely to commit looked-but-failed-to-see errors.[24,25] Drivers who expect motorcyclists are more likely to see them, whereas those who do not have that expectation are less likely to notice motorcycles on the roadway.

As research suggests that motorcycles are at particular risk from vehicles attempting to make left turns and U-turns, one way to reduce this risk is to prohibit vehicles from making left turns and U-turns on roadways where collisions with motorcycles occur. Eliminating these types of turns can be accomplished by installing movement-prohibition signs (i.e., No Left Turn (R3-4) or No U-Turn (R3-18)).[17] Movement-prohibition signs tend to be effective in reducing left-turn crashes.[26] The signs are quickly comprehended and driver compliance is high. However, movement-prohibition signs are not viable options for most intersections. Brich et al. note that No Left Turn signs should not be installed unless an alternate solution for drivers who wish to turn left is available (i.e., a jug-handle turn or a left turn within one block of the sign).[26] Otherwise navigational ability and roadway efficiency can be compromised. There is also a risk that a No Left Turn sign at one intersection will simply move the problem downstream to the next intersection. Additionally, excessive numbers of No Left Turn or No U-Turn signs result in reduced sign compliance. A survey of transportation agencies in Virginia found that No Left Turn signs are typically only installed at an intersection if an excessive number of crashes have occurred at that intersection (three to five per year depending on the agency) or if the intersection has high levels of traffic and there is no option for installing a left-turn lane on the roadway.[26] No U-Turn signs tend to be installed based on roadway geometry. In both cases, the decision about whether a movement-prohibition sign should be installed at a particular intersection is typically determined on a case-by-case basis, and motorcycle safety is only one of many factors that would contribute to the decision.

When movement-prohibition signs are not a viable option, another potential way of reducing motorcycle crashes at intersections is to try to update drivers' mental models of traffic to include motorcycles. Crundall found that simply having participants interact with images of motorcycles increased their ability to detect motorcycles at T-junctions.(27) The finding suggests that drivers' expectations about motorcycles are malleable. Some agencies have attempted to capitalize on this malleability by installing signs that remind drivers to look for motorcycles near potentially dangerous intersections. For example, the sign shown in figure 1 has been installed in Australia to increase motorcycle awareness.(15,29) In the United Sates, a warning sign with the phrase Watch for Motorcycles has been installed near select intersections determined to be at high risk for motorcycle crashes.(28)

Figure 1. Illustration. Sign designed to increase drivers' awareness of motorcycles.(29)

Advance Curve-Warning Signs

Motorcyclists are also more susceptible to crashes when riding on horizontal curves. Due to reduced points of contact with the road surface resulting from having only two tires, motorcyclists tend to lean and counter-steer when turning. Research indicates that this makes motorcyclists particularly susceptible to two general types of crashes when navigating curves: head-on and run-off-road collisions.(15) When leaning into a turn, the head and upper torso of a motorcyclist may cross into an adjacent lane, putting the rider at risk of a head-on collision. The reduced friction and increased skill required to navigate curves when operating a motorcycle, compared to that required when operating a passenger vehicle, also put motorcyclists at increased risk of run-off-road crashes.(15) Suitable advance curve-warning signs that alert motorcyclists to the presence and type of a curve can allow them to take appropriate action prior to entering a curve, thereby reducing crash risk.

Multiple studies have linked curves—in particular those having small curve radii, or sharp curves—to motorcycle crashes.(30,31,15) Motorcyclists are more likely to commit riding errors when riding on curves that have a radius less than 296 ft. Higher approach speeds add to the risk of run-off-road crashes.(15) When there is a series of curves with smaller radii, narrower lane widths, or limited sight distance, this increases the risk of motorcycle crashes even further. It is at these types of curves or curve combinations that advance curve-warning signs have the greatest probability of increasing motorcyclists' safety.

Advance curve-warning signs can help motorcyclists identify upcoming curves in a timely manner and inform them of the speed at which it is safe to navigate the curve. The MUTCD contains provisions for horizontal-curve-warning signs (W1-1 through W1-5, W1-11, W1-15) that are based on the speed limit approaching the curve in combination with the sharpness of the curve.[3] Although these signs are intended for all road users, they are of value to motorcyclists because they provide information about curve type. Figure 2 shows horizontal-alignment-warning signs from the MUTCD, including warning signs for Curve (W1-2), Combined Curve and Advisory Speed (W1-2a), Reverse Turn (W1-3), Hairpin Curve (W1-11), 270-Degree Curve (W1-15), and Winding Road (W1-5).[3] Except for the Winding Road sign, these signs reflect the intended direction of the curve. The Winding Road sign is intended to indicate that multiple curves will occur in the road ahead without indicating the specific direction of those curves. When there is sufficient difference between the speed limit and the advisory speed, chevron signs can be used to provide additional emphasis and guidance for a change in horizontal alignment. In addition to static signing, dynamic curve-warning signs or dynamic speed displays can be installed. Dynamic speed display signs have proven more effective at reducing crashes than static signs in areas such as school zones, presumably because they are better at catching road users' attention.[32] However, due to the cost of such systems, they are typically only installed at locations where static signs have not proven sufficiently effective at reducing crashes.

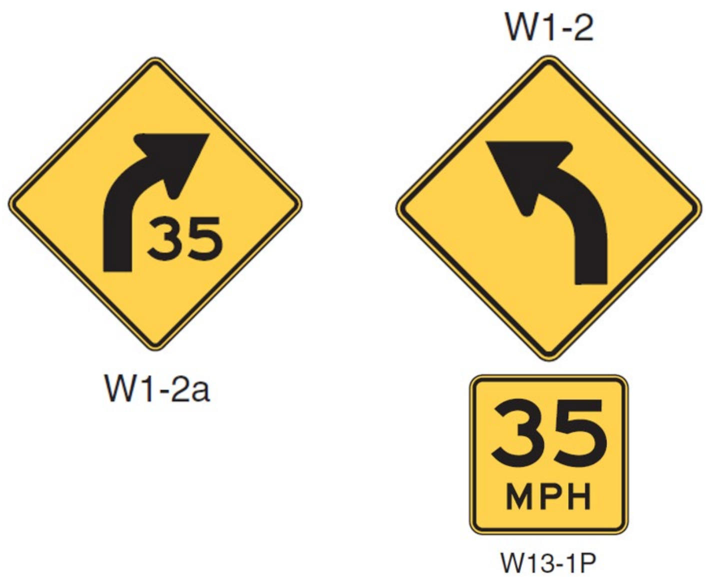
Source: FHWA; modified from the MUTCD.

Figure 2. Illustration. Horizontal alignment signs.[3]

It is important that curve-warning signs be easily comprehensible and clearly visible so that motorcyclists have time to react appropriately. Curve-warning signs should provide sufficient information about a curve's presence, radius, and direction so that motorcyclists can adjust their approach speed and select an appropriate riding path.[15] Considering these factors, the Australian road transport and traffic agency, Austroads, published guidelines for the installation of curve-warning signs designed specifically for motorcyclists. According to those guidelines, signs should be as follows (p. 93):[15]

- Conspicuous and clearly visible at a distance. A larger sign size or special curve-warning sign may be advantageous in some situations.
- Placed far enough in advance of the curve for a motorcyclist to have adequate time to react (consideration should be given to the effects of a combination of the current or likely surface conditions after wear and tear and motorcycle braking on the coefficient of deceleration).
- Accurate (i.e., reflect the curve type and radius).
- Installed clear of vegetation that is likely to grow over the sign face.

The Minnesota Department of Transportation (MnDOT) published a report to determine the feasibility of in-vehicle dynamic curve-speed warnings as deployed on a smartphone application.[32] To gauge sign comprehension, participants were shown the MUTCD-recommended curve-warning signs and asked to interpret their meaning. MnDOT found that, although participants could interpret the Combined Curve and Advisory Speed sign (W1-2a in figure 3) properly, they reported that it seemed too cluttered. Separate signs for speed (w13-1p) and curve (w1-2), as shown in figure 3, were more understandable and more authoritative.



Source: FHWA; modified from the MUTCD.

Figure 3. Illustration. Curve-warning signs tested by MnDOT.[3]

For particularly high degrees of curvature, Australia offers the option of adding a supplementary Curve Tightens plaque to standard curve-warning signs (figure 4).[15,29] Although not currently recommend in the MUTCD, similar Curve Sharpens signs are sometimes used in California (figure 5). Such signs, when used in combination with Advisory Speed plaques, have the potential to provide an additional warning to motorcyclists about particularly sharp curves.

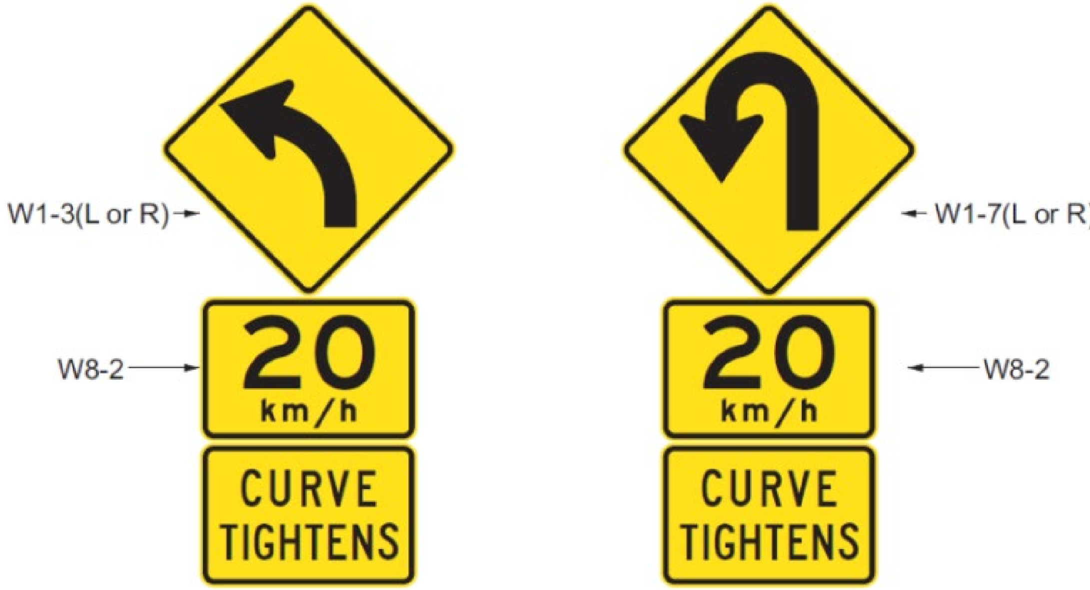


Figure 4. Illustration. Advance curve-warning sign with supplementary Curve Tightens plaque.[29]

Figure 5. Photo. Advance curve and speed sign with Curve Sharpens text.[33]

Pavement-Condition Signs

Motorcyclists are particularly susceptible to changes in the quality and condition of the roadway surface in part due to the fact that motorcycle operation requires advanced motor skills and focus in comparison with automobile operation. Motorcyclists must also use difficult and potentially counterintuitive techniques, such as counter-steering and balancing the front and rear brakes.[6] As a result, it is imperative for riders to be able to identify and react to pavement quality issues.

To this end, pavement-condition signs represent a potentially important traffic control strategy that can be used to reduce crash risk.

Several studies have considered how factors such as surface and weather conditions relate to the severity of injuries sustained by motorcyclists who are involved in a crash. For example, research has shown that crashes tend to be more severe when the road surface is characterized by rutting, corrugations, and potholes.(34) Interestingly, research has also shown that motorcycle crashes tend to be more severe under dry conditions in Iowa, North Carolina, and California as well as in other countries.(35–37) Research to examine the effect of surface conditions on the likelihood of severe crashes has been mixed, with some studies reporting a greater likelihood of severe crashes on smooth pavements and others failing to find any substantive effects.(34,38) However, it is important to note that motorcyclists are likely to adapt their behavior (e.g., decreasing speeds, riding less aggressively) under adverse weather and pavement conditions.

In any case, with all other things being equal, the risk of crash involvement is heightened under adverse pavement conditions due to reduced friction between the pavement surface and motorcycle tires. Furthermore, in a survey of motorcyclists in the United States, a number of respondents noted that motorcycle safety issues could be addressed by installing awareness signs near locations where pavement conditions are a contributing factor to motorcycle crashes.(39)

To this end, the use of targeted signs to alert motorcyclists of hazardous conditions represents a promising measure to improve motorcycle safety. A review of some of the signs used to warn motorcycle operators about potentially hazardous conditions follows. It is important to note that most of these signs do not comply with the MUTCD and, if not under official experimentation through FHWA, are noncompliant with national standards. Nonstandard MUTCD symbols and standard symbols not used in accordance with the provisions of the manual must be approved by the FHWA prior to use in the United States.(3)

Potential pavement-condition signs can include very general messages, such as an informational sign with a message that reads "Motorcycle Safety Enforcement Area next 50 km," which is used in Australia, as shown in figure 6.(40)

The South Dakota Department of Transportation (DOT) experiences heavy motorcycle volumes, particularly during the annual Sturgis Motorcycle Rally, and the agency has used signs such as the general warning shown in figure 7 to alert motorcyclists of potentially high-risk areas.

Figure 6. Photo. Sign for motorcyclist enforcement area in Australia.(40)

Figure 7. Photo. Motorcycles Use Extreme Caution sign in South Dakota.(41)

However, it is likely that signing would be more effective if targeted toward specific conditions. For example, the *Guidelines on Motorcycle and Bicycle Work Zone Safety* identifies four general categories of concern for motorcyclists in work zones.[42] Those categories are as follows:

- Degradations in roadway pavement surface quality (e.g., longitudinal grooves from pavement milling, unpaved or gravel surfaces, rough and broken pavement sections, longitudinal or lateral rumble strips).
- Degradations in pavement friction (e.g., loose gravel, sand, or soil; liquids on the pavement surface; blackout tape within the travel path; large pavement markings; steel plates).
- Pavement discontinuities and abrupt elevation changes (e.g., uneven lanes; loose or rough bridge and pavement joints; steel plates; manholes, drainage appurtenances).
- Degradations in roadway geometrics (e.g., travel lane alignment shifts).

The MUTCD currently provides a limited number of sign alternatives related to motorcycles. The most common application is the supplemental Motorcycle plaque (W8-15P), shown in figure 8, which can be used in combination with warning signs such as Grooved Pavement and Metal Bridge Deck.[3] Such signing is targeted toward locations where surface conditions may affect motorcyclists' ability to control the motorcycle under wet or dry conditions.

Source: FHWA; modified from the MUTCD.

Figure 8. Illustration. Supplemental warning plaques for motorcyclists.[3]

Agencies generally use supplemental motorcycle plaques in combination with various general-purpose signs that refer to site-specific pavement-related issues. For example, Florida DOT (FDOT) suggests the use of the W8-15P plaque in combination with the following sign types:

- Bump (W8-1).
- Loose Gravel (W8-7).
- Uneven Lanes (W8-11).
- Grooved Pavement (W8-15).
- Metal Bridge Deck (W8-16).
- Steel Plate Ahead (W8-24).

FDOT uses a yellow warning sign for general conditions as well as an orange variant for work zone environments.[43]

The British Columbia Ministry of Transportation and Highways includes a similar sign, denoted as W-115, which can be used to warn motorcyclists of specific conditions.[44] The sign can be complemented by sign W115-T, which is a Metal Bridge Deck sign, as shown in figure 9.

Figure 9. Photo. W-115 and W-115T motorcyclist warning signs.

Washington DOT has adopted an alternative to the W8-15P, which is a simple text-based sign that reads Motorcycles Use Extreme Caution (figure 10).[45] This sign is to be used in work zone settings if the work includes grooved pavement, abrupt lane edges, steel plates, or gravel surfaces.

Figure 10. Illustration. Text warning sign.

The Virginia DOT (VDOT) uses additional warning signs for expansion joints and open joints on bridges, with examples shown in figure 11.[46] VDOT also uses the W8-15P in combination with a general Rough Road sign, W8-8.[47]

© VDOT.

Figure 11. Illustration. Examples of joint signs used in Virginia.[46]

Tennessee DOT has issued an instructional bulletin that suggests designers should include a motorcycle-warning sign (figure 12) on interstate resurfacing projects that include grooved pavement.[48] The proliferation of different types of warning signs used by different transportation agencies speaks to the potential value of motorcycle-specific pavement-condition signs. However, without an empirical assessment of these signs, such as that required prior to being included in the MUTCD, it is unclear which, if any, of these signs would be effective in increasing motorcycle safety.

© Tennessee DOT.

Figure 12. Illustration. Grooved-pavement-warning sign used in work zones in Tennessee.[48]

Limited-Sight-Distance Signs

Both vertical and horizontal curves can create situations that limit a driver's view of the roadway. Limited sight distance can be a particular challenge for motorcyclists since they need to monitor the roadway closely for potential hazards, such as oncoming vehicles, debris, road flooding, or potholes.[15] Signs can be used to warn motorcyclists about locations where sight distance is limited and allow them to make appropriate changes to their behavior.

One of the first signs used to indicate limited sight distance is shown in figure 13. This diamond-shaped warning sign (W14-4) was recommended in the 1978 version of the MUTCD to warn drivers about reductions in sight distance caused by both vertical and horizontal curves.[17] However, the sign was not evaluated by FHWA for comprehension prior to being added to the

MUTCD, and the sign did not prove to be effective.[49] Road users did not understand the purpose of the sign, and it was not successful in changing drivers' behaviors or reducing crashes.[50,51] Following a fatal crash that prompted an investigation of the effectiveness of the sign, it was removed from the MUTCD in 1986.[52]

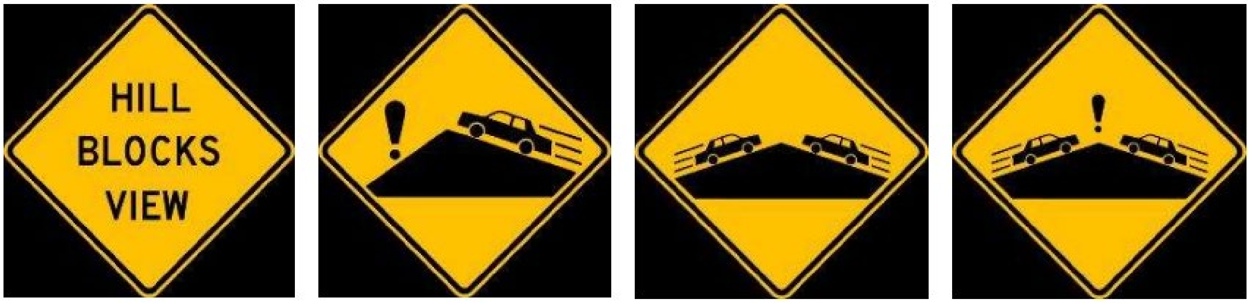
Source: FHWA.

Figure 13. Illustration. Limited-sight-distance sign no longer in use.

Freedman et al. conducted a series of studies in an attempt to determine an appropriate alternative to the limited-sight-distance sign.[51] Twenty-two novel signs designed to warn drivers about vertical curves with limited sight distance were generated. Twelve of the signs displayed verbal messages and 10 displayed various types of symbols. The research used a series of experiments to determine which design was most effective. First, a group of participants completed a sorting task wherein they judged the perceived effectiveness of each novel sign. Afterward, a new group of participants evaluated the comprehension and speed of detection for the five signs with the highest rankings. These metrics were compared to those found for the limited-sight-distance sign.

Generally, signs with verbal messages had better comprehension than symbol signs, but symbol signs were more quickly detected. A composite score that accounted for both comprehension and detection speed found that the text-based sign that read Slow, Hill Blocks View and the symbol sign featuring two cars approaching each other from either side of a hill each scored significantly higher than the limited-sight-distance sign. Based on this finding, a controlled field study was conducted in which participants drove a prescribed route that included passing either one of these two signs or the control limited-sight-distance sign. Responses to and memory for all signs were recorded. High recall rates and increased slowing were found for both novel signs relative to the control sign, but comprehension was highest for the verbal sign. A very similar sign, Hill Blocks View (W7-6), is in the current MUTCD.[3]

A recent study conducted by Balk, Kissner, and Katz highlights the ability of the Hill Blocks View sign to warn drivers about vertical curves that limit sight distance.[53] The authors tested this sign against three symbol signs as potential alternatives (figure 14). The Hill Blocks View sign was found to have the highest comprehension, the farthest legibility distance (i.e., could be read and understood by road users at a greater distance) and the highest subjective rankings of all the tested signs. The results support the MUTCD's continued use of the sign.



Source: FHWA.

Figure 14. Illustration. Signs tested by Balk, Kissner, and Katz.[53]

Past research suggests that the Hill Blocks View sign (W7-6) currently included in the MUTCD has high rates of both comprehension and legibility and is therefore sufficient to warn drivers about limited sight distance due to vertical curves. An equivalent sign to warn about limited sight distance due to horizontal curves is not currently part of the MUTCD.

CONCLUSION

Trueblood et al. identified four types of signs with the potential to serve as effective motorcycle-crash countermeasures: movement-prohibition, advance curve-warning, pavement-condition, and limited-sight-distance signs.[1] The research team conducted a literature review on the value of each sign type as a potential motorcycle-crash countermeasure. The review identified potential gaps that novel motorcycle-oriented signs could be developed to fill.

Movement-prohibition signs, such as No Left Turn (R3-4) and No U-Turn (R3-18), have the potential to reduce motorcycle crashes at intersections where drivers seeking to make a left turn or U-turn may fail to yield to motorcycles. These existing movement-prohibition signs have high comprehension rates and legibility distances, such that they are successful at reducing the number of collisions that occur where they are installed.[26] Nevertheless, not all intersections are good candidates for movement-prohibition signs.[26,18] Further, these signs cannot prevent collisions that occur at other locations where drivers fail to react appropriately to motorcyclists. In locations where movement-prohibition signs cannot be installed, motorcycle-awareness signs or signs that remind drivers to watch for motorcycles may have the potential to reduce crashes between motorcycles and other vehicles.[54,19]

Advance curve-warning-signs that alert motorcyclists about the presence of a curve can allow them to take appropriate action prior to entering the curve, thereby reducing crash risk. Sharp curves, or curves with small curve radii, are particularly hazardous to motorcyclists.[30,31,15] To mitigate this threat, some transportation agencies use signs that specifically warn about sharp or tightening curves.[15] Novel curve signs that are specifically designed to warn about sharp curves or locations with multiple curves could help motorcyclists navigate such locations more safely.

Pavement-condition signs represent a potentially important traffic control strategy for reducing crash risk among motorcyclists. Pavement-condition signs can help riders identify and react to pavement quality issues. Motorcyclists recognize the potential value of this sign type, and several transportation agencies use pavement-condition signs that are customized with images of motorcycles. (See references 34, 35, and 37–42.) Novel pavement-condition signs that specifically target motorcyclists have the potential to serve as a useful countermeasure for motorcycle crashes.

Limited-sight-distance signs have the potential to warn motorcyclists about situations where the road ahead is not visible due to either vertical or horizontal curves. Since motorcyclists need to monitor the roadway closely for hazards, such warnings have the potential to be particularly valuable to this road-user group. The Hill Blocks View sign (W7-6) has high comprehension and legibility rates among drivers. However, the potential for motorcyclists to benefit from signs that specifically target motorcyclists approaching vertical curves have not been tested. There is also a need for signs that warn drivers, and especially motorcyclists, of limited sight distance due to horizontal curves.

Warning signs have the potential to reduce motorcycle crashes by drawing the attention of riders and other road users to each other's presence as well as to selected areas and features of the roadway. Novel sign alternatives within the motorcycle-awareness, advance curve-warning, pavement-condition, and limited-sight-distance categories could serve as motorcycle-crash countermeasures provided these signs are shown to be effective through human factors studies of components such as comprehension, legibility, and proven changes to behavior.

CHAPTER 2. ONLINE QUESTIONNAIRE

The objectives of the current project were threefold: first, to develop novel highway sign alternatives that have the potential to act as countermeasures against motorcycle crashes; second, to conduct comprehension and legibility testing of these novel signs; and third, to develop a prioritized list of highway sign alternatives that may serve as effective motorcycle-crash countermeasures. The first step in this process was developing novel highway signs. To aid in sign development, the research team conducted a review of existing literature (chapter 1). This information was used to generate a preliminary set of signs that could act as potential crash countermeasures.

After generating a set of preliminary signs, the research team sought to reduce and refine the novel sign set based on the input and feedback of relevant stakeholders. To solicit this feedback, the research team created and distributed a questionnaire to members of the motorcycle-riding community. The questionnaire asked motorcyclists to rate the usefulness of each sign in the preliminary stimulus set. After viewing all the novel signs, participants were asked to select the three signs they felt were the most useful. Participants were then given the opportunity to provide written feedback about the signs they had seen and about any additional signs they thought could be used to increase motorcycle safety. This feedback was used to generate the final list of stimuli that would be used during the comprehension and legibility experiment reported in chapter 3.

METHOD

This section explains the methodology used to obtain feedback from the motorcycle riding community on the preliminary novel sign set.

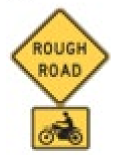
Participants

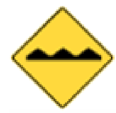
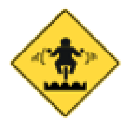
Motorcyclists were recruited online via a weblink, which was emailed to the leaders of motorcycle riding groups and motorcycle riding instructors. Recipients of the emails voluntarily distributed the link to motorcyclists in their organization via email or social media. A total of 1,025 participants completed the questionnaire.

Stimuli

Stimuli included in the questionnaire consisted of a preliminary set of novel signs. The research team generated the signs based on the literature review found in chapter 1 and an examination of signs currently in use by local, State, and international transportation agencies. A selection of signs that have already been approved by the MUTCD were also selected to serve as control stimuli to which the novel signs could be compared. The full stimulus set is displayed in table 1.

Table 1. Stimuli for online questionnaire organized by sign type.

Sign Type	Motorcycle Awareness	Advance Curve Warning	Pavement Change	Limited Sight Distance: Horizontal Curves	Limited Sight Distance: Vertical Curves
Existing	—	c  f  i 	l  n  q  s 	u 	y  z  aa 

Sign Type	Motorcycle Awareness	Advance Curve Warning	Pavement Change	Limited Sight Distance: Horizontal Curves	Limited Sight Distance: Vertical Curves
Novel	a  b 	d  e  g  h  j  k  	m  o  p  r  t 	v  w  x  	ab  ac  ad  ae 

Source: FHWA.

Procedure

Potential participants were first presented with a participant information sheet, which provided a description of the research being conducted. Consent was confirmed when the participant checked a box indicating “I hereby voluntarily consent to participate in this study” after reading the participant information sheet.

After consenting to participate and indicating that they were motorcyclists, participants answered questions about the signs. Participants were asked to indicate whether each sign was very useful, somewhat useful, not very useful, or not at all useful. Next, participants were shown a table containing all the novel signs and asked to indicate which sign was the most useful, second most useful, and third most useful. Participants were then provided space to type a written response to the following two prompts: “Please provide any additional feedback you have on any of the signs displayed above" and "Are there any additional signs that you think should be used to increase motorcycle safety? If yes, please describe."

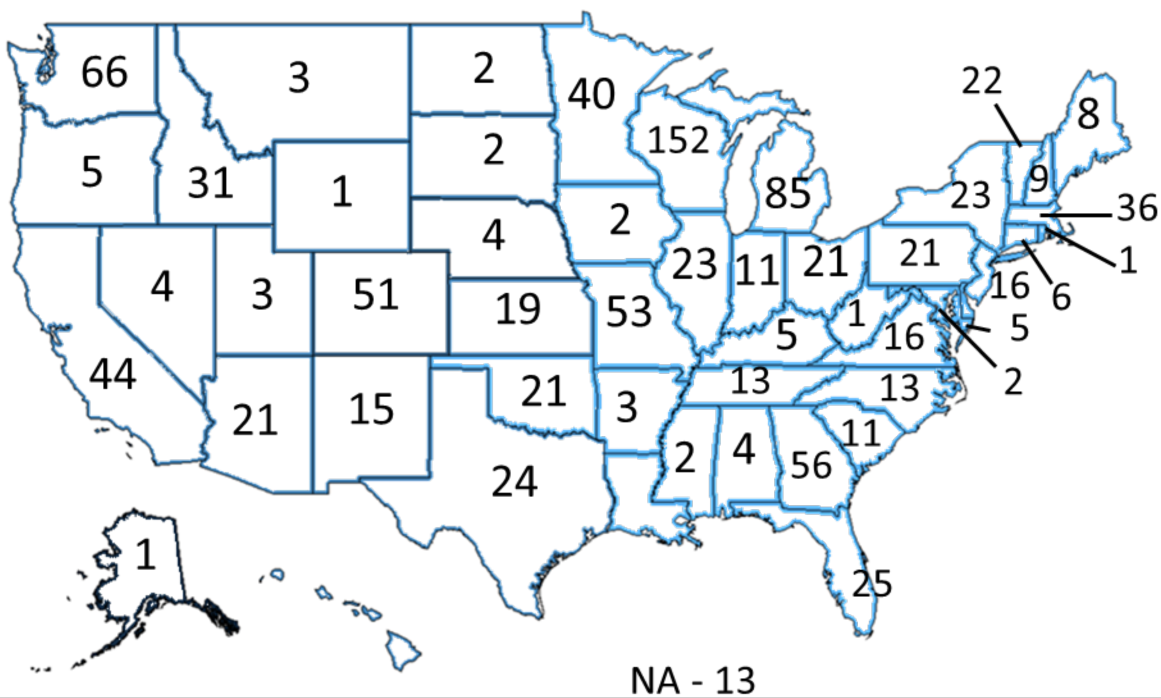
The final portion of the questionnaire solicited information about the participants. Participants were asked how many years of experience they had riding a motorcycle and whether they had ever been involved in a crash while riding. For those that answered in the affirmative to being involved in a crash while riding a motorcycle, a followup question asked what factor(s) contributed to, or could have helped prevent, their most recent motorcycle crash, and participants were able to type an open-ended response. Participants were also asked their gender, age, and the State in which they do most of their motorcycle riding.

RESULTS

This section describes the responses that participants provided when completing the questionnaires, including demographic information, information about their most recent crash, and their opinions about the usefulness of the signs in the preliminary stimulus set.

Demographic Information

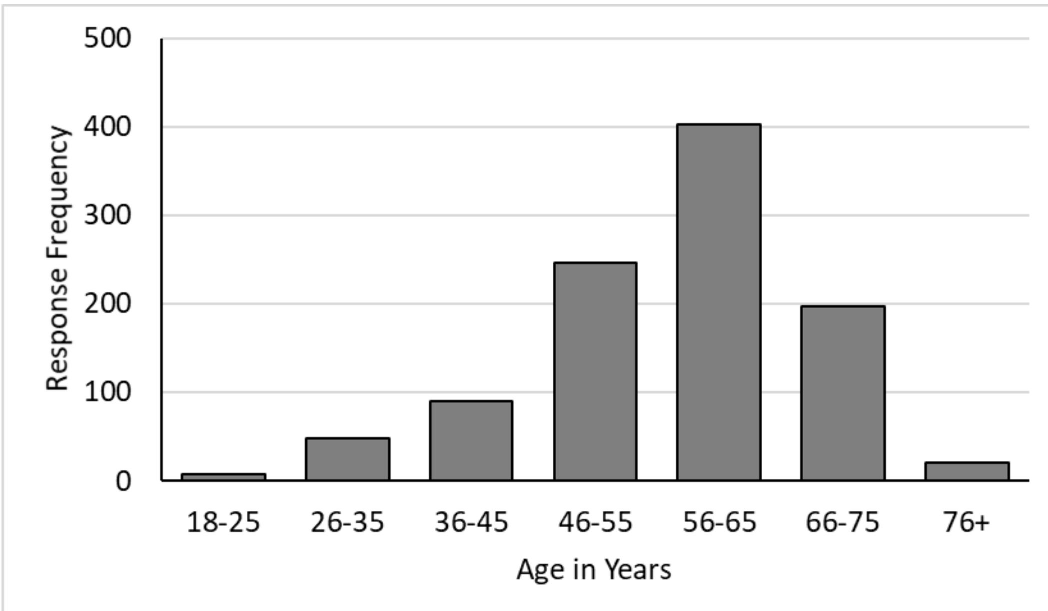
Figure 15 shows a map of the United States. The number overlaid on each State represents the total number of participants who indicated they did most of their motorcycle riding in that State. Overall, participants rode motorcycles in 47 different States plus the District of Columbia. The largest group of participants indicated they rode most in Wisconsin.



Source: FHWA.
NA = no answer.

Figure 15. Map. Map displaying the number of participants who indicated they did most of their motorcycle riding in each State.

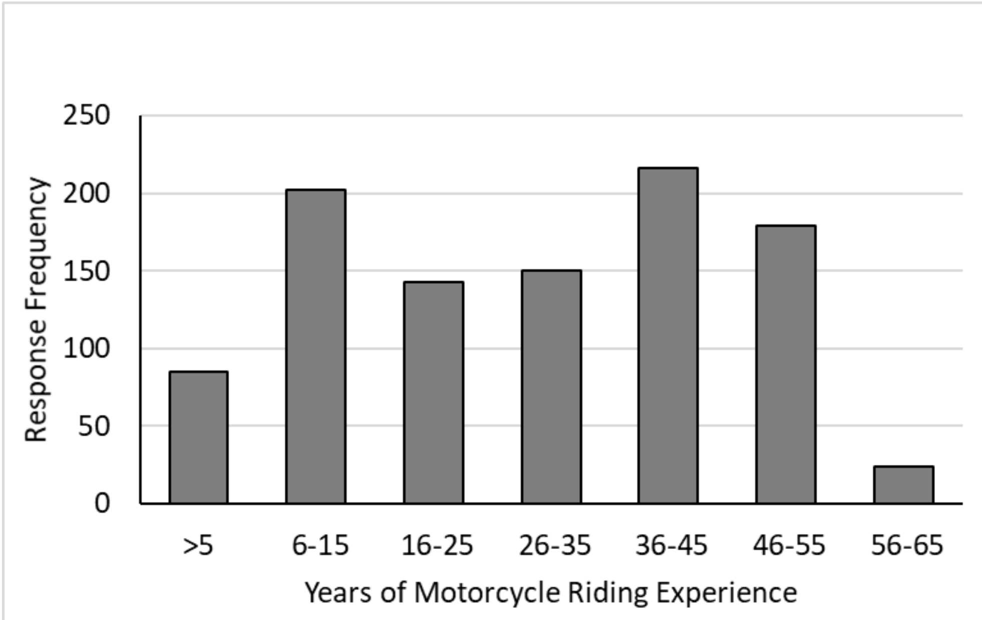
Seventy-six percent of participants indicated they were male, 23 percent were female, and 1 percent preferred not to answer. The age makeup of participants is presented in figure 16. Ages were relatively normally distributed, with the largest frequency of respondents between the ages of 56 and 65 yr. The age and gender distribution within the current sample of participants is similar to that found within the national population of motorcyclists. According to a 2018 Motorcycle Industry Council survey, 81 percent of riders in the United States are male, and the median age of riders is 50.[56] The skew toward older male riders within the current sample suggests that the motorcyclists who volunteered to participate in the current questionnaire are representative of the Nation's larger motorcycle-riding community.



Source: FHWA.

Figure 16. Graph. Distribution of participant ages.

Figure 17 shows the distribution of years of motorcycle riding experience among participants who completed the questionnaire. Participants ranged from riders who had been riding for less than 1 yr to riders who have been riding for 65 yr.

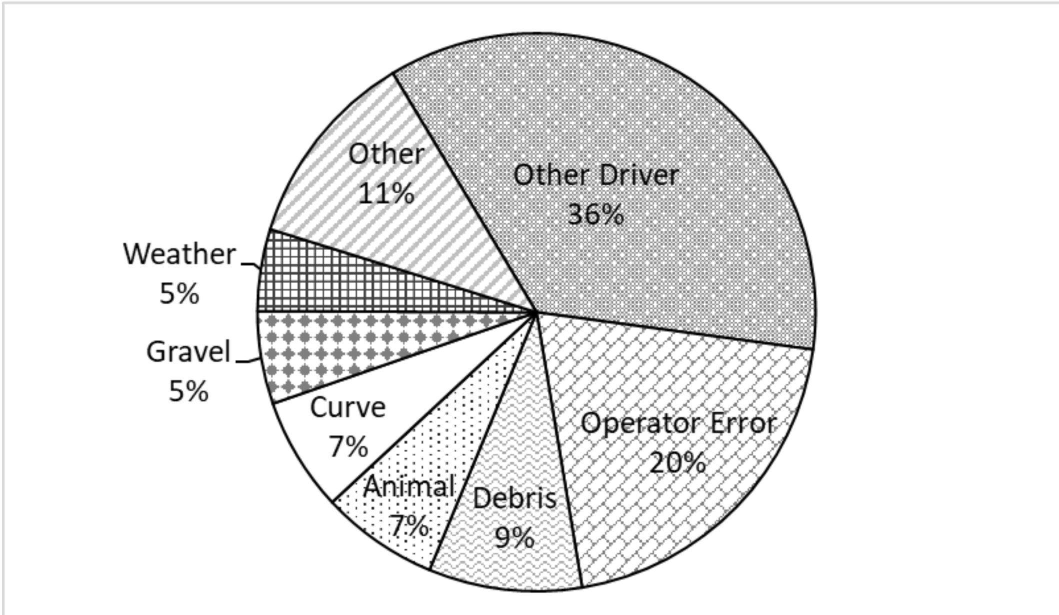


Source: FHWA.

Figure 17. Graph. Distribution of years of motorcycle riding experience among participants.

Motorcycle Crashes

Exactly half of participants indicated that they had been involved in a crash while riding their motorcycle. A team member trained to code survey responses read the description of each motorcycle crash and categorized the apparent cause. Categories that included less than 5 percent of responses were combined into a single "other" category. The remaining crashes fell within one of the seven categories displayed in figure 18. Over one-third of crashes (36 percent) were attributed to the behavior of other drivers on the roadway. This result is consistent with previous work noting that other drivers often fail to see and respond appropriately to motorcyclists.(8,11,18) The result also supports the use of motorcycle-awareness signs as a potential crash countermeasure. Two of the other types of hazards explored in the current study, curves and gravel (pavement conditions), also contributed to motorcycle crashes within the group of participants.



Source: FHWA.

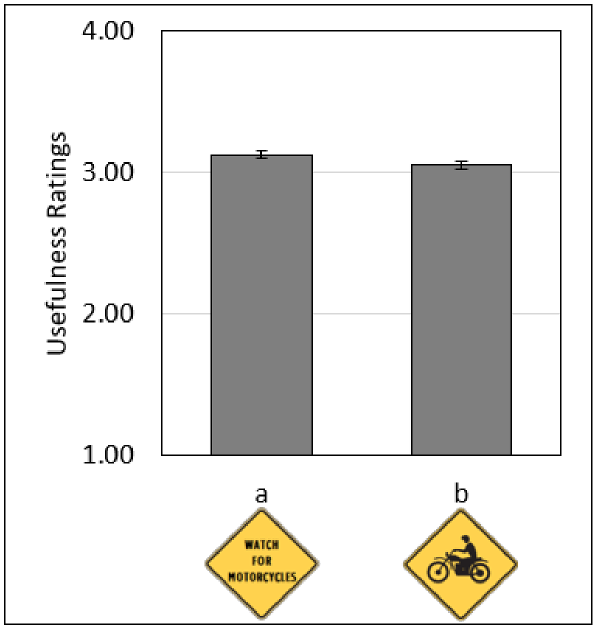
Figure 18. Graph. Percentage of respondents' most recent motorcycle crashes that were attributed to each causal factor.

Usefulness Ratings

Participants rated each sign as very useful, somewhat useful, not very useful, or not at all useful. Responses were converted into numbers (i.e., very useful = 1, somewhat useful = 2, not very useful = 3, or not at all useful = 4) and analyzed using a chi-squared (χ^2) test. An χ^2 test is a statistical test used to determine the probability (p value) that the responses obtained in the study would be likely to have occurred at random. When the probability of obtaining a result at random is less than 5 percent (i.e., $p < 0.05$), the result is considered statistically significant at a 95-percent confidence interval and assumed to be a result of the variable that was measured. The study team conducted separate χ^2 tests for each sign type to compare the usefulness ratings of each sign (effect of sign) and examined how the perceived usefulness of the novel signs compared to similar signs that are currently part of the MUTCD.

Motorcycle Awareness

Usefulness ratings for motorcycle-awareness signs are displayed in figure 19. Both signs fell within the somewhat useful range. There was a small but statistically significant difference in the usefulness ratings of the two motorcycle-awareness signs, $\chi^2(1) = 4.89$, $p = 0.027$. Sign a was rated as more useful than sign b.

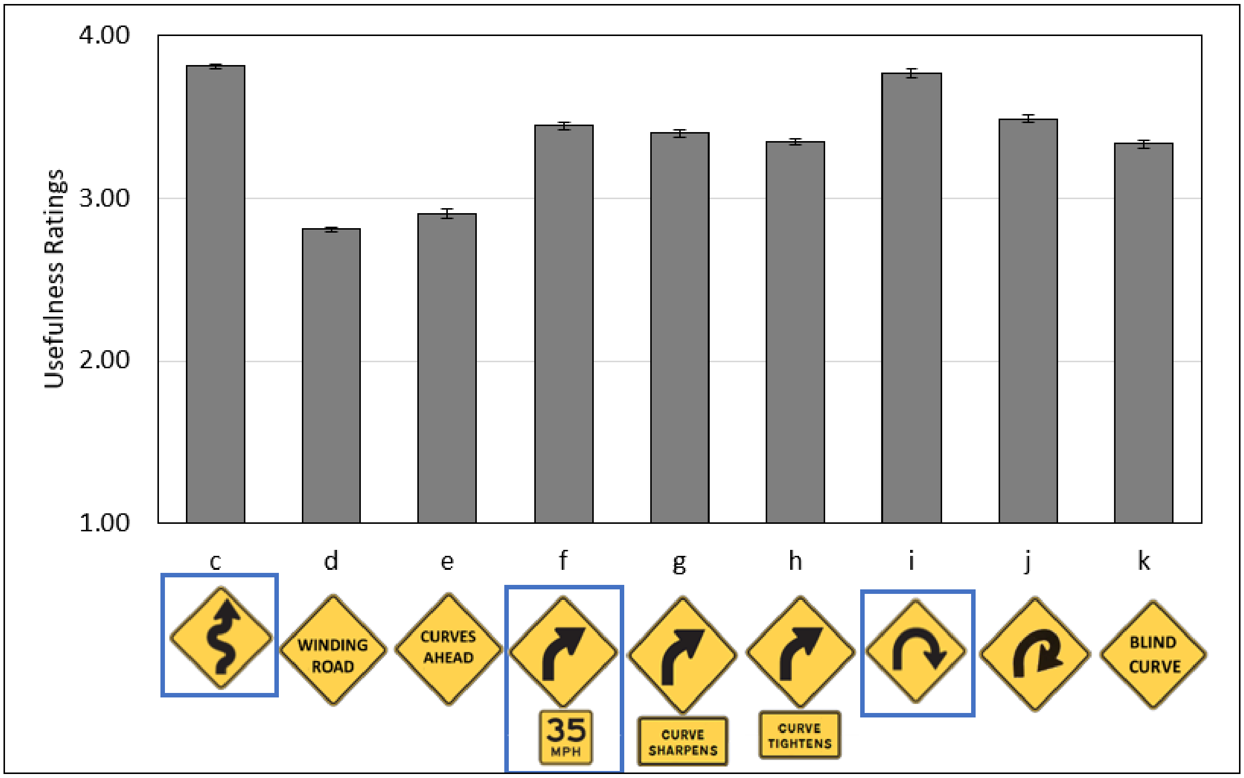


Source: FHWA.
Note: Error bars represent standard errors.

Figure 19. Graph. Mean usefulness ratings of motorcycle-awareness signs.

Advance Curve-Warning Signs

As displayed in figure 20, mean usefulness ratings for advance curve-warning signs varied by sign type, $\chi^2(8) = 1776.88$, $p < 0.001$. Sign c was rated as significantly more useful than either signs d or e. The result suggests that sign c, which is already part of the MUTCD, may be more suited for warning motorcyclists about a road with multiple curves than a sign containing text. Usefulness ratings for sign f did not differ significantly from those found for sign g, which did not differ significantly from those for sign h. The similarity in ratings for these signs suggest that a curve-warning sign with a plaque may be a useful way of alerting drivers to a particularly sharp curve. Sign i was rated as significantly more useful than sign j, which was rated as significantly more useful than sign k. While not rated as useful as sign i, which served as the control Arrow Curve sign, both signs j and k had usefulness ratings that fell within the very useful to somewhat useful range, suggesting that both could potentially be beneficial to motorcyclists.

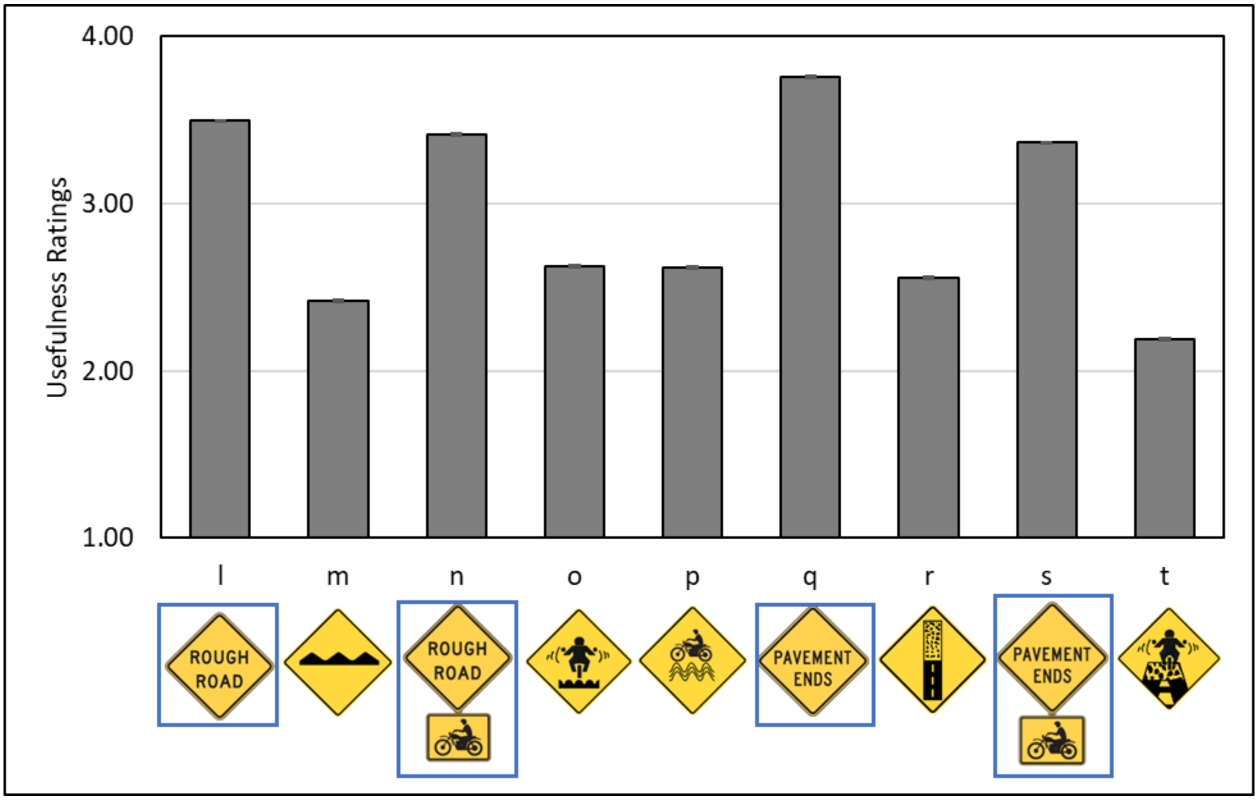


Source: FHWA.
Notes: Signs that are already included in the MUTCD are marked with blue boxes. Error bars represent standard errors.

Figure 20. Graph. Mean usefulness ratings for advance curve-warning signs.

Pavement-Condition Signs

Significant differences in usefulness ratings were also found among pavement-condition signs, $\chi^2(8) = 2483.60$, $p < 0.001$. As displayed in figure 21, the control signs (marked with blue boxes) tended to be rated as more useful than the novel pavement-condition signs. Surprisingly, participants also rated signs l and q, which did not include Motorcycle plaques, as more useful than signs n and s, which included the plaque. The results suggest that motorcyclists may prefer pavement-condition signs that include only text to those signs that include either symbols only or a combination of text and symbols. Of the novel signs tested, sign o was rated as more useful than signs p and r, whose ratings were similar. Sign t was rated as least useful.

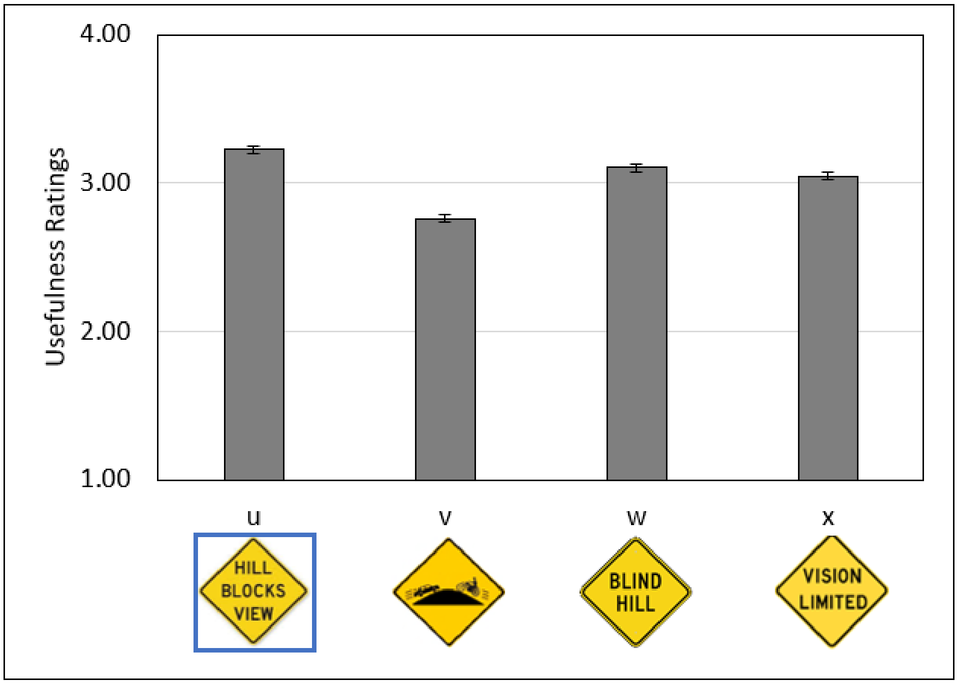


Source: FHWA.
Note: Signs that are already included in the MUTCD are marked with blue boxes. Error bars represent standard errors.

Figure 21. Graph. Mean usefulness ratings of pavement-condition signs.

Limited-Sight-Distance Signs

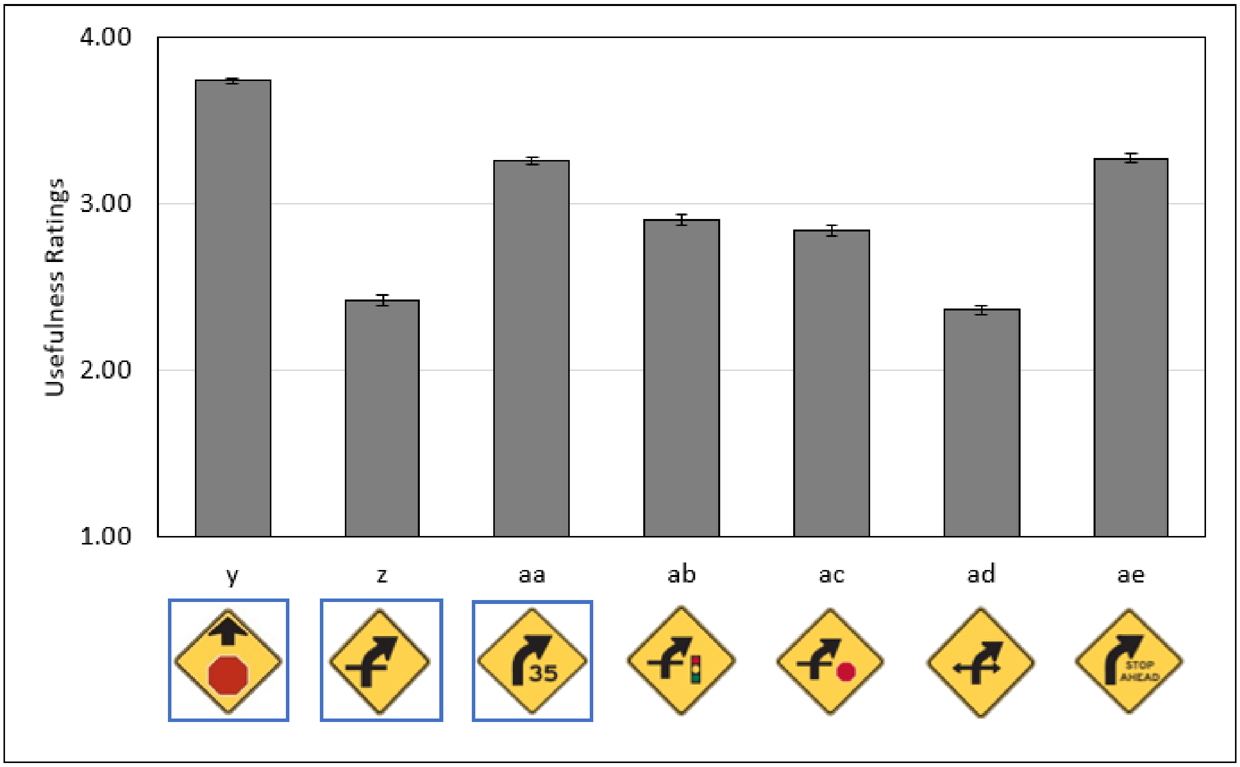
Mean usefulness ratings for the limited-sight-distance signs corresponding to vertical curves are displayed in figure 22. A significant effect of sign usefulness was found, $\chi^2(3) = 155.26$, $p < 0.001$. Sign u had higher usefulness ratings than any of the novel signs. Usefulness ratings for signs w and x did not differ from each other, and both had significantly higher ratings than sign v. The results suggest that motorcyclists see sign u, which is currently part of the MUTCD, as most useful for warning drivers about limited sight distance due to vertical curves.



Source: FHWA.
Note: Signs that are already included in the MUTCD are marked with blue boxes. Error bars represent standard errors.

Figure 22. Graph. Mean usefulness ratings for signs depicting limited sight distance due to vertical curves.

Figure 23 shows the mean usefulness ratings for signs depicting limited sight distance due to horizontal curves. Usefulness ratings varied by sign, $\chi^2(6) = 2218.42$, $p < 0.001$. Sign y had higher usefulness ratings than any of the other signs warning of limited sight distances on horizontal curves. Signs aa and ae received the next highest ratings, which did not differ significantly. Sign ab had higher usefulness ratings than sign ac, both of which had higher usefulness ratings than sign z. Ratings for sign z were lower than all other signs except for sign ad, which had similar usefulness ratings. The low usefulness ratings for sign z, which is already part of the MUTCD, suggests that motorcyclists see this sign as less useful than potential novel signs intended to convey information about where a stop would be encountered at an intersection.

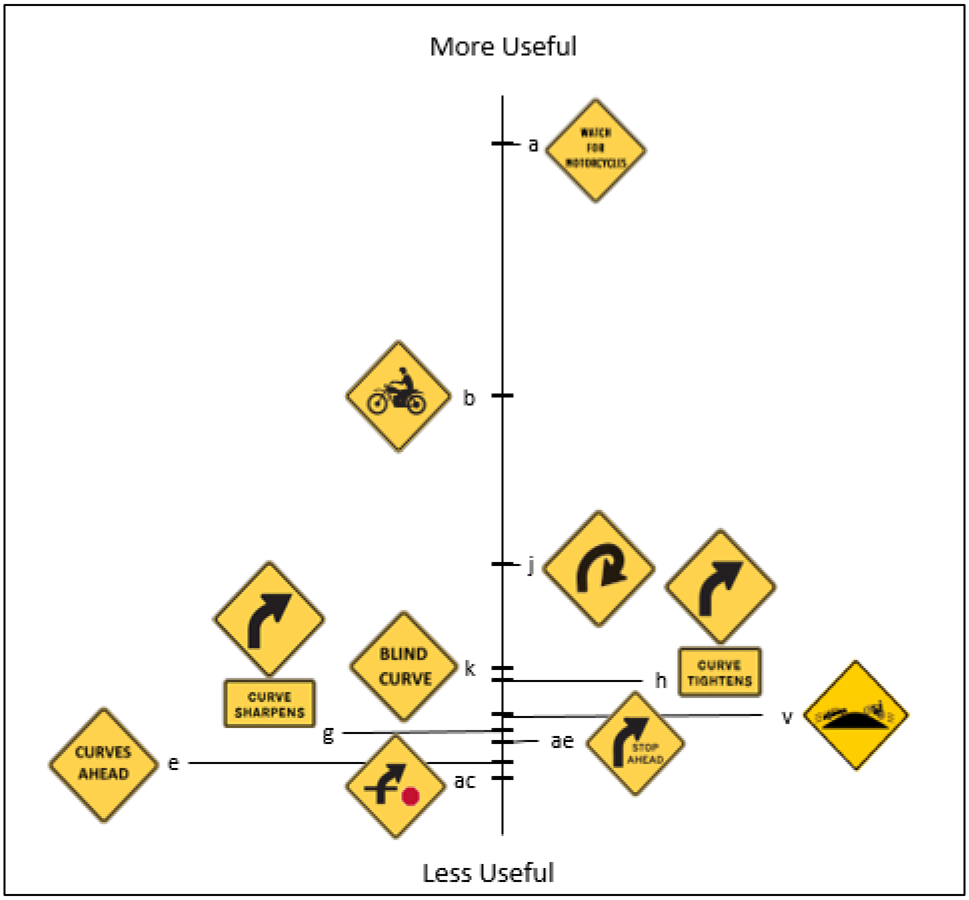


Source: FHWA.
Note: Signs that are already included in the MUTCD are marked with blue boxes. Error bars represent standard errors.

Figure 23. Graph. Mean usefulness ratings for signs depicting limited sight distance due to horizontal curves.

Most Useful Signs

After rating the usefulness of each sign, participants were asked to indicate which of the novel signs were the first, second, and third most useful. Responses were given weighted scores based on the frequency with which they were chosen for each position, with signs chosen as more useful receiving higher weights. The 10 signs with the highest scores, ordered by ranking, are shown in figure 24. The two motorcycle-awareness signs (a and b) scored highest. The 10 most useful signs also included 5 of the 6 novel signs designed to warn about curves (e, g, h, j, and k). The remaining three signs (v, ae, and ac) warned about limited sight distance.

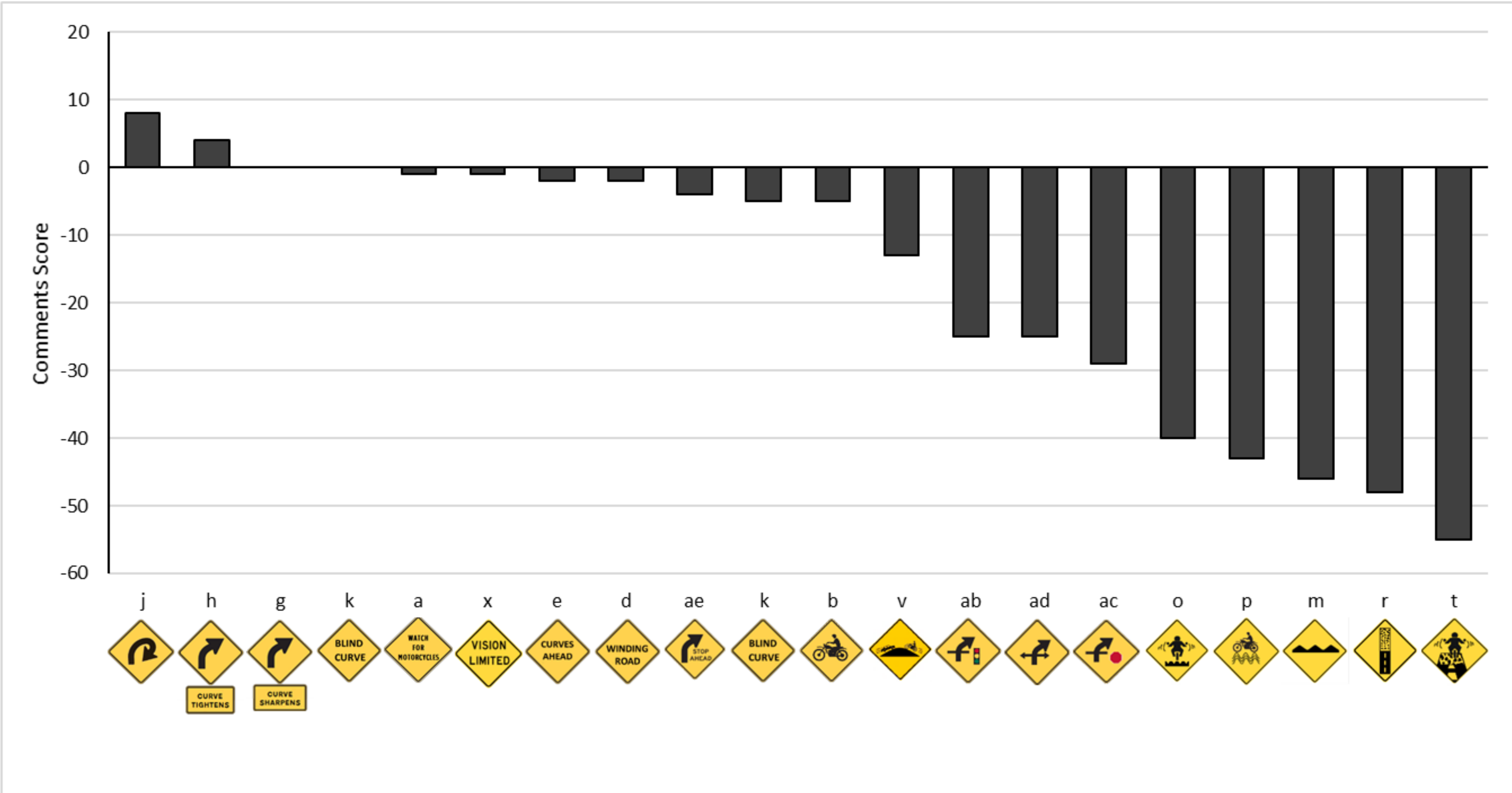


Source: FHWA.

Figure 24. Graph. Ten most useful signs ranked based on their total most useful sign scores.

Comment Scores

Participants were encouraged to provide comments about the signs that were presented and about additional signs that could be used to increase motorcycle safety. To quantify these comments a trained coder classified each comment about a specific sign as either positive (e.g., "[Sign j] actually might be the best. Riders get killed in curves, so those are important ones.") or negative (e.g., "[Sign m] resembles a mountain range ahead more than rough pavement."). The research team then calculated the total number of positive and negative comments about each sign. Signs were assigned a comment score equal to the number of positive comments about that sign minus the number of negative comments about that sign. Comment scores for all signs are displayed in figure 25. Most comments about the novel signs were critical or provided suggestions for improvement. Advance curve-warning signs j and h were the only signs to receive more positive than negative comments. The most negative comments were made about the novel pavement-condition signs.



Source: FHWA.

Note: Negative values indicate that more negative comments were made about a sign than positive comments.

Figure 25. Graph. Comment score for each of the novel signs.

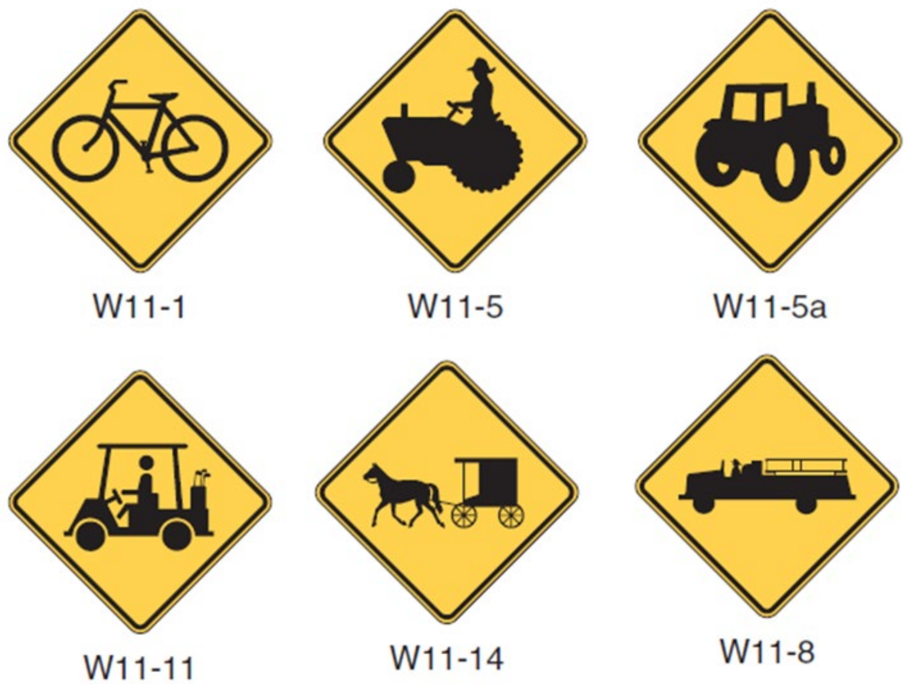
SIGN SELECTION

The following section describes how the research team used the feedback received from motorcyclists who completed the online questionnaire to narrow and refine the preliminary stimulus set to create the final set of stimuli that were included in the comprehension and legibility experiment described in chapter 3. Note that selection for inclusion in the study is not equivalent to inclusion in the MUTCD.

Motorcycle Awareness

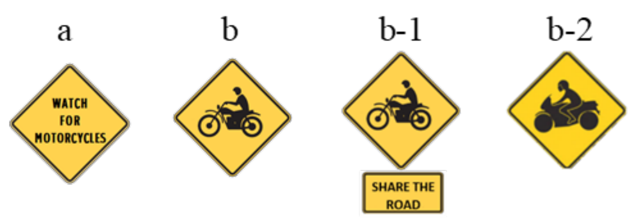
Literature on motorcycle crashes points to the potential value of motorcycle-awareness signs. The failure of other road users to notice, yield, or respond appropriately to motorcyclists is a common contributor to motorcycle crashes.(18,11,8) This finding, present in the larger motorcycle safety literature, was reiterated in the current sample. More than one-third of the participants who reported being in a motorcycle crash indicated that other drivers contributed to that crash. The two novel motorcycle-awareness signs that were assessed in the questionnaire and had high usefulness ratings were ranked as the first and second most useful signs. These results indicate that motorcyclists see the potential value of signs a and b as motorcycle-crash countermeasures. Thus, both were included in the comprehension and legibility experiment.

Although both received high usefulness ratings by the motorcyclists who completed the questionnaire, sign b was rated as significantly less useful than sign a. A review of the comments about sign b revealed two potential concerns with the sign. First, some riders expressed concern that drivers who encounter the sign may misinterpret the sign as referencing motorcycles that may be crossing the road or off-roading in the area, rather than understanding that the sign is meant to raise awareness of motorcycles that share the road with drivers. This potential concern is not unwarranted given sign b's similarity to some of the vehicular traffic warning signs currently included in the MUTCD. The MUTCD provides an option for the use of vehicular traffic warning signs, such as those displayed in figure 26, to be used to alert drivers about the unexpected entrance of vehicles onto the roadway. It is not unreasonable that drivers may view sign b as an additional warning about unexpected traffic entrances. To mitigate this potential confusion, a novel motorcycle-awareness sign (b-1) was created that combined sign b with a plaque containing the phrase Share the Road (figure 27).



Source: FHWA; modified from the MUTCD.

Figure 26. Illustration. Examples of vehicular traffic warning signs included in the MUTCD.[3]



Source: FHWA.

Figure 27. Illustration. Motorcycle-awareness signs included in the experiment.

A second concern about sign b related to the specific image used on the sign. The motorcycle symbol that appeared on sign b was taken from the Motorcycle plaque (W8-15P) under the assumption that the use of this symbol on existing signs would make it familiar to road users. However, many participants commented that the image looked more like a dirt bike than the type of motorcycle that would typically be interacting with traffic on a roadway. To address this concern, the research team constructed a fourth novel motorcycle-awareness sign (b-2) that replaced the motorcycle symbol on sign b with an alternative motorcycle symbol (figure 27). The image chosen was based on the symbol that currently appears on motorcycle-awareness signs in Australia.[15] This novel sign, along with the other motorcycle-awareness signs chosen for inclusion in the comprehension and legibility experiment, is displayed in figure 27.

Advance Curve Warning

Curve-warning signs show high potential as motorcycle-crash countermeasures. When asked to describe their most recent crash, 7 percent of participants who indicated they had been in a motorcycle crash identified curves as a causal factor in their most recent crash. Advance curve-warning signs tended to have high usefulness ratings, were among the 10 most useful signs, and were the only signs to receive more positive comments than negative comments. Of the six novel advance curve-warning signs tested, sign d, a text-based sign with the words "Winding Road," had the lowest usefulness rating (figure 20). It was also the only curve-warning sign that was not among the top 10 most useful signs. For this reason, sign d was not included in the comprehension and legibility experiment.

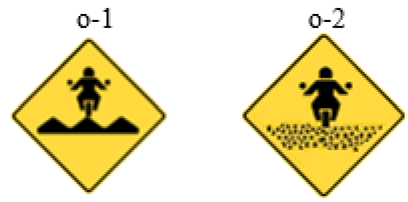
This set of novel curve-warning signs included two very similar signs: sign g, an arrow curve sign with a Curve Sharpens plaque, and sign h, a Curve sign with a Curve Tightens plaque. Due to the similarity between these two signs, only one of these signs was included in the experiment. The group of four novel curve-warning signs that were included in the comprehension and legibility experiment are presented in figure 28.

Source: FHWA.

Figure 28. Illustration. Advance curve-warning signs included in the experiment.

Pavement Condition

Changes in pavement condition are known to contribute to motorcycle crashes.[39] However, participants did not have a positive reaction to the set of five novel pavement-condition signs included in the current questionnaire. Of all the sign types tested, the novel pavement-condition signs had the lowest usefulness ratings and the highest number of negative comments. Nevertheless, the participant comments provided several suggestions on how to create pavement-condition signs that may be more effective as motorcycle-crash countermeasures. First, many respondents noted that they needed context to correctly recognize the hazards being depicted on the pavement-condition sign. For example, participants indicated that it was difficult to determine whether the symbol used to depict a hazard on sign m was meant to represent grooves in the roadway, bumps in the path, or mountains in the distance. Based on these comments it was determined that signs m and r, which did not include a motorcyclist for context, should not be included in the stimulus set that would be used for the comprehension and legibility experiment. Since sign o received significantly higher usefulness ratings than sign p, the motorcyclist symbol in sign o was chosen to provide context in the novel pavement-condition signs. Regarding sign o, participants commented that the sign was difficult to understand because it was too cluttered and the hazard in the sign was too small. This feedback was used to create a new version of sign o. To create a less cluttered sign, the movement lines surrounding the motorcyclist symbol were removed. The size of the hazard was also increased and moved to a more central location on the sign. The result was the novel Rough Road sign (o-1) shown in figure 29.



Source: FHWA.

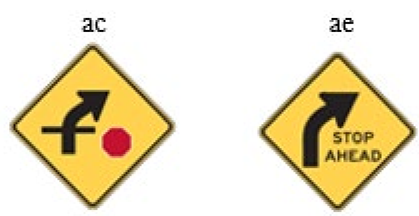
Figure 29. Illustration. Pavement-condition signs included in the experiment.

When asked about their most recent crash, 5 percent of respondents cited gravel as a causal factor. Gravel was the most frequently reported pavement-condition hazard among participants who reported being involved in a crash while riding their motorcycles. For this reason, the research team decided to replace the novel Pavement Ends sign with a sign depicting loose gravel (o-2). The revised pavement-condition signs used in the comprehension and legibility experiment are displayed in figure 29.

Limited Sight Distance

The questionnaire included two groups of limited-sight-distance signs: those that depicted limited sight due to vertical curves and those that depicted limited sight due to horizontal curves. Usefulness ratings for the control vertical-curve sign, sign u, were higher than for any of the novel signs tested. The results are similar to those found by Balk et al., who also found high levels of both comprehension and legibility for sign u.(53) Given the apparent robustness of this sign in both the current questionnaire and the larger literature, the research team decided that the comprehension and legibility experiment would focus on signs that warn about limited sight distance due to horizontal curves.

The research team tested four novel signs that depicted limited sight due to horizontal curves. Signs ac and ae, which depicted the need to stop while rounding a curve, were among the top 10 most useful signs. For this reason, it was decided to include both signs in the comprehension and legibility experiment (figure 30).



Source: FHWA.

Figure 30. Illustration. Limited-sight-distance signs included in the experiment.

CONCLUSION

This chapter described feedback received from motorcyclists about the potential usefulness of a preliminary set of novel motorcycle-awareness, advance curve-warning, pavement-condition, and limited-sight-distance signs. A large group of motorcyclists volunteered to provide feedback using an online questionnaire. The research team used their responses to narrow and refine the preliminary stimulus set and create the final set of 12 novel stimuli that were included in the comprehension and legibility experiment described in chapter 3. The results provide insight into the potential value that motorcyclists place on signs as crash countermeasures. The responses also provide information about the source of crashes motorcyclists experience. Finally, the large group of participants that volunteered to complete this questionnaire is indicative of the eagerness of motorcyclists to have their voices heard in matters that affect motorcycle safety.

CHAPTER 3. COMPREHENSION AND LEGIBILITY EXPERIMENT

The current study used comprehension testing to compare participants' responses to novel and existing signs. The research team also tested the legibility of the novel signs to determine whether the designs could be perceived at sight distances that are comparable to those of existing signs recommended by the MUTCD. Since the novel signs would be installed on roadways used by both motorcyclists and drivers of passenger vehicles, the current study assesses sign comprehension and legibility among both motorcyclists and nonmotorcyclists.

METHOD

This section describes the method used to collect data in the comprehension and legibility experiment, including information about the participants who completed the study, the apparatus used to collect data, the stimuli that were tested, and the study procedure.

Participants

Fifty licensed drivers participated in the study. A power analysis was not conducted to determine sample size due to an absence of effect-size reporting in the literature. Instead, sample size was selected based on similar, previously conducted work on sign comprehension.[57,58] All participants were at least 18 yr of age and were recruited from the Washington, DC, metropolitan area. Participants were recruited to represent the gender distribution of motorcyclists in the United States (i.e., 81 percent male and 19 percent female). The number, mean and standard deviation age, and drive frequency of male and female motorcyclists and nonmotorcyclists that participated in the study is displayed in table 2. Participants were compensated at a rate of $40 per h for their participation, which lasted for approximately 1 h.

Table 2. Number of participants, age, and hours driven per week by male and female motorcyclists and nonmotorcyclists.

Participant Group	Number of Participants	Mean Age (SD)	Mean Hours Driven per Week (SD)
Male motorcyclists	21	48.4 (16.9)	11.3 (13.6)
Female motorcyclists	4	43.8 (10.7)	12.3 (11.9)
Male nonmotorcyclists	19	51.0 (22.1)	13.6 (11.1)
Female nonmotorcyclists	6	47.5 (19.2)	17.5 (15.8)

SD = standard deviation.

Apparatus

Testing was conducted at the Turner-Fairbank Highway Research Center in the Highway Sign Design and Research Facility in McLean, VA. Signs were displayed on a 60-inch diagonal, light-emitting diode/liquid-crystal display monitor. Participants responded using a standard QWERTY keyboard and mouse. For some portions of the experiment, participants had the option to respond verbally and allow the researcher administering the experiment to enter their responses using a separate mouse and keyboard.

Stimuli

Signs were selected as stimuli based on feedback from stakeholders and the motorcycle riding community. As shown in table 3, stimuli consisted of novel signs and signs already approved in the MUTCD. The approved signs (i.e., signs labeled "existing" in table 3) served as control stimuli to which the novel signs were compared.

Table 3. Stimuli organized by sign type.

Sign Type	Motorcycle Awareness	Advance Curve Warning	Pavement Change	Limited Sight Distance
Existing	—	c11  c12 	p11  p12 	s11  s12 
Novel	m1  m2  m3  m4 	c1  c2  c3  c4 	p1  p2 	s1  s2 

Source: FHWA.
—No sign.

Procedure

Each session began with participants reviewing and signing an informed consent form. Participants were then asked to show a valid driver's license. Each participant's vision was assessed to confirm a minimum acuity of 20/40 (with correction), which is the minimum acuity required to obtain a driver's license in most States.

Comprehension Testing

Each participant took part in comprehension and legibility testing. During each trial, participants were shown an image of a sign positioned on the edge of a roadway (figure 31). Participants from the motorcycle riding community were asked to imagine they encountered the sign while riding their motorcycle. Participants who were not motorcyclists were asked to imagine they encountered the sign while driving. All participants were asked to describe the meaning of the sign, and open-ended responses were recorded. Next, participants were asked to indicate the intended audience for each sign to assess whether signs designed for motorcyclists are still seen as relevant to other drivers. Finally, participants were given a description of the intended meaning of the sign (figure 31) and were asked to rate how effectively the sign conveyed that message on a scale of 1 to 4, where 1 indicated very effective, 2 indicated somewhat effective, 3 indicated somewhat ineffective, and 4 indicated not at all effective. Participants answered this question for each sign. The experimental design randomized the order in which the signs were presented.

Next, the research team obtained rankings for the motorcycle-awareness signs. The four signs were presented on the screen at the same time and participants ranked the signs from most effective to least effective.

Source: FHWA.

Figure 31. Screenshot. Example of a sign used for comprehension testing.

Legibility Testing

To assess legibility, each sign was shown one at a time on a black background. Sign presentation began at a simulated distance of 1,000 ft. The signs then expanded in size to simulate an approach speed of 45 mi/h. Participants were instructed to keep their eyes on the sign and to press the space bar as soon as the sign became legible (i.e., as soon as they could identify the elements of the sign). When the participant pressed the button, the sign disappeared, and the participant described the sign aloud. The researcher then determined whether the description was correct or incorrect. Any response that confirmed that the sign was legible to the participant was considered correct. If the participant was correct, the legibility distance was recorded, and the participant proceeded to a new trial. If the participant's response was incorrect, the same sign reappeared and continued to increase in size, so the participant had another opportunity to press the button when the sign became legible. Allowing the participant a second chance to view the sign enabled the research team to measure the legibility distance for each sign.

Demographic Data

As crash risks have been shown to vary significantly based on factors such as age and riding experience, the team also collected demographic data from participants to assess potential relationships between sign comprehension and rider characteristics. Specifically, all participants were asked to indicate their age, gender, and how frequently they drive. Participants who were members of the motorcycle riding community were also asked how frequently they ride their motorcycle and how long they have been riding.

RESULTS

Sign Comprehension

Sign comprehension was assessed using a series of questions. To gauge initial understanding of each sign, participants first answered the open-ended question "What does this sign mean?" A second open-ended question "Who is this sign for?" assessed whether participants felt there was a specific intended audience for each sign. Afterwards, participants were given a description of the intended meaning of each sign and asked to rate how effective the sign was at conveying that meaning. Participants also took part in a task in which they ranked motorcycle-awareness signs from most effective to least effective.

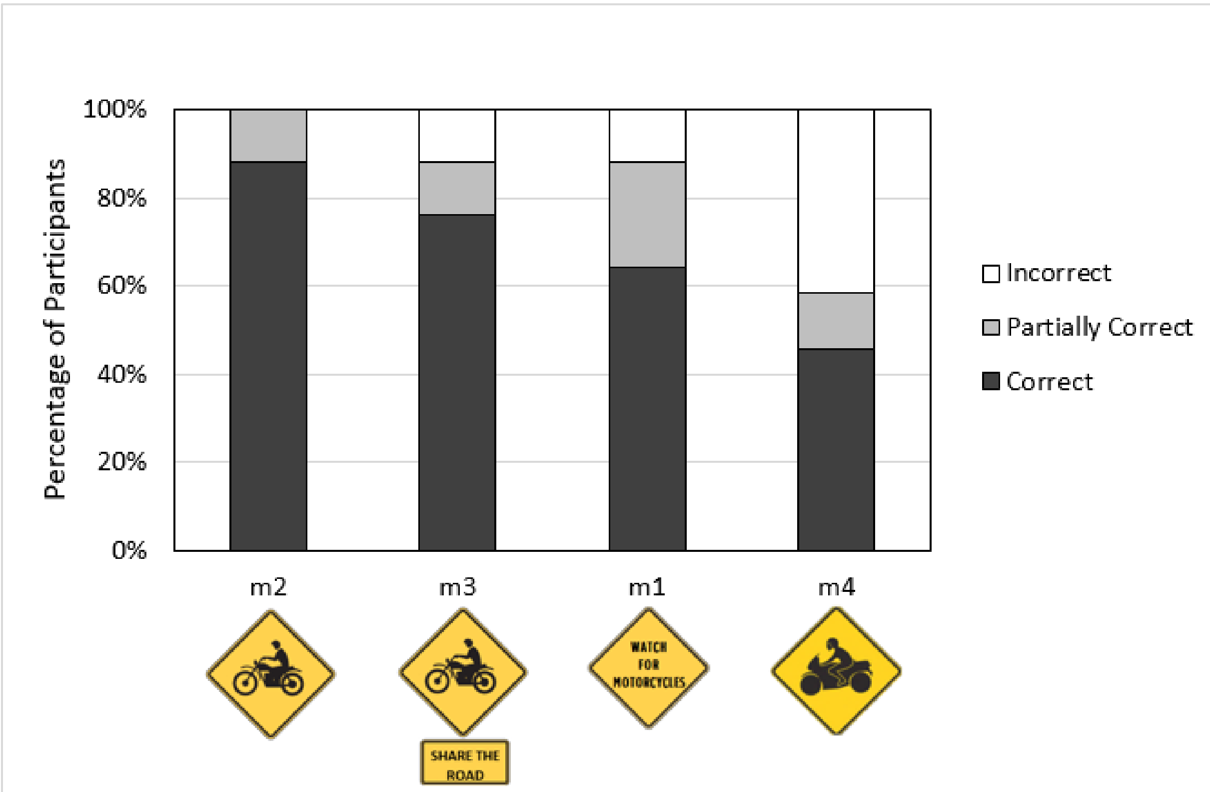
Sign Meaning

The open-ended question "What does this sign mean?" was used to evaluate participants' initial comprehension of each sign. Responses were coded as correct, partially correct, or incorrect by a trained coder. The coder was blind to all demographic information about the participant, including whether each participant was a motorcyclist. The research team then analyzed the responses using χ^2 tests. As discussed in chapter 2, this test is used to determine the probability (*p* value) that the responses obtained in the study occurred at random. When the probability of obtaining a result at random is less than 5 percent (i.e., $p < 0.05$), the result is considered statistically significant and assumed to be a result of the variable that was measured (rather than due to random chance).

For each of the sign types, the research team used χ^2 tests to assess the potential influence of the specific sign being tested (i.e., effect of sign), the potential influence of being a motorcyclist (i.e., effect of participant group), and the potential that the results depended on a combination of both the sign that was being tested and participant group (i.e., interaction of sign and participant group). Only those effects that were statistically significant at a 95-percent confidence interval are reported. In the current set of meaning analyses for signs, the potential influence of participant age was also assessed. However, age did not significantly affect sign meaning responses for any of the sign types and is therefore not reported. When a variable with more than two values (such as sign) was found to be significant, post hoc tests were conducted to determine the specific source of the effect. When conducting these pairwise followup tests, a Tukey–Kramer multiple comparison correction was applied. Conducting multiple post hoc tests can artificially inflate the probability that a result will be found to be significant. The Tukey–Kramer correction prevents this by ensuring that a post hoc test is not considered statistically significant unless the combined probability of all post hoc tests conducted for a specific variable remains less than 5 percent regardless of the number of tests conducted.

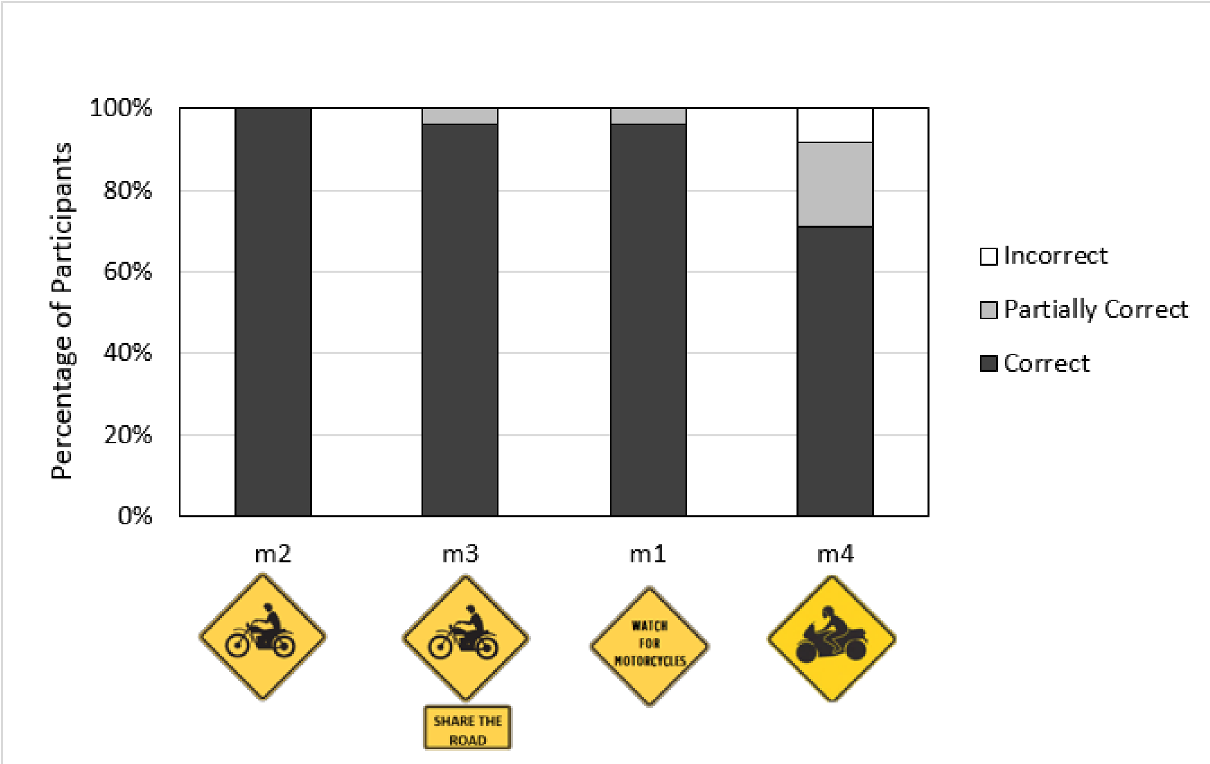
Motorcycle Awareness

Figure 32 displays the percentage of correct, partially correct, and incorrect descriptions of motorcycle-awareness signs for motorcyclists (figure 32-A) and nonmotorcyclists (figure 32-B). Percentage of correct descriptions varied by sign type, $\chi^2(3) = 33.07$, $p < 0.001$, indicating that whether a participant was able to correctly describe the sign depended on the specific sign being tested. Followup tests indicated that sign m2 was correctly described by a higher percentage of participants (94 percent) than sign m4 (58.3 percent). Across all signs, the percentage of correct descriptions was higher for nonmotorcyclists (90.1 percent) than for motorcyclists (68.7 percent), $\chi^2(1) = 19.11$, $p < 0.001$. However, this difference between participant groups was not present for sign m2, as indicated by a significant sign by participant group interaction, $\chi^2(3) = 8.42$, $p = 0.038$. When asked the meaning of sign m2, a high proportion of participants were able to describe the sign correctly. For the other motorcycle-awareness signs, the percentage of correct descriptions was higher for nonmotorcycle riders than for motorcyclists.



Source: FHWA.

A. Percentage of correct, partially correct, and incorrect descriptions for motorcycle-awareness signs among motorcyclists.



Source: FHWA.

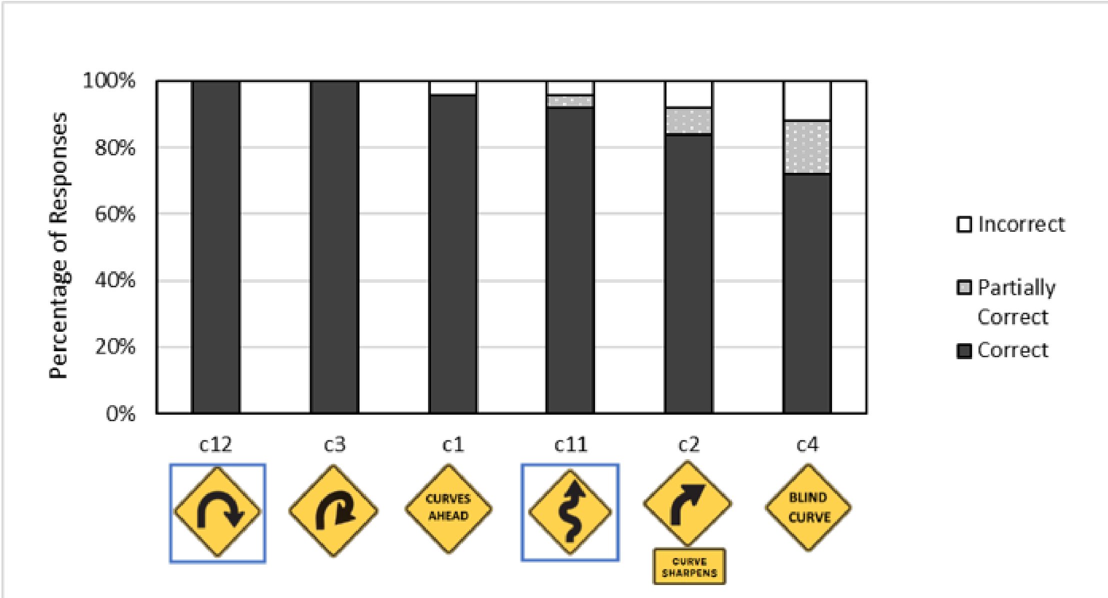
B. Percentage of correct, partially correct, and incorrect descriptions for motorcycle-awareness signs among nonmotorcyclists.

Figure 32. Graphs. Percentage of correct, partially correct, and incorrect descriptions for motorcycle-awareness signs as a function of sign and participant group.

Advance Curve Warning

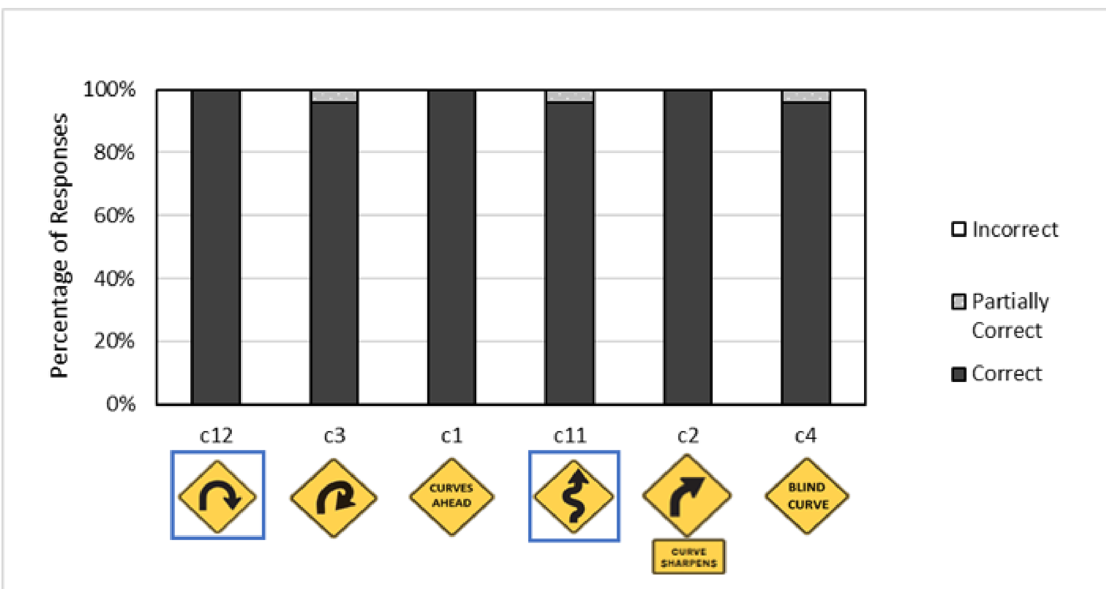
For advance curve-warning signs, the percentage of correct descriptions varied by sign, $\chi^2(5) = 18.47$, $p = 0.002$, and participant group, $\chi^2(1) = 10.20$, $p = 0.001$. A significant sign by participant group interaction was also found, $\chi^2(5) = 13.34$, $p = 0.020$, indicating that message comprehension depended both on the sign being tested and on whether or not the participant was a motorcyclist or a nonmotorcyclist. The following figure displays the percentage of correct, partially correct, and incorrect descriptions for each sign among motorcyclists (figure 33-A) and nonmotorcyclists (figure 33-B). Among motorcyclists, a greater percentage of participants correctly described signs c3 and c12 than sign c4. No statistically significant differences between signs were found for nonmotorcyclists. The results indicate that while nonmotorcyclists were able to comprehend all signs, initial comprehension among motorcyclists was greater for signs c12 and c3 than for sign c4.

Advance curve-warning signs can be supplemented with speed-advisory plaques; however, the current study did not evaluate the potential effects that such plaques may have on comprehension. Thus, the current findings are based only on comprehension of the signs themselves.



Source: FHWA.
Note: Signs that are already included in the MUTCD are marked with blue boxes.

A. Percentage of correct, partially correct, and incorrect descriptions for advance curve-warning signs among motorcyclists.



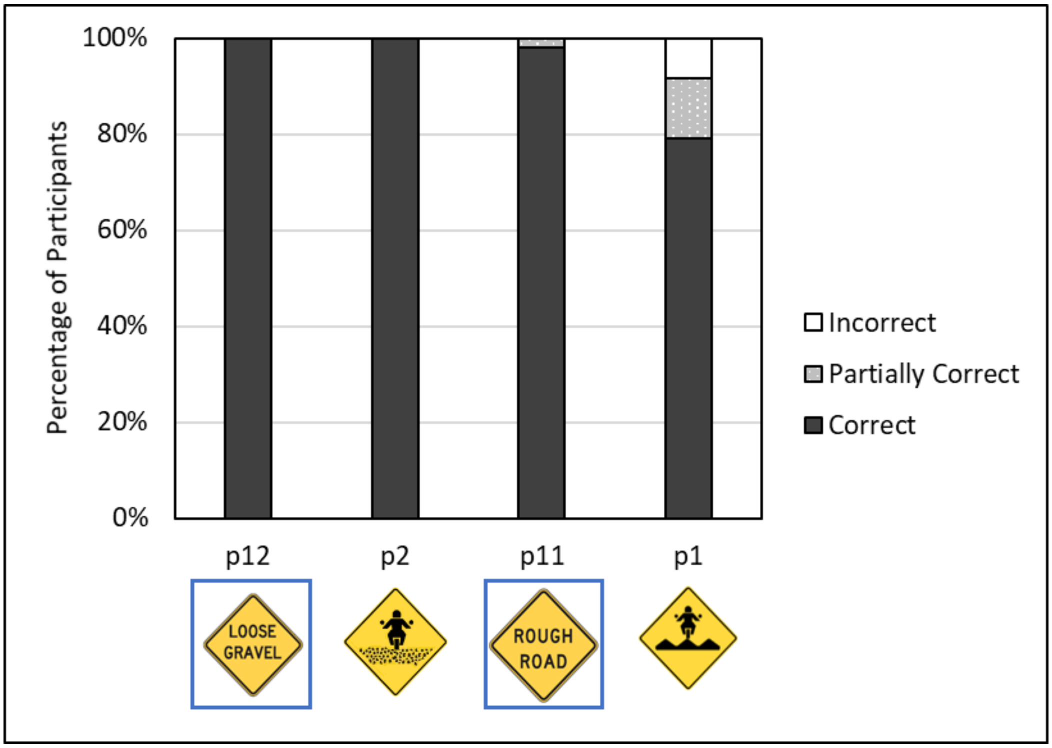
Source: FHWA.
Note: Signs that are already included in the MUTCD are marked with blue boxes.

B. Percentage of correct, partially correct, and incorrect descriptions for advance curve-warning signs among nonmotorcyclists.

Figure 33. Graphs. Percentage of correct, partially correct, and incorrect descriptions for advance curve-warning signs as a function of sign and participant group.

Pavement Condition

For pavement-condition signs, only a main effect of sign was significant, $\chi^2(3) = 12.89$, $p = 0.004$, indicating that the percentage of correct descriptions varied by the sign being tested, but was not influenced by participant group. As displayed in figure 34, participants correctly described sign p1 less often than any of the other pavement-condition signs. Participants found sign p1 more difficult to comprehend than other such signs, which they were almost always able to describe correctly.

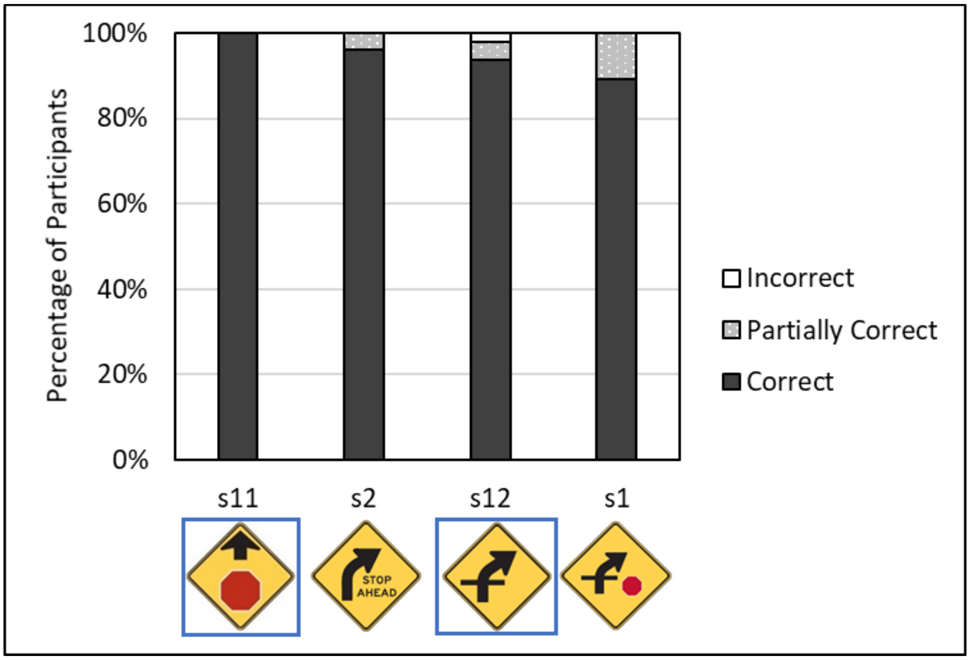


Source: FHWA.
Note: Signs that are already included in the MUTCD are marked with blue boxes.

Figure 34. Graph. Percentage of correct, partially correct, and incorrect descriptions for pavement-condition signs.

Limited Sight Distance

Figure 35 displays the percentage of correct, partially correct, and incorrect descriptions for limited-sight-distance signs. A main effect of sign was found, $\chi^2(3) = 10.25$, $p = 0.017$; however, none of the differences between the signs remained significant after correction for multiple comparisons. All signs were described correctly by the large majority of participants.



Source: FHWA.
Note: Signs that are already included in the MUTCD are marked with blue boxes.

Figure 35. Graph. Percentage of correct, partially correct, and incorrect descriptions for limited-sight-distance signs.

Intended Audience

After describing the meaning of a sign, participants were asked who the sign was for and open-ended responses were recorded. A trained coder classified the responses. Categories that included less than 1 percent of responses were combined into one “other responses” category. Four response categories were found: “all road users,” which made up 74.5 percent of responses; “motorcyclists,” which made up 4.5 percent of responses; “car and/or truck drivers,” which made up 19 percent of responses, and “other responses,” which made up 2 percent of responses.

The research team analyzed the data for significant differences using a multinomial logistic regression with a generalized logit link function to account for the nominal categorical responses. This statistical test is used to analyze nominal data, or data that fit into categories, as opposed to numerical data. The potential influence of the sign being tested, participant group, and age were explored for each sign type.

Motorcycle Awareness

Table 4 shows the number of responses that fell into each of the four response categories for each of the motorcycle-awareness signs. Most participants reported that the motorcycle-awareness signs applied to all road users. Almost one-fifth of participants reported that these signs applied to car and truck drivers. There was not a significant difference in response categorization for the four different signs. Responses were also not influenced by participant group or age.

Table 4. Percentage of intended audience responses that fell into each response category for each motorcycle-awareness sign.

Response Category	m1	m2	m3	m4
All road users	78	74	76	70
Motorcyclists	4	0	0	14
Car/truck drivers	18	24	22	12
Other responses	0	2	2	4

Advance Curve Warning

There were no significant differences in responses to advance curve-warning signs. Neither sign type nor participant group nor participant age had an effect. As displayed in table 5, almost all participants reported that the advance curve-warning signs were meant for all road users.

Table 5. Percentage of intended audience responses that fell into each response category for each advance curve-warning sign.

Response Category	c11	c12	c1	c2	c3	c4
All road users	96	96	98	98	92	96
Motorcyclists	2	0	0	0	2	2
Car/truck drivers	0	4	0	2	2	0
Other	2	0	2	0	4	2

Pavement Condition

Table 6 shows the number of responses that fell into each of the four response categories for each of the pavement-condition signs. A main effect of sign was found, $F(9,182) = 5.72$, $p < 0.001$. Participants tended to report that signs p11 and p12, the text-based signs that are already part of the MUTCD, were meant for all road users. In contrast, signs p1 and p2, which contained images of motorcycles, were significantly more likely to be described as intended for motorcyclists. This categorization was consistent across motorcyclists and nonmotorcyclists and did not vary by age.

Table 6. Percentage of intended audience responses that fell into each response category for each pavement-condition sign.

Response Category	p11	p12	p1	p2
All road users	98	86	32	24
Motorcyclists	2	12	64	72
Car/truck drivers	0	0	2	0
Other	0	2	2	4

Limited Sight Distance

As displayed in table 7, almost all participants reported that limited-sight-distance signs were intended for all road users. Responses did not vary as a function of sign, participant group, or age.

Table 7. Percentage of intended audience responses that fell into each response category for each limited-sight-distance sign.

Response Category	s11	s12	s1	s2
All road users	98	98	92	92
Motorcyclists	0	0	6	6
Car/truck drivers	0	0	0	0
Other	2	2	2	2

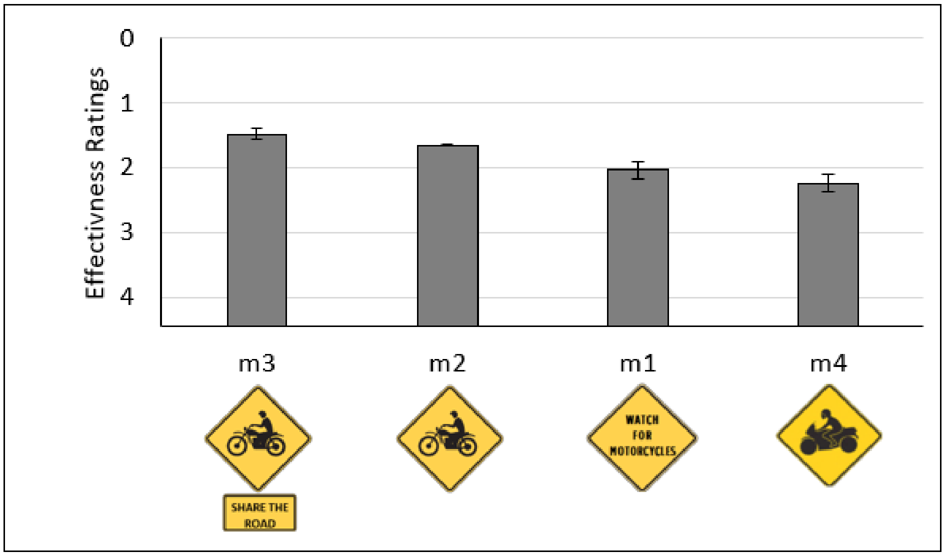
Sign Effectiveness Ratings

Participants were also asked to rate the effectiveness of each sign at conveying its intended meaning on a scale from 1 to 4, where 1 indicated very effective, 2 indicated somewhat effective, 3 indicated somewhat ineffective, and 4 indicated not at all effective. The research team used χ^2 tests to assess the potential influence of the specific sign being tested (i.e., effect of sign), the potential influence of being a motorcyclist (i.e., effect of participant group), and the potential influence of age (i.e., effect of age), as well as the potential that the results depended on a combination of these factors (i.e., interactions). Only those effects that were statistically significant are reported. When a significant effect was found, pairwise followup tests were conducted using Tukey–Kramer corrections for multiple comparisons. Note that the graphs in this portion of the report have inverted axes, such that larger bars correspond to increased ratings of effectiveness.

To foreshadow the following results, none of the main effects of the participant group were significant, indicating that effectiveness ratings were similar for both motorcyclists and nonmotorcyclists. However, there was a statistically significant interaction between the participant group and the sign for pavement-condition signs. In other words, ratings of the effectiveness of specific pavement-condition signs were different for participants who were motorcyclists than for participants who were not part of the motorcycle riding group. The details of this interaction are described in the section on pavement condition. For all sign types, a small but significant effect of age was found. Older participants tended to rate all signs as more effective than younger participants, likely a result of the older participants' increased experience responding to signs while driving.

Motorcycle Awareness

Mean effectiveness ratings for the four signs designed to increase motorcycle awareness are displayed in figure 36. Significant differences in effectiveness were found as an effect of sign, $\chi^2(3) = 69.52$, $p < 0.001$. Sign m3, which included a plaque, was rated as significantly more effective than signs m1 or m4. Sign m2 was rated as significantly more effective than sign m4. Ratings for signs m1 and m4 were not significantly different from each other. There was also a positive relationship between age and effectiveness ratings, $\chi^2(1) = 4.15$, $p = 0.040$. Older participants tended to rate all the motorcycle-awareness signs as more effective than younger participants.

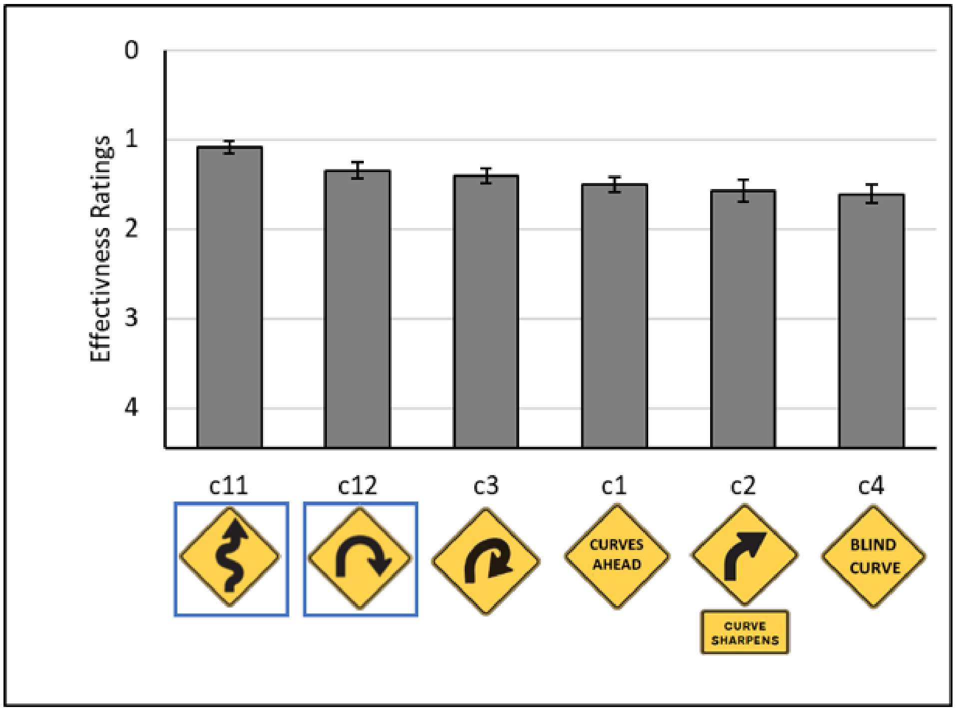


Source: FHWA.
Note: Error bars represent standard errors.

Figure 36. Mean effectiveness ratings for motorcycle-awareness signs.

Advance Curve Warning

There was a significant difference in effectiveness ratings found among the different advance curve-warning signs, $\chi^2(5) = 24.43$, $p = 0.001$ (figure 37). Sign c11 was rated as more effective than any of the novel advance curve-warning signs (c3, c1, c2, or c4). Effectiveness ratings for all the other advance curve-warning signs did not differ significantly from one another. There was also a positive relationship between age and effectiveness ratings, $\chi^2(1) = 13.37$, $p = 0.001$. Effectiveness ratings for all advance curve-warning signs tended to increase with participant age.

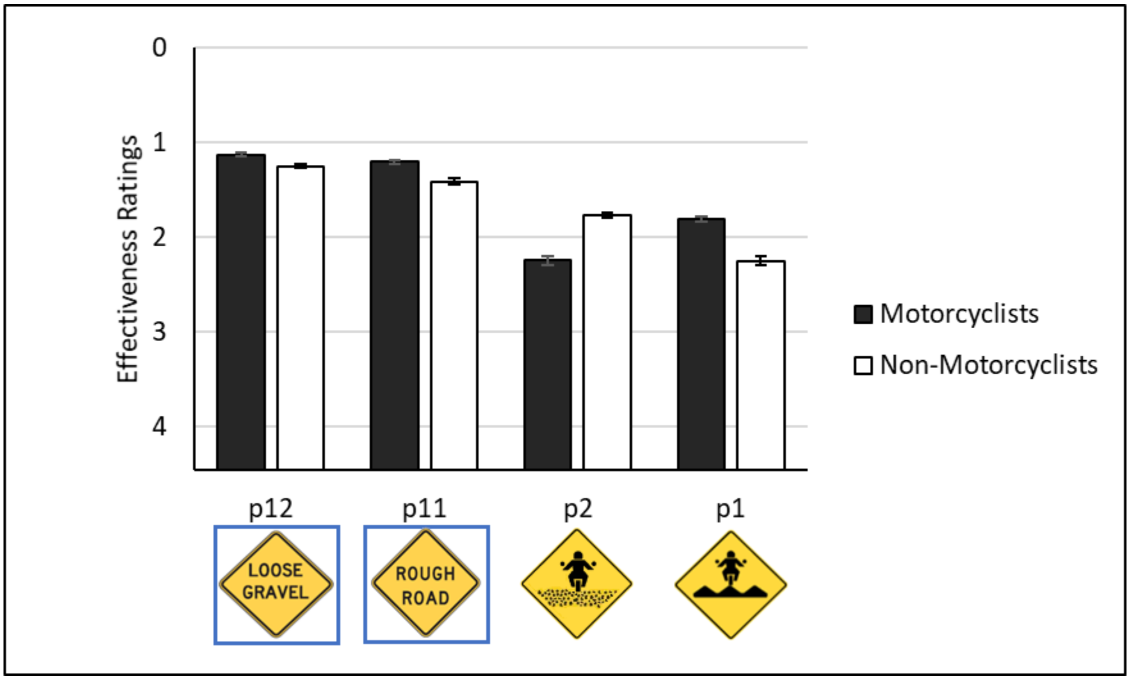


Source: FHWA.
Notes: Signs that are already included in the MUTCD are marked with blue boxes. Error bars represent standard errors.

Figure 37. Graph. Mean effectiveness ratings for advance curve-warning signs.

Pavement Condition

Effectiveness ratings for pavement-condition signs varied as an effect of sign, $\chi^2(3) = 41.46$, $p < 0.001$. This effect was qualified by a sign by participant group interaction, $\chi^2(3) = 104.04$, $p = 0.018$, meaning the effectiveness ratings varied depending on whether the participant was a motorcyclist or a nonmotorcyclist. Figure 38 displays the effectiveness of pavement-condition signs as a function of both sign and participant group. Motorcyclists rated signs p12 and p11, the two signs that are already part of the MUTCD, as significantly more effective than signs p2 and p1. Nonmotorcyclists rated sign p12 as significantly more effective than p1 but indicated that sign p11 and p2 had similar levels of effectiveness. Once again, there was also a significant positive relationship between age and effectiveness ratings, $\chi^2(1) = 4.96$, $p = 0.026$, such that older participants tended to rate all pavement-condition signs as more effective than younger participants.

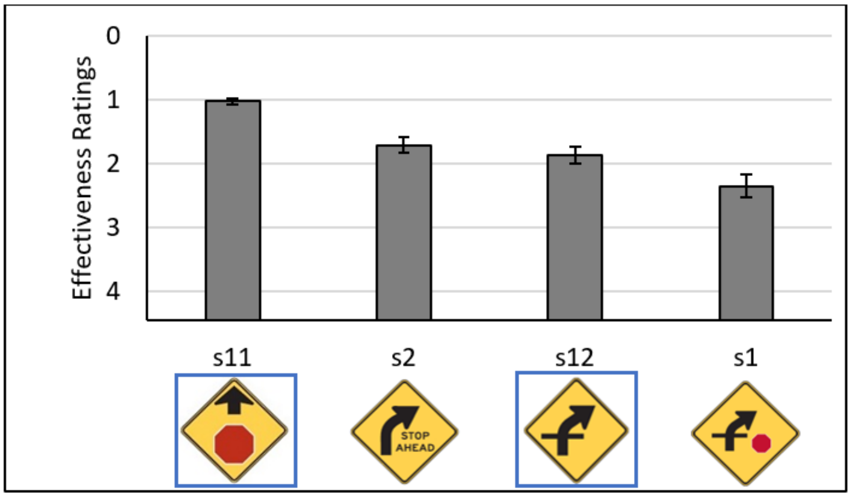


Source: FHWA.
Notes: Signs that are already included in the MUTCD are marked with blue boxes. Error bars represent standard errors.

Figure 38. Graph. Mean effectiveness ratings for pavement-condition signs.

Limited Sight Distance

The effectiveness ratings of the limited-sight-distance signs were influenced by the specific sign being tested, $\chi^2(3) = 85.01$, $p < 0.001$. As shown in figure 39, sign s11 (Stop Ahead) was rated as significantly more effective at conveying its intended meaning than any of the other limited-sight-distance signs (s2, s12, s1). Sign s2, which included text, was rated as being more effective than sign s1, which did not include text. Effectiveness ratings for sign s12 (Combination Horizontal Alignment and Intersection sign) did not differ from the ratings for signs s2 or s1. There was also a positive relationship between age and effectiveness ratings, $\chi^2(1) = 6.62$, $p = 0.010$, such that effectiveness ratings for all limited-sight-distance signs increased with age.



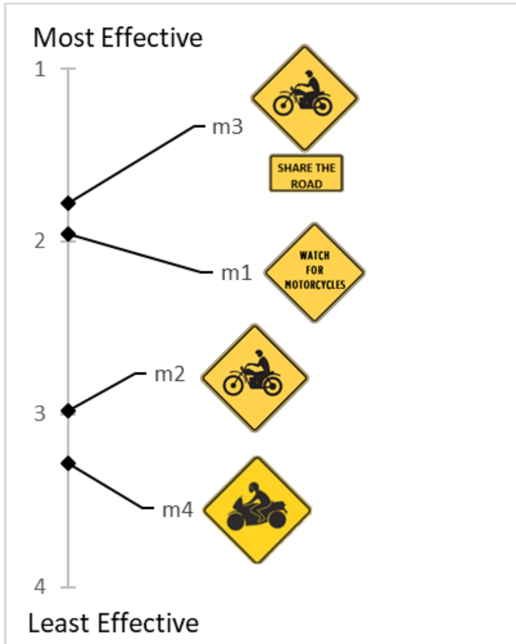
Source: FHWA.
Notes: Signs that are already included in the MUTCD are marked with blue boxes.
Error bars represent standard errors.

Figure 39. Graph. Mean effectiveness ratings for limited-sight-distance signs.

Sign Rankings

Sign rankings provided an additional assessment of the effectiveness of the motorcycle-awareness signs. Participants were asked to rank each sign from most to least effective. Mean values were calculated to compare rankings. Since messages were ranked from first to last in effectiveness, lower mean values indicate that the message was more effective. To determine if the rankings were significantly different from each other, Friedman rank tests were calculated. The Friedman rank test is a nonparametric analysis of variance appropriate for ranking data. It is used to determine whether there are statistically significant differences between data when data are not normally distributed.

Mean rankings of the motorcycle-awareness signs are displayed in figure 40. Signs m3 and m1 were ranked as more effective than signs m2 and m4, $\chi^2(3) = 69.52$, $p < 0.001$. Participant group did not influence sign rankings.



Source: FHWA.

Figure 40. Graph. Mean sign rankings.

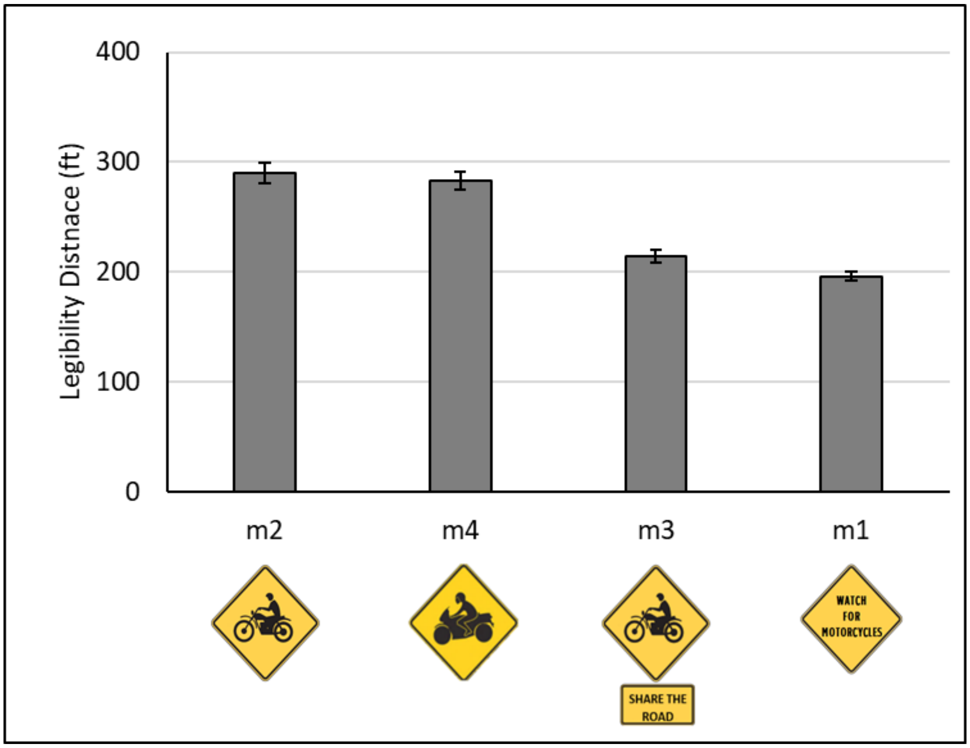
Legibility Distance

Signs with greater legibility distance have a better chance of being seen and obtaining a response. The research team used χ^2 tests to analyze legibility distances for each sign type. The potential influence of the specific sign being tested (i.e., effect of sign), the potential influence of being a motorcyclist (i.e., effect of group), and the potential influence of age (i.e., effect of age) were explored. The potential for legibility distance to be influenced by a combination of these variables was also explored (i.e., interactions). Significant effects were explored using a Tukey–Kramer multiple comparison correction, and only significant effects are reported.

To foreshadow the results reported in this section, none of the effects of participant group were significant within the current study. That is, both motorcyclists and nonmotorcyclists were able to identify the signs at similar distances. As is typical in studies of legibility, legibility distance had a negative association with age, such that younger participants were able to see signs at greater distances than older participants. In addition, signs that featured symbols tended to be legible from farther away than signs that included text.

Motorcycle Awareness

Mean legibility distances for the four signs designed to increase motorcycle awareness are displayed in figure 41. Significant differences in legibility distance were found for the different signs, $\chi^2(3) = 55.70$, $p < 0.001$. Signs m2 and m4, the two symbol signs, were legible at a significantly farther distance than signs m3 and m1, the two signs that contained words. Of the signs containing words, m3, which combined a symbol and a word plaque, was able to be seen from farther away than sign m1. There was also a negative relationship between age and legibility distance, $\chi^2(1) = 20.44$, $p < 0.001$. Older participants had reduced legibility distances for all motorcycle-awareness signs compared to younger participants.

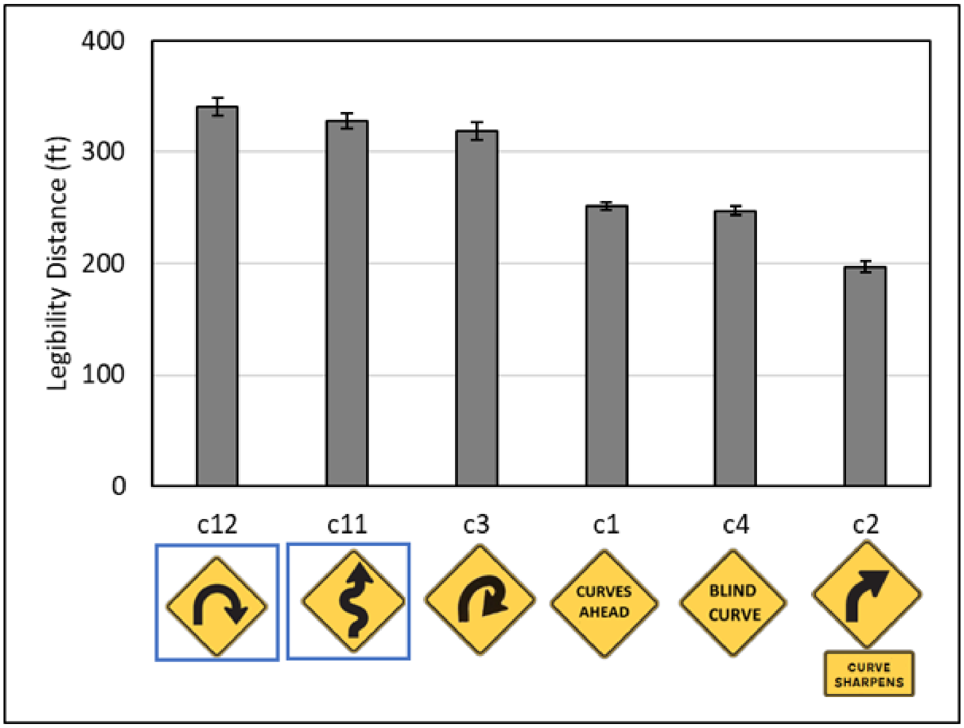


Source: FHWA.
Note: Error bars represent standard errors.

Figure 41. Graph. Mean legibility distances for motorcycle-awareness signs.

Advance Curve Warning

Significant differences in legibility distances were found among advance curve-warning signs, $\chi^2(5) = 91.58$, $p < 0.001$ (figure 42). Symbol signs c12, c11, and c3 had significantly greater legibility distances than all other signs. Signs c1 and c4, which were made up of text, were legible at a farther distance than sign c2, which included a text-based plaque. As expected, there was also a negative relationship between age and legibility distance, $\chi^2(1) = 26.15$, $p < 0.001$, such that as participant age increased, the distance at which the advance curve-warning sign was legible decreased.

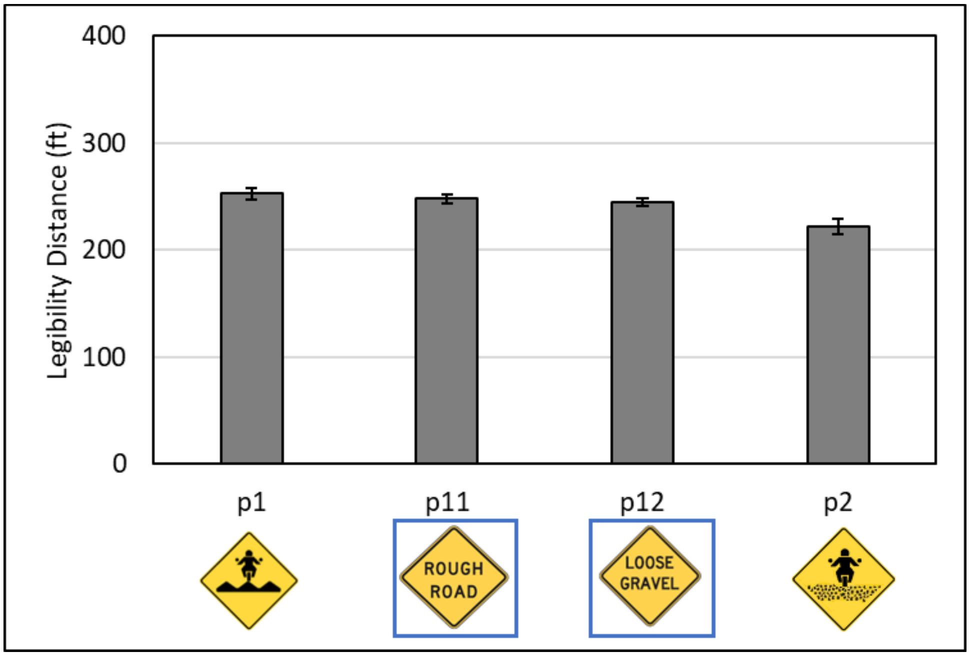


Source: FHWA.
Notes: Signs that are already included in the MUTCD are marked with blue boxes. Error bars represent standard errors.

Figure 42. Graph. Mean legibility distance for advance curve-warning signs.

Pavement Condition

Legibility distances for pavement-condition signs are displayed in figure 43. The effect of sign was significant, $\chi^2(3) = 28.61$, $p = 0.001$. The legibility distance of sign p2 was significantly less than that found for other pavement-condition signs, which did not differ from each other. There was also a negative relationship between age and legibility distance, $\chi^2(1) = 20.44$, $p < 0.001$. Older participants had reduced legibility distances for all pavement-condition signs relative to younger participants.

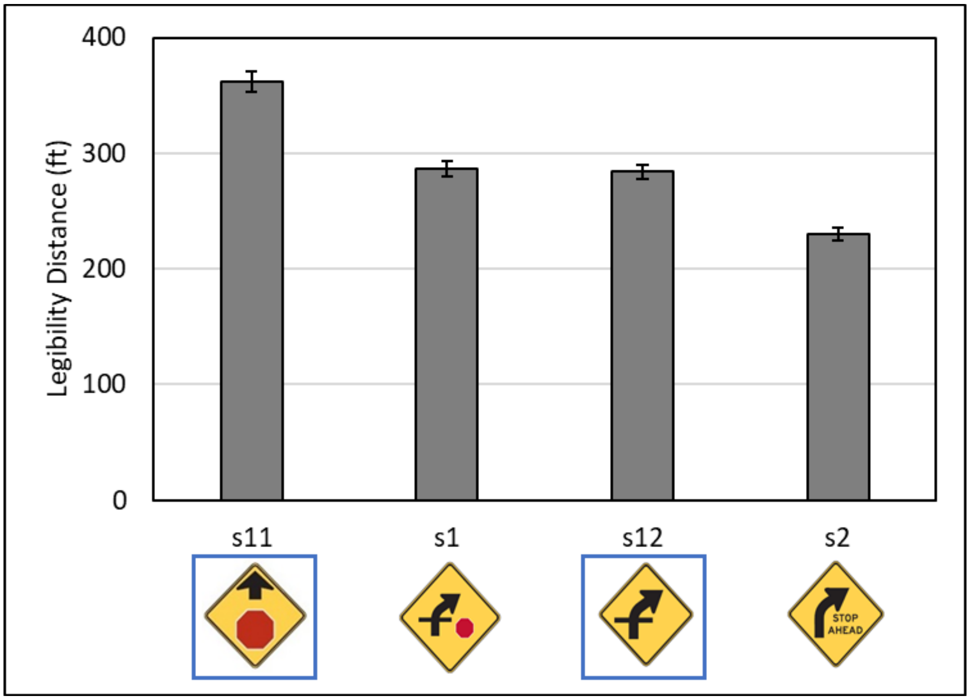


Source: FHWA.
Notes: Signs that are already included in the MUTCD are marked with blue boxes. Error bars represent standard errors.

Figure 43. Graph. Mean legibility distance for pavement-condition signs.

Limited Sight Distance

Significant differences in legibility distances were also found among the limited-sight-distance signs, $\chi^2(3) = 2173.84$, $p < 0.001$. As shown in figure 44, sign s11 (Stop Ahead) was legible at a farther distance than any of the other signs. Sign s1 had a legibility distance that did not differ significantly from that found for sign s12 (Combination Horizontal Alignment and Intersection sign). However, sign s2, which included text, had a significantly smaller legibility distance than any of the other limited-sight-distance signs. The effect of age was once again significant, $\chi^2(1) = 27.37$, $p < 0.001$. The older the participant, the smaller the legibility distance for the signs.

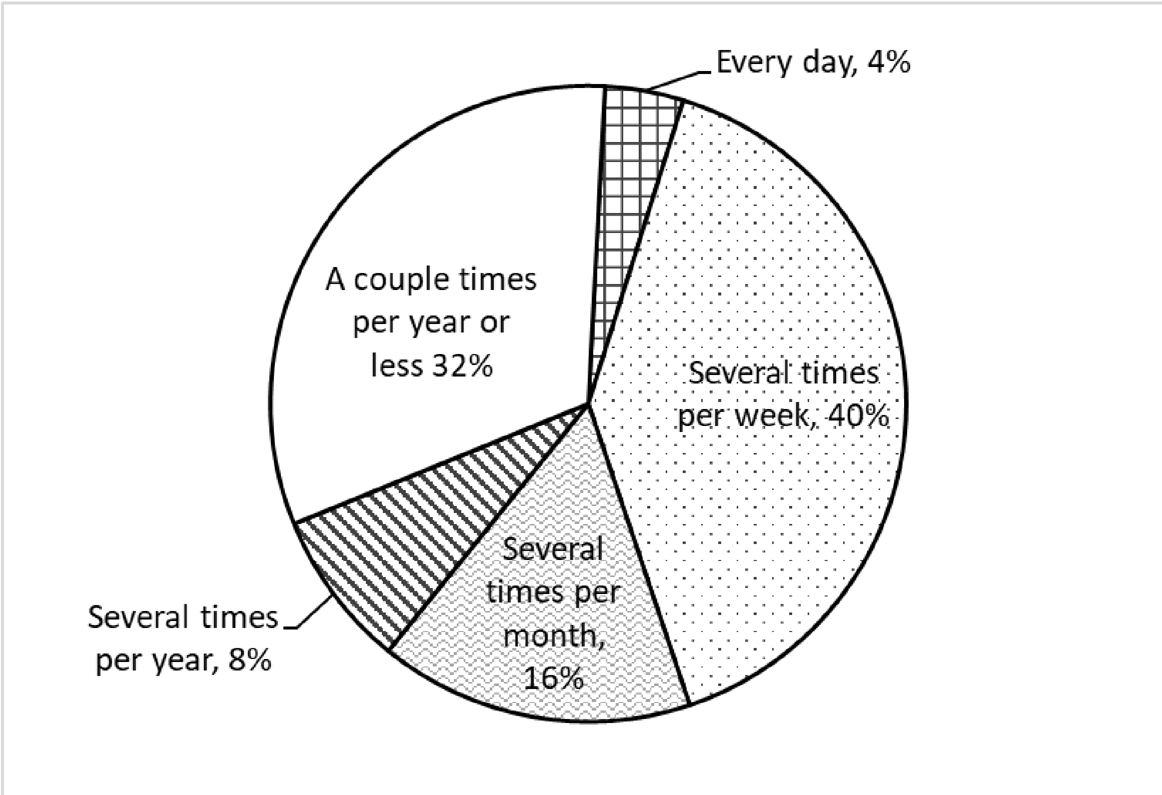


Source: FHWA.
Notes: Signs that are already included in the MUTCD are marked with blue boxes. Error bars represent standard errors.

Figure 44. Graph. Mean legibility distance for limited-sight-distance signs.

Motorcyclist Demographics

A range of motorcyclists participated in the study. When asked how long they had been riding, participants responded with a range of 2 to 56 yr. The average ride time was 24.1 yr (standard deviation = 16.6 yr). Participants were also asked how frequently they currently ride their motorcycle. The frequency that each response option was selected is displayed in figure 45. Almost half of all participants indicated that they rode their motorcycle several times a week. Another third of participants indicated that they rode only a couple of times per year or less.



Source: FHWA.

Figure 45. Graph. Percentage of motorcyclists indicating how frequently they currently ride their motorcycle.

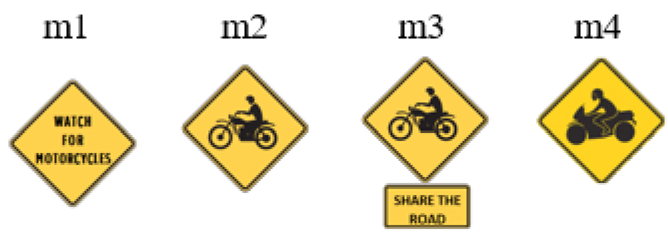
DISCUSSION

The current experiment examined comprehension and legibility rates for a set of novel signs designed as motorcycle-crash countermeasures. The results provide important insights as to the potential use of various novel motorcycle sign alternatives for the four areas of interest: motorcycle awareness, advance curve warning, pavement condition, and limited sight distance. This section of the report synthesizes the results of the sign comprehension and legibility assessments that were conducted within each of these areas.

In addition to the area-specific discussion, a few other general trends emerged as a part of the evaluations. Overall, the signs tended to perform equally well across motorcyclists and nonmotorcyclists, with a few exceptions. Differences did tend to emerge, however, with respect to the age of the participants. In general, older participants tended to assess the signs as more effective compared to younger participants. This result is likely to reflect the increased experience that older participants have using signs while driving. Older participants also showed reduced legibility distances compared to younger participants, a finding that is reflective of physiological differences associated with aging.

Motorcycle Awareness

The intent of motorcycle-awareness signs, illustrated in figure 46, is to increase awareness among the broader driving population (i.e., both motorcyclists and nonmotorcyclists) of the presence of motorcycles on the roadway. The goal is to change road users' mental models of vehicles on the roadway to include motorcycles and thus reduce the potential that drivers will act in ways that may be dangerous to motorcyclists. To this end, it is interesting to note that this series of signs were correctly described at a higher rate among nonmotorcyclists (90.1 percent) than motorcyclists (68.7 percent), except for sign m2. The nature of this result is unclear and may reflect the sample of motorcyclists who participated in this study as similar results were shown for several of the sign comparisons.



Source: FHWA.

Figure 46. Illustration. Motorcycle-awareness sign alternatives.

Sign m2, which included the image of the motorcycle from Motorcycle plaque W8-15P was correctly described by the highest percentage of respondents, while sign m4 showed the lowest comprehension. The latter sign illustrates a sports bike, which shows less clearly defined features than signs m2 and m3, both of which show a cruiser-style motorcycle. Sign m3 includes a supplementary plaque (reading Share the Road), which appeared to aid in comprehension. Sign m3 had the highest comprehension ratings. When asked to rank the effectiveness of the group of novel motorcycle signs, the signs that included text, m3 and m1, were rated more positively than those signs that included only images. However, these same signs had reduced legibility compared to the symbol-based signs. Ultimately, these results demonstrate important differences in sign efficacy. The symbol-based signs are generally recognizable at greater distances, but they tend to be less well understood. Among the candidate signs, m4 appears to be the least effective, while the other signs present more promising alternatives for field deployment.

One potential concern noted by motorcyclists who completed the online questionnaire was that motorcycle-awareness signs may be confused with vehicular-traffic-warning signs, which are designed to warn drivers about locations where unexpected, slow-moving vehicles, such as tractors or bicycles, may enter or cross the roadway. The novel motorcycle-awareness signs tested in this study are intended to provide awareness to a specific vehicle type (motorcycles) that are traveling on the roadway with other road users. Concern that drivers may misinterpret these signs based on their similarity to vehicular-traffic-warning signs that are part of the MUTCD led to the creation of sign m3, which includes a Share the Road plaque. However, the results of the comprehension testing conducted as part of this study suggest that this concern may have been unwarranted. The meaning of sign m2, the sign that was most similar to the vehicular traffic–warning signs, was correctly described by 94 percent of participants, a percentage that was higher than all of the other motorcycle-awareness signs, including sign m3. The results suggest that drivers are correctly able to interpret motorcycle-awareness signs.

Motorcycle-awareness signs show potential to increase motorcycle safety. However, it is important to note that the use and placement of these types of signs are likely to present some practical challenges. Motorcycle-awareness signs are likely to be most effective in locations that are prone to high volumes of motorcycle traffic and activity. Similar Share the Road signs are frequently used to alert road users of locations that are subject to high levels of bicycle traffic. In general, such locations are relatively straightforward to identify as bicycle-involved trips tend to be of shorter length and generally occur in either urban areas with well-established bicycle networks or along recreational bike routes. In contrast, motorcycle traffic tends to be significantly more dispersed across the road network, and it will likely be challenging to identify candidate locations for motorcycle-awareness signs.

Advance Curve Warning

Advance curve-warning signs, shown in table 8, are of particular interest since prior research has consistently shown that crash risks among motorcyclists are very pronounced at sharp curves.[15] These signs also introduce benefits for other (nonmotorcycle) vehicles as the crash risks for all vehicles tend to be greater on curves.

Table 8. Advance curve-warning signs.

MUTCD Advance Curve-Warning Signs	Novel Advance Curve-Warning Signs
c11 c12 	c1 c2 c3 c4 

Source: FHWA.

The largest percentage of respondents correctly described novel sign c3 and existing sign c12. Both signs are reflective of very tight curves, with sign c3 showing a slightly more exaggerated, sharper curve. The results suggest that symbol-based signs that indicate sharper curvature are easy to understand. In contrast, sign c4 (Blind Curve) was the least well understood. Since this sign is text based, this could suggest a comprehension issue where respondents are not familiar with the terminology (i.e., what a blind curve is). Similarly, the inability of drivers to understand terminology is the reason the limited-sight-distance sign shown in figure 13 was removed from the MUTCD.[52] In assessing comprehension ratings, the Winding Road sign (c11) was rated highest among the six alternatives.

Legibility distance for advance curve-warning signs followed the same general trends as those for motorcycle-awareness signs. The symbol-based signs (c12, c11, and c3) showed greater legibility distances than the signs that included only text (c1 and c4). The Curve sign with a

Curve Sharpens plaque (c2) had the shortest legibility distance. Collectively, the results in this area tend to suggest that signs with symbols may be most effective for both comprehension and legibility. However, it is not necessarily advisable to use a symbol that overstates the sharpness of the upcoming curve. Thus, while sign c3 shows high potential value as an advance curve-warning sign, installation of the sign would need to be carefully considered to ensure that the tightness of the curve in the warning sign is an accurate representation of the curve on the roadway.

Pavement Condition

Pavement-condition signs, shown in table 9, include two traditional text-based signs (p11, Rough Road, and p12, Loose Gravel) as well as two symbol-based signs (p1 and p2) that are similar to those used in some other countries.[(44)] Comprehension was very high and similar for all except for sign p1, which shows a motorcyclist riding over a rough road. It appears respondents had difficulty identifying the specific hazard being featured in sign p1. In contrast, sign p2 shows a depiction of loose gravel that was more easily discernible to the study participants. Signs p1 and p2 were the only signs participants described as specifically intended for motorcyclists more frequently than being intended for all road users, a finding resulting from the use of motorcycle images on the sign. Although the motorcyclist image on the sign allowed the sign to target motorcyclists, it did not increase the comprehension ratings among that group. Motorcyclists rated the traditional text-based signs (p12 and p11) as more effective at conveying their intended meanings than the novel signs (p1 and p2). These differences were less pronounced among nonmotorcyclists. For the novel signs, p1 was rated as more effective by motorcyclists and p2 was rated as more effective by nonmotorcyclists, although these differences were not statistically significant. Sign p2, where the gravel appears to be somewhat inconspicuous, showed reduced legibility distance relative to the other signs.

Table 9. Pavement-condition signs.

MUTCD Pavement-Condition Signs	Novel Pavement-Condition Signs
p11  p12 	p1  p2 

Source: FHWA.

Based on the current results, it is unlikely that the novel signs would be more effective crash countermeasures than the existing text-based signs. However, sign p1 may be a candidate for installation in situations where a text-based sign would not be appropriate, such as on a roadway where English is not the native language for many motorcyclists. In such situations sign p1 could be used to warn riders about the presence of transverse rumble strips (e.g., upstream of stop-controlled intersections or work zones), which represent a particular safety challenge for motorcyclists. Other locations of interest include bridge decks or locations where pavement conditions have been shown to be a contributing factor to motorcycle crashes.[(39)]

Limited Sight Distance

Four signs that focused on alerting drivers to locations where sight-distance limitations exist were evaluated (table 10). The limited-sight-distance signs included two traditional symbol-based options: a Stop Ahead sign (s11) and a sign indicating the presence of an intersection along a horizontal curve (s12). The novel signs both included a horizontal curve symbol paired with either a text-based Stop Ahead message (s2) or the combination of symbol-based intersection and stop-sign messages (s1).

Table 10. Limited-sight-distance signs.

MUTCD Limited-Sight-Distance Signs	Novel Limited-Sight-Distance Signs
s11  s12 	s1  s2 

Source: FHWA.

When asked to describe the meaning of each sign, participants were able to describe all four signs with almost perfect accuracy. The results of the effectiveness ratings indicated that the Stop Ahead sign (s11) was significantly more effective than the other three signs. This sign was also identified at greater distances as compared to the three alternatives. Sign s2 had greater comprehension ratings than sign s1, but smaller legibility distances. These results are consistent with the findings for the other sign types. The text featured in sign s2 made this sign easier to comprehend than the symbols in sign s1, but the small text also made it more difficult to identify from a distance.

It is important to note that sign s11, which was tested as part of the limited-sight-distance signs, is intended to be used in different context than the other signs that were tested. Although sign s11 tended to show the best performance among the four alternatives, from a safety perspective, this type of sign would appear to have the least utility for motorcyclists. Sign s11 is indicative of a circumstance where a stop sign is ahead on the approach along which the driver is traveling. In contrast, signs s12, s1, and s2 reference a situation where a curve in the roads limits the road user's ability to see a cross street. In the case of sign s1 and s2, the road user will be required to stop at that cross street. Using the signs that are included in the most current version of the MUTCD, warning road users about this situation would require multiple signs. For example, sign s11 would be used in sequence with an additional curve-warning sign. Given the success of the current comprehension study, additional assessments of how behavior in response to these novel signs compare to the current two-sign approach is warranted. The novel signs have the potential to alert motorcyclists and other road users to vehicles who may pull out in front of them while rounding a curve. Prior research, including the *Motorcycle Crash Causation Study*, has shown that drivers failing to identify an approaching motorcyclist tend to be of particular concern.(17) In contrast, sign s11 is appropriate for locations where the ability to detect a Stop sign ahead is challenging. Given the superior braking capability of motorcycles as compared to other vehicle types, this sign may provide less value to the motorcycle riding community.

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

The current study examined the potential for novel signs to be used as motorcycle-crash countermeasures. First, the research team conducted a literature review of warning signs (chapter 1). During the literature review, the research team identified potential needs for new signs that specifically target motorcyclists (chapter 1). Based on these needs, the team generated a preliminary set of novel signs. Feedback on this preliminary sign set was solicited from motorcyclists via an online questionnaire. Results from the questionnaire were then used to narrow and refine the stimulus set (chapter 2). An experimental assessment of sign comprehension and legibility was then conducted using both motorcyclists and nonmotorcyclists (chapter 3). This chapter highlights the findings of this research project and provides recommendations based on those findings.

This study assessed four specific sign types: motorcycle-awareness, advance curve-warning, pavement-condition, and limited-sight-distance signs. The goal was to create a list of novel signs with the potential to serve as motorcycle-crash countermeasures. Descriptions of the specific signs included in this list are provided in the sections that follow.

MOTORCYCLE-AWARENESS SIGNS

The motivation to develop and test motorcycle-awareness signs was based on the overrepresentation of motorcycle crashes involving moving violations by drivers of other vehicles.(8,18,11) Drivers often report failing to see a motorcycle despite looking in the motorcycle's direction.(15,16) One potential method for reducing these errors is to use motorcycle-awareness signs to remind drivers to watch for motorcycles.(15,28) While this type of sign has been used in other countries, motorcycle-awareness signs are not currently part of the MUTCD.(28)

When questioned about the potential usefulness of motorcycle-awareness signs, members of the motorcycle-riding community who completed the online questionnaire tended to indicate they believed the signs would be useful. Motorcyclists who completed the online questionnaire selected the two motorcycle-awareness signs (a and b) as the signs they thought would be the most useful of all the novel signs they were presented with (table 11). The motorcyclists also made suggestions for how the signs could be made even more effective. Motorcyclists suggested including an alternative image of a motorcycle to decrease the possibility that the motorcycle-awareness signs would be confused with vehicular traffic–warning signs. The study team used these suggestions to create the two additional signs that were included in the comprehension and legibility experiment conducted in a laboratory.

The comprehension and legibility experiment assessed which of the four, novel motorcycle-awareness signs may have the most utility (table 11). Of the signs tested, sign m2, which featured an image of a motorcycle, was described accurately most often during the open-ended response portion of the comprehension testing and had the greatest legibility distance. Sign m3 used the same image of a motorcycle and included a Share the Road plaque to help decrease the possibility that the sign would be confused with vehicular traffic–warning signs. Sign m3 had the highest ratings of effectiveness and was ranked as most effective at raising motorcycle awareness during the ranking task. Overall, the results speak to the potential for signs m2 and m3 to serve as motorcycle-crash countermeasures. However, determining locations where these signs would be most useful may be difficult. As noted previously, similar Share the Road signs are frequently used to alert road users of locations that are subject to high levels of bicycle traffic. These locations are generally straightforward to identify as bicycle trips tend to be of shorter length and generally occur either in urban areas with well-established bicycle networks or along recreational bicycle routes. In contrast, motorcycle traffic tends to be significantly more dispersed across the road network. As a result, it will likely be challenging to identify candidate locations for motorcycle-awareness signs.

Table 11. Motorcycle-awareness signs assessed in the online questionnaire and the comprehension and legibility experiment.

Motorcycle-Awareness Signs Assessed in the Online Questionnaire	Motorcycle-Awareness Signs Assessed in the Comprehension and Legibility Experiment
a  b 	m1  m2  m3  m4 

Source: FHWA.

Advancements in wireless communication, particularly vehicle-to-vehicle (V2V) communication, could help increase other motorists' awareness of motorcyclists. V2V technologies could detect motorcyclists on the roadway and communicate that information to the motorist using in-vehicle alerts with messages similar to those tested in the current study.

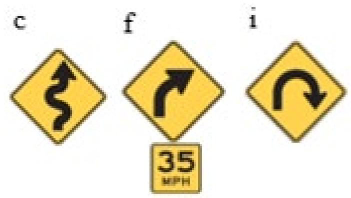
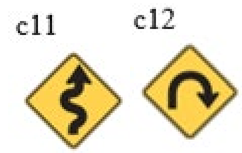
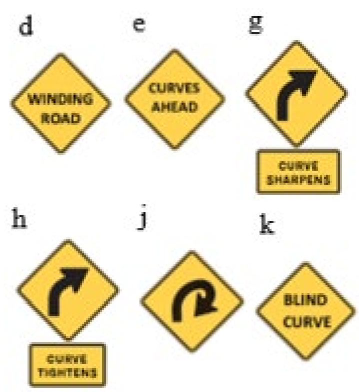
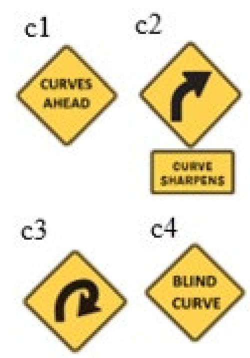
ADVANCE CURVE-WARNING SIGNS

A wealth of literature links curves, especially sharp curves, to motorcycle crashes.[30,31,15] The reduced friction and increased skill required to navigate curves when operating a motorcycle compared to that required when operating a passenger vehicle put motorcyclists at increased risk. Advance curve-warning signs have the potential to serve as a motorcycle-crash countermeasure by assisting riders in identifying upcoming curves, giving them adequate time to react, and helping them anticipate the direction and degree of a curve.[15] Arrow signs that accurately reflect the curve type and radius may be particularly useful in this regard.

When asked to assess the potential usefulness of novel advance curve-warning signs, motorcyclists who volunteered to complete the online questionnaire asserted the potential value of novel curve signs that warn about particularly tight or sharp curves (table 12). Signs g, h, and i, which warned about sharp curves and received high usefulness ratings, comprise 3 of the 10 most useful novel signs. They were also the only signs to receive more positive than negative comments in the online questionnaire.

During the comprehension and legibility study, sign c3, which depicted a particularly sharp curve, had high potential utility as a crash countermeasure (table 12). The sign had comprehension rates that were both higher than other novel signs tested and similar to the comprehension rates for signs c11 (W1-5) and c12 (W1-11), which are Winding Road and Curve signs, respectively, already contained in the MUTCD and labeled “Existing” in table 12. Similarly, legibility distances for sign c3 were greater than for the other novel signs tested and were not significantly different from those for existing signs c11 or c12. The findings suggest that sign c3 may have value as a crash countermeasure for motorcycles, provided it is installed in locations where the curve depicted in the sign can serve as an accurate representation of the curve it is installed to warn about. Further, consideration also needs to be given to the potential overuse of curve-warning signs, as overuse of any type of sign has the potential to diminish its effectiveness and create visual clutter on the roadway.

Table 12. Advance curve-warning signs assessed in the online questionnaire and the comprehension and legibility experiment.

Advance Curve-Warning Sign Type	Advance Curve-Warning Signs Assessed in the Online Questionnaire	Advance Curve-Warning Signs Assessed in the Comprehension and Legibility Experiment
Existing		
Novel		

Source: FHWA.

PAVEMENT-CONDITION SIGNS

Adverse pavement conditions and sudden changes in pavement increase the risk that a motorcycle will be involved in a crash. For example, the presence of transverse rumble strips (e.g., upstream of stop-controlled intersections or work zones) represents a particular safety challenge for motorcyclists and are an area where advance signage is warranted. Other locations of interest include bridge decks or locations where pavement conditions have been shown to be a contributing factor to motorcycle crashes.[39] Pavement-condition signs have the potential to help motorcyclists identify and react to pavement quality issues. In fact, signs that indicate changes in pavement conditions are the only signs in the MUTCD that can be customized for motorcyclists by adding supplemental plaque W8-15P.[3] In addition, a number of transportation agencies have created customized signs that include images of a motorcycle to warn motorcyclists about changes in pavement both on the roadway and within work zones. (See references 34, 35, and 37–42.)

Results from the online questionnaire seem to question the usefulness of this practice. In the online questionnaire, motorcyclists were asked to rate the usefulness of pavement-condition signs l and q, which included only text; pavement-condition signs n and s, which included the supplemental Motorcycle plaque; and novel pavement-condition signs o, p, and t, which included images of motorcyclists (table 13). Surprisingly, motorcycle operators preferred pavement-condition signs that were not customized for motorcyclists. Participants rated text-based signs l and q as more useful than signs n and s, which included the Motorcycle plaque. They also rated signs that included the plaque as more useful than signs o, p, and t, which included an image of a motorcycle within the sign itself. Of all the novel signs tested, novel pavement-condition signs (both with and without images of a motorcycle) received the most negative comments.

Table 13. Pavement-condition signs assessed in the online questionnaire and the comprehension and legibility experiment.

Pavement-Condition Sign Type	Pavement-Condition Signs Assessed in the Online Questionnaire	Pavement-Condition Signs Assessed in the Comprehension and Legibility Experiment
Existing	l  n  q  s 	p11  p12 
Novel	m  o  p  r  t 	p1  p2 

Source: FHWA.

During the comprehension and legibility experiment, novel pavement-condition sign p1, which depicts a motorcycle on a rough road, and sign p2, which depicts a motorcycle on loose gravel, were rated as less effective at conveying their intended meaning than the existing text-based signs p11 (Rough Road (W8-8)) and p12 (Loose Gravel (W8-7)). The legibility distance for sign p1 was similar to that found for sign p11, while the legibility distance for sign p2 was smaller relative to sign p12. Based on these results, it can be concluded that the existing text-based pavement-conditions signs (p11, p12) have high legibility distances and comprehension rates and are considered useful to motorcyclists. The novel pavement-condition signs tested in the current study are not likely to be as effective as these existing signs in preventing motorcycle crashes.

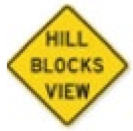
LIMITED-SIGHT-DISTANCE SIGNS

Limited sight distance can be a particular challenge for motorcyclists since they need to monitor the roadway closely for potential hazards, such as debris, road flooding, or potholes.[15] Limited-sight-distance signs that warn a motorcyclist about locations where vertical or horizontal curves limit sight can allow motorcyclists to make appropriate changes in operating their motorcycle.

The research team asked motorcyclists to rate the usefulness of novel limited-sight-distance signs that warned about horizontal and vertical curves in the online questionnaire (table 14). Three of the limited-sight-distance signs were rated among the top 10 most useful novel signs: 1 that warned about limited sight distance due to a vertical curve (v) and 2 that warned about limited sight due to a horizontal curve (ac and ae). However, the vertical-curve sign was rated as significantly less useful than control sign u (i.e., W7-6, Hill Blocks View, in the MUTCD). For that reason, only signs that indicated limited sight distance due to horizontal curves were tested in the comprehension and legibility experiment.

When participants in the comprehension and legibility experiment were asked the meaning of the novel limited-sight-distance signs (i.e., s1 and s2), both signs were described with nearly perfect accuracy (table 14). Additional ratings of comprehension and legibility revealed that sign s1, which uses symbols, had higher legibility distances but lower comprehension ratings than sign s2, which included text. Both signs depict a situation that is not addressed by any single sign that is currently part of the MUTCD. If field testing indicates that these signs increase road safety relative to the sequence of stop-ahead and advance curve-warning signs that would be used to warn motorists about this situation using signs currently included in the MUTCD, then the novel signs offer potential as a motorcycle-crash countermeasure.

Table 14. Limited-sight-distance signs assessed in the online questionnaire and the comprehension and legibility experiment.

Limited-Sight-Distance Sign Type	Limited-Sight-Distance Signs Assessed in the Online Questionnaire: Vertical Curves	Limited-Sight-Distance Signs Assessed in the Online Questionnaire: Horizontal Curves	Limited-Sight-Distance Signs Assessed in the Comprehension and Legibility Experiment
Existing	u 	y  z  aa 	s11  s12 
Novel	v  w  x 	ab  ac  ad  ae 	s1  s2 

Source: FHWA.

RECOMMENDATIONS AND CONCLUSIONS

In consideration of the results of the human-factors evaluation, including both comprehension and legibility, as well as the practical applicability of the various sign alternatives, a list of the novel signs that have the potential to serve as motorcycle-crash countermeasures is displayed in table 15.

Table 15. List of sign alternatives.

Advance Curve-Warning Sign Alternatives	Limited-Sight-Distance Sign Alternatives	Motorcycle-Awareness Sign Alternatives
c3 	s1 s2 	m2 m3 

Source: FHWA.

Advance curve-warning and limited-sight-distance signs may be easier to implement than motorcycle-awareness signs because candidate locations for these signs are likely to be easier to identify than those for motorcycle-awareness signs. The following list provides recommendations for potential MUTCD experimentation for on-road use. Conclusions regarding the use of these potential sign alternatives follows:

- Consistent with the broad human-factors research, text-based signs are generally easier to understand than symbols (at least among literate and/or native-language-speaking adults), though symbols are easier to see from a distance. Combining text with symbols does not necessarily address these concerns, in part because the font size is smaller when included jointly with a symbol or as a plaque.

- From a practical standpoint, the sign types that are likely to produce the most tangible impacts on driver reactions are likely to be advance curve-warning and limited-sight-distance signs, in that order. In each case, candidate locations for the available sign alternatives are likely to be straightforward to identify as they are based upon crash data, roadway inventory data, or local knowledge of the roadway network. In contrast, motorcycle-awareness signs will be more challenging to deploy, an issue that is exacerbated by the fact that detailed motorcycle-specific volume data continues to be a long-term research need. This is particularly true for the rural, two-lane highways where much of the motorcycle traffic tends to occur.

- Advance curve-warning signs are likely to present the most potential for safety improvement. To this end, the existing Winding Road sign (c11) showed the strongest performance but is generally reserved for use in specific cases where a series of reverse curves appear in sequence. However, this traditional sign shows better performance than the Curves Ahead sign (c1), which is somewhat ambiguous. Other signs identify individual curves of concern. Among these, sign c3 appears to have the greatest impact due to how pronounced the curve symbol is on this sign. However, as noted previously, this sign should not necessarily be installed at all types of curves as the sign impacts may degrade if installed at gradual (i.e., large radius) curves where the symbol tends to overstate the actual sharpness of the curve. In addition, consideration should be given to the comprehension of the sign when combined with an Advisory Speed plaque, and the effect that this combination would have on motorcyclists and other road users' behavior.

- Limited-sight-distance signs include two novel signs in the evaluation. These signs (s1 and s2) are similar in nature to sign s12, except that they provide additional information to indicate that the approaching intersection is stop-controlled. Research has shown that sight distance is more of a concern on horizontal curves that have a hidden intersection or driveway; this scenario is where such signage is likely to have the greatest impact.

REFERENCES

1. Trueblood, A., Manser, M., Shipp, E., and Havemann, C. (2018). *Identifying Infrastructure-Based Motorcycle-Crash Countermeasures: Phase I*, Report No. FHWA-HRT-18-062, Washington, DC.

2. NHTSA. (2018). *Traffic Safety Facts 2016*, Report No. DOT HS 812 554, National Highway Traffic Safety Administration, Washington, DC.

3. FHWA. (2009). *Manual on Uniform Traffic Control Devices for Streets and Highways,* Federal Highway Administration, Washington, DC.

4. Savolainen, P., and Mannering, F. (2007). "Probabilistic Models of Motorcyclists' Injury Severities in Single-and Multi-Vehicle Crashes." *Accident Analysis & Prevention*, *39*(5), pp. 955–963, Elsevier, Amsterdam, Netherlands.

5. Daniello, A., Gabler, H.C., and Mehta, Y.A. (2009). "Effectiveness of Motorcycle Training and Licensing." *Transportation Research Record*, *2140*, pp. 206–213, Transportation Research Board of the National Academies of Science, Washington, DC.

6. Mannering, F.L., and Grodsky, L.L. (1995). "Statistical Analysis of Motorcyclists' Perceived Accident Risk." *Accident Analysis & Prevention*, *27*(1), pp. 21–31, Elsevier, Amsterdam, Netherlands.

7. de Lapparent, M. (2006). "Empirical Bayesian Analysis of Accident Severity for Motorcyclists in Large French Urban Areas." *Accident Analysis & Prevention*, *38*(2), pp. 260–268, Elsevier, Amsterdam, Netherlands.

8. Haworth, N., Smith, R., Brumen, I., and Pronk, N. (1997). *Case Control Study of Motorcycle Crashes (CR174)*, Federal Office of Road Safety, Canberra, ACT, Australia.

9. Lourens, P.F., Vissers, J.A.M.M., and Jessurun, M. (1999). "Annual Mileage, Driving Violations, and Accident Involvement in Relation to Drivers' Sex, Age, and Level of Education." *Accident Analysis and Prevention*, *31*(5), pp. 593–597, Elsevier, Amsterdam, Netherlands.

10. Özkan, T., Lajunen, T., Dogruyol, B., Yildirim, Z., and Çoymak, A. (2012). "Motorcycle Accidents, Rider Behaviour, and Psychological Models." *Accident Analysis and Prevention*, *49*, pp. 124–132, Elsevier, Amsterdam, Netherlands.

11. Hurt, H.H., Ouellet, J.V, and Thom, D.R. (1981). *Motorcycle Accident Cause Factors and Identification of Countermeasures, Vol. 2*, National Highway Traffic Safety Administration, Washington, DC.

12. Lardelli-Claret, P., Jiménez-Moleón, J.J., de Dios Luna-del-Castillo, J., García-Martín, M., Bueno-Cavanillas, A., and Gálvez-Vargas, R. (2005). "Driver Dependent Factors and the Risk of Causing a Collision for Two Wheeled Motor Vehicles." *Injury Prevention*, *11*(4), pp. 225–231, BMJ Publishing, London, UK.

13. Peek-Asa, C., and Kraus, J.F. (1996). "Alcohol Use, Driver, and Crash Characteristics among Injured Motorcycle Drivers." *The Journal of Trauma: Injury, Infection, and Critical Care*, *41*(6), pp. 989–93, American Association for the Surgery of Trauma, Chicago, IL.

14. Kraus, J.F., Anderson, C., Zador, P., Williams, A., Arzemanian, S., C Li, W., and Salatka, M. (1991). "Motorcycle Licensure, Ownership, and Injury Crash Involvement." *American Journal of Public Health*, *81*(2), pp. 172–176, American Public Health Association, Washington, DC.

15. Milling, D., Affum, J., Chong, L., and Taylor, S. (2016). *Infrastructure Improvements to Reduce Motorcycle Casualties,* Publication No. AP-R515-16, Austroads, Ltd., Sydney NSW, Australia.

16. Nicol, D.A., Heuer, D.W., Chrysler, S.T., Baron, J.S., Bloschock, M.J., Cota, K.A., Degges, P.D., et al. (2012). *Infrastructure Countermeasures to Mitigate Motorcyclist Crashes in Europe*, Report No. FHWA-PL-12-028, Federal Highway Administration, Washington, DC.

17. Bents, F., Das, S., Flannagan, C., Florence, D., Higgins, L., Manser, M., Schulz, N., et al. (2018). *Task B: MCCS Data Analysis Report and Literature Review Final Report*, Texas A&M Transportation Institute, College Station, TX.

18. de Craen, S., Doumen, M.J.A., and Norden, Y. Van. (2014). "A Different Perspective on Conspicuity Related Motorcycle Crashes." *Accident Analysis and Prevention*, *63*, pp. 133–137, Elsevier, Amsterdam, Netherlands.

19. Wells, S., Mullin, B., Norton, R., Langley, J., Connor, J., Jackson, R., and Lay-Yee, R. (2004). "Motorcycle Rider Conspicuity and Crash Related Injury: Case-Control Study." *British Medical Journal*, *328*(7444), p. 857, BMJ Publishing Group, London, UK.

20. Soto, D., and Humphreys, G.W. (2007). "Automatic Guidance of Visual Attention from Verbal Working Memory." *Journal of Experimental Psychology: Human Perception and Performance*, *33*(3), pp. 730–737, American Psychological Association, Washington, DC.

21. Woodman, G.F., and Luck, S.J. (2007). "Do the Contents of Visual Working Memory Automatically Influence Attentional Selection during Visual Search?" *Journal of Experimental Psychology: Human Perception and Performance*, *33*(2), pp. 363–377, American Psychological Association, Washington, DC.

22. Weaver, S.M., and Arrington, C.M. (2010). "What's on Your Mind: The Influence of the Contents of Working Memory on Choice." *Quarterly Journal of Experimental Psychology*, *63*(4), pp. 726–737, SAGE Publications, Thousand Oaks, CA.

23. Sterzer, P., Frith, C., and Petrovic, P. (2008). "Believing Is Seeing: Expectations Alter Visual Awareness." *Current Biology*, *18*(16), pp. R697–698, Elsevier, Amsterdam, Netherlands.

24. Brooks, P., and Guppy, A. (1990). "Driver Awareness and Motorcycle Accidents." In *Proceedings of the International Motorcycle Safety Conference*, *2*(10), pp. 27–56, Motorcycle Safety Foundation, Washington, DC.

25. Magazzù, D., Comelli, M., and Marinoni, A. (2006). "Are Car Drivers Holding a Motorcycle Licence Less Responsible for Motorcycle—Car Crash Occurrence?: A Non-Parametric Approach." *Accident Analysis & Prevention*, *38*(2), pp. 365–370, Elsevier, Amsterdam, Netherlands.

26. Brich, S.C., and Cottrell, B.H. (1994). *Guidelines for the Use of No U-Turn and No-Left Turn Signs*, Report No. VTRC 95-R5, Virginia Transportation Research Council, Charlottesville, VA.

27. Crundall, D., Howard, A., and Young, A. (2017). "Perceptual Training to Increase Drivers' Ability to Spot Motorcycles at T-Junctions." *Transportation Research Part F: Traffic Psychology and Behaviour*, *48*, pp. 1–12, Elsevier, Amsterdam, Netherlands.

28. Allstate. (2017). "Allstate Mobilizes Riding Community to Install 'Watch for Motorcycles' Warning Signs Across the Country." Available online: https://www.allstatenewsroom.com/news/allstate-mobilizes-riding-community-to-install-watch-for-motorcycles-warning-signs-across-the-country/, last accessed May 25, 2019.

29. The State of Queensland. (2020). "Department of Transport and Main Roads." Available online: https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/TC-signs, last accessed June 20, 2020.

30. Molinero, A., Margaritis, D., Gelau, C., Martín, O., Perandones, J.M., and Pedrero, D. (2009). "Characteristics of Powered Two Wheelers Accidents Susceptible to Be Avoided and Minimized through ADAS and IVIS Implementations." In *Proceedings of the 21st International Technical Conference on the Enhanced Safety of Vehicles*, National Highway Traffic Safety Administration, Washington, DC.

31. Biral, F., Bosetti, P., and Lot, R. (2014). "Experimental Evaluation of a System for Assisting Motorcyclists to Safely Ride Road Bends." *European Transport Research Review*, *6*(4), pp. 411–423, Springer, New York, NY.

32. Davis, B., Morris, N., Achtemeier, J., and Patzer, B. (2018). *In-Vehicle Dynamic Curve-Speed Warnings at High-Risk Rural Curves*, Report No. MN/RC 2018-12, Minnesota Department of Transportation, Minneapolis, MN.

33. Fagen, A. (2013). "Curve Sharpens." Flickr. Available online: https://www.flickr.com/photos/afagen/10917904166, last accessed June 30, 2020.

34. Manan, M.M.A., Várhelyi, A., Çelik, A.K., and Hashim, H.H. (2017). "Road Characteristics and Environment Factors Associated with Motorcycle Fatal Crashes in Malaysia." *IATSS Research*, *42*(4), pp. 207–220, Elsevier, Amsterdam, Netherlands.

35. Shaheed, M.S.B., Gkritza, K., Zhang, W., and Hans, Z. (2013). "A Mixed Logit Analysis of Two-Vehicle Crash Severities Involving a Motorcycle." *Accident Analysis & Prevention*, *61*, pp. 119–128, Elsevier, Amsterdam, Netherlands.

36. Pour-Rouholamin, M., Jalayer, M., and Zhou, H. (2017). "Modelling Single-Vehicle, Single-Rider Motorcycle Crash Injury Severity: An Ordinal Logistic Regression Approach." *International Journal of Urban Sciences*, *21*(3), pp. 344–363, Taylor & Francis, Abingdon, UK.

37. Waseem, M., Ahmed, A., and Saeed, T.U. (2019). "Factors Affecting Motorcyclists' Injury Severities: An Empirical Assessment Using Random Parameters Logit Model with Heterogeneity in Means and Variances." *Accident Analysis & Prevention, 123*, pp. 12–19, Elsevier, Amsterdam, Netherlands.

38. Theofilatos, A., and Ziakopoulos, A. (2018). "Examining Injury Severity of Moped and Motorcycle Occupants with Real-Time Traffic and Weather Data." *Journal of Transportation Engineering, Part A: Systems*, *144*(11), American Society of Civil Engineers, Reston, VA.

39. Fagnant, D.J., and Kockelman, K.M. (2015). "Motorcycle Use in the United States: Crash Experiences, Safety Perspectives, and Countermeasures." *Journal of Transportation Safety & Security*, *7*(1), pp. 20–39, Taylor & Francis, Abingdon, UK.

40. Ma, A., Leavy, D., Eveleigh, M., Fernandes, R., and O'Reilly, M. (2016). "NSW Motorcycle Strategy: A Model for Consultative Strategy Development and Implementation." Presented at the 2016 Australasian Road Safety Conference, Canberra, ACT, Australia.

41. Google®. (2020). Google Earth™. Mountain View, CA. Available online: https://earth.google.com/web/@44.04524167,-103.4935314,1547.27075195a,0d,60y,9.7056h,90t,-0r/data=IhoKFnBGTjI3b09YM0ZMd0tZNTFjam9lMGcQAg?utm_source=earth7&utm_campaign=vine&hl=en, last accessed June 30, 2020.

42. Roadway Safety Consortium. (2010). *Guidelines on Motorcycle and Bicycle Work Zone Safety*. Grant Agreement No. DTFH61-06-G-00007, Federal Highway Administration, Washington, DC.

43. FDOT. (n.d.). "Florida's Highway Warning Signs." (website) Tallahassee, FL. Available online: https://www.fdot.gov/traffic/trafficservices/signlibrary/warning/warning.shtm, last accessed June 4, 2019.

44. British Columbia Ministry of Transportation and Highways. (2000). *Manual of Standard Traffic Signs & Pavement Markings*, Victoria, BC.

45. Washington State Legislature. (n.d.). Washington Administrative Code, § 468-95-306. Available online: https://app.leg.wa.gov/WAC/default.aspx?cite=468-95-306, last accessed June 4, 2019.

46. VDOT. (2005). *Virginia Work Area Protection Manual: Standards and Guidelines for Temporary Traffic Control*, Virginia Department of Transportation, Richmond, VA.

47. VDOT. (2005) "Get Your Motor Running: Motorcycle Safety." Available online: www.virginiadot.org/programs/resources/MotorbikeSafetyfinal.pdf, last accessed April 6, 2019.

48. TDOT. (2007). "Instructional Bulletin No. 07-05," Tennessee Department of Transportation, Nashville, TN.

49. National Transportation Safety Board. (1980). "Safety Recommendation: H-80-50." Available online: https://www.ntsb.gov/SAFETY/safety-recs/_layouts/ntsb.recsearch/Recommendation.aspx?Rec=H-80-050, last accessed June 30, 2020.

50. Kostyniuk, L.F., and Cleveland, D.E. (1986). "Sight Distance, Signing, and Safety on Verticle Curves." *ITE Journal*, *56*(5), pp. 25–28, Institute of Transportation Engineers, Washington, DC.

51. Freedman, M., Staplin, L.K., Decina, L.E., and Farber, E.I. (1984). *Limited Sight Distance Warning for Vertical Curves*, Report No. FHWA/RD-85/046, Federal Highway Administration, Washington, DC.

52. National Transportation Safety Board. (1988). "Safety Recommendation H-80-051." Available online: https://www.ntsb.gov/safety/safety-recs/_layouts/ntsb.recsearch/Recommendation.aspx?Rec=H-80-051, last accessed June 30, 2020.

53. Balk, S.A., Kissner, E., and Katz, B. (2017). *Comprehension and Legibility of Selected Symbol Signs, Phase IV: Final Report*, Federal Highway Administration, Washington, DC.

54. Scopatz, B., DeFisher, J., and Lyon, C. (2018). *Emerging Practices for Addressing Motorcycle Crashes at Intersections*, Report No. FHWA-SA-18-045, Federal Highway Administration, Washington DC.

55. Thomas, A., Smart, W., de Roos, M., Webster, K., Gibbs, C., and Roads, N.S.W. (2011). "Motorcycle Safety Route Review: A Case Study." In *Proceedings of the 2011 Australasian Road Safety Research, Policing and Education Conference*, Perth, Australia.

56. Motorcycle Industry Council. (2018). *Motorcycle Industry Council 2018 Statistical Annual*, Motorcycle Industry Council, Irvine, CA.

57. Ben-Bassat, T., and Shinar, D. (2006). "Ergonomic Guidelines for Traffic Sign Design Increase Sign Comprehension." *Human Factors*, *48*(1), pp. 182–195, SAGE Publications, Thousand Oaks, CA.

58. Shinar, D., and Vogelzang, M. (2013). "Comprehension of Traffic Signs with Symbolic versus Text Displays." *Transportation Research Part F: Traffic Psychology and Behaviour*, *18*, pp. 72–82, Elsevier, Amsterdam, Netherlands.

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