DEVELOPMENT OF AN AUTOMOTIVE ICON FOR INDICATION OF SIGNIFICANT TIRE UNDERINFLATION

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In the TREAD Act of November 1, 2000, Congress required the National Highway Traffic Safety Administration (NHTSA) to develop a rule requiring all new light vehicles to be equipped with a warning system to indicate to the driver when a tire is significantly underinflated. Research was conducted to assess the ability of two existing ISO symbols and 13 proposed alternative symbols to communicate the message of tire underinflation. An existing dashboard icon representing an engine was included as a baseline. A comprehension test was conducted in which each of 120 subjects was asked to report the meaning of one tire pressure icon and the engine icon. Results showed 25 and 37.5% comprehension for the ISO tire icons. All of the 13 alternative icons had better comprehension: 6 of 13 had 100%; 2 of 13 had 87.5% comprehension. The type of wheel pictured in tire image based icons was found to affect comprehension. Results suggest that alternatives to the ISO icons should be considered for use in alerting drivers to tire inflation problems.

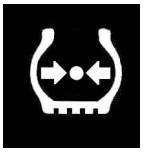
INTRODUCTION

In the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act of November 1, 2000, the U. S. Congress required the National Highway Traffic Safety Administration (NHTSA) to develop a rule requiring light vehicles to be equipped with a warning system to indicate to the operator when a tire is significantly underinflated. This rule was required to be effective within two years of the final rule date of November 1, 2001. In response to this requirement, NHTSA undertook an evaluation of existing original equipment (OEM) and aftermarket tire pressure monitoring systems. In this evaluation NHTSA determined the capabilities of existing technologies and the methods of warning the driver that were in use or under consideration by manufacturers of tire pressure monitoring systems. Vehicles have been sold in the U.S. equipped with tire pressure monitoring systems as early as 1995 and aftermarket systems appeared even earlier. To support development of a minimum standard for tire pressure monitoring systems, NHTSA investigated methods of presenting tire pressure warning information and sought to determine the best way to provide tire underinflation information to the driver.

The primary function of a tire pressure monitoring system (TPMS) is to warn of tire underinflation. Most pressure-sensor based systems have a two stage warning approach. The first driver notification of underinflation is an "underinflation advisory" meant to inform of low tire pressure that should be corrected at the next available opportunity. The second driver notification of underinflation is a "significant underinflated warning" meant to inform of a significantly, and dangerously low tire that must be immediately remedied.

Icons K.10 and K.11 (shown in Table 1), developed by the International Organization for Standardization (ISO), are currently used in some vehicles to alert the driver that one or more tires on the vehicle are significantly underinflated.

Table 1. ISO Tire Pressure Icons Tested

Tire Failure (K.10)	
Tire Pressure (K.11)	

Attendees of committee meetings held by the Society of Automotive Engineers in 2000 to discuss

tire pressure monitoring systems expressed dissatisfaction with the ISO icons and anticipated poor comprehension of its meaning. These attendees included representatives of tire and vehicle manufacturers. Based on these reactions, NHTSA research staff concluded that the icons' meanings were not well understood. Specifically, it was felt that the perspective of a tire image as portrayed in the icons was not likely to be readily visualized and thus understood by the average driver. Furthermore, investigation of the history of these icons did not produce any indications that they had been tested for comprehension. As a result, NHTSA staff set out to assess the comprehensibility of the two ISO tire icons.

In an effort to develop recommendations for methods of presenting tire pressure warning information, NHTSA examined existing ISO icons and investigated several alternative icons for "tire pressure". This research focused on testing icons for alerting drivers to the condition of significant tire underinflation, which requires immediate attention. However, it was assumed that this icon would also be used as part of the lower-level underinflation advisory warning as well.

The possibility of providing underinflation information for individual tires was not ruled out. This paper outlines these efforts to assess methods of providing tire underinflation information to drivers through use of a visual symbol. Auditory signals, although important to the communication of warnings, were not investigated and are not discussed in this paper.

METHOD

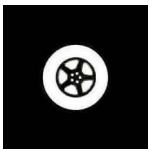
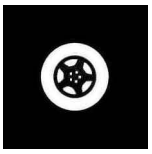
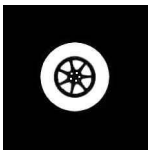
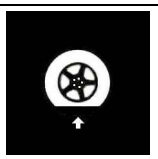
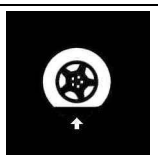
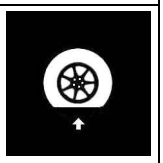
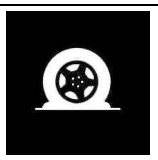
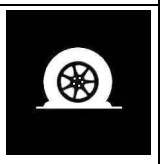
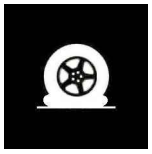
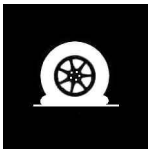
Identification of Alternative Tire Pressure Warning Icons to be Tested

An examination of the driver interfaces for existing tire pressure monitoring systems found a number of different methods in use for providing information to drivers regarding tire underinflation. Visual indications of significant tire underinflation were provided, using in some cases ISO icons K.10 and K.11 (both to indicate lower tire pressure, not tire failure), Other systems presented tire pressure warnings using red LED text messages such as "TIRE DEFECT", "Lo", and "Fr_Lo_" (meant to indicate "front right low"). Others used different types of vehicle images with the ability to indicate that a specific tire, or tires, was underinflated. Some systems provided two levels of warning, an indication of low tire pressure and an indication of significant underinflation.

Candidate icons for use in presenting tire pressure warning information were developed through informal production tests in which research staff produced drawings to represent tire underinflation, examination of existing systems, and review of relevant literature. Four icon versions were developed which all made use of the side image of a tire mounted on a wheel, as shown in Table 2. Each of the four icon versions was drawn with 3 different wheel designs to permit assessment of which would be most recognizable as a wheel.

Icon versions "Flat 1" and "Flat 2" were variations of an icon presented in Green (1979a), which differed only in the way that the flat part of the tire and ground were depicted. "Flat 1" and "Flat 2" also differed from the icon presented in Green (1979a) by the design (six spokes versus eight) and detail of the wheel.

Table 2. Alternative Tire Pressure Icons Tested

Icon Version	Wheel Design: Wheel 1	Wheel 2	Wheel 3
Tire			
Flat tire w/arrow			
Flat 1			
Flat 2			
Vehicle			

Another icon was developed which consisted of a top-view line drawing of a vehicle with one tire shaded (indicating a warning associated with that

tire). These alternative icons were tested along with the ISO icon K.11 (version with filled in arrows) (ISO 2575) representing "tire pressure". ISO icon K.10, representing "tire failure" was also tested to assess whether in comprehension tests it could be comprehended and distinguished from K.11. An existing dashboard icon indicating, "engine" (ISO F.01) was used as a baseline, as shown in Table 3.

Table 3. ISO Engine Icon Used as a Baseline

Engine (F.01)	

Comprehension Test Method

Participants in the comprehension test were 120 employees of the Transportation Research Center Inc. They consisted mostly of entry-level test drivers, but also included office employees, technical staff members, and mechanics, none of whom would be expected to have any specific technical knowledge that would influence their responses.

Participants were given a sheet of letter size paper containing images of two icons, including one of the 15 tire pressure icons and the ISO engine icon. Also printed on the sheet was the instruction to look at the pictures and then fill in the blanks in the statements printed immediately below each icon. The statement used was adapted from a study by Green (1993). The statement consisted of the following:

> "This image has just appeared on your vehicle's dashboard. It is a warning for _____."

Each participant was given only one pair of icons resulting in 120 data points for the engine icon and 8 data points for each of the other 15 icons presented.

Icons used were black and white and identical to those shown in Tables 1, 2, and 3. ISO tire icons as printed were approximately 28 mm by 28 mm. All alternative tire pressure icons as printed were approximately 33 mm by 33 mm. The printed dimensions of the engine icon were 25 mm wide by 15 mm high.

The percentage of correct responses was calculated for each icon. Correct responses were also examined as a function of icon version and wheel design. Trends in incorrect responses to particular icons were summarized. Patterns in phrasing used by respondents in the free response task were also assessed.

RESULTS

Comprehension Test Results

Correct responses were given a value of 1 and incorrect responses were assigned a value of 0. Responses for the ISO engine icon were considered correct if they contained the word "engine" or "motor". Given that the realm of tire-related problems is quite limited (i.e., tire wear, which is visually observable, and tire inflation issues, which may not be visually observable depending on tire design and degree of underinflation), responses to icons intended to communicate tire underinflation were given 1 point if they contained the word "tire". Tire icon responses containing the word "wheel" but not the word "tire", were given half of one point.

Results of the comprehension test of the 16 symbols are provided in Table 4. Respondents showed near-perfect comprehension results (114 correct out of 120 responses), 95%, for the existing engine icon. Recognition percentages for the ISO tire pressure and tire failure icons were the lowest of the 16 icons tested, 37.5 percent and 25 percent, respectively. All of the 13 proposed alternative tire pressure icons had better comprehension. Percent correct responses observed for the icons based on tire images ranged from approximately 62% to 100% (6 of the 12 had 100 percent comprehension). The percentage of correct responses associated with the vehicle image icon was 81.3 percent.

Table 4. Icon Comprehension Test Results

Icon / Icon Version	Number Correct	% Correct
Engine	114	95
ISO K.10	2	25
ISO K.11	3	38
Tire	18.5	77
Flat Tire with Arrow	21	88
Flat 1	23	96
Flat 2	21	88
Vehicle Top-view	6.5	81

Table 5. Icon Comprehension Test Results for Wheel-based Icons by Wheel Design

		Wheel Design					
		Wheel 1		Wheel 2		Wheel 3	
		Number correct (N= 8)	% correct	Number correct (N= 8)	% correct	Number correct (N= 8)	% correct
Icon Version	Tire	5.5	69	8	100	5	63
	Flat Tire with Arrow	7	88	8	100	6	75
	Flat 1	8	100	8	100	7	88
	Flat 2	8	100	8	100	5	63
	Total	**28.5**	**89**	**32**	**100**	**23**	**72**

To assess which of the icon versions and wheel designs had the best comprehension, the number of correct responses for icons were summarized by these factors. The column totals in Table 5 contain the number of correct responses for alternative tire image based icons by wheel design. The icon version "Flat 1" had the best comprehension results of all the icon versions. These data also show Wheel 2 to have better comprehension than the other two wheel designs.

A variety of incorrect responses were observed for the icons tested. Examples of incorrect responses for the interpretation of the ISO icon for tire pressure included "airbag", "light out", disengaged gearshift", and "connection check (fuses)". Similar problems were found with the interpretation of the ISO tire failure icon, including responses such as "traction control", "check engine", "low oil", and "don't know". Incorrect responses for Wheel 1 included "brake problems" and "electrical". Wheel 3 was predominantly mistaken to represent a steering related problem (such as "power steering" or "steering problem"), however, it was also mistaken as an indicator for "brakes", "lights", and "turbo".

Tables 6 and 7 summarize response phrases obtained by wheel design and icon version, respectively. Overall, "flat tire" was the phrase given most frequently (35 percent) in response to tire pressure icons tested. However, when examining responses to the two ISO icons, most of the responses fell into the "other" category (i.e., terms not relating to tire, wheel, etc.). "Flat tire" was the predominant response given for the "Flat Tire with Arrow" icon (54.17 percent), the "Flat 1" icon (75.00 percent), and the "Flat 2" icon (35.42 percent). For the vehicle icon, the most common responses were "flat tire" and "low tire pressure," both of which received 25 percent. "Flat tire" was also the most frequent response for each of the three wheel designs. In all, the alternative icons did a better job of communicating the idea that a condition relating to tire inflation warrants the driver's attention than did either of the ISO icons.

Table 6. Summary of Percent Response Phrases by Wheel Design

Response Phrase	Wheel 1	Wheel 2	Wheel 3
Tire(s)	9.4	12.5	0
Check tires	0	3.1	3.1
Tire problem	3.1	3.1	4.7
Tire pressure	9.4	3.1	3.1
Tire inflation pressure	3.1	0	0
Low air	9.4	0	0
Low tire	3.1	9.4	9.4
Low tire pressure	7.8	20.3	3.1
Flat tire	39.1	45.3	42.2
Underinflated tire	0	3.1	0
Wheel	9.4	0	12.5
Other	6.3	0	21.9
Total	**100.0**	**100.0**	**100.0**

DISCUSSION

Results of comprehension tests of the 16 symbols showed that all of the icons proposed as alternatives to the ISO tire pressure icon were found to communicate at least some degree of tire inflation condition much better than the ISO icons. Based on these results, it was suggested that alternatives to the existing ISO icons be considered for use in alerting drivers to tire inflation related problems. The icon "Wheel 2-Flat 1" was determined to be the best candidate of the 16 icons tested for use as a dashboard icon to indicate significant tire underinflation. The top-view vehicle icon was also found to be a viable option as an alternative to the "Wheel 2-Flat 1" icon for systems that have the ability to provide underinflation information for each tire independently.

Table 7. Summary of Percent Response Phrases by Icon Version, Including ISO Tire Pressure Icons

Response Phrase	ISO Tire	Tire	Flat Tire with Arrow	Flat 1	Flat 2	Vehicle
Tire(s)	0	25.0	0	4.2	0	12.5
Check tires	0	4.2	4.2	0	0	0
Tire problem	0	14.6	0	0	0	12.5
Tire pressure	6.3	0	4.2	4.2	12.5	0
Tire inflation pressure	0	4.2	0	0	0	0
Low air	0	0	4.2	0	8.3	0
Low tire	12.5	0	4.2	8.3	16.7	0
Low tire pressure	6.3	16.7	12.5	2.1	10.4	25.0
Flat tire	0	4.2	54.2	75.0	35.4	25.0
Underinflated tire	0	0	0	0	4.2	0
Punctured tire	6.3	0	0	0	0	0
Wheel	0	14.6	8.3	6.3	0	12.5
Other	68.8	16.7	8.3	0	12.5	12.5
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

The authors found it interesting that wheel design, which was thought to be a relatively minor component of the icon, significantly influenced comprehension. Indeed, the results indicate that the design of the wheel was more influential than the icon version in determining comprehension.

CONCLUSIONS

Alternative icons for warning drivers of significant tire underinflation were developed and tested. The alternative icons were found to perform better in comprehension tests than did ISO icons related to tire pressure. Based on these results, it was suggested that alternatives to the existing ISO icons be considered for use in alerting drivers to tire inflation related problems.

A complete description of NHTSA's research relating to tire pressure monitoring systems can be found in "An Evaluation of Existing Tire Pressure Monitoring Systems" by Grygier et al (2001).

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