Quantitative Evaluation of Display Readability in a Car Simulator under Ambient Light Conditions

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Abstract

This paper introduces a new approach to evaluate the influence of anti-reflective and anti-glare surface treatments on the readability of automotive displays. A car simulator was equipped with an illumination setup to mimic real ambient light scenarios. During the experiments we measured the ability of the driver to collect information from the display while driving. Our results validate this approach and demonstrate that the choice of surface treatment depends on the scenarios considered by the car manufacturers.

Author Keywords

Display readability; AR/AG surface treatments; ambient lighting situation

1. Background of the study

Reports suggest that the risk of adverse events (crashes) generally increases as the total number of glances, length of individual glances, and total glance time that a driver looks away from the roadway increases (Klauer et al., 2006; NHTSA, 2013; Bärgman et al., 2015). A major factor in the amount of time that a driver looks away from the road when interacting with in-vehicle displays is the ease with which informational content in the display can be extracted by the driver. Ease of extraction can fluctuate as a function of a number of variables such as the amount of information provided, intrinsic legibility, screen positioning, etc.

It is also recognized that factors such as glare and the reflective characteristics of a display under different lighting conditions can negatively impact what might otherwise be an excellent display design. Minimizing glare and reflective visual interference can logically be assumed to increase the relative safety associated with looking at an in-vehicle display. And, while increasing safety is a primary concern, reducing eyestrain and increasing the ease with which a driver can take-in information from a display is likely to increase customer satisfaction and the overall user experience.

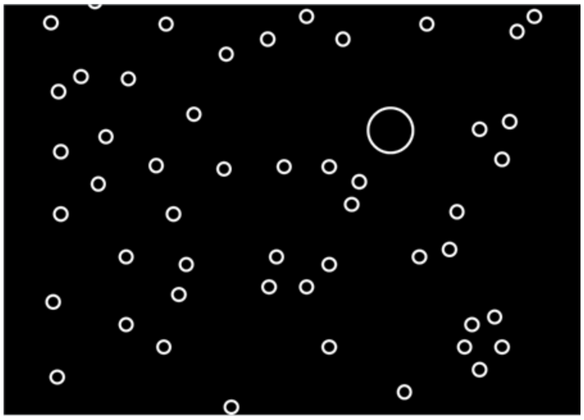
Antiglare (AG) and antireflective (AR) optical surface treatments have been developed by Corning Incorporated for use in a variety of environments including automotive interior displays. Corning expressed an interest in the development of objective driver behavior data to help communicate to both the automotive industry and the consumer an understanding of the extent to which the use of such treatments may offer benefits within the context of automotive displays. Corning and the MIT AgeLab thus agreed to develop experimental work to be conducted in the AgeLab's driving simulator to obtain functional measures of drivers' interactions with an in-vehicle display with and without such surface treatments. Volvo Car Corporation provided OEM insight and expertise on use conditions for a realistic assessment.

2. Approach

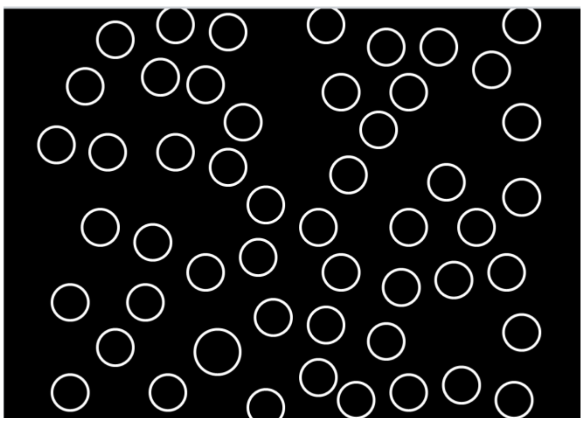
The research team at the MIT AgeLab proposed, and Corning adopted an objective measure of display "readability" that was independent of features such as font type and other content related design considerations. To do this, a target identification task that has been used in the context of in-vehicle display evaluations was selected. The Surrogate Reference Task (SURT) was first published as an ISO standard in 2012 and a second edition of the document containing the technical specification was published in 2019 (ISO/TS 14198). It is explicitly presented as a calibration task for assessing driver demand due to the use of in-vehicle information systems.

As stated in the ISO document, the SURT provides for a standardized visual search paradigm. Participants are asked to indicate whether or not a pre-specified target is embedded in a multi-item array of symbols, forms, colors or words. The non-target items are referred to as "distractors". Most often in automotive research contexts, an array of circles is presented, with one larger circle serving as the target. The difficulty of the task can be systematically varied by adjusting the degree to which the target circle and the distractor circles differ in size (other aspects can be varied as well, such as the number of distractor items).

In the example below, the goal for the participant is to indicate the side of the screen where the target (larger) circle appears (left or right). This can be done using a touch screen or by using physical buttons to select left or right; the MIT AgeLab has used both methods in the past. In the present work, physical left and right response buttons were used. This was done so that there would not be an issue of oils from participants' fingers changing the quality of the display screen. Performance on the task can be scored in various ways, such as in terms of the time it takes for the participant to make a selection (response time), the number of correct selections, or other metrics.



(a)



(b)

Figure 1: A SURT task with two different levels of difficulty. The size of the target circle remains constant, and the size of the distractor circles is varied. (a) An easy level – target is on the upper right side. (b) A harder level – target is on lower left side

Two features were added to the traditional SURT methodology to increase the relevance of the approach to the context of safe interaction with an interface in an active driving context. First, participants were given a limited window of time within which to interact with the display and make their selection. Research has shown that glance times away from the roadway of more than 2 seconds in duration begin to dramatically increase crash risk. Consequently, participants needed to make a response within a maximum window of 2 seconds, after which the screen would clear, and the trial would be scored as an error / incorrect response. Second, rather than arbitrarily timing the start of a display window, participants selected when they were ready to start a new trial by pressing a start button. In this way, engagement with the display was more realistically linked to how a real driver might interact with a display screen, e.g., they could choose when to look off the road to the display taking into consideration what surrounding traffic in the simulated driving environment was doing, when they felt it was safe to look at the display, etc.

3. Experimental setup

The experiment was performed in the MIT AgeLab simulator. Figure 2 shows pictures of the car in which the displays with different surface treatments and the illumination setup were integrated.

Figure 2: MIT AgeLab car simulator in the experiment

Driving scenarios are projected on three screens in front of the car. Figure 3 shows in further details the illumination setup and the displays used in the experiment.

Figure 3: Illumination setup and display

On the passenger seat, a Lambertian diffuser with black stripes was added to simulate the so-called “white shirt effect”, which simulates the presence of a passenger with a striped shirt whose image is reflected by the display and superposed on the display image. Spotlights were located on the passenger side and the rear of the vehicle to simulate diffuse and directional ambient light. The total illuminance at the display was 5,200 lux. The displays used in the experiments were based on currently used mass-production displays from AlpsAlpine according to specifications defined by Volvo Cars but modified with Corning-supplied cover glasses including different AG and AR surface treatments for the purposes of the present study. In this regard, four surface treatments were evaluated using this display: bare glass, AG only, AR only and AG+AR. For this study of the measurement / evaluation principle, we used “middle of the road” surface treatments, not “best in breed” surfaces, also acknowledging that the choice of specific AG and AR surfaces is always a careful trade-off between different conflicting priorities. Figure 4 shows the optical data measured from the display with the four different surface treatments applied to the cover glass.

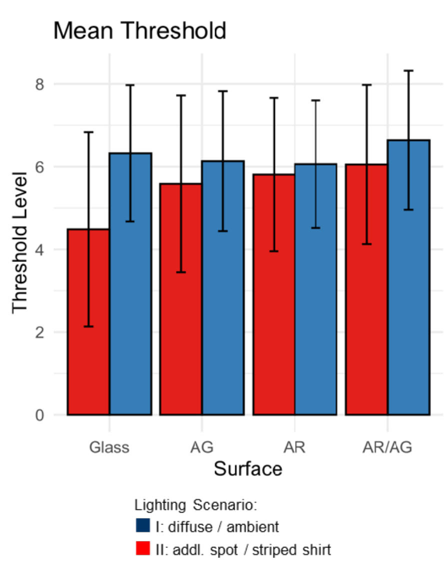
		Bare	AG	AR	AG+AR
Display + Coverglass	%R(SCI)	4.85	4.7	1.1	1.1
	%R(SCE)	0.15	0.4	0.1	0.15
	Gloss 60	90-100	60-65	50-55	35-40
	Haze (R)	0	15	0	1-2
	DOI	100	96	99	97.5

Figure 4: Optical measurements in reflection from the display with cover glass with 4 different surface treatments

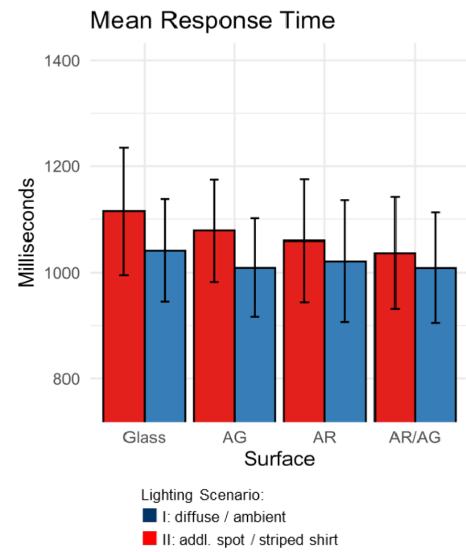
Each test subject interacted experiment with the four display configurations during each of two illumination scenarios. The first scenario used only diffuse and directional ambient light while the second used an additional spotlight to illuminate the "white shirt" effect surrogate in addition to the diffuse and directional ambient light.

4. Experimental results

Two measurements evaluate the response of the test subject for each experiment: mean response time for correct answers and the mean difficulty threshold. Note: higher readability thresholds (a more positive result) indicate that a subject was able to discriminate smaller differences between the size of the target and distractor circles. Figure 5 shows the summary of the data collected from 24 participants.



(a)



(b)

Figure 5: Mean difficulty threshold (a) and mean response time (b) data, collected from the experiment including 24 participants (13 males, 11 females, mean age 38.1 years, SD 14.2 years)

Statistical analyses were performed in R (R Core Team, 2021) and an alpha level of 0.05 was used for statistical significance assessment to evaluate the presence of differences based on the surface treatment. Tables visualizing the significance and the direction of the comparisons are shown in figure 6 and 7 for the mean threshold and the response time metrics respectively.

	bare glass	AG	AR	AG+AR
bare glass				
AG				
AR				
AG+AR				

	row entry worse than column entry
	no statistically significant difference
	row entry better than column entry

Figure 6: Threshold

	bare glass	AG	AR	AG+AR
bare glass				
AG				
AR				
AG+AR				

	row entry worse than column entry
	no statistically significant difference
	row entry better than column entry

Figure 7: Response time

Both the response time and the difficulty threshold metrics show that bare glass is the least preferable option for automotive cover glass, as expected from user experience and scientific literature. This result validates qualitatively our approach. The threshold metrics differentiate all pairs of surface treatments except for the comparison between AG and AR. Also, this metrics shows the AG+AR is better than all other options for the use case simulated in this experiment (illumination configuration, choice of display).

Based on our experience to date, the joint team between Corning, Volvo Cars and the MIT AgeLab has identified several key areas to consider to further differentiate the three surface treatments (AG only, AR only and AG+AR). Now that the fundamental concept has been verified, there are several avenues for follow-up studies: First, our illumination setup was limited in terms of illuminance to 5,200 lux, which is lower than in several critical real life ambient light scenarios; it hence limited the use cases that could be simulated in this study. However, it remained in the magnitude of what is used in most standards for diffuse ambient light which is usually around 5,000 lux. Expanding these capabilities would also allow simulating direct sunlight onto the display, which is a use case when AG often performs very poorly by creating a washout effect. Contrary to the findings in this study, in that particular use case, AR may have outperformed AG+AR. Additionally, we chose surface treatments that are standard and not to specifically respond to the use case we investigated. Our objective was to use industry-typical surface treatments available commercially in the automotive industry and offered by Corning, not necessarily high-performing solutions that even might have been optimized for a specific use case. The same applies to the choice of display. All the results must be interpreted with these considerations in mind.

5. Conclusions

We have proposed a method to evaluate the optical performance of surface treatment applied to coverglass for automotive displays using human perception metrics in a car simulator environment. This approach has been validated by a use case defined by a choice of illumination configuration, and commercially available displays and surface treatments.

Our results suggest that bare glass is the least optimal surface treatment for automotive cover glass. The display readability can be improved by AG+AR surface treatment. However, there is no generic conclusion that can be quantified to differentiate between AG only, AR only and AG+AR. The optimal combination of display and surface treatments depend on the use cases that matter the most to the customer and the car maker. Therefore, this approach can be used to select or validate a system if the illumination use case can be properly simulated.

Next steps consist in evaluating additional use cases (direct sunlight), using additional illumination setups and optimized surface treatments and displays to connect this human perception metrics with metrics calculated from actual physical measurements such as ambient contrast ratio.

6. Acknowledgements

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