Forward Collision Warning Systems Using Heads-Up Displays: Testing Usability of Two New Metaphors

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***Abstract*— The incorporation of Augmented Reality (AR) in the windshield of automobiles using heads-up displays (HUD) is starting to be implemented by some manufacturers and is proving to be very useful in some situations, including safety distance keeping. This paper reports on a system that warns the driver via the car's HUD when he violates the predefined safety distance, to avoid a possible forward collision, and proposes two different visualization metaphors based on traffic signals. The metaphors are compared, with and without warning sounds, through computer simulations performed by 22 participants from different age groups and driving experiences. One of the metaphors corresponds to a variant of the traffic sign C10 that forbids circulating from the preceding vehicle shorter than a certain minimum headway, whereas the other corresponds to the road safety marks, which recommend the safety distance to be observed from the vehicle ahead. Results show that the metaphor derived from the safety marks, with warning sounds, is preferred by the participants, and was considered the most useful, intuitive and adequate to a forward collision warning. We also found that this metaphor was preferred by all participants that were 42 or more years old, whereas participants between 28 and 41 years old were divided between the two metaphors, with warning sounds.**

I. INTRODUCTION

Due to the strong technological evolution in the last decades, motor vehicles have undergone significant changes and improvements. These efforts led to safer driving, powerful driving engines, improved comfort and entertainment, and overall improved driving experience. However, according to the European Commission [1] and World Health Organization [2], driving accidents are a major death and injury cause in modern societies. This is often associated with human error [3–5], which somehow defeats the purpose of many technology achievements in this area. Therefore, the human factor is recognized as a major problem to be tackled. For instance, according to Tönnis et al. [6], many car "accidents are caused by human errors in longitudinal and lateral control". Every time a vehicle is moving, it occupies a space in the road with a length equal to its reaction distance plus the distance needed to conduct the maneuver in order to avoid the accident (braking distance). According to Instituto da Mobilidade e dos Transportes Terrestres (IMTT) [7], this area will be greater the higher the velocity, the mass of the vehicle, and the less surface adherence, being also affected by the road inclination, and the type and state of the braking components of the vehicle. The driver must be able to look at the road ahead for a distance of at least 3 to 5 seconds, foreseeing the space that each vehicle, pedestrian or animal may occupy in that period of time. If some of these entities enter this zone in a time inferior to the driver's reaction time, the collision may be unavoidable. So, drivers should keep enough distance from the other vehicles to allow them to stop safely in case of braking or sudden immobilization, and to avoid a collision or other sort of accidents. Such a distance is known as the safety distance, which is calculated based on the circulation velocity, the driver's mean reaction time (1 to 1.5 seconds [1, 10]), reaction distance (*RD*), braking distance (*BD*), stopping distance ($SD = RD + DT$), surface adherence conditions, visibility [7], and other parameters. Since it is difficult for a driver to quickly and accurately calculate the safety distance, due to the associated high mental workload, which is prone to human errors, it would be very useful if the vehicle itself provided this information to the driver, warning him when he violates the safety distance. Thus, one way to help ensure the safety of the vehicle occupants, is by keeping the recommended safety distance, an idea shared by [8–10] that assume the number of accidents may be reduced if the driver knows more precisely how far he can stop.

With Advanced Driver Assistance Systems (ADAS) such as collision warning systems, drivers can receive warnings as sound notifications when an obstacle is compromising the drivers' safety. However, with the advent of Heads-Up Displays (HUD) and Augmented Reality (AR) applied to vehicles, it seems that displaying visually this information is more useful than an ambiguous non-visual alert [11]. Furthermore, it is believed that this kind of systems is less distractive than secondary devices [9] (e.g., onboard computer), since the drivers do not need to look away from the road to perceive the shown information, with the advantage of seeing it overlapped with the road reality in their field of view.

In this paper we propose two distinct metaphors for presenting warnings in a Forward Collision Warning (FCW) system in the HUD of a vehicle, using a low-cost driving simulator, in order to evaluate their impact on driving performance, as well as the driver's subjective experience. For the purpose of clarity, the metaphor definition presented in [12] is used. What differentiates our proposed metaphors from others is our effort in using only traffic signs to present the information, with some modifications for HUD and

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driving context adaptation, which we believe would be fairly intuitive for any driver holding a driving license. With this approach we intend to introduce a broader presentation scheme, which assumes that if drivers are educated and trained to understand those traffic signs while getting their driving license, then they will process and associate the signs to the presented type of danger much quicker. Fig. 1 shows the chosen signs. The first metaphor is based on the traffic sign C10, which forbids circulating closer than a certain minimum distance from the vehicle ahead. The second metaphor is inspired from the road safety marks, which recommends the safety distance to maintain from the preceding vehicle (horizontally painted on the road, or presented as vertical signs).

Figure 1. Traffic signals used to create the proposed metaphors. Both signals (traffic sign C10 on the left, and road safety marks on the right) are associated with the headway distance.

In order to validate the chosen metaphors, computer simulation experiences were carried out with 22 participants from several age groups. Objective variables were recorded from the simulations, processed and analyzed. Subjective variables were also gathered from two small questionnaires, before and after the experiments.

The next section presents the literature review considered most relevant for this work. Section III describes the proposed metaphors. The method used and the experiments are described in section IV, whereas section V presents the obtained results and their respective discussion. Finally, some conclusions are drawn and suggestions for future work are presented.

II. Related Work

The existence of integrated systems in the cars' instruments panel or in other devices, which allow drivers to have a safer driving is a dream come true, such as the Opel Ampera system [13]. This system already allows traffic signs recognition, lane deviation warnings, and safety distance indication, as well as forward collision warnings, among other automated functionalities. Also, systems that make use of AR in the car's windshield through HUD already exist, such as the BMW's HUD [14] that projects the car's velocity, road speed limits, or navigation instructions. From those still under investigation, systems that present several types of information, using different approaches, whether for cars, planes or ships can be highlighted. However, only some related to the automotive industry will be on focus in this paper.

Tönnis and Klinker [9] present two visualization metaphors for warning imminent dangers outside the driver's field of view. One of the metaphors uses an animated 3D arrow that appears over the car's head bumper that points to the source of danger, the other presents a car with a 2D arrow, viewed from the bird's-eye-view perspective, both accompanied of 3D sound. Through simulation experiments with human subjects, they showed that the results for the 3D arrow were better than those for the scheme with the bird's-eye-view perspective.

The Driver Assistance by Augmented Reality for Intelligent Automobile (DAARIA) system, proposed by George et al. [15], intends to detect obstacles on the road based on the drivers gaze direction. This system uses a visualization metaphor based on weathervanes, since it is egocentric and allows the indication of various dangers at the same time. To indicate the type of danger, authors use traffic signs since they are familiar to the drivers. The severity of the danger is shown based on color changes from green (safety) to red (danger). The more critical the dangers the larger are the weathervane arrows.

Considering the information on the braking distance, Tönnis et al. [6] propose two visualization schemes for longitudinal and lateral assistance on the cars' HUD. One of the schemes consists on a horizontal bar that shows up in front of the car over the road, and the other extends the first one by drawing the path that will be traveled by the car until it comes to a halt. The bar indicates the place where the car would immobilize in case of a sudden braking. Simulation experiments with participants showed that aid with visualization schemes was preferred against to the non-existence of a visual assistance, helping drivers' performance without increasing mental workload. However, the scheme with the path worsened the driver's behavior in keeping the lane trajectory. Authors suggest that, according to the design principles for visual aids in time-critical systems, they should be as minimal as possible and easy to perceive, and that therefore the bar scheme was preferred to the path scheme.

Plavsic et al. [16] compare already existing systems for the visualization of concealed dangers, aiming to find a metaphor that represents those dangers in an intuitive way to the drivers, helping in the correct perception of their distance to the car. Focusing more on crossroads and intersection scenarios for being more likely to hide dangers, they propose four visualization metaphors, two of them combined with traffic signs of the Highway Code.

From the works found that were related to safety warnings, i.e. warnings used to supply drivers with the needed information so they can drive as safely as possible, some make use of visualization schemes based on traffic signs, such as the example schemes proposed by George et al. [15] and Plavsic et al. [16]. Believing, not only due to our driving experience, but also to the literature review, that the use of traffic signs can be easier to perceive by drivers, the proposed metaphors in our approach are based on traffic signs.

III. The Proposed Approach

This section presents our approach to represent the proposed traffic signs, in an attempt to be the most perceptible and intuitive as possible to the drivers. The visualization metaphor proposed to represent the C10 traffic sign, hereafter designated as metaphor or symbol M1, is represented in Fig. 2 (a). Because we thought it would better warn the driver to keep the safety distance, the mandatory sign was adapted into a warning sign (triangular shape), and the information on the mandatory distance was replaced by an exclamation character between arrows. As proposed by Plavsic et al. [16], the symbol has the orange color, following existing standards for visualization schemes. The visualization metaphor proposed to represent the safety marks, hereafter designated as metaphor or symbol M2, is composed of 3 arrows pointing towards the driving direction and is depicted in Fig. 2 (b). The symbol changes color in the approximation of imminent danger, being yellow immediately when the driver violates the safety distance and red in the imminence of a collision. The arrows appear animated to draw more attention from the driver, lighting up intermittently in the driving direction, according to the scheme in Fig. 2 (c).

(a) M1 symbol used to indicate violation of the safety distance.

(b) M2 symbol with a binary color scheme to indicate the safety distance violation level of danger.

(c) Sequence used for animating the M2 symbol.

Figure 2. Symbols proposed for the safety distance violation metaphors.

Accounting for the work developed by the US National Highway Traffic Safety Administration (NHTSA) [17], two alert levels for triggering the symbols were considered: the precaution level and the imminent danger level, where the precaution level triggers as soon as the safety distance is violated, and the imminent danger level when the vehicle is too close to the preceding vehicle, i.e., if the front car comes to a halt, collision occurs. In the case of metaphor M1, an initial warning sound is issued in the precaution level. For the imminent danger level, both metaphors start to blink synchronously with a warning sound in a 4 Hz frequency [18], identical in both metaphors. The calculations made for triggering the warning symbols are described next.

A. Safety Distance Calculation

Since the study idea was to compare and analyze the adequacy and perception of the symbols by the participants, the atmospheric conditions and vehicles characteristics, among other factors that influence the safety distance calculus, were not taken into account. Therefore, the triggering of the warning symbols was based on calculations based only on distances and velocities in order to look as credibly as possible to the participants.

From the IMTT reference values table for the stopping distance vs. current velocity [7], a scatter plot with a potential regression line was built, resulting in a correlation of $R^2 = 0.9985$. From the obtained formula, the car stopping distance was calculated based on its velocity (1), where d_p corresponds to the stopping distance in meters, and v to the car's circulation velocity in Km/h. As for the issuing of the precaution warning, (2) was used, where d_{actual} corresponds to the host vehicle (vehicle that hosts the navigation system) current distance from the reference vehicle (preceding vehicle), and d_{min} to the minimum distance to issue the warning, i.e. when $d_{min} < 0$ the warning is triggered.

$$d_p = 0.0717\, v^{1.5274} \quad (1)$$

$$d_{min} = d_{actual} - d_p \quad (2)$$

As for the issuing of imminent danger warnings, (3) was taken into account, which calculates the difference between the stopping distances of both vehicles in case they suddenly brake.

$$\Delta_{FinalPos} = pos_{FinalRef} - pos_{FinalHost} \quad (3)$$

If $\Delta_{FinalPos} < 0$, the host vehicle will stop in the same position of the reference vehicle, i.e., will collide. $pos_{FinalRef}$ refers to the difference between the reference vehicle current position and its stopping distance. The same applies to $pos_{FinalHost}$, but for the host vehicle.

IV. Experimental Setup

Several computer simulation experiments, as demonstrated in Fig. 3, were carried out to validate the proposed metaphors, with participants from several age groups and driving experiences, i.e. they were all drivers in real life, holding valid driving licenses.

We used the Serious Driving [19] game for implementing the simulation. The simulated circuit consisted in a straight line freeway (i.e., without curves to avoid biasing the stabilization maneuvers before, during or after making a curve, so drivers could easily focus on the driving task), with a 120 Km/h maximum speed limit. At the beginning of the simulation a car (car_{ref}) appeared in front of the participant's car (car_{host}), being the participant forbidden of overtaking that car, so we could study the way he approached or kept away from car_{ref}. The car_{ref} vehicle had 4 different behaviors, 3 of which happened randomly: constant circulation at 50 Km/h, 90 Km/h or 120 Km/h. Close to the end of each simulation, the car_{ref} performed a sudden stop coming to a halt. Each participant performed 5 tests with an approximate duration of 2 minutes each, also done randomly to avoid the introduction of biases in the results, corresponding to the combination of the proposed metaphors with and without warning sounds, and a base test without metaphors. The baseline test was performed with the purpose of checking if there were any differences in the driving compared to the tests with the FCW system. All tests had the four car_{ref} referred behaviors. Before performing the tests, the participants performed a driving test in the simulator so they could learn and get acquainted to the use of the steering wheel and pedals, only advancing to the tests when they felt prepared.

The warning triggers were made through a continuous monitoring based on events, i.e., the warnings only appeared in situations of safety distance violation, according to the two levels of alert described in section III.

Figure 3. Image of a participant carrying out an experiment in our low-cost simulator.

TABLE I. DESIGNATION OF EACH PERFORMED EXPERIMENT PER PARTICIPANT.

Experiment	Description
Baseline	No metaphor.
M1S0	Metaphor 1 without sound.
M1S1	Metaphor 1 with sound.
M2S0	Metaphor 2 without sound.
M2S1	Metaphor 2 with sound.

The following objective variables were recorded for each experiment: timestamp, position (*x, z*) of the two cars mass center; position (*x, z*) of the invisible object placed at the host car's front foremost point and of the invisible object placed at the reference car rearmost point; intensity applied to the accelerator pedal by the participant (*0* to *1*); intensity applied to the brake pedal by the participant (*0* to *1*); and, timestamp when the warning symbols were triggered. By knowing the position of the invisible objects, it was possible to determine the distance between both cars, and therefore determine whether there was collision or not. By knowing the timestamp when the warnings appeared, it was possible to know whether the driver violated or maintained the safety distance. The velocity vectors allowed the calculation of the cars' velocity, which combined to the intensity applied to the acceleration pedal helped determine whether the driver reduced the speed to keep the safety distance. The same can be said for the intensity applied to the brake pedal, determining whether the participant braked or not to keep the safety distance and/or avoid a collision. Based on the distance between the cars and their respective circulation velocities, it is possible to calculate the Time To Collision (*TTC*) [20]. From the time the reference car braked and the participant pressed the brake pedal, it was possible to assess his reaction time. The two cars position also allowed the extraction of the number of collisions that occurred.

Besides recording the aforementioned metrics, two questionnaires were applied. A pre-questionnaire was conducted before the experiments, showing the proposed symbols and asking the participant to choose from a set of options the one that corresponded to each symbol. A post-questionnaire was also applied after the simulations, with subjective questions on the participant's simulation experience, most of them based on a 5-point Likert scale, as follows:

- Which of the tested approaches you considered most appropriate to help maintain the safety distance?
- The orange triangle warning hindered your driving?
- The blinking arrows warning hindered your driving?
- Comparing the 4 approaches, how would you classify their utility?
- How easily could you perceive the meaning of each symbol?
- The warning sounds hindered your driving?
- The warning sounds were adequate to the situation and intensity of danger that was happening?
- Would you like to have a system like this in your car's windshield? If yes, which one?

V. RESULTS AND DISCUSSION

A. *Participant's characterization*

According to their age, participants were equally divided into 3 age groups (33.3%): ≤ 27 years, between 28 and 41 years and > 41 years. The youngest participant was 22 years old, whereas the oldest was 64, being the mean 36 years with a standard deviation of 12.1. Only 4 participants were female. Regarding the driving frequency, 59% was used to drive every day, 23% only on the weekends, 9% several times a week, and the other 9% rarely. The driving experience varied from 3 to 43 years, with a mean of 17 years of experience and a standard deviation of 11.3.

B. *Pre-questionnaire*

When asked about the meaning of each symbol, it was found, as predicted, that symbol *M2* was less perceptible, with only 77% of correct identifications. Symbol *M1* was the most perceptible, with 91% of correct identifications.

C. *Post-questionnaire*

After analyzing the responses obtained in the post-questionnaire, it was found that 91% of the participants considered metaphors *M1* and *M2* with warning sounds more adequate than the ones with no sound. Regarding the perception of the symbols, the responses were contrary to the expected and to what was observed in the pre-questionnaire: only 63% of the participants considered *M1* as the most intuitive symbol, and 86% considered *M2* as the most intuitive. That is, out of the context, observing just the symbols, *M1* was easier to associate with a safety distance warning, but in the context of driving, built-in the car's HUD, symbol *M2* was easiest associated with a safety distance warning.

When questioned on whether they wanted a FCW system in their car, all participants said yes, where 55% wanted metaphor *M2* with warning sounds, 36% preferred metaphor *M1* also with warning sounds, and the remaining 2 participants indicated other metaphors.

As it can be seen in Fig. 4, all participants from age group 3 (older than 41 years old) chose *M2S1* as the preferred metaphor. Participants with 27 years or less were mostly divided between *M1S1* and *M2S1* metaphors. Participants with 28 to 41 years mostly preferred metaphor *M1S1*, followed by *M2S1*.

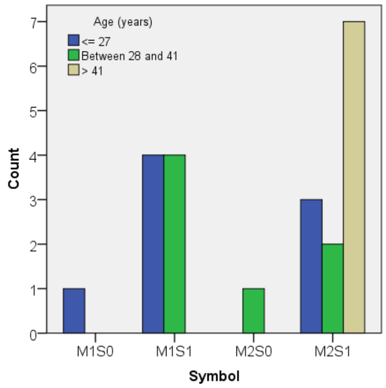

Figure 4. Metaphor preferences by age groups.

These findings are interesting for two main reasons. First, 91% of the participants preferred metaphors with warning sounds over the muted ones. According to [9] we verified that sound was perceived as useful despite there were no significant differences in the driving performance. The second finding was the concentration of the older age group in a single metaphor, while the younger age groups tended to disperse somehow over the other choices. We interpret these results as an evidence of the relevant contrast that age has over drivers' preferences. The reasons for these preferences are not clear, thus further investigation will be made.

D. Simulation Data Analysis

After preparing and processing the data recorded during the experiments, it was found that, in general, the participants had a similar behavior in all experiments (Fig. 5) meaning the distance they kept from the reference vehicle was not influenced by the type of symbol or existence/absence of warning sounds. But when compared to the baseline experiment, most of the participants violated more the safety distance without a FCW system than those with one. As it can be seen in Table II, the precaution warning percentage was varied. The most aged participants (> 41 years old) were the most conservative drivers, having a less percentage of safety distance violations. However, all participants violated more the safety distance without warning symbols (baseline experiments), especially the ones with 28 to 41 years of age (age group 2), meaning that the FCW system helped the drivers in better keeping the safety distance. Group 2 had a higher percentage of violation distance in the baseline experiments maybe because they felt kind of lost or free without the warnings, approaching too much the front vehicle. Since the older ones (age group 3) were more conservative, they also kept that type of behavior in the baseline experiments, although with less precaution, maybe because of the same motives as group 2.

Comparing experiments with warning symbols, the younger ones (≤ 27 years old) violated more often the safety distance than the other age groups. This occurred maybe because they were more inexperienced drivers and/or had a more aggressive driving behaviour.

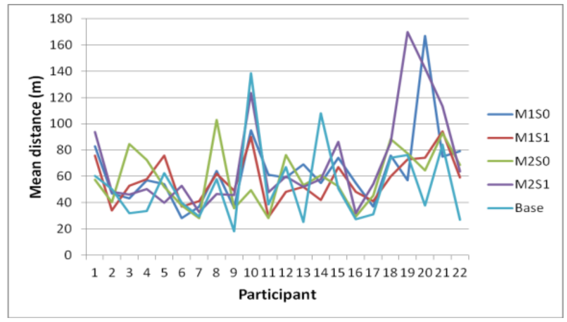

Figure 5. Average distance from the reference car per participant, in meters.

TABLE II. PRECAUTION WARNING APPEARANCE PERCENTAGE MEDIAN VALUE (%) PER AGE GROUP

	Precaution Warning Appearance Percentage Median (%)				
Age	***M1S0***	***M1S1***	***M2S0***	***M2S1***	***Baseline***
≥ 27	26.7	32.7	21.8	44.1	47.1
28 to 41	14.8	14.7	37.2	16.8	70.8
> 41	15.7	25.8	10.9	5.9	39.8

a. The baseline values correspond to the processing of the internal records of the warning appearances, since the warnings did not actually appear in that type of experiment.

Some works [5] [21] [22] also noticed distinct driver assistance systems effectiveness according to age, however, in our case, the number of participants was not enough to say whether the driving performances were significantly different. Concerning the number of collisions, only one collision was detected during all the experiments. Therefore, this metric did not help effectively in the metaphors' comparison.

We also analyzed the reaction time, counting from when the reference vehicle started to brake until the participant hit the brake pedal. In the cases where participants were already braking when the reference vehicle also started, the metaphor average value was calculated. The results are presented in Table III. Overall, the best result was achieved by *M2S0*, although there were no significant statistical differences between metaphor results.

TABLE III. REACTION TIME, IN SECONDS, FOR EACH METAPHOR PER AGE GROUP

		Reaction Time (seconds)				
Age	**Stat.**	***Baseline***	***M1S0***	***M1S1***	***M2S0***	***M2S1***
≥ 27	***Mean***	1.03	1.47	1.29	1.24	0.97
	SD	0.40	1.42	0.91	0.27	0.67
28 to 41	***Mean***	2.24	1.45	2.08	1.34	2.40
	SD	2.93	1.28	1.88	0.37	1.72
> 41	***Mean***	1.60	2.37	1.41	1.01	1.52
	SD	1.36	1.13	0.67	0.55	0.63

VI. CONCLUSION

The existence of a FCW system built in cars that warns the driver whenever he is violating the safety distance is already a reality. However, most of the systems are integrated in the instruments panel, which tends to make the driver look away from the road ahead to see the possible warnings that may appear. The integration of this type of systems in the cars' HUD is a great innovation, meaning the driver does not need to look away from his field of view, with the advantage of seeing the warnings/information superimposed with the reality in the road ahead, which may lead to a safer driving scenario. The idea of making drivers more prudent and followers of the Highway Code can therefore be helped with these systems.

Looking to find a more intuitive and adequate metaphor for a FCW system in a car HUD, two metaphors were conceived, namely *M1* and *M2*, based on traffic signs of the Highway Code. In the discussed experiments, it was found that most of the drivers recognized the warning symbols *M1* and *M2*, and that they kept more the safety distance with these warnings than without them. This was proven by comparing the results obtained for the 4 metaphors combination against the baseline results (experiment without warnings), meaning that the implemented FCW system helped drivers to better keep the safety distance. It was also found that the heard warning sounds did not negatively influence the results in a significant way and that the symbols with warning sounds were considered as the most useful.

Symbol *M1* was considered the most perceptible before the simulations (out of the context), but within the context, i.e. in the car's HUD in the simulation, symbol *M2* was considered the most perceptible, useful and adequate by most of the participants. In fact, and in general, after the simulations, participants said they preferred symbol *M2* with warning sounds (*M2S1*), and that they would like to have such kind of warning in their car's windshield. An interesting finding was that all the older participants (42 years or more) preferred *M2S1*, which can be used to customize the system to have this warning symbol for this age group.

As for future work, it is intended to continue the simulations, increasing the number of female participants to match the number of male participants to make gender comparisons possible. Also, we would like to investigate deeper into why older drivers prefer metaphor *M2* to *M1*. In the context of a broader project, we intend to benefit from an instrumented vehicle to perform the same experiments, but in a real-car environment following itineraries on real freeway networks.

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