



Measuring the effect of the rainfall on the windshield in terms of visual performance

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ARTICLE INFO

Article history:

Received 26 April 2013

Received in revised form

23 September 2013

Accepted 10 October 2013

Keywords:

Visual performance

Driving

Rain

Methodology

ABSTRACT

Driving through rain results in reduced visual performance, and car designers have proposed countermeasures in order to reduce the impact of rain on driving performance. In this paper, we propose a methodology dedicated to the quantitative estimation of the loss of visual performance due to the falling rain. We have considered the rain falling on the windshield as the main factor which reduces visual performance in driving. A laboratory experiment was conducted with 40 participants. The reduction of visual performance through rain was considered with respect to two driving tasks: the detection of an object on the road (contrast threshold) and reading a road sign. This experiment was conducted in a laboratory under controlled artificial rain. Two levels of rain intensity were compared, as well as two wiper conditions (new and worn), while the reference condition was without rain. The reference driving situation was night driving. Effects of both the rain level and the wipers characteristics were found, which validates the proposed methodology for the quantitative estimation of rain countermeasures in terms of visual performance.

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1. Road safety under rain

Rain may affect driving performance, and since the beginning of automotive transport, car designers have considered this issue. They have proposed countermeasures in order to reduce the impact of rain as early as 1903, when Mary Anderson proposed the first patent for a windshield wiper (Anderson, 1903). In addition to wipers, rain effects are also mitigated by improved windshield design, automotive lighting and road lighting. Considering the high impact of rain on vision, and even though the main impact of rain on driving addresses the road skid resistance, one may be surprised that the quantitative impact of rain on the driver's visual performance led to very few studies to date.

In his accidentology review, Parkari (2009) found that low visibility conditions, such as rain, fog and night driving, increase the risk of having an accident. More specifically, in rainy conditions, accidents with three and more vehicles are more frequent. The risk increases due to rain also depend on road conditions (higher on motorways, in curves and slopes) and on the road user (higher for cars and pedestrians). He also found that the risk increase is higher under strong rain compared to light rain.

Based on a comparison of accident data with and without rain, Andrey and Yagar (1993) found that the crash risk was 70% higher under falling rain compared to without rain. Interestingly, they found that this higher risk does not appear after rain, driving on a wet road. They proposed an explanation in terms of risk compensation (Wilde, 1988), arguing that drivers compensate for the skid resistance risk associated to a wet road, but not for the lowered visibility due to the falling rain. These results were confirmed by Chung et al. (2005) on the Tokyo Metropolitan Expressway, with an accident rate of 1.5/h under rain vs. 0.8 without rain. Another study in Melbourne (Australia) found that rain, rain intensity and night situation all three result in higher risk levels (Keay and Simmonds, 2005).

These results about accident rates are however mitigated by the accident severity data. From 10 years of accident studies in the UK, Edwards (1998) found that the severity of accidents under rain is less important compared to without rain, which may be due to the lower speed (Khatkhatkhat et al., 1998).

In addition to the higher risk due to a lower skid resistance, these results from accident studies could be expected from the visual effects of rain on visual performance. Three main effects can be anticipated: first, wet surfaces differ in their visual appearance from dry surfaces; second, the rain lowers the contrast between the objects and their background, thus lowering the driver's detection performance; third and most important, the raindrops on the windshield alter the visibility, in a way which is not well understood.

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A wet road surface changes the conditions of perception on the road by two main factors. First, a wet road is specular, and thus reflects in some situations the adverse light sources toward the driver (from either automotive or road lighting), which may lead to disability glare and discomfort glare (CIE, 2002). Second, retro-reflective road markings are almost inefficient under a water film, motivating the development of all-weather pavement markings as a countermeasure.

Rain drops are similar to optical lenses. According to Garg and Nayar (2007), they are close to fish-eye lenses with 165° of opening. Light is refracted and attenuated when crossing a rain drop, resulting in dynamic changes in the visual signal the driver receives. From far away, rain can be thought to as a diffusive media, just as fog. In that sense, light intensity is attenuated when crossing a distance d according to:

$$I = I_0 \cdot e^{-kd} \quad (1)$$

where I_0 is the light intensity without rain, d the distance between the object and the driver, and k the extinction coefficient, which depends on the rain intensity and on the raindrops size.

On a windshield, raindrops do not coalesce in water films, they rather behave as small moving balls, with dynamic properties in relation to the windshield material and shape, wiper speed and shape, and the driver's speed. The raindrops optical perturbation lowers the driver's visual performance, even in the presence of wipers (Green et al., 2008). These perturbations result, for instance, in eye glances at nearer distances, compared to rain-free situations (Zwahlen, 1980), which can be understood as a reduced driving anticipation or an increased mental workload (Shinar, 2007). Sayer and Mefford (2001) tested the impact of hydrophobic and hydrophilic windshields in terms of the driver's performance and comfort. They found a positive impact of hydrophobic windshield on both visual acuity and subjective feeling, but no effect of hydrophilic windshields. According to Andrey and Knaper (2003), the reduced visibility under rainy conditions is mainly due to the visual perturbation on the windshield, rather than the atmospheric effect of the falling rain (Eq. (1)). The reduction of visibility is even higher under low luminance levels (such as in night driving), low speed wipers, and small raindrops (OECD, 1976; Ivey and Mounce, 1984). In this paper, we focus on the "raindrops on the windshield" factor, and on night driving conditions.

If one wishes to link rainfall and visual performance, quantitative approaches are not easy. Thirty years ago, Bhise et al. (1981) conducted two series of experiments, on a closed test track and on the road. They measured the visibility distance as a function of ambient lighting, rain intensity and vehicle speed. Based on these experiments, they proposed a quantitative model of the detection distance of a vehicle, under rain, without wipers. From a field test too, Morris et al. (1977) proposed a quantitative model to link visual acuity to wiper speed and rain intensity. More recently, a comparison of visual performances under wet and rainy conditions was conducted on the Smart Road, at the VTTI (Blanco, 2002). Various automotive lighting systems were tested, and detection distances were recorded on various targets. The authors found a decrease in distance detection around 70% under rain.

From this body of results, rain appears as an important road safety issue. At the same time, there seems to be a lack of reference methodologies for the assessment of countermeasures (such as wipers) in terms of visual performance. In this paper, we propose such an experimental methodology, in order to measure two key visual performances with respect to the driving activity: target detection and reading. Two rainfall levels were considered, as the visual performance was expected to decrease with increasing rain level; and two wiper systems were considered, because it is the main countermeasure to the loss of visibility due to rain. This methodology was demonstrated in night-time conditions, and

proved to be selective enough to discriminate the visual performance both with respect to the wiper characteristics and with respect to the rainfall level.

2. Materials and methods

Based on our literature review, we have considered the rain falling on the windshield as the main factor which reduces the visual performance in driving. An experiment was conducted in order to quantify the reduction of visual performance through rain with respect to two reference driving tasks: the detection of an object on the road and reading a road sign. This experiment was conducted in a laboratory under controlled artificial rain. Two levels of rain intensity were compared, as well as two wiper conditions, while the reference condition was without rain. Visual performance was measured in terms of contrast threshold for the target detection task and reaction time for the reading task.

2.1. Participants

Forty volunteers (12 women, 28 men), with a mean age of 42 years (SD=12), participated in the experiment. They were all licensed drivers with normal or optically corrected vision.

Although they were recruited among DLCF employees, all participants were naive to the purpose of the experiment. They were given a full explanation of the experimental procedure, and a written informed consent was obtained before participation, with the option to withdraw from the study at any time.

2.2. Apparatus

2.2.1. Experimental room

The experiment took place in a 15 m long dark tunnel dedicated to photometrically controlled psycho-visual experiments in fog and rain conditions, at the Département Laboratoire de Clermont-Ferrand (DLCF), Clermont-Ferrand, France (Cavallo et al., 2001). The participants sat in a Renault Clio situated at one end of the tunnel.

During the experiment, low light levels were used, around 1 cd/m², in order to be close to the light levels usually encountered in urban places at night. The volunteers participated in two successive experiments, in order to measure two kinds of visual performance: target detection and reading performance. Two main variables were manipulated: the rainfall intensity and the wiper characteristics. Two more variables were considered: the target contrast with the background in the target detection task, and the "words" vs. "non-words" condition in the reading task.

The visual stimuli were displayed on a PC screen, at a distance of 5.15 meters from the participants. The reaction time was recorded using the RT Direct software, defined as the elapsed time between the stimulus onset and the key pressed on a keyboard.

2.2.2. Rain simulation

The rain projection system was manufactured by the SPRAI SAS Company. It was adapted in order to simulate rain on a car's windshield while controlling the rain intensity and a methodology was defined in order to produce artificial rain. This system can project various rain levels on the windshield of a vehicle installed in the platform. It allows producing artificial rain whose characteristics are very close to those of natural rain (rainfall, size, number and velocity of droplets); the range of rain intensity is relevant for natural rainfall, that is from 2 to 25 mm/h and the droplets' velocity ranges between 1 and 8 m/s. The system (see Fig. 1) consists of a removable structure, a reservoir, a hydraulic wardrobe and two sprayers, along with a control panel and a control software.

The sprayers are two meters above the windshield and can be controlled in terms of flow rate and rotational speed. Selected



Fig. 1. The two sprayers of the rain simulation system (left) and the spectro-pluviometer (right).

values of these parameters allow producing a total range of rainfall whose intensity varies from 0.2 to 150 mm/h.

In the DLCF platform, the rain simulation experiments involve a static car, whereas in real world conditions, the reduction of visibility depends on the rain intensity, the natural raindrop speed, and the car speed. In order to counterbalance the static condition of the experiment, one has the opportunity to increase the rain intensity. Thus, it is interesting to link the rainfall intensity, falling on the static windshield, to the rain intensity falling on the same windshield, on a running car. It is actually possible to compute the “dynamic” rain intensity I_d , when the driver runs the car at speed s , to the “static” rain intensity I_s (Holden et al., 1995; Peterson and Wallis, 1997). The relation between I_s and I_d follows:

$$u \cdot I_s = s \cdot I_d \cdot \tan(\alpha) \quad (2)$$

where α is the angle between the windshield and the horizon, and u is the raindrops speed.

Preliminary experiments were conducted in order to test the reproducibility of the rain characteristics with this system. The rainfall was measured with a rain spectrometer at 0.1 Hz situated 1.20 m above the ground (corresponding to the position of a typical driver’s eye in a vehicle). In the experiment, two rain intensity levels were produced, around 65 and 125 mm/h. For each intensity level, six rainfall sessions (S1–S6, see Table 1) were simulated during 1 h each, showing a good reproducibility.

Thanks to Eq. (2), these two rain levels can be described with respect to the driver’s speed. A static rain of about 65 mm/h corresponds to a range of dynamic rain natural intensity between 6 mm/h (running at 130 km/h) and 15 mm/h (running at 50 km/h). It is referred to as the “weak rain” condition in the following. A static rain of about 125 mm/h corresponds to a range of dynamic rain natural intensity between 12 mm/h (running at 130 km/h) and 30 mm/h (running at 50 km/h). It is referred to as the “hard rain” condition in the following.

2.2.3. Stimuli

Two performance tests were selected based on their relevance with respect to a driving task: target detection and reading. The corresponding stimuli were displayed on a computer screen, allowing a good control on the parameters (presentation time, luminance contrast, angular size). For the detection task, the reference variable was the luminance contrast between a square target and the background, which is uniform. This contrast was computed from luminance values measured with a LMK 98-4 Color Scientec videophotometer. The target was presented on a screen at a distance of 5.15 m (Fig. 2, left). The participant had to indicate as soon as possible when s/he saw a target by pressing a key. The dependent variable was the target detection (with value 0 or 1), as measured from a press key with the Direct RT software.

From the driver’s position, the square angular size was 0.48° . A trial consisted in 1.4 s of “random noise” on the screen, followed by a

dark screen with a central fixation cross, again during 1.4 s (the participants were asked to fixate this cross). Then, a dark background was presented during 4.2 s, and a stimulus appeared randomly in space during this last step; it appeared with a small eccentricity (0.83°) with respect to the central cross, at a random position on a circle.

Each square target was characterized by its luminance contrast. The luminance background was set to 0.1 cd/m^2 all along the experiment, and thirty contrasts could be generated between 0.12 and 8.39. In order to limit the experiment duration, only 15 contrast values were presented to each observer (with 4 repetitions). These contrast values depended on the observer’s sensitivity: in a pre-experiment, the detection contrast threshold $C_t(i)$ was estimated for each observer i , using targets of increasing contrasts, in the “without rain” condition. Then, in the target detection experiment, observer i was presented with 15 contrasts: $C_t(i)$, 7 contrasts above and 7 contrasts below $C_t(i)$. Our hypothesis was that the contrast threshold would increase both with rain intensity and with poorer quality wipers. Each displayed contrast was presented 4 times per observer; hence each observer was presented with 60 stimuli for each of the 5 conditions, that is, 300 stimuli.

A lexical task was considered to account for reading in driving. In this lexical task, 20 series of 6 letters were presented to each participant, with a high luminance contrast. These series could be either words (e.g. “CHEVAL”, that is, HORSE in English) or non-words (e.g. BEZGHU, which does not mean anything, even in French), and the participants had to decide whether a stimulus was a word or a non-word, and to respond with the keyboard as soon as possible. Using this kind of experimental protocol, one expects that the Reaction Time (RT) is longer with non-words compared to words. The rationale for this methodology is to engage the participants to a cognitive task relevant with respect to reading, but insensitive to the word’s content. Two dependent variables were recorded: the answer value (good or wrong response) and the RT (in milliseconds).

Considering both tasks, our main hypothesis was that a reduced visibility would increase the RT and lower the detection performance.

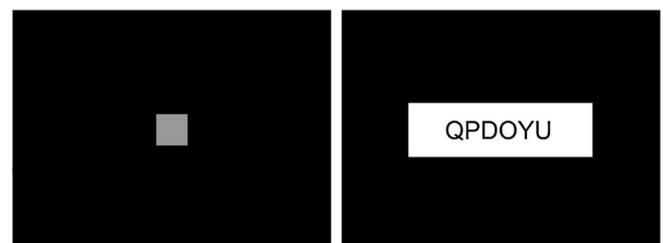


Fig. 2. Target stimulus for the detection task (left) and non-word stimulus for the legibility task (right).

Table 1
Reproducibility tests for two levels of rain intensity, across 6 sessions (labeled 1–6). Mean values in mm/h, with standard deviations in brackets.

	S1	S2	S3	S4	S5	S6	Mean
Level 1	69.52 (3.13)	68.41 (3.81)	64.96 (3.57)	66.38 (2.49)	65.63 (2.68)	65.81 (2.65)	66.79 (3.06)
Level 2	130.13 (9.19)	128.68 (9.43)	129.50 (9.78)	122.62 (11.52)	123.13 (8.26)	119.44 (8.10)	125.68 (9.38)

2.3. Experimental design

The participants were asked to sit down in the car, in the driver position, and were given the keyboard in order to record their answers. They first had to perform the pre-experiment, in order to select their individual contrast threshold for the target detection experiment.

In the first experiment (target detection), 5 blocks of 60 stimuli were defined, for the 5 conditions: without rain, weak rain or hard rain, and new wipers or worn wipers. Rain levels were tuned around 65 (weak rain) and 125 mm/h (hard rain). The wipers were new and worn wipers of the same model, provided by Valeo Visibility Systems. In each block, the 15 contrast values were repeated 4 times. The presentation order of the stimuli was randomized in each block, and the block order was also randomized, except for the “no rain” condition, which was always in the first session for practical reasons.

In the second experiment (reading task), 5 blocks of 60 stimuli were defined as above. Half of the stimuli were words, the other half were non-words. The presentation order of the stimuli was randomized in each block, and the bloc order was also randomized, except for the “no rain” condition, which was always in the first session as in the first experiment. The full session lasted around 2 h per participant.

2.4. Statistical analysis

Two dependent variables (DV) were recorded in this experiment, the participant’s answer value (either good or wrong answer) and the Reaction Time. Each participant was presented with two categories of stimuli (words and non-words), 10 of each for all five conditions, leading to 100 stimuli per participant. All data were checked for normality prior to analysis.

The two DV were first analyzed using repeated measure ANOVAs with Word and Rain as within-participants factors (Word (2) × Rain (3)). Then, in order to check for a potential effect of the wiper characteristics, the “no rain” condition was removed from the data and repeated measure ANOVAs were computed with Word, Rain and Wipers as within-participants factors (Word (2) × Rain (2) × Wipers (2)). For each significant effect, the effect size was computed using η^2 . The threshold for statistical significance was set to 0.05.

The target detection performance was measured repeatedly for 40 participants across 15 contrast conditions, two wipers conditions and three rain conditions (in the “no-rain” conditions, no wiper was activated). Given that the contrast is a continuous variable, 10 classes of contrast were built for further analysis. Contrasts lower than 0.10 were gathered in class 0: it corresponds to contrasts which are never detected. Contrasts higher than 1.0 were gathered in class 9: it corresponds to contrasts which were almost always detected. Between 0.1 and 1, eight classes were defined with equal width in the log domain.

As for the reading performance, Target Detection was first analyzed using a repeated measure ANOVA with Contrast and Rain as within-participants factors (Contrast (10) × Rain (3)). Then, in order to check for a potential effect of the wiper characteristics, the “no rain” condition was removed from the data and a repeated measure ANOVA was computed with Contrast, Rain and Wipers as within-participants factors (Contrast (10) × Rain (2) × Wipers (2)).

ANOVA were corrected for sphericity violations where necessary by use of the Greenhouse–Geisser modifications (Colomb et al., 2008; Greenhouse and Geisser, 1959). We found that the first class of contrast had a null variance in all conditions (the contrasts were so small that no one could see any stimulus); thus, these data were removed for the statistical analysis.

3. Results

3.1. Target detection performance

An ANOVA with Word and Rain as within-participants factors (Word (2) × Rain (3)) showed an effect of the contrast class as expected ($F_{(8,312)} = 222.22$; $\eta^2 = 0.85$; $p < .05$), as well as an effect of the rain level ($F_{(2,78)} = 29.75$; $\eta^2 = 0.433$; $p < .05$), and an interaction between contrast class and Rain ($F_{(16,624)} = 2.82$; $\eta^2 = 0.068$; $p < .05$).

After removing the “no rain” condition, in an ANOVA with Word, Rain and Wipers as within-participants factors (Word (2) × Rain (2) × Wipers (2)), the effect of the wipers was found marginally non-significant ($F_{(1,37)} = 3.79$; $\eta^2 = 0.093$; $p = .059$), and no interaction was found between Rain and Wipers ($F_{(1,37)} = 0.47$; $p = .495$).

Fig. 3 shows the psychometric curves in the 5 experimental conditions, reconstructed from the mean performance of the participants. These data have been fitted with Weibull functions in order to estimate the detection threshold in each condition for a given threshold. For instance, a 50% contrast threshold means that there is 50% chance that a participant would detect the target. The 50% contrast thresholds are given in Table 2. The 50% contrast threshold without rain was $Ct = 0.29$ in the present experiment, but this value is not significant in itself, because it strongly depends on the experimental conditions (target size, luminance background, etc.).

The rationale of the proposed methodology is not focused on the absolute detection threshold; it is to quantify the loss of visual performance due to an experimental condition, with respect to a baseline condition (without rain). Therefore, we have computed the ratio of the contrast threshold in any condition with respect to the contrast threshold in the baseline condition (Table 2).

3.2. Reading performance

3.2.1. Answer value

An ANOVA with Word and Rain as within-participants factors (Word (2) × Rain (3)) showed an effect of the rain level on the answer value ($F_{(2,78)} = 3.23$; $\eta^2 = 0.076$; $p < .05$). The only significant difference (contrast rain vs. no rain: $F_{(1,39)} = 5.16$; $p < .05$), showed more accurate responses in the “no rain” ($M = 99.1\%$, $SD = 9.6\%$) than in the “rain” condition ($M = 97.4\%$, $SD = 16.1\%$). No effect of the word type was found ($F_{(1,39)} = 0.70$; $p = .409$) and no interaction ($F_{(2,78)} = 2.44$; $p = .093$).

Table 2

Mean contrast value at detection threshold, for a detection probability of 50% [80% in brackets], in the 5 experimental conditions. These thresholds are computed after fitting of the experimental data with Weibull functions. C1, without rain; C2, weak rain, new wipers; C3, weak rain, worn wipers; C4, hard rain, new wipers; C5, hard rain, worn wipers.

Condition	C1	C2	C3	C4	C5
Contrast	0.29 [0.47]	0.34 [0.57]	0.35 [0.60]	0.38 [0.63]	0.44 [0.70]
Ratio	1.0 [1.0]	1.17 [1.21]	1.21 [1.28]	1.31 [1.34]	1.52 [1.49]

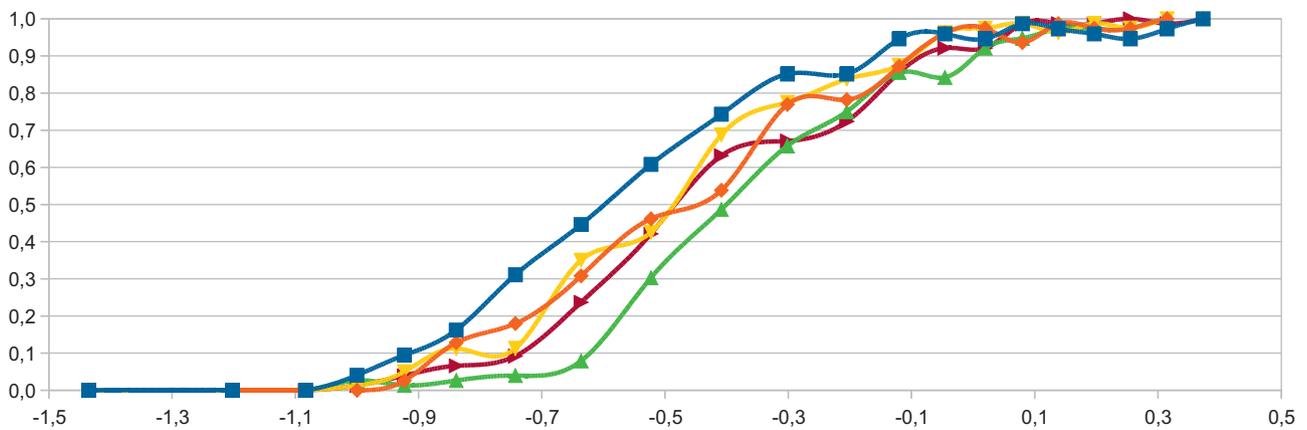


Fig. 3. Mean detection rate for the 5 experimental conditions, as a function of the log of the target luminance contrast with its background. Blue: no rain. Yellow: weak rain, new wipers. Red: weak rain, worn wipers. Brown: hard rain, new wipers. Green: hard rain, worn wipers. (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.)

After removing the “no rain” condition, an ANOVA with Word, Rain and Wipers as within-participants factors (Word (2) \times Rain (2) \times Wipers (2)) showed no effect of the wiper characteristics on the answer value ($F_{(1,39)} = 0.66$; $p = .423$) and no interaction between the Wiper and Rain factors ($F_{(1,39)} = 0.05$; $p = .830$).

3.2.2. Reaction time

An ANOVA with Word and Rain as within-participants factors (Word (2) \times Rain (3)) showed an effect of the rain level on the RT ($F_{(2,78)} = 18.60$; $\eta^2 = 0.323$; $p < .05$) with faster responses in the “no rain” condition ($M = 845.7$ ms, $SD = 259.7$ ms) compared to the “weak rain” condition ($M = 928.5$ ms, $SD = 265.3$ ms; contrast: $F_{(1,39)} = 18.51$, $p < .05$), and faster responses in the “weak rain” condition compared to the “hard rain” condition ($M = 981.7$ ms, $SD = 321.1$ ms; contrast: $F_{(1,39)} = 9.93$, $p < .05$).

An effect of the Word type was found ($F_{(1,39)} = 78.69$; $\eta^2 = 0.669$; $p < .05$), with faster responses for words ($M = 862.1$ ms, $SD = 268.1$ ms) than for non-words ($M = 992.1$ ms, $SD = 304.7$ ms), as expected. No interaction was found ($F_{(2,78)} = 1.49$; $p = .232$).

After removing the “no rain” condition, an ANOVA with Word, Rain and Wipers as within-participants factors (Word (2) \times Rain (2) \times Wipers (2)) found main effects of the rain level ($F_{(1,39)} = 8.40$; $\eta^2 = 0.177$; $p < .05$) and of the word type ($F_{(1,39)} = 84.06$; $\eta^2 = 0.683$; $p < .05$) on the RT, which was expected from the previous ANOVA. More interestingly, an effect of the Wiper characteristics was found on the RT ($F_{(1,39)} = 6.64$; $\eta^2 = 0.145$; $p < .05$), with faster responses for new wipers ($M = 922.5$ ms, $SD = 248.6$ ms) than for worn wipers ($M = 985.7$ ms, $SD = 329.2$ ms), showing a degradation of reading performance with worn wipers. No interaction was found (Word/Wiper: $F_{(1,39)} = 0.12$; $p = .730$; Rain/Wiper: $F_{(1,39)} = 0.00$; $p = .977$).

4. Discussion

A methodology was developed, in order to assess the performance of a driver visibility system through rain. The system consists in two parts: first, a laboratory system, where calibrated rain can be produced in order to simulate rain over a car’s windshield, in a dark tunnel, under controlled illumination. The second part of the methodology consists in an experimental protocol. Two visual tasks have been selected, one related to hazard detection (target detection), the other related to road sign reading (word vs. non-word discrimination).

The experiment gave evidence that this methodology is sensitive enough to measure a statistically significant difference between rain intensity conditions and between visibility system

conditions (wiper characteristics), for the reaction time for the legibility task. Significant differences were also found for the rain factor in the detection task, however the wipers effect was only marginally non-significant ($p = .059$).

These results suggest that the legibility task is more sensitive than the detection task, as far as visual performance in rain is concerned. However, looking for standards of visual performance assessment, we propose to keep these two indexes because they truly refer to different components of the driving task. Detection is more related to road safety at short temporal range, while reading may be related to navigation as well as road safety, but not in the same temporal range.

It is also interesting to note that from the designer’s point of view, the proposed methodology allows comparing various technical solutions, with a sensitivity which proved to be good enough to distinguish between two kinds of wipers in terms of visual performance through rain. Incidentally, our results make clear that the wipers quality is a key issue for visual performance on the road, which may deserve more research and also suggests that legal authorities could propose visual performance thresholds for these systems under controlled conditions.

The underlying approach was to split the visibility effects of rain into several effects (on the windshield, in the air medium, and on the object’s surfaces), and to limit the evaluation to the windshield effect. Given that these effects are assumed to be cumulative, the choice of the windshield was based on a literature review, suggesting that this was the main visual effect of rain on the driver’s visual performance. However, further studies may be conducted on the two other factors, based on the same tests. For instance, the same detection and legibility tasks could be conducted in foggy conditions, as it is expected to share some visual feature with the rainfall medium (small standing raindrops instead of big falling raindrops).

It is also obvious that we cannot take into account, with this methodology, all aspects of vision in driving, and for instance we do not consider the target (or road sign) apparent motion during driving, task complexity (which could be addressed with the double task paradigm), or specific driving subtasks such as car following. To our opinion, driving simulation protocols would be more relevant (and complementary to the proposed methodology) if one wishes to rate these components of the visual performance (Brémond et al., 2013); however, realistic rain is not easy to simulate in the current state of the art in Computer Graphics.

Another issue is the illumination conditions. The study in this paper simulated night-time conditions, as this situation was pointed in the literature review as very important in terms of road safety under rain. However, the experimental conditions could be

easily adapted to daylight conditions, using background and target luminance levels corresponding to daylight, and adding some controlled illumination in the experimental room.

This work gives way to the future development of more objective evaluation standards for automotive systems in terms of visual performance for the driver, such as automotive lighting, wipers, windshield and their interactions. For instance, it could be possible to make some kind of Advanced Driving Aiding Systems (ADAS) benchmark, taking the ADAS performance without rain as a baseline. Moreover, it may help in choosing trigger situations about when to switch on and off specific ADAS. However, such applications are not straightforward, because the current methodology is limited to comparing a system performance, under rain, to a baseline performance without rain. Looking for absolute thresholds would involve some more realistic driving scenarios, from which targets parameters could be chosen in order to select appropriate visibility thresholds.

To our opinion, the main application of the proposed methodology would be to rate and compare visibility systems, in terms of visual performance through rain. For instance, this could address the comparison of several wiper designs or speeds, the comparison of windshields, and even the comparison of automotive lighting systems. One important benefit of the proposed methodology is to allow testing the interactions of several components of the visibility system, such as windshield plus wipers.

Acknowledgements

We wish to thank Jérôme Cazard, Jean-Luc Bicard and Philippe Morange, who participated to the rain system settings and experiment passing, Eric Dumont for helpful discussions on the manuscript, and Stéphane Jourdain (Valeo) who supplied the wipers. This work was partially supported by the SURVIE FUI project.

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