A DRIVING SIMULATOR METHODOLOGY FOR EVALUATING ENHANCED MOTORCYCLE CONSPICUITY

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ABSTRACT

A methodology was developed for evaluating enhanced powered two wheeler (PTW) conspicuity in a driving simulator environment. In order to evaluate the methodology, a driving simulator experiment was conducted involving n = 10 European car drivers. Testing involved full-task, "blind" experiments in which the driver subjects did not know the true purpose of the experiment, which was to measure differences in behavior due to various PTW frontal lighting treatments. Realistic driving was performed in urban and rural conditions, with drivers performing various realistic primary and secondary driving tasks. Drivers navigated a road circuit that included several real PTW accident sites and scenarios from MAIDS (Motorcycle Accidents In Depth Study) that were accurately modeled in the driving simulator. The lighting treatments included the baseline PTW lighting treatment, which was a single dipped-beam headlamp of a typical sport motorcycle, and three hypothetical lighting treatment examples. The effects of car daytime running lamps were also evaluated, with either 10 or 90% of cars operating with headlights on. The following parameters were measured: detection distance of opposing vehicle (OV), decision as to whether to turn in front of OV, and minimum distance to OV. From these data, the probability of collision with an OV was calculated. Based on this, the potential reduction in the overall number of accidents was estimated based on the subjective relevance of the experimental findings to each of 129 accident configurations in the MAIDS database. In addition, the driving simulator was validated by performing a vehicle detection task in both simulator and full-scale environments. The validation tests indicated similar motorcycle detection rates between the simulator and the full-scale environments. Overall, the simulator methodology was found to provide a powerful tool for researching differences in driver behaviour and collision probability due to daytime lighting treatments in this sample of real accident scenarios.

INTRODUCTION

Background

The current study comprises one part of ACEM's overall safety programme, which is aimed at improving powered two wheeler (PTW) active safety (i.e., accident avoidance). This programme is based on increasing the understanding of how and why PTW accidents occur, in particular by means of the recent "Motorcycle Accidents In Depth Study" (MAIDS) of n = 921 accidents in 5 EU countries (ACEM, 2004).

The topic of PTW conspicuity as a strategic means for improving PTW safety had been identified by ACEM during MAIDS and in previous years, by reference to several findings:

- The relatively high frequency at which "Other vehicle (OV) driver perception failures" had been identified in PTW in-depth accident research (e.g., Hurt et al., 1981; Vis, 1995; ACEM, 2004);
- Prior research indicating that many vulnerable road users (e.g., pedestrians, bicyclists and PTWs) have relatively low conspicuity in traffic due to their small sizes and relatively low exposure frequencies;
- Increasing, and possible future mandatory, use of specialized daytime running lights on cars (e.g., as indicated in ECE R87, with amendments);

- Worldwide harmonization of lighting regulations (e.g., as in ECE/WP29/GRE), including discussions of PTW amber position lights, among other topics.

Together, these have led to ACEM's current policy in regard to enhancement of PTW conspicuity. Namely, the first step: automatic headlamp on (AHO); second step: research of enhanced PTW conspicuity; third (more long term) step: use of ITS/Telematics. It is on one part of the second step of these that the current paper is focused.

Objectives

Against the background in Europe of the overall objective of reducing road casualties, accidents between cars and powered two wheelers (PTWs) are being studied. PTWs are expected to be increasingly operating in a car daytime running light (DRL) and PTW automatic headlamp-on (AHO) environment, and many stakeholders are considering further increases in the conspicuity of PTW lighting systems.

The objective of the work reported in this paper was to develop a methodology that was capable of scientifically measuring increases in active (i.e., sensory, visual performance, photometric) and passive (i.e., behavioural, task performance, cognitive) conspicuity in realistic traffic, lighting and accident scenarios.

Previous Accident Research

There have been several in-depth accident investigations culminating with the recent MAIDS report (ACEM, 2004), which have helped to identify "primary contributing factors" in PTW accidents. Several examples are mentioned here that provide impetus to this study on PTW conspicuity.

Table 1 gives a distribution of which vehicle had priority in n = 259 PTW accidents in the Netherlands (NL) reported by Vis (1995). This data suggests that the PTW had priority in the great majority of cases (211 of 259 cases, or 81%).

Table 1.
Priority by road user (Vis, 1995)

Priority by:	Sign / Rule	Traffic Lights
PTW	190	21
Car	18	14
Unknown	7	9
Total	215	44

Table 2 lists the collision avoidance action of PTWs and cars in these same accidents. As can be seen, in 72% of the cases the car driver took no evasive action before the PTW was struck. This suggests several possible contributing factors: a lack of driver perception of the PTW, improper speed-distance perception, or disregard for PTWs. It is important to attempt to further clarify the relative frequencies of these different mechanisms in order to devise suitable countermeasures, and this was a goal of the current research.

Table 2.
Collision avoidance action (Vis, 1995)

	PTW	Car
Nothing	26%	72%
Braking	51%	17%
Steering	12%	5%
Accelerating	2%	1%
Other	9%	5%
Total	100%	100%

Table 3 indicates the distribution of whether the car driver or PTW rider saw the other party prior to the crash, in the same NL study. The drivers reported that in 50% of cases they did not see the PTW, and in 20% of cases that they saw the PTW "too late" (versus 5% and 20% for the PTW rider, respectively). The same data indicate that the PTW rider saw the car in 70% of cases, but the driver saw the PTW in only 25% of cases.

Table 3.
Did you see the other party? (Vis, 1995)

	PTW	Car
Yes	70%	25%
But, too late	20%	20%
Not at all	5%	50%
Unknown	5%	5%
Total	100%	100%

Table 4 summarizes the frequency of various PTW accident conditions for the two larger in-depth PTW "regional census" studies (Hurt et al., 1981; ACEM, 2004). These are two of the best-known in-depth investigations of motorcycle accidents. The data from both studies indicate that the majority of accidents occurred in daylight (75 and 73%, respectively); clear weather (84 and 90%); involved two-vehicle collisions (75 and 80%); with an "other vehicle" bearing from the PTW of 11 to 1 o'clock (77 and 71%); and light to moderate traffic (85 and 85%). In addition, the Hurt data indicated that the other vehicle violated the PTW priority in 51% of cases and the PTW was considered to have "low" or "no" conspicuity in 46% of cases.

Table 4.
Accident conditions (Hurt, 1981; ACEM, 2004)

Accident Condition	% of all PTW accidents Hurt et al. (n=900)	ACEM (n=921)
Daylight	75	73
Clear weather	84	90
Two-vehicle collision (MC-OV)	75	80
Other vehicle (OV) violates PTW priority	51	NR
PTW “low” or “no” [sensory] conspicuity	46	NR
OV “low” or “no” [sensory] conspicuity	5	NR
Bearing of OV from PTW, 11 to 1 o’clock	77	71
Light or moderate traffic, no congestion	85	86
Headlamp off (daylight)	51	moped: 41 MC: 11

NR = Not reported

The two-vehicle (MC-OV) collision was the largest category of collision type, as noted in Table 4. Within the two-vehicle collision category, the highest percentage of collisions was due to "other vehicle driver perception failures" (n = 337 or 37% of all accidents from MAIDS). Other relevant types of two-vehicle PTW accidents within and outside this category include: OV turning in front of PTW from perpendicular path (n = 57 or 6%); PTW background or clothing contributed to lack of conspicuity (n = 35 or 4%); OV/MC paths perpendicular (n = 60 or 7%); and MC/OV traveling in opposite directions (n = 73 or 8%). In addition, other conspicuity-related accident types as coded by the investigators included "driver comprehension failures" (n = 13 or 1%) such as speed-distance misjudgment; other driver decision failures (n = 91 or 10%) which involve improper judgment of PTW collision threat; and partial, moving or complete view obstructions (n = 31 or 3%) where low PTW conspicuity (as it re-appeared) may have worsened the outcome. Together, these conspicuity-related accident typologies form a very sizeable fraction (i.e., the majority) of PTW accidents.

Conspicuity Research and Applications

A comprehensive review of daytime running lights was provided by Rumar (2003). Overall, the review indicates a rapidly increasing trend toward "daytime lighting" on both cars and PTWs in Europe as well as in other regions.

For cars, a standard for universal daytime running lights has been proposed, and implementation plans are considering "automatic dipped beams-on" versus "dedicated DRL's" in the mid-term, and "adaptive lighting systems" in the longer term.

For PTWs, ACEM members already equip PTWs with "automatic headlamp-on" (AHO). In addition, riders are required to use headlamps during daytime in Denmark, Spain, France, Germany, Italy, Lithuania, Poland, Sweden and Finland.

A typical PTW asymmetric beam pattern that meets ECE R20 (today R112) provides high illumination in nighttime, mostly in below horizontal, forward-road zones. The illuminance at the opposing driver's eye point (DEP: located at the eye of the driver in a car at 25 m distance in the opposing lane) is required to be less than 0.4 lux. However, there are several important considerations surrounding this fact. First, there is a wide variation in the market of illuminance values at the DEP (usually far below the maximum), and also in the areas surrounding this point (because they are unregulated). Second, this zone is of primary importance for "daytime conspicuity" of the PTW to the opposing driver. Third, the legal maximum intensity for dipped beams at the DEP is far below the minimum recommended by Rumar (2003) for daytime lighting. This means that dipped beams, which are designed for nighttime, may not be optimal for daytime conspicuity improvement applications.

The vehicle lighting industry has reported in numerous publications that current and new technology provides many solutions for "dedicated DRLs" for cars which are designed to be visible at the DEP, and which are not required to project very great levels of illumination on the roadway at night. For this reason, such "dedicated DRLs" are claimed to have advantages of very low energy consumption, low cost, as well as flexible packaging alternatives. At the time of initiation of this study there were no production dedicated DRLs in the EU market.

Most prior research on PTW conspicuity has focused on various treatments for the PTW and the rider, often with limited or greatly simplified methodologies and unclear or conflicting findings. Since rider preferences for clothing and helmet colour should not be standardized or regulated, it may be more feasible to focus on enhancement of conspicuity (and in particular in daytime lighting) improvements for the PTW itself. Due to the relatively high frequency of "11 to 1 o'clock" opposing vehicle "bearings" in PTW accidents, the most promising area for PTW treatment enhancement may be in forward directions, which could consist of a combination of headlamps, position lamps and running lamps, or any other technology that would improve PTW perception and conspicuity. These lighting treatments have numerous characteristics that could be varied including size, number, location, intensity, and colour and possibly modulation rate and level, in order to determine the most effective combinations.

Past research has been done regarding the behaviour of typical car drivers interacting with PTWs in hypothetical or laboratory conditions. Understanding the behaviour of the opposing driver in real traffic situations helps guide efforts for increasing PTW conspicuity. Therefore, placing drivers in realistic potential accident situations using simulated PTWs can help to better define the problem from the perspective of driver behaviour.

Driving simulator experiments have been recommended by various researchers to be the most desirable means to study PTW conspicuity. The simulator can be used to re-create accident situations for comparison with the real-world situations. The simulator allows these accident re-creations to depict real accident situations, a feature that full-scale testing cannot provide. The high levels of experimental control and repeatability of the simulator environment are also key benefits. A naturalistic, blind driving experiment can be readily performed in a simulator with no risk to the driver subject and can involve real life distractions and workload. The conspicuity (enhancing) technologies can be (photometrically) calibrated to match the real world, and validation can be made against full-scale PTW detection tests. Simulator tests are safer, and also typically require fewer research team members to participate in the testing. Finally, the human and vehicle input and output variables are more easily measured in driving simulators.

METHODOLOGY

Driving Simulator

All pilot testing and main testing was performed in the Dynamic Research, Inc. (DRI) moving-base Driving Simulator. The Driving Simulator is a research grade, dynamically realistic, moving base, "driver-in-the-loop" device. The application takes advantage of the experimental control, flexibility, measurement ease and safety that are provided thereby.

Driver subjects sat in a vehicle cab equipped with instrumented controls and displays. The vehicle dynamic model used in the simulator for these experiments was a BMW 3-series car with automatic transmission, which had been used routinely in previous driver/vehicle response and performance studies. The driver interactively applied all steering, braking, and throttle actions needed to control the vehicle. The Driving Simulator utilized complex high texture computer-generated roadway scenes, which were displayed on a 180-degree forward field-of-view in front of the driver, projected to display the view from the driver's eye point. The roadway graphics consisted of photographically realistic, texture-mapped images and suitably calibrated ambient and vehicle lighting. Buildings and other objects used digital photographic images that were "wallpapered" onto 3D polygons. An ambient (solar) lighting model was used and standardized to be representative of typical motorcycle operating conditions in Europe. Simulator motion was provided by a 6 degree-of-freedom hexapod motion system. A synthesizer generated traffic noise, including the Doppler effect, in order to be as realistic as possible. A research assistant was present in the cab with the driver subject at all times.

All driver and vehicle motion and control measures were recorded for data analysis. The simulator has the capability to measure and record virtually all motion and control states. The driver's line-of-sight in the visual field was also recorded, by means of an ISCAN eye tracking system (Razdan et al., 1988).

Road Circuit

The road circuit used for this study consisted of a total of 5 intersections from the MAIDS accident database, each presented two times during one lap, in different orders. The 5 sampled cases were those in which combinations of conspicuity factors were identified by the MAIDS investigation teams. These were: "Opposing vehicle driver perception failure" plus "motorcycle background or rider clothing contribution to lack of conspicuity."

The road circuit, shown in Fig 1, was about 7 kilometers in length. Two-lane roads connected each of the intersections (one lane in each direction).

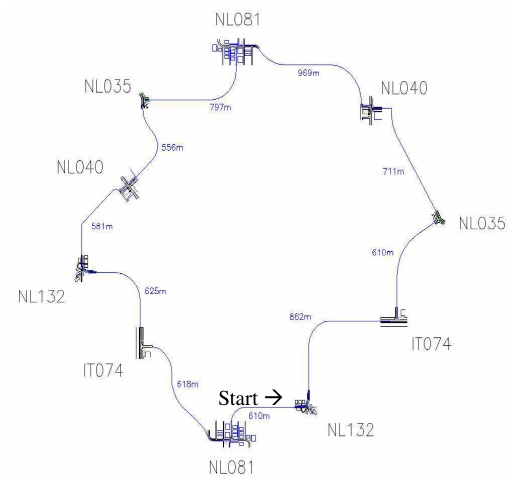

Figure 1. Simulator road circuit.

Accident Scenarios

At each of the intersections, and based on the conditions coded by the accident investigation teams, several vehicles were situated and moving such that the subject vehicle would be presented with a random-appearing but exactly repeatable sequence of events. The general scenario at each intersection was one in which a platoon of vehicles approached the intersection (from a direction that depended on the intersection and real accident), and the driver subject had to decide when it was appropriate to proceed through that intersection, in view of the positions and speeds of the opposing vehicles. In order to ensure that the vehicle platoon was at the proper location each time, the vehicle platoon matched the speed of the subject vehicle until the subject vehicle was very close to the intersection. Once it was close to the intersection, the vehicle platoon speed was set to the speeds encoded in the actual accident. To the driver subjects, the platoon spacing, position and speeds appeared to be effectively random.

Of the five different intersections, there were two general types: "left-turns" across oncoming traffic (3 intersections), and "crossings" of perpendicular traffic (2 intersections). The three left-turn intersections were MAIDS cases NL081, NL132, and IT074. The two crossing intersections were MAIDS cases NL035 and NL040. The platoon speeds were those actually recorded in each accident. The inter-vehicle gap sizes were selected so as to appear to be randomized overall, but also to present to the driver a so-called "medium risk" gap size in front of each opposing vehicle lighting treatment, to be described subsequently.

The general left-turn scenario is shown in Fig 2. As the subject vehicle approached the intersection, the vehicle platoon approached in the on-coming lane. The vehicle platoon included a lead vehicle, an opposing vehicle, and a trailing vehicle, with a distracter vehicle positioned on a cross street. When the lead vehicle passed the distracter vehicle, the distracter vehicle proceeded and turned left. The opposing vehicle was positioned at a fixed gap size behind the lead vehicle. If the opposing vehicle was a PTW, the gap size (bumper-to-bumper) was 3.7 seconds. If the opposing vehicle was a car, the gap size was 2.7, 3.7, or 4.7 seconds, randomized and equally distributed in frequency. The trailing vehicle was always 4.0 seconds behind the opposing vehicle. If the opposing vehicle was not present, the trailing vehicle was located 4.0 seconds behind where the opposing vehicle would have been, thus creating a gap of 7.7 seconds between the lead vehicle and the trailing vehicle.

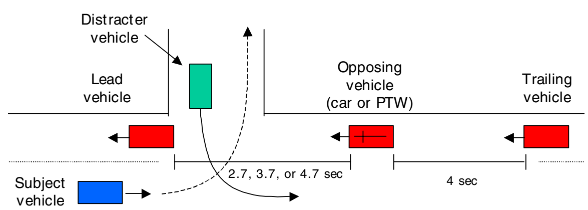

Figure 2. General left-turn scenario (NL081, NL132, IT074).

There were two different types of crossing intersections: a left-turn across perpendicular traffic (MAIDS case NL035), and crossing perpendicular traffic with a slight jog to the right (MAIDS case NL040). "Yield" signs were located at both intersections, so the subject vehicle usually came to a full stop before proceeding.

The first crossing intersection scenario type is shown in Fig 3 (left-turn across perpendicular traffic). As the subject vehicle approached the intersection, the vehicle platoon approached from the left. Again, the vehicle platoon included a lead vehicle, an opposing vehicle, and a trailing vehicle, with a separate distracter vehicle approaching from the right (the opposite direction). First, the distracter vehicle passed in front of the subject vehicle. Then the lead vehicle passed the subject vehicle shortly thereafter, as the subject vehicle was positioned at the "Yield" sign. The opposing vehicle was positioned at a fixed gap size behind the lead vehicle. If the opposing vehicle was a PTW, the gap size (bumper-to-bumper) was 3.0 seconds. If the opposing vehicle was a car, the gap size was 2.0, 3.0, or 4.0 seconds, randomized and equally distributed in frequency. The trailing vehicle was always 4.0 seconds behind the opposing vehicle. If the opposing vehicle was not present, the trailing vehicle was located 4.0 seconds behind where the opposing vehicle would have been, thus creating a gap of 7.0 seconds between the lead vehicle and the trailing vehicle.

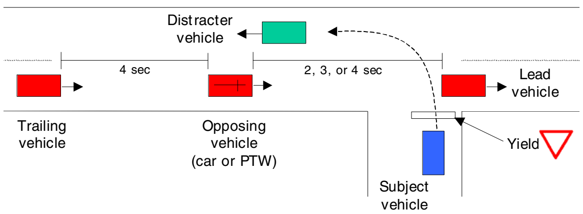

Figure 3. General crossing intersection scenario type 1 (NL035).

The second crossing intersection scenario type is shown in Fig 4 (crossing perpendicular traffic with a slight jog to the right). As the subject vehicle approached the intersection, the vehicle platoon approached from the right. The vehicle platoon included a lead vehicle, an opposing vehicle, and a trailing vehicle, with a separate distracter vehicle approaching from the left (the opposite direction). First, the distracter vehicle passed in front of the subject vehicle. Then the lead vehicle passed the subject vehicle shortly thereafter, as the subject vehicle was positioned at the "Yield" sign. The opposing vehicle was positioned at a fixed gap size behind the lead vehicle. If the opposing vehicle was a PTW, the gap size (bumper-to-bumper) was 3.0 seconds. If the opposing vehicle was a car, the gap size was either 2.0, 3.0, or 4.0 seconds, equally distributed. The trailing vehicle was always 4.0 seconds behind the opposing vehicle. If the opposing vehicle was not present, the trailing vehicle was located 4.0 seconds behind where the opposing vehicle would have been, thus creating a gap of 7.0 seconds between the lead vehicle and the trailing vehicle.

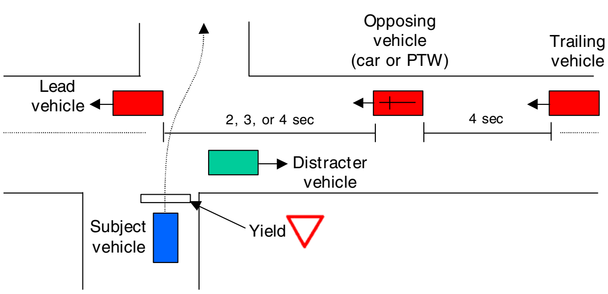

Figure 4. General crossing intersection scenario type 2 (NL040).

Subject Protocols

All driver subjects were given the same specific instructions at specific times. In general, subjects were instructed to drive "as quickly and safely as possible through the road course." Subjects were asked to follow road signs to a hospital while following speed limits for various portions of the road circuit: 50 km/h in "built-up" areas (the areas surrounding the intersections), and 80 km/h in all other places. The sound of a car horn was heard each time a speed limit was exceeded.

In order to provide a suitable and realistic driver workload, subjects were also asked to perform a radio tuning task at various intervals while driving. At various locations along the road circuit, a voice prompt told the subject to tune to a randomized radio station frequency. Tuning was accomplished by rotating a tuning knob located on the right side of the radio. The tunings were a simple, single-station tuning, with less than 10 MHz of movement between radio channels. Tunings were performed between most intersections, at seven different locations along the road circuit.

A structure of small monetary penalties and rewards was also implemented in order to encourage realistic driving behaviour. Subjects were told that they started each run with USD 4 and that each speed limit violation incurred a penalty of USD 1. In addition, a reward of USD 2 was given for road circuit completion within a certain time limit, and a penalty of USD 2 was incurred for exceeding the time limit. The actual time limit was arbitrary, although a typical circuit time would be about 8 minutes for realistic, "quick but safe" driving.

Drivers were encouraged, by means of controlled comments from the Experimenter, to adopt a moderate rate of choosing to "GO" in front of the opposing vehicle, since no useful information would be gained from drivers always going or never going in front of the opposing vehicles. This was found to be necessary because it was observed during the Pilot Tests that, over long periods of time, drivers behaviour tended to "drift" gradually toward either an "always GO" pattern (representing a very high level of risk, or so-called "video game" behaviour); or toward a "never GO" pattern (or "zero risk") behaviour. Whilst such behaviors may or may not occur in the real world, the objective of the research was to examine the so-called "medium risk" situations most typical of real accidents, namely, those situations in which there is roughly an equal probability of "GO" or "no GO." These are situations that require conscious sensing, recognition, speed-distance estimation and decision-making by drivers, which was the main objective of these experiments.

In view of these objectives and factors, the following protocol was implemented in the last Pilot Test and in the Main Tests. If and when drivers did not choose at least 1 "GO" in the most recent 5 intersections, they were read the following statement:

> "In order to receive your time bonus, you may need to take more risk at the intersections."

If and when drivers chose at least 4 "GOs" in the most recent 5 intersections, they were read the following statement:

> "You can still receive your time bonus even if you do not take quite so much risk at the intersections."

In this way, the subjects were allowed (but not forced) to adjust their risk level. This was done in such a way, in the presence of randomized gap size and treatment, that the subjects tended to choose a "medium risk" level, overall. No other coaching or discussion in relation to this was given.

Example Treatments

Overall, a total of 15 lighting treatments were used in various phases of the study. Pilot Test 1 examined the greatest number of treatments, while Pilot Tests 2 and 3 were used to refine the final selections for the Main Tests.

Figure 4 illustrates the approximate appearance of the baseline lighting treatment selected for use in the Main tests. This comprises a "sport" type moped with a sport type motorcycle headlamp of 186 mm diameter and 273 cd at the opposing driver's eye point (DEP) location.

Ultimately, hypothetical treatments were selected for use in the Main Tests based in part on:

- Total intensity (detection theory)
- Multi-lamp separation (speed-distance estimation theory)
- Signature/pattern and signature/colour (recognition theory)

These criteria and the results of pilot testing were used to select the final treatments for the Main Tests.

Figure 4. Appearance of baseline lighting treatment.

Photometric Calibration

Photometric calibrations of the lighting treatments were conducted in order:

- To compare simulated and real-world daytime contrast ratios for treatments;
- To determine the feasible contrast ratio for the Driving Simulator;
- To establish a maximum simulated luminance value for the simulator tests.

The first step was to examine luminance measurements that would occur at a typical Driver Eye Point (DEP) for the various lighting treatments that would be used in the testing. Next, laboratory measurements of an existing headlamp were made. Then real-world daytime luminance and contrast ratio measurements were taken. Then the maximum luminance to be simulated was established from the various lighting measurements that had been made. Finally, luminance measurements were made in the Driving Simulator of the implemented lighting treatments, and contrast ratios were calculated and compared to those from real-world conditions.

Generally speaking, for this series of daytime lighting experiments, it was found that a simulated maximum contrast ratio (i.e., saturated white-to-18% horizontal grey card surface) of 6.4 to 1 was sufficient to capture the real-world contrast ratios present with current typical car and PTW normal headlamps under typical "bright" daylight conditions.

The ambient lighting of the scene was therefore adjusted to achieve this contrast ratio with the brightest of the treatments set to saturated (pure) white. The contrast ratio as used here is defined as the ratio of the luminance of the lighting treatment as measured at the DEP minus the luminance of the background as measured at the DEP, divided by the luminance of the background. The standard luminance of the background was taken to be 1750 cd/m^2 based on mid-day luminance measurements using a horizontal 18% grey photographic reference card, recorded outdoors at 35 degrees north latitude during several weeks around the vernal equinox, under a wide variety of cloud conditions. This was considered to represent typical worst-case "bright" conditions. Darker daytime ambient lighting (as in more northern latitude and/or winter conditions) would be expected to lead to higher detection and effectiveness of the lighting treatments studied, and in addition are less representative of typical motorcycle operating conditions.

The screen luminance of all of the simulated scenes as measured at the DEP were in the photopic (i.e., greater than 1 cd/m^2) region, and therefore, although they were 1000 times (i.e., 60 decibels) dimmer than full-scale, they involved the same human sensory apparatus (i.e., photopic luminance contrast) as full-scale.

In all other regards, the simulated luminance of each headlamp was modeled in the Simulator in accordance with the lighting manufacturer data, as a function of the vertical and horizontal angles from the driver's eye to the headlamp central axis, and the distance-squared from the headlamp to the driver's eye.

Experimental Matrix

The Main Tests involved 10 driver subjects and examined 4 different PTW lighting treatments. The overall experimental variables included the 4 PTW lighting treatments, 5 unique intersections, 2 DRL mixes, and 2 repeats. A single gap size was used when the PTW was the opposing vehicle. The experimental variables and the total runs required are shown in Table 5. The experimental variables resulted in a total of 24 road circuit loops per subject.

Table 5.
Main test experimental variables and total runs required

Number of intersections	5
PTW Lighting treatments (baseline and 3 others)	x 4
Gap size (PTW as Opposing vehicle)	x 1
Percentage of Cars having lights on (10 or 90%)	x 2
Repeats	x 2
PTW exposures per subject:	= 80
(33% occurrence rate of PTWs)	x 3
Intersections required per subject:	= 240
Intersections per road circuit loop:	/ 10
Total number of road circuit loops per subject:	= 24

Measurements

For each run (i.e., one lap of the circuit), several different types of data were collected. Continuous time history data were collected, including:

- Positions of all vehicles
- Speed
- Brake pedal force
- Throttle pedal position
- Lateral and longitudinal acceleration
- Steering wheel angle

Driver eye fixations on the opposing vehicle were also collected from a head-mounted eye tracker. The time of the driver's first fixation on each opposing vehicle was recorded in post-processing of the video data, and the resulting variable was the distance to the opposing vehicle at the time of the first fixation.

Two video recordings were made. One recording was of the split images of the driver's face, forward road scene, and cab interior, shown in Fig 6. Note that the driver is wearing the eye tracking equipment; the area around the eye that appears to be lit is infrared wavelength light and therefore not visible to the driver. The second video recording was from the head-mounted wide angle camera, with the eye fixation crosshair superimposed, shown in Fig 7.

Figure 6. Split images of driver face (1), forward road scene (2), and cab interior (3).

Figure 7. Video image from head-mounted camera, at an instant when eye is fixated on PTW, and head is facing left window of car.

METHODOLOGY VALIDATION

In addition to the pilot testing, validation tests were performed in order to compare driver detection of vehicles in real world (full-scale) versus the simulator. The technical approach was to measure and compare motorcycle detection rates using full-scale and simulator occlusion experiments.

The protocols and setup for full-scale testing and simulator testing were the same. Both phases of the validation test used the same subject. The methodology was somewhat similar to that used by Donne et al. (1985) comprising a forward view occlusion test with a scene geometry somewhat similar to that of Cobb (1992).

The subject was seated in the driver's seat of a parked vehicle, wearing occlusion goggles that gave a 0.100 sec glimpse of the forward scene. This glimpse time was similar to that used by Donne et al. (1985), and consistent with human glance durations, which can be about 0.070 sec and greater. A motorcycle, car, both or neither would be presented to the subject. The motorcycle, if present, appeared in front of the subject in 1 of 4 possible locations, and the car appeared in 1 of 3 possible locations. The motorcycle headlamp could be on or off, and the car headlamp was always on. After the occlusion shutter was opened then closed, the subject was asked:

- Which vehicles were seen?
- Where was each vehicle located? and
- Was each vehicle's headlamp on or off?

Upon completion of full-scale and simulator testing, the data was reduced and analyzed. Vehicle detection was the primary concern, with headlamp detection being of secondary interest. The possible vehicle detection error types were: omission errors, insertion errors, and substitution errors. Omission errors occurred when a vehicle was present, but not reported. Insertion errors occurred when a vehicle was not present, but was reported. Substitution errors occurred when a vehicle was present, but was reported as another vehicle type (car or motorcycle). Of the different error types, omission errors were considered to be the most important with respect to motorcycle conspicuity.

Overall, omission error rates were similar in full-scale and simulator testing. All motorcycle omission errors occurred with the headlamp off. More omission errors occurred to the left, which was a somewhat larger visual angle from the subject's line-of-sight than the position to the right. No errors of omission occurred in the centre positions.

The probability of motorcycle detection that resulted from the full-scale and simulator testing was also compared to a simple hypothesized, detection probability model using a primitive "detection index" (DI). This index was similar to the "area-weighted contrast" models mentioned by Blackwell (1946) and Witus et al. (2001) as historical models for describing human detection of simple objects against plain backgrounds. The index is defined in Equation 1 as:

$$DI = | \text{Area x Contrast ratio} | \quad (1).$$

Such primitive models have been found to be of less value in complex scenes involving complicated targets and cluttered backgrounds. This equation is valid for one exposure time (in this case, 0.100 sec) in time-dependent models such as those discussed by Witus et al. (2001).

The hypothesized "probability of detection" model, shown in Equation 2, is a simple heuristic model of logistic form, as a function of the hypothesized detection index, and with a correction for eccentricity (i.e., horizontal angle from the line of sight).

Probability of detection = $(1 - e^{-DI/b}) \cos^{b/DI} \Phi$ (2).

where: b = detection constant
Φ = horizontal angle

The exponential cosine correction is suggested as being similar in form to the data presented by Arnow and Geisler (1996).

Figure 8 shows the probability of motorcycle detection for the hypothesized detection index model (fitted to the current data), as well as for the full-scale and simulator tests. The full-scale and simulator tests include data for both headlamp-on and headlamp-off. For all cases, at a 5 degree offset (foveal view) the probability of detection was the same, at 1.0. At a 35-45 degree offset (peripheral view) the probability of detection was slightly greater in the Simulator than in full-scale. Figures 9 and 10 show the probability of detection for headlamp-on and headlamp-off conditions. In the headlamp-on condition, the probability of detection was 1.0 for all angles in both full-scale and simulator tests. For the headlamp-off condition, the probability of detection in full-scale for the right peripheral view was about 0.9 and for the left peripheral view was about 0.8, being somewhat greater than this in the Simulator.

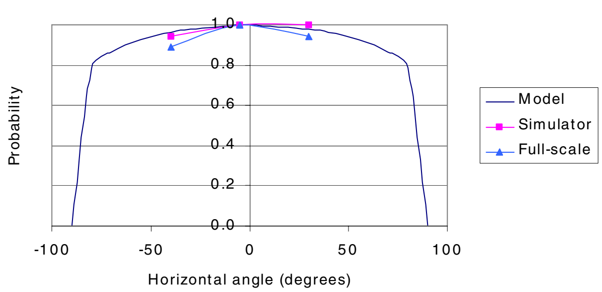

Figure 8. Probability of motorcycle detection for model, simulator, and full-scale tests, all conditions.

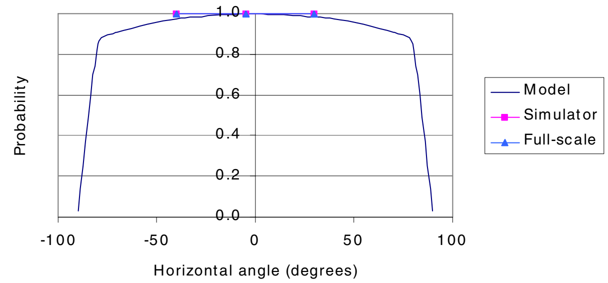

Figure 9. Probability of motorcycle detection for model, simulator, and full-scale tests, headlamp-on conditions.

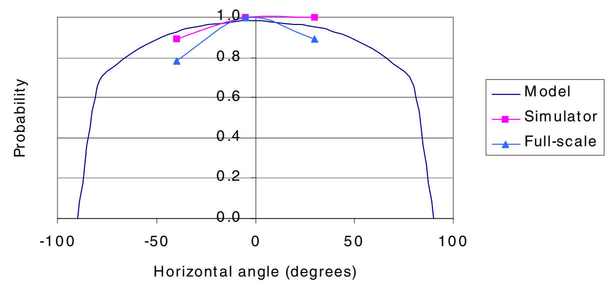

Figure 10. Probability of motorcycle detection for model, simulator, and full-scale tests, headlamp-off conditions.

Validation Test Conclusions

The results of Validation Testing indicate that for short 0.100 second glances at 5 degrees, the simulator gave the same probability of detection as full-scale for all motorcycle headlamp on/off conditions. At 35-45 degrees, the simulator gave the same probability of detection as full-scale for headlamp-on conditions. At 35-45 degrees, the simulator gave somewhat greater probability of detection than full-scale for headlamp-off conditions. One possible reason for this difference might be that "solar glare" from the car in the full-scale test competed with the headlamp-off motorcycle.

In general, solar glare reflections from vehicles and the environment in sunny conditions can be much brighter than, and can reduce the effectiveness of, typical dipped beam headlamps (not to mention the conspicuity of a headlamp-off vehicle). In full-scale outdoor tests, the amount of solar glare can vary over time, and is an extraneous variable. A driving simulator can control and keep the solar glare constant. So in order to minimize the effects of extraneous variables, it was concluded that the simulator tests should use "cloudy-overcastbright" conditions and not excessive levels of object shininess or "specularity." These conditions are typical for much of Europe in much of the motorcycle riding season.

Overall, the results of the Validation Tests also suggest that the effectiveness of lighting treatments measured in the simulator might be less in the real world for large horizontal viewing angles (e.g., crossing-type accidents) in sunny regions. In fact, the Main Test lighting treatments (which were dipped beam headlamps) were not so effective in such "wide angle" conditions, even in the Simulator. Otherwise, the simulator was found to give accurate and valid results for the rapid glimpse conditions examined, in comparison to real world full-scale motorcycle detection rates.

Finally, a simple rough "Detection Index" model was able to describe, at least in form, the main "probability of detection" effects observed in the Validation Tests.

EXAMPLE DATA FROM MAIN TESTS

Whilst presentation and discussion of the detailed results of the Main Tests is beyond the scope of the current paper, the purpose of which is to describe the experimental methodology, nevertheless, a few examples of typical resulting data illustrate the discriminating power of the methodology.

Several hypothetical frontal lighting treatments were considered, with four (A, B, C and D) being evaluated in the Main Tests. Treatment A was the baseline PTW treatment previously described. None of the hypothetical treatments B, C or D considered real-world practicability. Data for cars is also shown.

Statistical differences between sets of data were reported when appropriate. The statistical test that was typically performed was an independent samples t-Test. The output of the statistical test is a p-value, where values less than 0.05 indicate a significant difference between the data sets.

The probability of eye fixation on the opposing vehicle was analyzed by PTW treatment, shown in Fig 11. The overall probability of eye fixation was lower for PTWs than for cars, but the difference in fixation probability was not significant (p=0.17). None of the PTW lighting treatments were significantly different from the others in terms of the probability of eye fixation. However, the probability of eye fixation on a car was significantly greater than for PTW treatments C (p=0.04) and D (p=0.03), while differences from PTW treatments A (p=0.06) and B (p=0.08) were not significant.

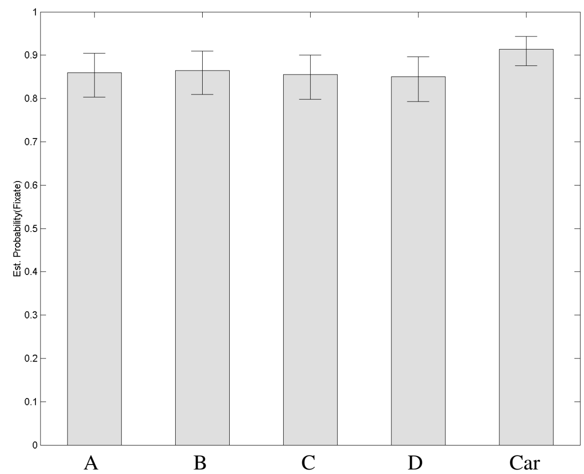

Figure 11. Probability of eye fixation on opposing vehicle for treatments.

Figure 12 shows the distance to the opposing vehicle at the 1st eye fixation for both left-turn and crossing intersections. This was the distance where the driver subject first observed the opposing vehicle. For left-turn intersections, the fixation distances were similar. For crossing intersections, the mean fixation distance for Treatment A was 5 to 8 m less than for the other (greater intensity) PTW treatments and for cars, but this difference was not significant.

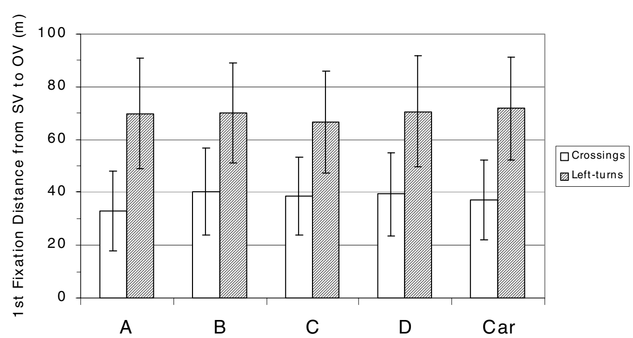

Figure 12. Distance to opposing vehicle at 1st eye fixation, left-turn and crossing intersections.

The probability of "GO" was analyzed by PTW treatment and combined across intersection type, shown in Fig 13. Overall, cars had a significantly lower probability of "GO" than PTW treatment A. Also, PTW treatment B and cars had significantly lower probability of "GO" than PTW treatment D.

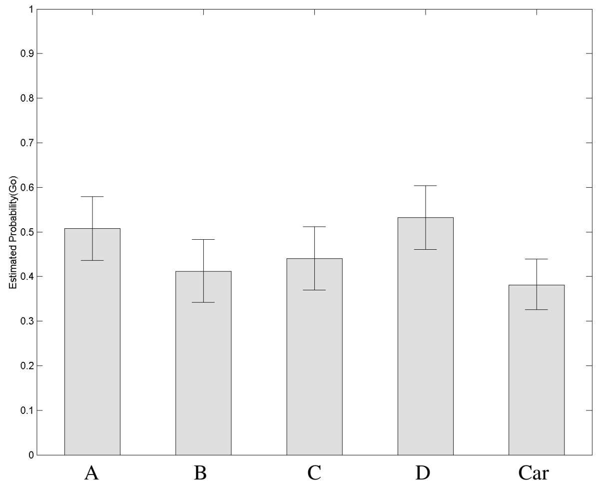

Figure 13. Probability of "GO" by treatment.

The cumulative distributions of minimum distances to the opposing vehicle in "GO" conditions were combined across intersection type, and graphed on a normal probability scale shown in Fig 14. The linear distributions when graphed on a "normal" scale indicated that the distributions were "normal." This increased the reliability of the intercept (i.e., collision probability) calculation. Overall, PTW treatment A had the greatest probability of collision overall, having the greatest number of near-miss incidents. PTW treatment B had the least probability of collision overall.

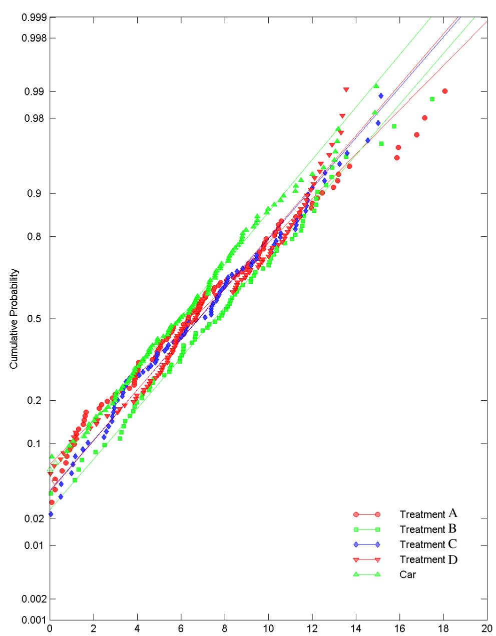

Figure 14. Cumulative distributions of minimum distances to opposing vehicles.

Probability of Collision

The overall probability of a collision was defined as the probability of a "GO" multiplied by the probability of a collision given a "GO," shown in Equation 3:

$$P(\text{Collision}) = P(\text{"GO"}) \times P(\text{Collision})|_{\text{"GO"}} \quad (3).$$

The data for these calculations, given in the previous subsection, was pooled over all 10 driver subjects. The probability (or estimated observed frequency) at 0 distance indicates the probability of a collision, and a constant slope when graphed on a "normal" scale indicates a normal distribution.

Figure 14 (shown previously) is the cumulative distribution of minimum distances to the opposing vehicle and Fig 15 summarizes the resulting probability of collision for each PTW treatment. Treatment B had by far the lowest mean probability of collision, and this was significantly lower than Treatment A.

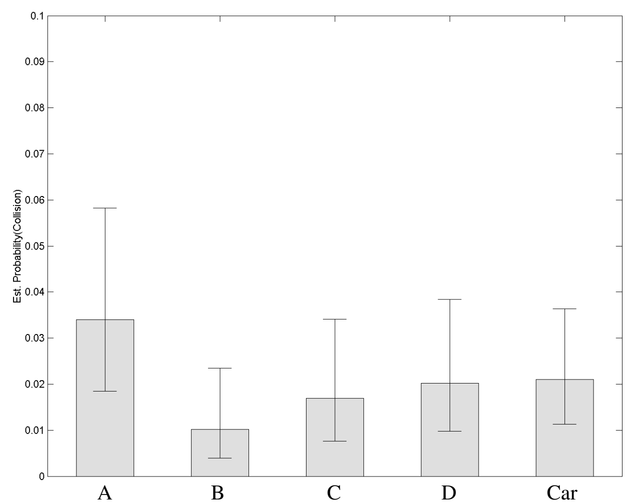

Figure 15. Probability of collision for each PTW treatment.

Preliminary Overall Effectiveness Estimate

The preliminary estimated overall effectiveness of each PTW lighting treatment was calculated using the Main Test data and aggregated MAIDS data for the various categories of accidents.

The methodology used to make these estimates used both quantitative data from the simulator experiments and from the MAIDS accident database, and subjective judgments of "effectiveness weighting" in each category of MAIDS accident.

The method first listed 129 relevant categories of PTW accidents using the OECD Common Methodology Data Summary Sheets. Next, the number of cases in MAIDS falling into each accident category was listed. Next, it was noted that in 37% (337) of the n = 921 MAIDS accidents, "other vehicle driver perception failure" was coded as the primary contributing factor (and this was the largest primary contributing factor). It was assumed that the visual background had a negative effect on motorcycle conspicuity in some of these cases of "other vehicle driver perception failure." Therefore, the MAIDS data was evaluated in order to develop an estimate of the number of PTW accident typologies that may have included a visual background that had a negative effect upon PTW conspicuity.

The data from MAIDS indicated that the visual background had a negative effect on MC conspicuity in n = 112 cases. This is 33% of the n = 337 "OV driver perception failure" cases.

CONCLUSIONS

An experimental investigation was conducted to verify whether potential PTW conspicuity improvements could be studied in driving simulator experiments. The driving simulator consisted of an instrumented car with interactive steering, braking and throttle controls; a 180-degree high resolution real-time visual display; a road circuit involving five real accident sites and scenarios from the Motorcycle Accidents In Depth Study (MAIDS); left turn and crossing intersections with randomized gap size in front of opposing vehicles; 3D photographic images of the accident sites; and motorcycle and car lighting treatments photometrically calibrated against full-scale in terms of measured luminance contrast ratios.

In addition to photometric calibration against real headlamp contrast ratio data, the simulator was validated using human visual occlusion tests involving vehicle detection. In these tests with 0.100 sec glimpse times, the driver's detection of motorcycles in the simulator was identical to that in the full-scale tests under most conditions (i.e., in the foveal, or central, zone), with headlamp-on and headlamp-off; and in the peripheral zone with headlamp-on); and only somewhat greater than in the full-scale tests in one condition (peripheral, headlamp-off). The latter small difference is attributed to the presence of solar glare in the full-scale tests. This extraneous and variable condition reduced the conspicuity of the motorcycle headlamp-off condition. Overall, the validation tests indicated that the simulator is valid for rapid detection tasks in the foveal as well as the peripheral regions.

Main Tests were conducted with n = 10 European car drivers, and involved full-task, "blind" experiments in the calibrated and validated driving simulator. Driver subjects did not know the true purpose of the experiment, which involved realistic driving in urban and rural conditions and various primary and secondary realistic driving tasks. A protocol was developed which resulted in all subjects driving with similar levels of "medium risk" at intersections.

Measurements were made of driver eye fixations (i.e., detection) of opposing vehicles (i.e., PTWs or cars); probability of "GO" in front of an opposing vehicle; and minimum distance to the opposing vehicle, enabling calculation of the "probability of collision." Each driver subject (10) was exposed to each lighting treatment (4) at each accident site (5) twice for two different car DRL conditions, yielding a total of n = 800 treatment exposures.

Overall, the simulator methodology was found to provide a powerful tool for researching differences in driver behaviour and collision probability due to daytime lighting treatments in this sample of real accident scenarios.

RECOMMENDATIONS

An initial peer review with experts from the human factors and lighting research communities has suggested that whilst the simulator methodology appears to be robust and valid, further validation and application would be helpful, in terms of elucidating and extending the initial findings. This additional research could include: investigating various simulator and protocol issues (e.g., driver short term learning effects; separating the effects of driver long term learning and background DRL percentage changes; wider variations in speed and intersection type); further validation of detection with greater numbers of drivers; validation in over-the-road experiments; investigation of a wider range of treatments and technologies; and refinement of the overall effectiveness estimation method.

The simulator methodology might also be useful in the in-depth and realistic evaluation of other safety technologies, such as telematics and e-safety, which aim at improving PTW conspicuity.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Association des Constructeurs Européens de Motocycles (2004), "MAIDS, in-depth investigations of accidents involving powered two wheelers," Final Report 1.2.
[2] Hurt, H., J. Ouellet, and D. Thom (1981), "Motorcycle accident cause factors and identification of countermeasures, v.1 technical report," DOT HS 5-01160.
[3] Vis, A. (1995), "De onveiligheid van motorrijden nader bekeken: een beschrijving van de aard en omvang van het probleem," SWOV.
[4] Rumar, K. (2003), "Functional requirements for daytime running lights," UMTRI-2003-11.
[5] Razdan, R. and A. Kielar (1988). "Eye tracking for man/machine interfaces," Sensors, Sept. 1988.
[6] Donne, G., E. Fulton, and P. Stroud (1985), "Motorcycle conspicuity in daylight," 10th ESV, pp. 1119-1122.
[7] Cobb, J. (1992), "Daytime conspicuity lights," Transport Research Laboratory WP/RUB/14.
[8] Blackwell, H. (1946), "Contrast thresholds of the human eye," Journal of the Optical Society of America, 36, 624-643, 1946.
[9] Witus, G., G. Gerhart, and R. Ellis (2001), "Contrast model for three-dimensional vehicles in natural lighting and search performance analysis," Optical Engineering, 40, 1858-1868.
[10] Arnow, T. and W. Geisler (1996), "Visual detection following retinal damage: Predictions of an inhomogeneous retino-cortical model," Proceedings of SPIE, 2674, 119-130.