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The Effects of Retroreflective Conspicuity Tape on Motorcycle Detection Distance among Car Drivers

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ABSTRACT

This study was carried out to determine whether or not retroreflective conspicuity tapes installed onto the side of a motorcycle would improve its night-time visibility, in terms of detection distance by car drivers and other motorists. In total, 32 configurations were tested to suit the motorcycle conspicuity related issues on Malaysian roads. The configurations included the presence of reflective tapes on the test motorcycle, the motorcycle head- and tail-light status, location of roadways (urban or rural), types of road and junction, and road condition. The motorcycle detection distance as indicated by the study participants were then recorded during an experiment performed in a controlled condition; under the supervision of trained technical staffs. On average, the findings gave a motorcycle detection distance of 44 meters as the baseline for motorcycles ridden without lights and conspicuity tapes installed. In relative terms, lights or reflective tapes increased the detection distance by about 60% as compared to the baseline condition of no conspicuity. When the lights and reflective tapes were combined, the average detection distance was 86 meters, an increase of 95% as compared to the baseline. Further analysis of the results showed that the conspicuity tapes complemented the motorcycle lights. In general, motorcycles with conspicuity tapes could be detected from a further distance in almost every configuration and driving situation as compared to motorcycles without the tapes. In conclusion, proper use of retroreflective conspicuity tapes on a motorcycle can increase its visibility, assist in reducing night-time related crashes and eventually help save lives.

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1. Introduction

Road traffic injuries and fatalities have been especially high in Malaysia, where motorcycle, scooter and moped crashes are the major contributors to this calamity (WHO, 2018). For ease of comprehension, the term 'motorcycle' is used in this paper to represent two-wheeled vehicles as stated above. Among the key contributing factor to motorcycle crash is the visibility or conspicuity of the vehicle and its users, especially in low light environment such as at dawn, dusk and night. Such crashes constituted about 26% of the total fatalities (Abdul Manan & Varhelyi., 2012; Samuel, 2015). Conspicuity-related crashes is defined as "any crash involving motorcycles moving straight or turning with the right of way when pedestrians and other vehicles cross their paths". Motorcycle conspicuity is commonly associated with one of these three definitions, namely the ability for a motorcycle to be detected when the location is known (visibility), when it has to be searched within a scene (search conspicuity), and when it is not deliberately searched although the observer is viewing the scene (attention conspicuity) (Helman, 2012). In normal circumstances, the observer is able see a motorcycle clearly if the vehicle is expected to appear from a certain direction. However, in mixed-mode traffic, the characteristic of motorcycle riding with multi-directional movement (non-lane based and frequently changing lane position) has basically diminished anticipation by other road users, particularly from the peripheral visual field (Ledbetter et al., 2012; Pinto et al., 2014; Ranchet et al., 2016; Rößger et al., 2012).

By design, motorcycles have significantly smaller width relative to other motorized vehicles which makes them visually hard to be detected. The size of the motorcycle is commonly associated with its high involvement in traffic conflicts and crashes (de Craen et al., 2014; Law et al., 2016, Rogé et al., 2018). All motorcycles are equipped with the front and tail lights and also a rear retro-reflective device to enhance their visibility on the road. However, in many circumstances, these default fitments seem inadequate for visual motorcycle detection in low light situation, especially at intersections. It is not uncommon to see a motorcycle on the road with unlighted tail lamp, in particular, due to fused circuit, blown bulbs and poor upkeeping of the lighting system. In addition, the motorcyclists' attire is equally important in enhancing their visibility (Solah et al., 2019). Bright color attire may help in enhancing visibility, thus, helping to avoid motorcycle conspicuity-related road crashes (Law et al., 2016). Correspondingly, the introduction of day-running-light (DRL) ruling in Malaysia years ago has led to a 30% reduction in motorcycle crashes (Solah et al., 2013; Rahman et al., 2013; Radin Umar et al., 1995). Enhancing the visibility of motorcycles at night time may help reduce the risk of crashes (Wells et al., 2004) and among the options is to use visibility enhancers such as a retroreflective tape which is considered as simple and cost effective. Studies on tapes fitted onto the rear end of trucks have shown great potential in enhancing their conspicuity (Lan et al., 2019).

In Malaysia, more than 60% of road fatalities involve motorcyclists and most motorcycle crashes occur at night in rural areas where the roads are poorly lit (RMP, 2018). This explains why motorcycle conspicuity is an important area to be focused on to reduce road crashes. Therefore, this study attempts to determine motorcycle detection distance at night through the use of a retroreflective tape. The detection distance of a motorcycle without lights and without retroreflective markings was used as a control or baseline measure in the study.

2. Method

2.1. Participants

As this study measures motorcycle detection from a car driver, all the study participants were required to have a valid driving license. Of the thirty participants (13 female), a large majority (67%) were between 31 and 40 years old. Most of the participants had more than 10 years of driving experience. At the start of the experiment, all of them underwent a screening of motion sickness and color-blind test. They then provided a written consent of their involvement. All the participants reported to have normal vision. The attributes of the participants are listed in Table 1 below.

2.2. Materials

2.2.1. Reflex reflectors

Per local regulations, a motorcycle would need to have a red-colored rectangular reflex reflector above the rear number plate (dimension size: 9cm x 3cm), and a yellow-colored circular reflex reflector on each side of the body just below the end of the seat (diameter of 5.5cm). These three reflex reflectors would provide a baseline measure of night time visibility in all four levels of night time conspicuity.

2.2.2. Retroreflective markings

The retroreflective markings provided were yellow-coloured Diamond Grade™ Conspicuity Marking Series 983 (3M Materials). The markings are compliant with UNECE Regulation 104, class C. The installation of retroreflective markings was done in collaboration with the technical team of supplier. Markings were applied on the front wind shield, rear fender and on both sides of a motorcycle body (on the fuel tank and underneath the seat). Refer to Table 2 and Figure 1 for application layout details.

2.2.3. Video recordings

Recording of the motorcycle encounters required a site and scheme to direct the flow of traffic in a sub-urban environment. Wetland Park, Putrajaya was selected as the site, as its network of straight and curved roadways had only few road lights (Figure 2). Furthermore, the site provided a safe environment for recording the videos as the local government would close the park to regular traffic at night time. Prior to each video recording, all the team members were briefed on the overall planning as well as safety measures.

A total of 15 video recordings were made for this study. A video recording may have two to four different motorcycle encounters depending on the road type and length of a course. Varying the number of motorcycle encounters per video would also reduce bias in the experimental trials.

Table 1: Participant demographics.

Description	Category	Frequency	Percentage (%)
Age	21 – 30	6	20.0
	31 – 40	20	66.7
	41 – 50	3	10.0
	51 and above	1	3.3
Range: 21 – 62	*Mean: 34.8*	*Median: 34.0*	*Std. Deviation: 7.95*
Gender	Male	17	56.7
	Female	13	43.3
Education	Primary – Secondary School	4	13.3
	STPM – Foundation – Diploma	12	40.0
	Bachelor Degree	11	36.7
	Master – PhD	3	10.0
License ownership	Motorcycle Riding License (B2, B1, B Full)	21	70.0
	Motor Car Driving License (D, DA)	30	100.0
Driving Experience	1 – 5 years	3	10.0
	6 – 10 years	6	20.0
	More than 10 years	21	70.0

Table 2: Size of retroreflective markings on a motorcycle.

Area	Size of the Retroreflective Marking (length x width in cm)	Estimated Area Ratio of the Marking Relative to Motorcycle Projection (%)
Front windshield	25 x 1.4 (x4 strips)	18 %
Side-on gas tank	20 x 1.4 (x2 sides)	12 %
Side-above rear wheel	70 x 1.4 (x2 sides)	
Rear fender	15 x 2.5 (x2 strips)	30 %

Figure 1: Yellow-coloured Diamond Grade Conspicuity Markings Series 983 applied on two motorcycles [also visible are the rear and side reflex reflectors as mandated per regulation].

An Apple iPhone was used to record high definition video and GPS coordinates of the car and motorcycles. The video was recorded at 50 Hz, while GPS location data were collected every 0.5s. To reduce vibrations and windshield reflections, the iPhone was mounted on a stabilizer arm attached to the windscreen of the vehicle (Figure 3). The phone's camera was aligned with the line of sight of an average driver.

In-house software computed the instantaneous distance between the car and a motorcycle based on time stamps of their GPS coordinates.

Figure 2: A representative image of the roadway in the rural setting (Wetland Park, Putrajaya).

Figure 3: The Apple iPhone installation on the outside of the car windscreen.

2.3. Experimental Design

A within-subject repeated-measures design was used with detection distance as the dependent measure. The independent measures were:

i. Night time conspicuity with four levels; (a) No conspicuity; (b) Lights only; (c) Retroreflective markings only; (d) Lights and markings combined – 4 levels;
ii. Motorcycle approach – 4 levels (see Figure 4); and
iii. Traffic density (light vs busy) – 2 levels.

This made for a total of 4 x 4 x 2 = 32 different configurations.

Four different scenarios of a driver approaching a motorcycle in the dark were studied (Figure 4). In two of the scenarios, the car and motorcycle were both driving on a straight roadway, and either riding in the same or the opposing directions. In the other two scenarios, the car was approaching a motorcycle that stopped before an intersection (traffic junction), with the motorcycle either on the driver's side or passenger's side (shown on passenger side in Figure 5). Together, these four scenarios allowed for evaluation of the reflective tape on the rear, front and sides on the motorcycle.

2.4. Procedure

Seated behind a keyboard, the study participants watched the recordings of the motorcycle encounters (as shown in Figure 6) with the instruction to click the space bar of the keyboard as soon as they noticed a motorcycle. In the meantime, the participants performed a secondary task of repeating any auditory number. Every one (1) second, the participant would hear a single digit number, chosen randomly between "0" to "9". The task of repeating each auditory number is known as the 0-back Verbal Response Delayed Digit Recall Task (Mehler et al., 2011; Mohd Siam et al., 2015). The attention needed to perform this secondary task was meant to simulate the attention (cognitive load) required to drive in real-life conditions. Any moment a participant would fail to repeat a number correctly, a restart of the trial of that particular moment was required.

In a series of test trials, the participants familiarized themselves with this procedure. During the experimental trials, only a small number of participants (<5) were found to make mistakes in repeating numbers and they reported to be somewhat fatigued or sleepy during the test.

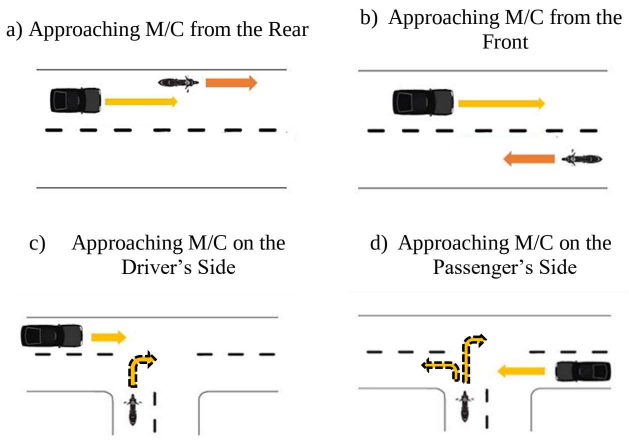

Figure 4: Approaching Motorcycles (M/C) from different Orientations.

Figure 5: Interfaces of software for the experiments.

Figure 6: Situation during data collection by one of the participants.

2.5. Data Processing

The detection distance was the main dependent measure of this study. In two cases, a participant did not report seeing a motorcycle, even when a motorcycle was present in the video. The detection distance was set to 0 meters. In some cases, a participant reported to seeing a motorcycle when none was present in the scene. We believe that the participant may have confused a light source such as a traffic sign, with the presence of motorcycle. Such reports were removed before statistical analysis. SPSS version 21.0 was used to analyse the collected data. Repeated measurements ANOVA procedures and independent t-tests were used to evaluate the differences in detection distance between groups. A p-value of <0.05 was deemed significant.

3. Results

This study examined respondents' feedback on detection distance of motorcycle based on four different scenarios. The scenarios are: (1) approaching motorcycle from the rear (Figure 4a); (2) approaching a motorcycle riding in the opposing lane (Figure 4b); (3) approaching an intersection with a motorcycle waiting on the passenger side (Figure 4c); and (4) approaching a motorcycle waiting on the driver's side (Figure 4d). The comparisons were made based on conspicuity measures versus baseline condition whereby the baseline condition was a motorcycle without conspicuity aids (without head light, taillight and retroreflective tape) while the conspicuity measures include head light, taillight, retroreflective tape and a combination of both.

3.1. Overall Detection Distance

Across the conditions of motorcycle encounter and traffic volume, the detection distance averaged 44m for a motorcycle without conspicuity features, i.e. no lights and no retroreflective markings (Figure 7). The detection distance increased significantly with the addition of one or two conspicuity features.

With the lights turned on, a motorcycle was detected at an average distance of 69m, and it was detected at 72m when retroreflective markings were applied. In relative terms, lights or markings increased the detection distance by about 60% compared to the baseline condition of no conspicuity. When the lights and retroreflective markings were combined, the average detection distance was 86m, an increase of 95% compared to the baseline. A within subject ANOVA analysis determined that these differences in detection distance were significant ($F(3, 956) = 77.5$, $p = 0.000$), which was also evident from the lack of overlap between error bars in Figure 7. A Tukey post hoc test (Table 3) also revealed that all the conspicuity measures had significantly improved motorcycle detection distance at night.

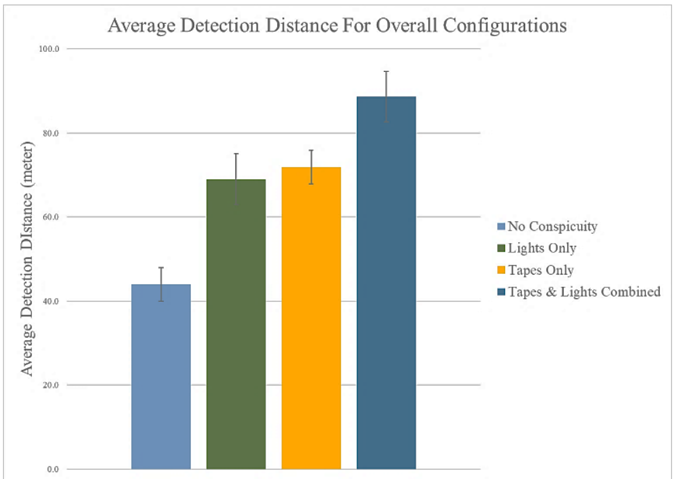

Figure 7: The main effect of conspicuity on the detection distance of a motorcycle—data is averaged across the eight different conditions of encountering (Motorcycle Approach x Traffic Density).

Table 3: Tukey post hoc test results.

Motorcycle Condition (i)	Motorcycle Condition (j)	Mean	Mean Difference (i-j)	P-value
No conspicuity (Baseline)	Lights Only	68.99 (SD=42.50)	25.05	0.000
	Tapes Only	71.54 (SD=27.18)	27.56	0.000
	Tapes & Lights Combined	88.61 (SD=35.67)	44.64	0.000

Significant value is p < 0.05

3.2. Approaching a Motorcycle from the Rear and Front

For the first scenario whereby the test motorcycle (with its taillight turned off) approached from the rear within the same lane (Figure 8), the retroreflective markings on the motorcycle's rear fender provided the largest gain in detection distance (approximately 40m).

For the motorcycle with only its taillight turned on, the gain recorded was less than 20m, which was significantly lesser than the gain for retroreflective markings. Combining the retroreflective markings and lights, the gain recorded was just over 30m, which was not significantly different from using retroreflective markings only.

When approaching a motorcycle riding on the opposing lane (Figure 9), the headlights of the motorcycle provided the largest gain in detection distance (about 70m). The strips of retroreflective markings on the front fender of the motorcycle provided a gain of less than 15m. Combining retroreflective markings and lights for the same scenario revealed that the recorded gain was 70m and equal to that of the headlight only.

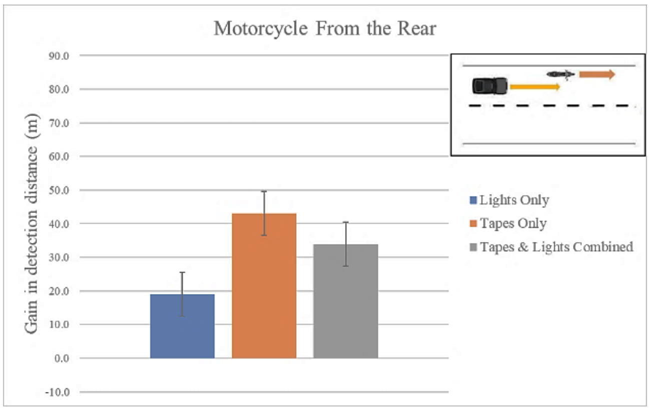

Figure 8: The gain in detection distance for a driver approaching a motorcycle from the rear. The gain is plotted as the difference from the detection distance of a motorcycle without conspicuity.

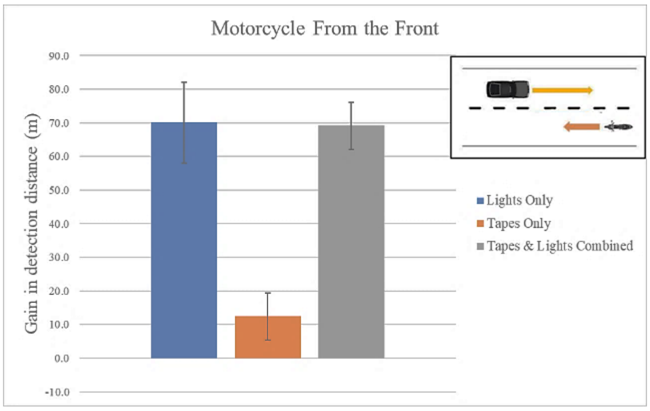

Figure 9: The gain in detection distance for a driver approaching a motorcycle from the front. The gain is plotted as the difference from the detection distance of a motorcycle without conspicuity.

3.3. Approaching an Intersection with a Motorcycle Waiting on the Passenger & Driver's Side

Another scenario involved approaching an intersection with a motorcycle waiting on the passenger side (Figure 10), where the largest gain was provided by the combined use of lights and retroreflective markings (approximately 45m gain).

With just the strips of retroreflective markings on the side body of a motorcycle, the recorded gain was around 25m. With the lights turned on, the gain was negative with -5m, and was not different from the baseline condition.

The 45m gain in detection distance for combined lights and retroreflective markings was more than double the combined gain of lights only and retroreflective markings only (20m). The lights by themselves were insufficient to make the motorcycle visible.

In absolute measures, a motorcycle was detected at about 50m when it only had its lights turned on, whereas it was detected at approximately 100m when it had both lights and markings. The last scenario was when approaching a motorcycle waiting on the driver's side (Figure 11).

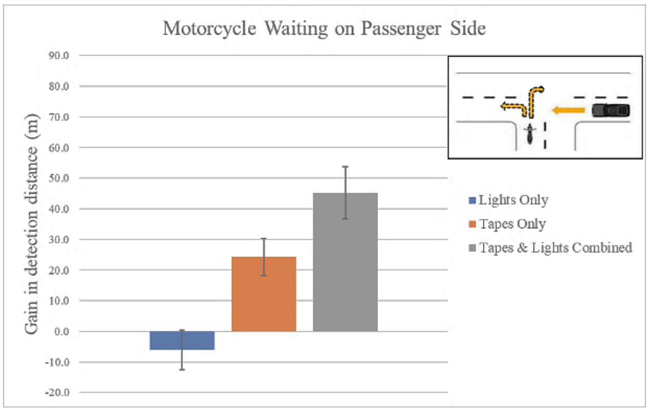

Figure 10: The gain in detection distance for a driver approaching a motorcycle waiting on the passenger's side. The gain is plotted as the difference from the detection distance of a motorcycle without conspicuity.

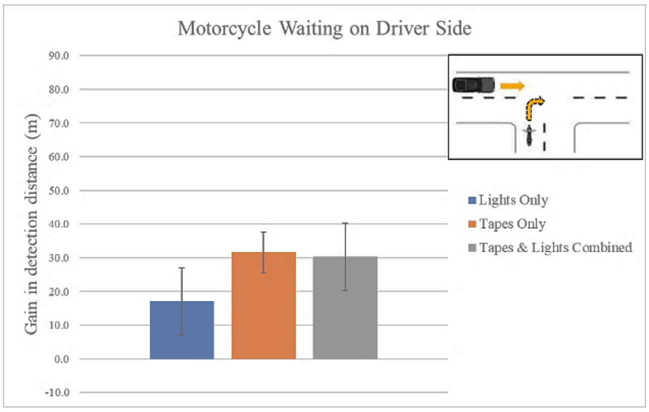

Figure 11: The gain in detection distance for a driver approaching a motorcycle waiting on the driver's side. The gain is plotted as the difference from the detection distance of a motorcycle without conspicuity.

The gains in detection distance were found for all three levels of conspicuity and ranged from 15m to 30m. While gains were not significantly different from each other (overlap between error bars), the gains were trending to be higher for retroreflective markings only and for retroreflective markings and lights combined.

Thus, the main finding of the study is that retroreflective markings make motorcycles visibly better at night, both for a motorcycle with its lights off and for a motorcycle with its lights on. It makes sense that the luminance from the markings would enhance the visibility of a motorcycle with it lights off, as the markings become the dominant source of luminance. However, it is interestingly that the luminance from the retroreflective markings also enhanced the visibility of a motorcycle with its lights on. The application of markings next to the front and rear lights may have enlarged the total size of the luminous surface. In addition, the application of retroreflective markings on the sides of the body may have added a new luminous visual feature or set of features. To better understand such contributions, we analysed the impact of retroreflective markings separately for each motorcycle encounter.

4. Discussion

Low motorcycle conspicuity or the inability of a motorcycle and its rider to be seen by other road users is thought to be an important factor associated with the risk of motorcycle crashes (Williams & Hoffmann, 1979; Radin Umar et al., 1995). Research by NTSB (2018) revealed other vehicle drivers were more likely to experience a perception failure than motorcycle riders usually involving sight distance and conspicuity issues. To overcome the motorcycle conspicuity and visibility issue in Malaysia, a few rules have been put on place; mandatory daytime running headlight for motorcycle which was found effective in 1992 and enhancement of motorcycle lighting via adoption of United Nations Regulation No. 53 (UN R53). In general, the UN R53 already covered side and rear retroreflector in which the reflectors provide significant visibility to motorcycle at night (Rahman et al., 2013). Even though statistics showed that most motorcycle crashes in Malaysia occurred during the day, the aim of this study is to highlight the effectiveness of having an additional reflective sticker on the motorcycle to increase its visibility at night.

In terms of visibility, it is proven that the addition of retroreflective markings provides better sight distance especially during night time. Further, the retroreflective marking is proven as a very cost-effective and simple-to-adopt solution (Olson et al., 1980; Green et al., 1979; Berces, 2011; Eric & Fullarton, 1997). Based on the data analysis of the study, it is shown that overall detection distance averaged 44m for a motorcycle without conspicuity features. The detection distance increased significantly with the addition of one or two conspicuity features. With the motorcycle lights turned on, a motorcycle was detected at an average distance of 69m, and it was detected at 72m when retroreflective markings were applied. In relative terms, lights or markings increased the detection distance by about 60% as compared to the baseline condition of no conspicuity. When the lights and retroreflective markings were combined, the average detection distance was 86m, an increase of 95% as compared to baseline.

Further analysis showed that, when motorists were approaching motorcycles on intersections, the conspicuity on the side of the motorcycles could significantly enhance the detection distance of the motorcycles by the motorists. It appears that, the conspicuity tapes and the headlight and taillight worked together in making the motorcycles much more conspicuous to car drivers (Figure 10).

It is to be noted that the analysis provided in this paper is based on preliminary findings whereby association with respondent's demography, effective size and location of markers and vehicle speed factors are yet to be determined. In addition, there is a critical need to determine why retroreflective markings located at the rear fender provided better sight distance when the taillight was turned off although the taillight complied with United Nations Regulation No. 53.

Given the potential benefits of retroreflective markings, future studies should explore other conditions where visibility is a known problem, such as the atmosphere conditions of rain, fog, heavy air pollution (smog) and dust.

5. Conclusion and Recommendations

This study proves that different conspicuity measures or a combination of it have a significant effect in drivers' ability to detect a motorcycle at night and thus, enhanced motorcycle conspicuity.

However, the results may differ with different road environment such as heavy traffic conditions, day time, rainy or foggy environment. Thus, future studies may consider including other factors in the similar scope of study.

To conclude, we found that retroreflective markings applied to the front, rear and sides of a motorcycle significantly increase the night time visibility of motorcycles and help drivers detect motorcycles at longer distances. This effect is most pronounced for situations where the head and taillights of a motorcycle are not enough to make a motorcycle visible from all directions.

Thus, to enhance the night time visibility of a motorcycle from any direction, retroreflective markings should be applied to the front, rear and sides of a motorcycle. Such application of retroreflective markings to motorcycles is expected to increase reaction time, reduce night-time related crashes and help save lives.

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