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Research Paper

Effect of Road Darkness on Young Driver Behaviour when Approaching Parked or Slow-moving Vehicles in Malaysia

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Abstract

Traffic accidents at night are higher than in other periods, especially on a dark road. This study explores the impact of the dark road on driver behaviours when approaching a parked or slowed-moving vehicle at the front. An experiment was conducted on a racing track at night, with and without road lighting. Different sizes of obstacles were used to represent other vehicles as a lorry, a car, and a motorcycle. The results show that the obstacles can be detected by drivers much earlier with the help of road lighting, and they tend to increase their speed, probably preparing to overtake the obstacles.

Keywords: Road darkness; Road lighting; Driver behaviour

1. Introduction

Road traffic accidents are one of the leading causes of death worldwide. In 2019, Malaysia recorded a death rate of 24.71 per 100,000 individuals [1], with an average of 18 individuals killed in daily road accidents [2]. This number can be considered a high rate compared to the estimated Malaysian population of around 32 million [3]. In addition, according to Manan *et al.* [4], most fatal crashes associated with a motorcycle between 2010 and 2012 happened at night in Malaysia, and midnight riding was found to be one of the causes of severe injury in crashes [5].

Most of the roads in the world at night are operating under daylight road lighting, ambient light, or in darkness. In Malaysia, state highways, town roads and village roads can be found without any road lighting [6]. When driving in the dark, the driver's forward view is constrained by the vehicle's headlamps' reach (**Figure 1**).

Regardless of the vehicle's speed, the distance between the vehicle and the object at the front is the same. Thus the faster the vehicle moves, the smaller the available time required for the driver to detect the object and react accordingly [7]. For example, a driver driving on a dark road will immediately avoid any obstacle without seeing the side view mirror. These obstacles, such as a slow vehicle without taillights or no reflector at the back, could worsen the situation. These conditions could cause accidents if another vehicle approaches the other side of the road.

How the driver reacts also depends on the visibility of the road. Matanzo and Rockwell [8] found that a driver can also drive at a constant speed and maintain a continuous lane position at

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Figure 1. Typical road in Malaysia at night (a) with road lighting, (b) without road lighting (source: [6])

very high degrees of visual degradation. This statement can be further explained by Jägerbrand and Sjöbergh [9] study that found no differences in driver behaviour regarding the light conditions. They suggested that drivers fail to reduce their speed when driving at reduced visibility at night. Furthermore, how drivers also behave probably depends on which country they live in. For example, Taubman-Ben-Ari *et al*. [10] identified eight types of driving styles of Israeli drivers using the Multidimensional Driving Style Inventory (MDSI). On the other hand, van Huysduynen [11] found six types of driving styles among Netherlands drivers, while Karjanto *et al*. [12] identified four types of driving styles among Malaysian drivers. These findings show that it is crucial to have an independent study based on the country itself.

In Malaysia, most studies related to dark roads or the road lighting impact focus on flow characteristics such as traffic speed, travel time, traffic volume and density [13]–[15]. These studies were in the form of observation and were done on the expressway. Compared to other studies outside Malaysia, the methods were mixed between observation (either based on traffic roads or existing data) and on-field experiments. A summary of earlier studies relating to road darkness and driver behaviour is in **Table 1**. The year difference can be noticeable, lacking in driver behaviour studies, especially driving in the dark. Consequently, those with the most recent year of publication should be referred to because their studies may have followed current trends. Hence, the factors and the parameters to be explored should also be considered in the previous studies.

In this paper, a conducted experiment is explained that aims to study the correlation of the road darkness level with the driver behaviour when suddenly facing an object. The independent variables are the darkness level, the location of the obstacle, and the obstacle size. In contrast, the independent variable is the awareness distance between the driver and the obstacle, the vehicle's speed, and the vehicle's trajectory.

2. Methods

2.1. *Experimental Design*

Twelve participants underwent one out of three experimental test conditions (based on the three sizes of the obstacle in the shape of a motorbike, a sedan car, and a lorry). All conditions consist of two levels of road darkness (with light and without light) and two locations of the obstacle (on the road, on the roadside). In each condition, a fully counterbalanced order of road darkness levels and the obstacle locations was applied to mitigate any learning effects. The dependent variables were the awareness distance between the driver and the obstacle, the changes in vehicle speed and vehicle trajectory. The study was conducted at a racing track during night-time.

2.2. *Equipment*

2.2.1. *Test Location*

The Tangkak Racing Track (TRT) has been chosen as the test location (**Figure 2**). TRT is a

Table 1. Past studies related to darkness road

Year	Title	Experiment / Observation	Methods	Subjects	Area of Observation/ Experiment	Parameters
1996	Differentiation of visibility and alcohol as contributors to twilight road fatalities [16]	**Objective:** To assess reduced visibility and driver's consumption of alcohol as contributions to the fatal crash. **Results:** Both variables play a major role in night-time road fatalities.	Observation of existing data	Driver	Roadway	• Reduced visibility • Alcohol consumption
1996	Age differences in visual abilities in night-time driving field conditions [17]	**Objective:** To analyse the age differences in sign legibility and object detection. **Results:** Older drivers' legibility distances were 65% compared to the younger drivers, and their object detection task reduced from 20% to 45% across visibility conditions.	Experiment	• Older drivers • Younger drivers	Private road	Object detection
1967	Driving performance under night-time conditions of visual degradation [8]	**Objective:** To analyse different driving tasks and four levels of visual degradation. **Results:** A driver can also drive at a constant speed and maintain a constant lane position at very high degrees of visual degradation.	Experiment	Driver	Roadway	• Driving tasks • Visual degradation • Driving speed • Distance from shoulder line
1999	Risk compensation – the case of road lighting [18]	**Objective:** To investigate the risk compensation in term of road lighting. **Results:** Drivers compensate for road lighting in terms of increased speed and reduced concentration.	Experiment	Driver	Route E18 in southern Norway	• Road lighting • Speed & concentration • Behaviour
2000	Effect of darkness on the capacity of long-term freeway reconstruction zones [19]	**Objective:** To investigate the effect of darkness on freeway capacity at long-term reconstruction sites. **Results:** Suggest that darkness has a significant effect on freeway capacity at freeway reconstruction work zones.	Observation on site	Driver	Freeway	Freeway capacity
2003	Threshold visibility levels for the Adrian visibility model under night-time driving conditions [20]	**Objective:** To determine the visibility levels which are required for detection under night-time driving conditions. **Results:** Driver age significantly affected the visibility level at target detection, with older drivers requiring a higher visibility level than younger drivers. Headlights beam patterns were also found to affect visibility level at target detection significantly. A higher visibility level was needed under high beam	Experiment	Drivers	Private rural road	• Visibility levels • Response distance

Year	Title	Experiment / Observation	Methods	Subjects	Area of Observation/ Experiment	Parameters
		lighting than under low beam lighting.				
2003	Night-time time driving, passenger transport, and injury crash rates of young drivers [21]	**Objective:** To examine the association of night-time time driving and the carrying of passengers with the rate of motor vehicle crashes that resulted in severe or fatal injury to young drivers. **Results:** Driving at night, driving without adult supervision, driving with passengers, using alcohol, being 16, and being male were associated with high rates of driver injury crash.	Observations on existing data	Driver	Highway California	• Driving exposure • Night-time driving • Risk of injury
2007	Relationship between night myopia and Night-time motor vehicle accidents [22]	**Objective:** To investigate the relationship between night myopia and the occurrence of night-time motor vehicle accidents in a group of professional drivers. **Results:** No statistically significant difference between these drivers and the rest of the group in the results of the visual complaints questionnaire, or the number of accidents occurring during the day.	Experiment	Driver	Israel Defence Forces Transportation Centre	• Night myopia • Rates of accidents
2008	Night-time vehicle detection for driving assistance light beam controller [23]	**Objective:** To analyse a system for detecting vehicles in front of a Camera-assisted vehicle during night-time driving. **Results:** The system performance is very good for head lights but on the other hand, the performance for taillights must be increased.	Observation on site	Driver	Not specified	• Effective system for detecting vehicles in front • Detect image bright objects
2009	Effects of road lighting: An analysis based on Dutch accident statistics 1987-2006 [24]	**Objective:** To estimate effect of road lighting on accidents in darkness on Dutch roads. **Results:** The risk of injury accidents was found to increase in darkness.	Observations on existing data	Number injury accidents	• Rural area • Urban area	• Road lighting • Road safety
2009	A new method for assessing the risk of accident with darkness [25]	**Objective:** To assess the risk of accidents with darkness. **Results:** The risk of an injury accident increases by nearly 30% in darkness in urban areas, by nearly 50% in rural areas, and 40% for urban and rural areas combined.	Observation on existing data.	Pedestrians	• Urban area • Rural area	Risk of injury
2010	Effect of simulated visual impairment on night-time	**Objective:** To investigate the effects of simulated visual impairment on night-time driving performance and	Experiment	Driver	Closed road circuit	• Effects of simulated impairment • Pedestrian recognition

Year	Title	Experiment / Observation	Methods	Subjects	Area of Observation/ Experiment	Parameters
	driving performance [26]	pedestrian recognition under real-road conditions. **Results:** Simulated visual impairment significantly reduced participant's ability to recognise road sign, avoid road hazards, and increased the time taken to complete the driving course.				
2012	Fatal crashes of 16- to 17-year-old drivers involving alcohol, night-time driving, and passengers [27]	**Objective:** To analyse the alcohol-impaired driving problem among 16- to 17-year-olds on night-time driving. **Results:** During the five years, 15 per cent of the 8664 16- to 17-year-old drivers in fatal crashes had positive blood alcohol concentrations, most of which were 0.08 per cent or greater. Drivers in alcohol-related crashes were more likely than non-alcohol-related crashes to be male, unbelted, single vehicles, and speeding. Their crashes were more likely to occur on Saturday or Sunday, at night, and when passengers were present. Of the alcohol-related crashes, 88 per cent took place at night or with passengers present or both, as did 67 per cent of the non-alcohol-related crashes.	Observations on existing data	Drivers of passenger vehicles	Public roads (United States)	• Fatal crash • Alcohol consumption • Crash characteristics
2012	Effect of glare on night-time driving in alcoholic versus non-alcoholic professional drivers [28]	**Objective:** To compare the glare recovery time in alcoholic versus non-alcoholic drivers. **Results:** The glare recovery time got prolonged in alcoholic drivers, and they also complained of more problems during night-time driving as compared to non-alcoholic drivers.	Experiment	Driver	Not specified	• Glare recovery time • Alcohol vs non-alcohol • Alcohol consumption
2013	Risk of accidents during darkness on roads with different technical standards [29]	**Objective:** To Identify the main factors that may affect road accidents during visibility restrictions in darkness. **Results:** All presented methods of relative road safety risks estimations in darkness compared to daylight, it can be stated that the accident risk in darkness on national roads is about 60% higher, when compared to daytime.	Observation on existing data	Number of accidents	National and regional roads	• Traffic accidents • Visibility • Fatalities • Road infrastructure • Accident risk

Year	Title	Experiment / Observation	Methods	Subjects	Area of Observation/ Experiment	Parameters
2014	Seeing pedestrians at night: effect of driver age and visual abilities [30]	**Objective:** To quantify the effects of driver age on night-time pedestrians and determine whether individual differences in visual performance can predict driver ability to recognise pedestrians at night. **Results:** The night-time pedestrian recognition capacity of older drivers was significantly worse than that of younger drivers. The distance at which drivers first recognised pedestrians at night was best predicted by a test of motion sensitivity.	Experiment	Driver	• Laboratory • Closed-road circuit	• Driver age • Visual performance • Pedestrian clothing • Pedestrian recognition distances
2016	Effects of weather conditions, light conditions, and road lighting on vehicle speed [9]	**Objective:** To examine whether vehicle speed on roads is higher in daylight and under road lighting than in darkness, and determined the combined effects of light conditions, posted speed limit and weather conditions on driving speed. **Results:** The analysis did not reveal any differences attributable to light conditions. The author conclude that traffic accidents and darkness or low light conditions could be explained by drivers failing to adjust their speed to the reduced visibility in dark conditions.	Observations on traffic flow	Driver	Public road	• Vehicle speed • Light conditions
2017	The severity of driver fatigue in terms of line crossing: a pilot study comparing day- and night-time driving in simulator [31]	**Objective:** To compare daytime driving with night-time driving looking at line crossings during self-reported sleepiness and long blinks. **Results:** No differences in the percentage of Line Crossings to the left during high levels of Karolinska Sleepiness Scale during daytime (33%) compared to night-time (40%). A long blink durations are associated with more line crossing when they appear during night-time than during daytime.	Experiment	Driver	Driving simulator	• Driver behaviour • Sleepiness and long blinks • Risks for line crossings
2018	Exploring driver behaviour under conditions of darkness: Shedding	**Objective:** To assess driver performance and behaviour under the night-time condition in order gain insight into traffic crash patterns and driving behaviour at night-time.	Observations on existing data	Driver	Roadway	• Driver performance and behaviour • Traffic fatalities • Speed limit

Year	Title	Experiment / Observation	Methods	Subjects	Area of Observation/ Experiment	Parameters
	light on the night-time traffic death toll [32]	**Results:** The high number of traffic fatalities happened at night.				
2018	Contributing factors to Run-Off-Road crashes involving large trucks under lighted and dark conditions [33]	**Objective:** To study the effect of lighting conditions on the injury severity of Run-Off-Road crashes that involve large trucks. **Results:** There are significant differences between dark and lighted conditions, that several complex interactions between factors highly influenced the level of injury severity outcomes, and that the effects of some factors could vary across observations.	Observation on existing data	Truck drivers	Roadway	• Lighting conditions • Injury severity
2019	Exploring the factors affecting myopic driver driving skills and risk perception in night-time driving [34]	**Objective:** To investigate how various factors affect myopic driver night-time driving skills and night-time risk perception. **Results:** Non-myopic drivers reported a lower night-time risk perception than myopic drivers, whereas their night-time driving skill was significantly higher than myopic drivers.	Field survey	Driver	Hefei, China (large cities)	• Driving skills • Myopic drivers • Visual characteristics • Quality of life
2020	Effects of night-time bicycling visibility aids on vehicle passing distance [35]	**Objective:** To assess the impact of different bicyclist visibility configurations on vehicle passing distances at night-time. **Results:** Overall, additional visibility aids resulted in wider vehicle passing distances, likely due to enhanced visual cues for drivers.	Experiment	Driver	Closed road circuit	Bicyclist visibility on vehicle passing distances
2020	Motorcycle safety after-dark: The factors associated with greater risk of road-traffic collisions [36]	**Objective:** The effect of ambient light level on road traffic collision involving a motorcycle was investigated. **Results:** The risk of road traffic collisions occurring was significantly higher after dark than daylight for motorcycles and four-wheel motor vehicles.	Observations on existing data	Motorcycles & four-wheel motor vehicle	• Urban area • Rural area	• Ambient light level • Contextual factors • Spring and Autumn

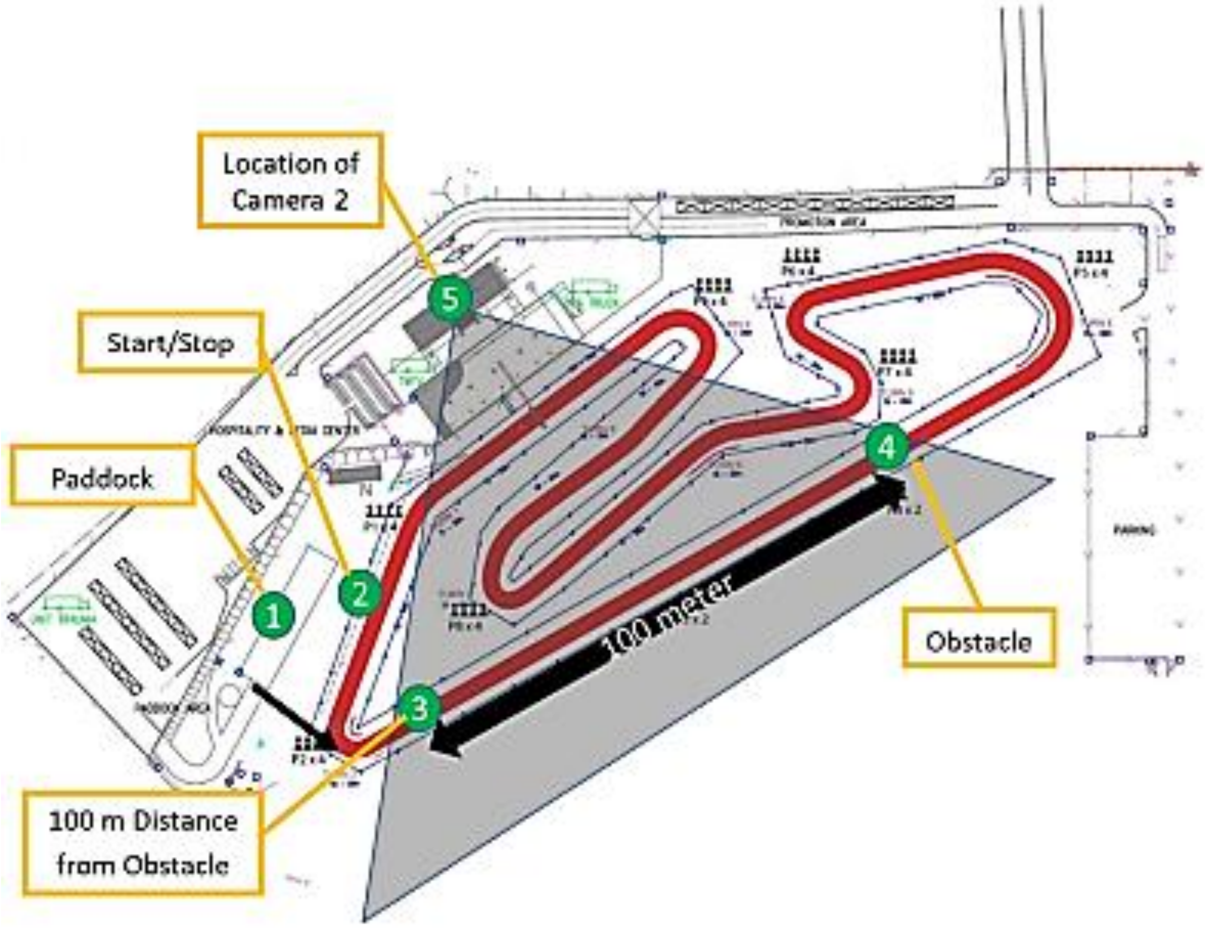

Figure 2. Tangkak Racing Track (TRT), Johor, Malaysia

Malaysian motorsport racetrack located near Gerisek, Johor, Malaysia. Although it is mainly built for an underbone or moped racing series for motorcycles with displacements from 100 to 150cc, it is suitable to drive a car at a low speed. The track has an overall length of 1.2 kilometres with 290 meters long back straight. In **Figure 2**, the essential locations for this study were labelled by numbers in the green circle. Point 1 is the paddock, which functioned as the participant's waiting area. Point 2 is the start and stop location in the study. Point 3 is marked as a 100 meters distance to the obstacle location. At this point, a baton warning light is placed at the roadside. Point 4 is where the obstacles are placed on the road or roadside. At point 5, a Camera 2 is located on the grandstand. The shaded area on the map is the view area that can be captured by Camera 2.

At Points 4 and 5, several designated personnel were located to perform the changes of the obstacle and to control Camera 2. One experimenter (Experimenter A) is responsible for giving instructions to the participant from the start to the end of the study. He is also responsible for managing Camera 1 inside the instrumented car. Another experimenter (Experimenter B) is assigned to monitor and control the flow of the entire study. His location is at point 5, where he can oversee the whole study process.

2.2.2. *The Instrumented Car*

The instrumented car is a customised Proton Saga FLX model with an automatic transmission (**Figure 3**). It was equipped with two LED lights, namely LED 1, LED 2, and a switch button connected to the car's power source (see **Figure 4a**). LED 1 is placed on the car dashboard, and LED 2 is the high-illumination LED placed on the car roof. The button is placed on the steering wheel for the participant to press when they see the obstacle. When the button is pressed, both LEDs light up. Instead of using the car speedometer, a digital speedometer using a smartphone was attached to the middle of the dashboard. The original speedometer was replaced due to the small digits that could not be recorded with

Camera 1 (**Figure 4b**). Both LEDs are used to pinpoint the time stamp in the recorded video. The lighted LED 1 will be recorded with Camera 1, while the lighted LED 2 will be captured by Camera 2, placed at the grandstand (refer to **Figure 2**).

2.2.3. *The Obstacles*

The obstacles were made from inflatable swimming pools. These pools were chosen due to their lightweight rubber material for safety reasons. If the participants accidentally collide with the obstacle, it can just bounce from the instrumented car with minimal to no damage. Each obstacle is represented by a different set of a banner of rear-view graphics of a vehicle (motorcycle, car, or lorry) in their actual size and in black colour. (**Figure 5**). Based on the study scenarios, the obstacle was placed on the roadside or on the road (**Figure 6**). These two locations represent a parked vehicle on the roadside or a slow-moving vehicle on the road.

2.2.4. *The Road Lighting*

In simulating driving in the dark with road lighting, a 300W solar street light was used in this study. The light is attached to a pole about 4 meters above the ground and can be controlled using a remote. The light was set at the highest brightness level, and a 13.71 Lux was recorded on the ground level using a light intensity meter. On the other hand, 1.10 Lux was recorded when the light was off.

Figure 3. The instrumented car

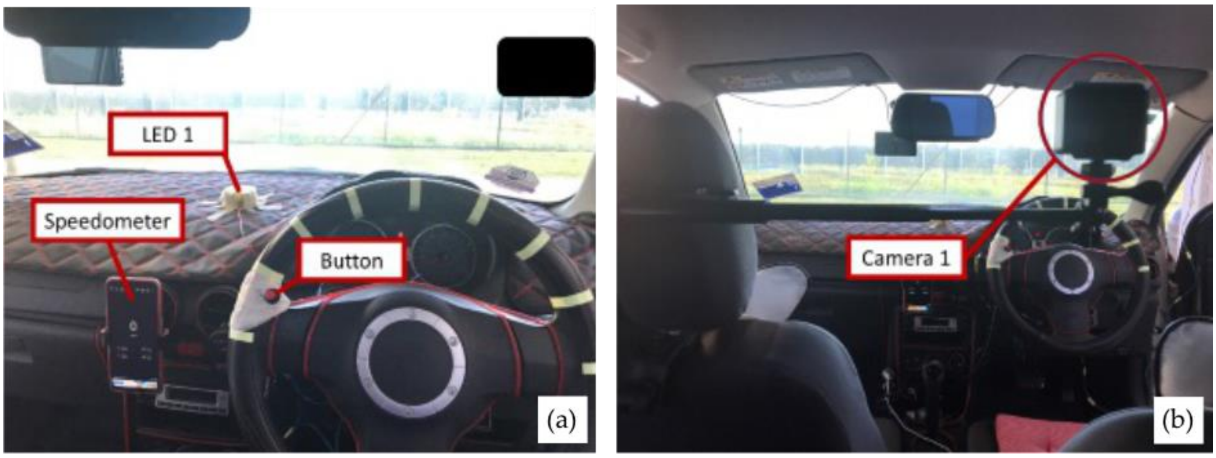

Figure 4. The Interior of the instrumented car: (a) location of LED 1, speedometer, and button, (b) location of the Camera 1

Figure 5. Example of the Obstacle (Lorry)

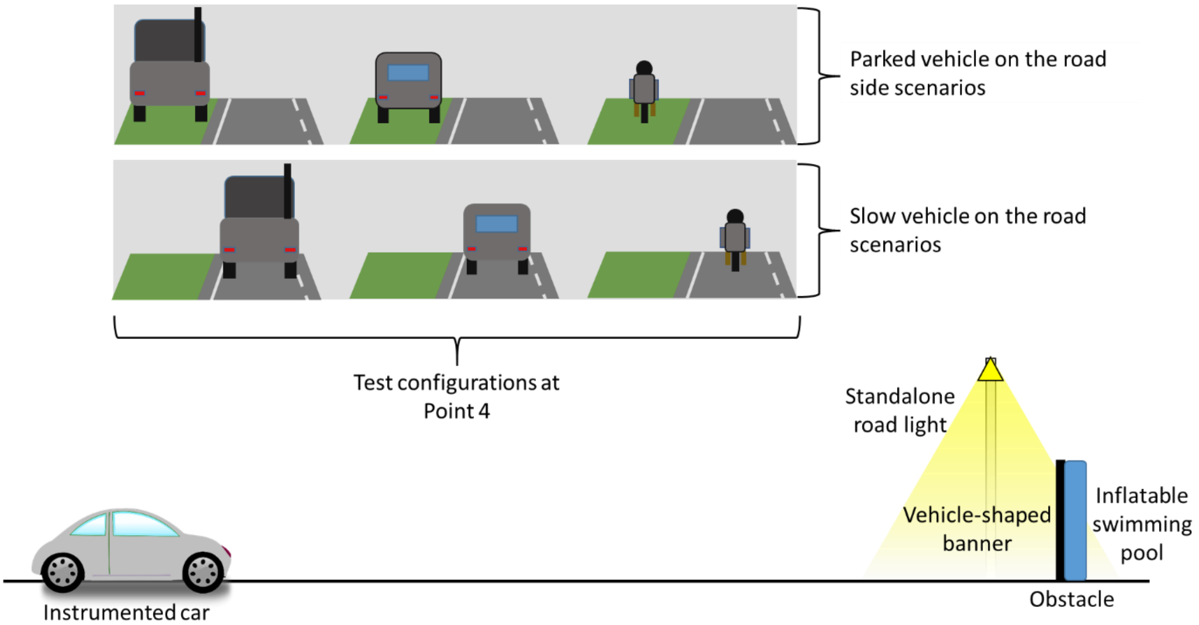

Figure 6. Obstacle Locations based on Scenarios

2.2.5. *Participants*

The 12 healthy male participants, aged between 22 and 25 (median = 24, standard deviation = 1.16), participated in the study. All participants are students from Universiti Tun Hussein Onn Malaysia (UTHM) Pagoh Campus. They were recruited through the Google Form distributed via social media and flyers across the UTHM. All participants have a valid driving license with a minimum driving experience of 2 years and an average driving experience of 800 kilometres per year. In addition, they reported no vision difficulties such as glare, presbyopia, myopia and night blindness during driving. They were paid RM 50 for their participation.

2.3. *Procedure*

Upon the participant's arrival at point 1 (refer to Figure 2), he will be briefed by Experimenter A on the nature of the experiment. This brief includes his right to withdraw from the study at any moment. Before being directed to the instrumented car, the participant will be requested to sign an informed consent form and complete a questionnaire related to the demographic and driving experience.

After that, the participant is directed to the instrumented car and sits in the driver's seat. He will always be reminded to wear a seatbelt and to follow all traffic rules during study sessions. In this study, the participant must maintain a speed of around 40 km/h and only use low-beam headlight. Then, they have about 5 minutes for a test drive on the track to familiarise driving with the instrumented car. During this test drive, no obstacle is presented either on the roadside or the road. At the end of this test drive, the participant is instructed to stop at point 2 (start/stop).

Then, the participant is required to complete four laps (from the first to the fourth lap) of driving with the obstacle is appeared at point 4, representing the scenarios of the situation (**Table 2**). For example, S1 represent a situation where there is a parked vehicle on the roadside with no road lighting available. In contrast, S4 represents a situation where a slow-moving vehicle is ahead with road lighting available. Each participant started with a different scenario to reduce the learning effect of the configurations that can bias the results. Throughout these sessions, Experimenter A is seated in the back seat of the instrumented car.

After finishing all four scenarios, the participant was instructed to drive back the instrumented vehicle to the Paddock (point 1). The participant and Experimenter A exited the vehicle, and a debriefing was performed. Compensation for participation was paid at the end of the experiment.

2.4. *Data Collection*

The distance between the instrumented car and the obstacle is recorded when the participant sees the obstacle and presses the steering wheel button (**Figure 4**). The lighted LED 2 (**Figure 3**) is recorded as a video by Camera 2 (**Figure 2**). Based on the video recorded, the distance between the obstacle and instrumented car is measured using a ratio scale (**Figure 7**). The scale was compared between the actual distance and the distance on video player screen size. The 100 meters in exact distance equals the 11.5 centimetres on the video player screen size. The distance between the instrumented car and the obstacle (namely as y in meters) is calculated using the equation:

$$y = \frac{x\ (cm)}{11.5\ (cm)} \times 100\ (m) \tag{1}$$

The speed of the instrumented car is recorded to assess whether the participant is braking, accelerating, or doing nothing (no changes in the speed) when he approaches the obstacle. The data is recorded in a video format using Camera 1 (**Figure 4**). The initial speed (taken from the digital

Table 2. Scenarios Setup

Participant ID	Scenarios			
	1st Lap	2nd Lap	3rd Lap	4th Lap
M001	S1	S2	S3	S4
M002	S2	S3	S4	S1
M003	S3	S4	S1	S2
M004	S4	S1	S2	S3
C001	S1	S2	S3	S4
C002	S2	S3	S4	S1
C003	S3	S4	S1	S2
C004	S4	S1	S2	S3
L001	S1	S2	S3	S4
L002	S2	S3	S4	S1
L003	S3	S4	S1	S2
L004	S4	S1	S2	S3

Note:
Vehicle type: M = motorcycle; C = car; L = lorry
S1 = vehicle on the roadside, without road lighting
S2 = vehicle on the roadside, with road lighting
S3 = vehicle on the road, without road lighting
S4 = vehicle on the road, with road lighting

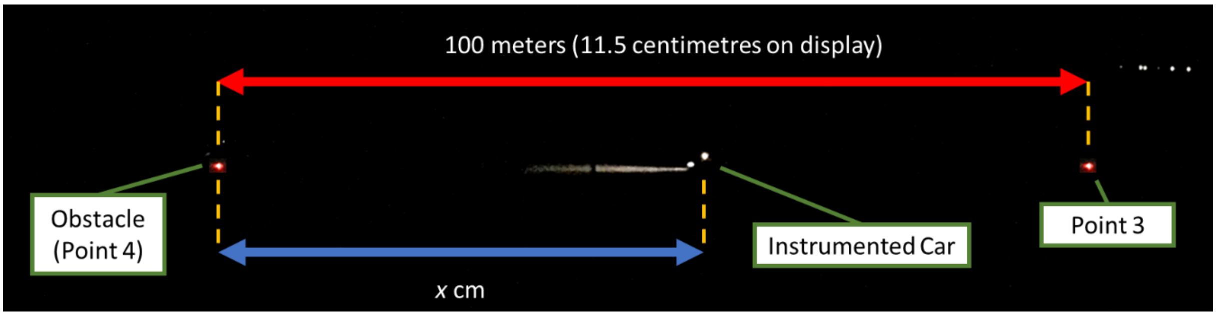

Figure 7. The distance between the obstacle and Point 3 (red arrow) and the instrumented car (blue arrow)

speedometer) is recorded when LED 1 lights up (**Figure 8**). The final speed is recorded when the instrumented car passes the obstacle (**Figure 9**). The differences between these two speeds are used to determine the participant's behaviour on speed.

The instrumented car trajectory refers to the maximum turning angle of the front tire after the participant sees the obstacle (indicated by lighted LED 2). Multiple glow-in-the-dark tapes were attached to the steering wheel to assess the approximate front tire angle and were recorded with Camera 1. These tapes have 22.5 degrees equidistant from each other. Since the instrumented car has a steering ratio of 20:1, every 20 degrees of steering wheel rotation is equivalent to 1 degree of front tire rotation. The angle of the steering wheel is measured on the smartphone application's video player screen before the front tire rotation is calculated (**Figure 10**).

Figure 8. Recording initial speed

Figure 9. Recording final speed

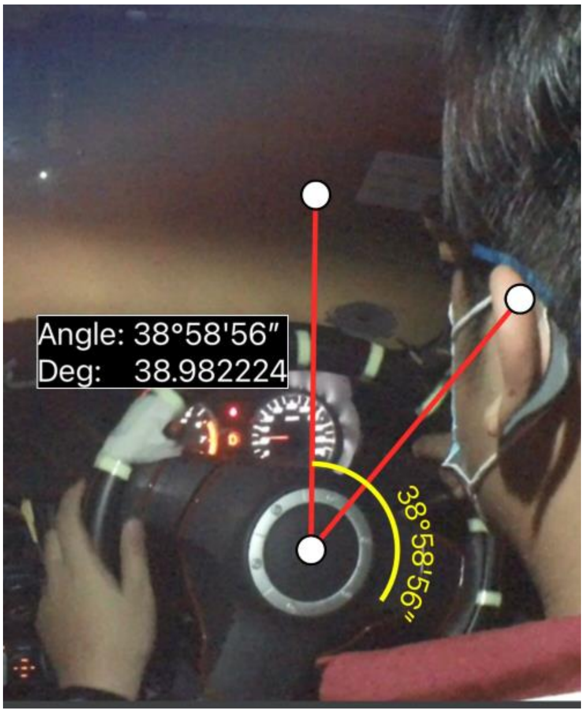

Figure 10. Angle measurement using a smartphone application

3. Results

3.1. Awareness Distance

In general, there is not much difference regarding the awareness distance between the instrumented car and the obstacles in S2 and S3 (Figure 11). All participants can be considered aware of the obstacle at the front at a similar distance, whether the obstacle is on the roadside with road lighting (mean = 26.2 m (motorcycle), 42.8 m (car), and 78.3 m (lorry)) or on the road without road lighting (mean = 30.7 m (motorcycle), 46.5 m (car), and 72.0 m (lorry)).

On the other hand, when comparing the awareness distance of the obstacles on the roadside with (S1) and without (S2) road lighting, participants have an average of 16.4 m, 24.9 m, and 47.3 m additional distances to react when approaching motorcycle, car, and lorry respectively. Similarly, the obstacles on the road can be seen earlier with road lighting (S4) compared to without road lighting (S3). Participants have an additional 20.3 m, 17.7 m, and 37.8 m additional distances to react when approaching a motorcycle, car, and lorry, respectively.

The obstacle's size also affects the awareness distance. In the dark, a lorry can be seen at a range of 30.9 m on the roadside and 72.0 m on the road. However, participants have difficulty being aware of a motorcycle in front of them until at a distance of about 9.8 m.

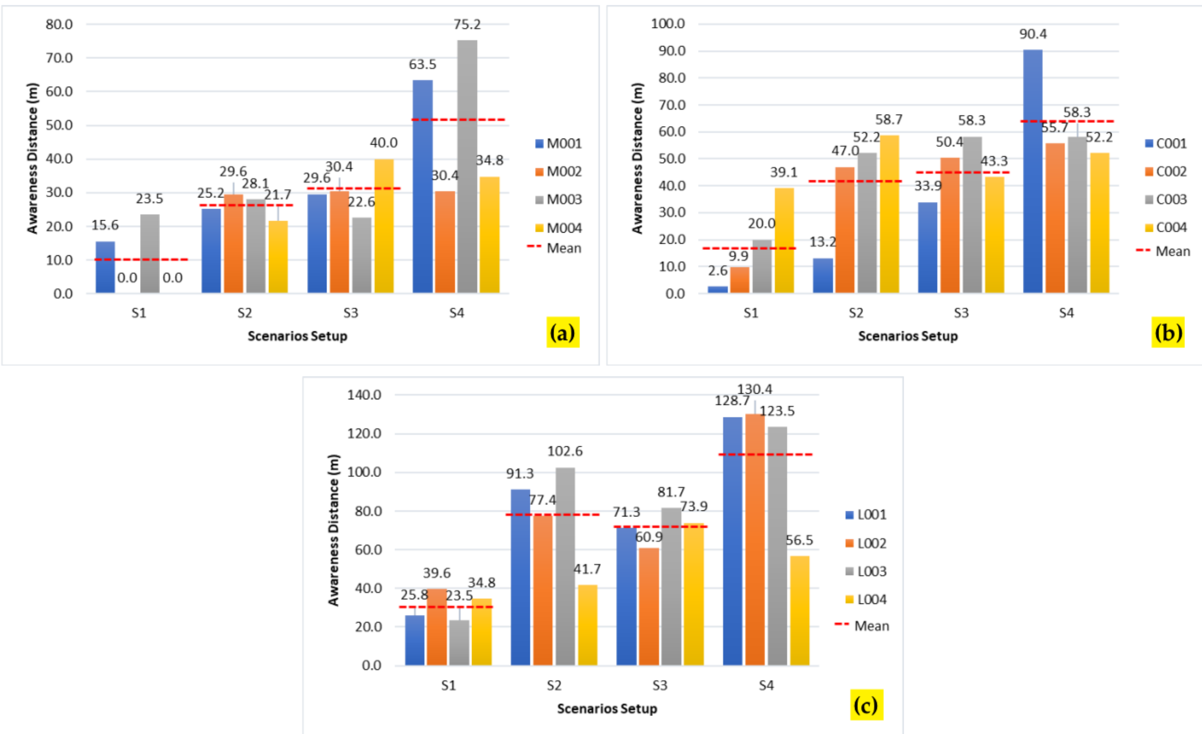

Figure 11. Awareness distance between instrumented car and (a) motorcycle obstacle, (b) car obstacle, and (c) lorry obstacle

3.2. Changes of Speed

In S1 and S2, there are few differences in speed changes when approaching the obstacles with and without road lighting, with an average between 0.1 km/h and 0.3 km/h (**Figure 12**). However, the S3 result shows that a driver will slow down with an average of 3.2 km/h when approaching a slowed or parked vehicle in the dark. Unexpectedly, the speed is increasing by about 5.1 km/h in S4.

3.3. Trajectory of Manoeuvres

Although the obstacles were placed on the roadside (S1), the participants tended to spare some space between the instrumented car and the obstacles when they passed through point 4 (**Figure 13**). This space becomes larger when there is road lighting in S2. On the other hand, in S3 and S4, the average trajectories are almost similar, either with or without road lighting.

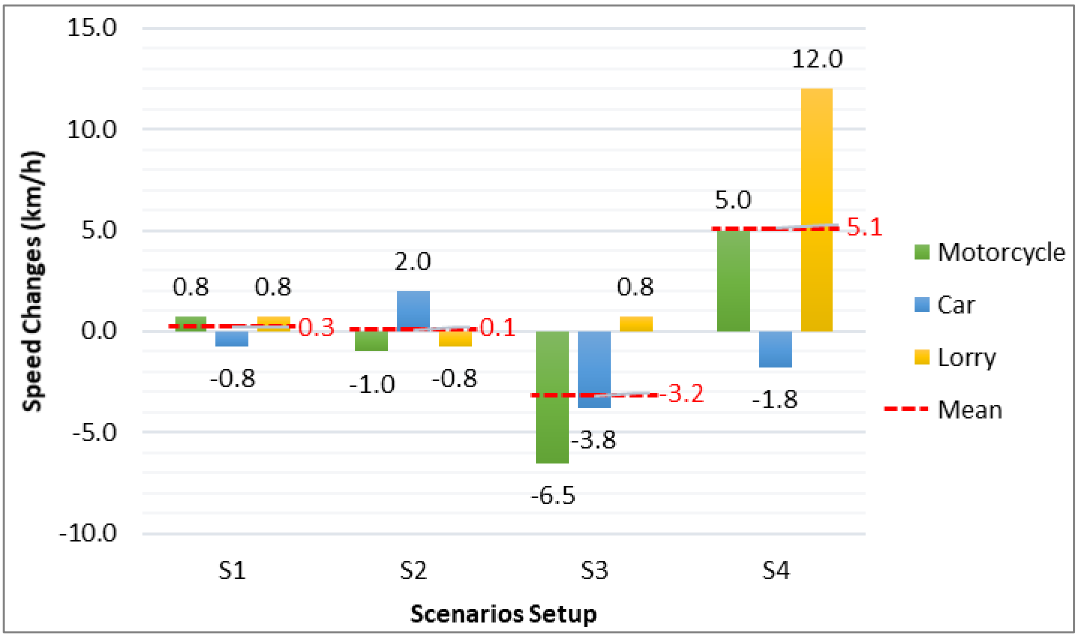

Figure 12. Changes of speed when approaching a vehicle

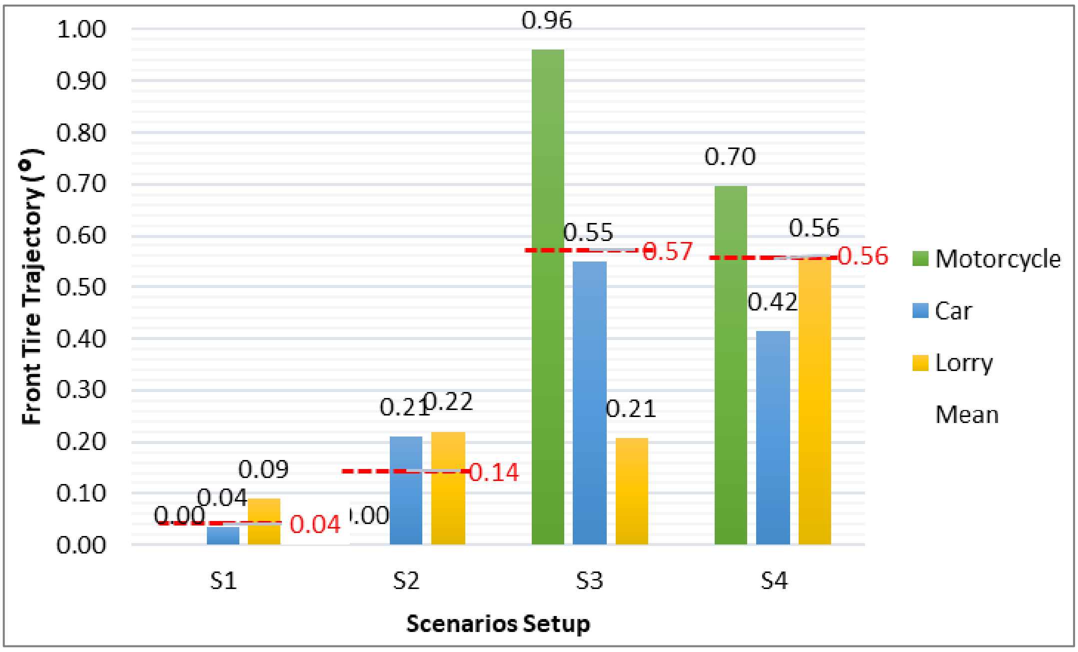

Figure 13. Front tire trajectory (to the left)

4. Discussion

This study showed that the awareness distance was further with the road lighting and the vehicle under it. However, the awareness distance is almost identical in S2 (vehicle on the roadside, with road lighting) and S3 (vehicle on the road, without road lighting) because the road lighting in S2 was not lighted directly to the vehicle, and the participant probably aware but not sure [37], [38]. In addition, the study's low-beam headlights and dark-coloured obstacles affected the participant's visibility. Leibowitz *et al*. [39] mentioned that a young driver can only identify the pedestrian in black clothes at a distance between 15 and 45 metres using a low-beam headlight.

Based on S1 and S2 in **Figure 12**, although participants could detect the obstacles much earlier with a road lighting setup, it can be assumed that when a vehicle is parked on the roadside, an incoming driver might not be concerned about the parked vehicle. Hence, not so many changes in vehicle speed. In addition, Herd *et al*. [40] found that traffic speeds are generally the same in day and night conditions. However, if the obstacles are considered as a parked vehicle on the road, the traffic speed is found to be reduced [41]. On the other hand, a driver might need more time to assess the situation before deciding to stop, slow down, avoid swerving, or overtake the vehicle, especially at night [37], [38].

Nevertheless, with the help of road lighting, most participants chose to increase their speed when approaching the obstacles. This situation could be that they have enough time to assess the situation from far away and can overtake the obstacle easily on the racing track. However, as mentioned by Owens [42], the drivers might be unaware of the driving in the dark limitation and might be overconfident in their capability to drive safely.

Similar to the assessment of the manoeuvre's trajectories, this overconfident phenomenon [42] might lead drivers to overtake any vehicle in front of them in the same manner, regardless of the size of that vehicle, except when avoiding a motorcycle as far as they can. In addition, young male drivers exhibited a risky driving style compared to female or older drivers [43]. However, this interpretation must be considered that all participants understood that the experiment was conducted on a racing track with no other traffic.

5. Conclusion

Based on the results and the discussion, road lighting is essential, especially in areas with no ambient or natural light available at night. It can increase the awareness distance of a vehicle in front and minimise risks, such as manoeuvring to an oncoming vehicle on the other side of the road or not having enough time to stop completely during any unexpected driving situation. In addition, the findings can be considered as an insight for authorities to develop roads. In future, more studies can be conducted to assess driver behaviour on a dark road at corners.

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Author's Declaration

Authors' contributions and responsibilities

Conceived and designed the experiments (N.M.Y, J.K, M.Z.H, Z.M.J); Performed the experiments (N.M.Y, J.K, S.S, A.F.H.Z); Analysed and interpreted the data (N.M.Y, J.K A.A.A.R); Wrote the original paper (N.M.Y, J.K, M.Z.H); and Wrote the revised manuscript (N.M.Y, J.K, S.S, A.F.H.Z, A.A.A.R, Z.M.J, K.A.A.K).

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

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