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Experimental Evaluation of Brake Response Time on Motorcycle Brake Lamp

Muhammad Akmal Izzat Azmi[1], **Norrizal Mustaffa**[1]*

[1]Department of Mechanical Engineering Technology, Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA

*Corresponding Author Designation

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Abstract: Rear-end collisions are one of the highest contributors to road accidents fatalities, especially motorcycles which made up to 60.00 % of the total of accidents that occur. The reasons that trigger such accidents are careless, dangerous turning (lane splitting and weaving between vehicles) and speeding, thus causing the awareness of the following vehicles to decline. That is why this study is conducted to find out the effectiveness of flashing brake lamps compared to conventional brake lamps on motorcycles. The experiment involves the driving experience, the distance between vehicles and gender as the factors that affect the brake response time (BRT) on brake lamps. The data collected are analysed and the findings showed that driving experience can influence the BRT, where experienced drivers have faster BRT (0.575 s) compared to others, however, beginner drivers demonstrate the highest BRT reduction by 13.40 % (0.123 s). The analysis of the BRT based on the distance between vehicles displayed the driver's adaptation to flashing brake lamps. The 10 m distance has the highest BRT reduction among other distances by 18.09 % (0.142 s) even though the 6 m and 8 m distances presented a quite small BRT reduction, only around 0.04 s. Gender also illustrated the biggest impact of BRT on brake lamps, where males seem to be quicker to respond than females by 23.51 % and 28.62 % for conventional and flashing lamps respectively. As a whole, the flashing lamps portrayed shorter BRT than the conventional lamps by 9.87 % (0.074 s). thus, it is suggested that flashing brake lamps is proven to reduce the BRT of the rear drivers and are suitable for implementation on motorcycles. Therefore, this study will benefit the future improvement and increase the conspicuity of motorcycle brake lamps.

Keywords: Rear-End Collisions, Brake Response Time, Flashing Brake Lamp, Motorcycle

1. Introduction

Every year, there are millions of accidents were reported with fatalities all around the globe. Among the Association of Southeast Asian Nations (ASEAN) countries, Malaysia has the second highest road

*Corresponding author: norrizal@uthm.edu.my

fatalities after Thailand, with more than 60.00 % of the accidents involving motorcyclists' death for the last 10 years since 2009 and the trends do not seem to be improved although many efforts to prevent them have been implemented from national to community levels [1,2]. There are many types of crashes such as head-on crashes, side-impact crashes, rear-end crashes, single-vehicle crashes and sideswipe collisions. The rear-end collision accounted for 14.80 % of all of the accidents that occur, which is caused by one vehicle striking the rear of another vehicle when both vehicles are in the same traffic lane and are heading in the same direction [1]. This is usually due to careless driving, dangerous turning and speeding, which is claimed to be 34.00 % to 45.20 % for all levels of severity of the accident [3]. From the factors discussed, it is more likely to assume that the following drivers' awareness has reduced, and they cannot pay enough attention to the signal braking of the brake lights, causing their reaction and braking response time to be disturbed. Brake response time (BRT) can be interpreted as the period between the activation of the lead vehicle brake light and the first foot contact with the brake pedal, as defined by SAE J29 [4]. The BRT is an indication to measure the response of the rear driver upon the braking of the leading vehicle. In this study, the BRT is an element that will affect the distance of braking to stop, resulting in the effect of the number of rear-end collisions.

The concerning issue that is suspected of causing the rise in the number of rear-end accidents is both the taillights and brake lights have similar colours with only a difference in luminance. The differing luminance may have increased following driver's awareness, however, luminance cues are usually affected by various environmental factors such as ambient lighting, distance, varieties of size, shape, and number of lamps used on different vehicles and the limitations of human perception which cause judgement of luminance differences to be erroneous. Considering the multi-directional movement characteristic of motorcycle riding (lane splitting and weaving between vehicles) that usually occurs in a short period of time, has reduced anticipation by other road users, especially from the peripheral visual field. In this case, the conventional brake lamps are not enough to provide awareness for the rear vehicles. In addition, there are not enough researches done to evaluate the effect of flashing brake lamps on the motorcycle in-depth, although the same cannot be said for other types of vehicles. CHMSL has been around for almost two decades, however, the application of flashing brake lights is still not available, especially in ASEAN countries. Taking into consideration that the motorcycle brake lamps is already smaller in size compare to other vehicle and not all motorcycle has spoiler lamp to install the CHMSL since in most ASEAN countries like Thailand, Malaysia, Indonesia and Vietnam are said to be the 'scooter' category which is between 50cc to 250cc. Not to mention that Formula 1 has already implemented the flashing brake lamp for obvious reasons. Therefore, the idea to improve the rear brake lights by changing them from continuous to flashing in motorcycles is advantageously suggested in evaluating the impact on rear vehicle response, especially the BRT of the drivers.

1.1 Importance of brake lamp

There are two kinds of brake lamps; the one that has been integrated with the rear lamp and CHMSL. The purpose of both of the lamps is to indicate the intention of the driver to decelerate or stop. This is important as the following vehicle does not know the leading driver desire without these lamps so they make it possible to interact with road users behind. Unlike the other lamps like the license plate light and tail light, the brake lamp is much similar to the turn signal lamp and reversing lamp in the aspect where their job is to deliver the intention of the driver rather than attract the attention of the vehicle's presence and judging the width and distance of the vehicle [3]. The CHMSL has been found capable to reduce 4.30 % of the number of rear-end collisions in a long-term period, however, they were more competent in a simpler accident than the complex one [4,5].

1.2 Flashing brake lamp

The flashing brake lamp is not something new introduced in the vehicle. The flasher devices are something that turns signal indicator already used. The difference is none of the flashing brake lights patents has been validated for passenger cars usage may due to their small merits of performance [6], although there are numerous patents of flashing brake lamps that were invented with the purpose to increase the conspicuity of vehicles, for example, the Peter P. Kim and Asim Tewari designs. Kim [7] proposed an automatic flashing brake light that varied in the flashing frequencies corresponding to the G-force measured by the G-force meter while Tewari [8] developed a method for the brake lamps activation to change its intensity and flashing according to the rate of vehicle decelerate. This type of brake lamp is said to be better than the continuous brake lamp, especially in drivers' peripheral visual field when the drivers are not looking directly at the road or being distracted like sleepiness, handphone usage and simply lost in thoughts. Researchers like Neurauter found out the RT of the driver was shortened by 1.82 s, which is a 30% reduction when using the flashing rear lights compared to the conventional ones [9].

However, the frequency of flashing seems to be a significant factor to achieve that RT reduction. The flashing frequency of 1.5 Hz and 5 Hz have no major difference to the drivers' brake RT due to assumed irregular setup but the same thing does not happen when 1.5 Hz frequency when used in motorcycle, where there were 80 milliseconds (ms) of RT reduction compared to the conventional lamps [9]. Nevertheless, the flashing frequency of 4 Hz has equal intervals between the dark and lights may be the ideal flash frequency for warning signals, which has also been supported by the Wierwille study and used by Elschner in his study [8,9].

1.3 Rear driver response on brake lamp

The brake lamp as mentioned before is to deliver the intention of the leading driver to decelerate or stop. That is why the response of the rear driver is important to prevent unwanted rear-end collisions happen. In this matter, the BRT is the main element that will be taken into consideration for the experiments. The reason BRT is chosen is due to its capacity to be affected by several factors like the characteristics of the brake lamp itself, that is the number of the lights, luminous intensity, colour, size of the lights and flashing lights, and also the ambient lighting [5]. Meanwhile, the factors that can be affected by the BRT are braking distance, time to a full stop, percentage of brake depression and many more, which will not be considered and measured in this study.

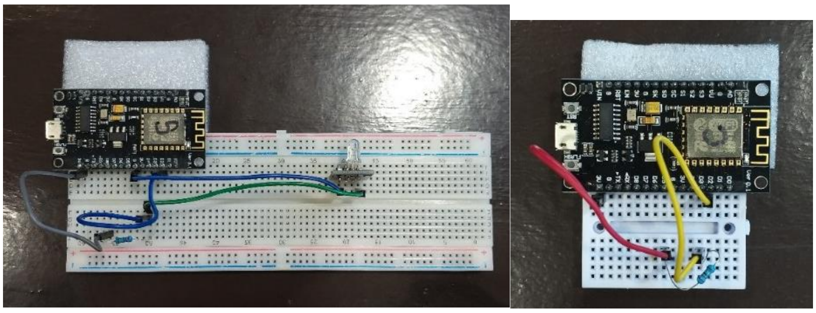
Firstly, the number of lights can be related to the addition of CHMSL as a requirement on rear lights which has been studied and demonstrated that it could contribute to minimizing the rear-end collisions[6,8]. However, the installation of CHMSL on motorcycles are considered unfeasible due to the small size. Therefore, the flashing lamps are seen as the alternative especially in a limited view, to increase the conspicuity of the brake lamps [11]. Berg, Berglund, Strang et al [10] found that using flashing brake lamps of 20 Hz frequency has an effect in reducing the RT and is said to be more attention-grabbing than continuous ones. This is very similar to the hypothesis of this experiment, which want to show that flashing brake lamps are better than the conventional in terms of BRT. Meanwhile, Sohrabi [12] found that gender had a significant difference in brake reaction time where women tend to have a slower brake reaction time than men. He also found that the different driving experiences also played an important part, where the experienced drivers have shorter mean BRT compared to the beginner drivers [12]. This has also been supported by Palaniappan, Mouli, Fringi et al [13], where they found that experienced drivers have a faster reaction time than inexperienced to release the accelerator pedal means they are faster to detect the light activation than inexperienced drivers.

2. Equipment and Methodology

Methodology in a research study is a guide of specific procedures or methods to conduct the experiments. The methodology must be apparent on how the data accumulated throughout the process and be able to deliver the explanation of the data as it is a work plan to solve the problem discussed that started the studies conducted. At the same time, it will give the research studies more credibility and show the feasibility of the results obtained.

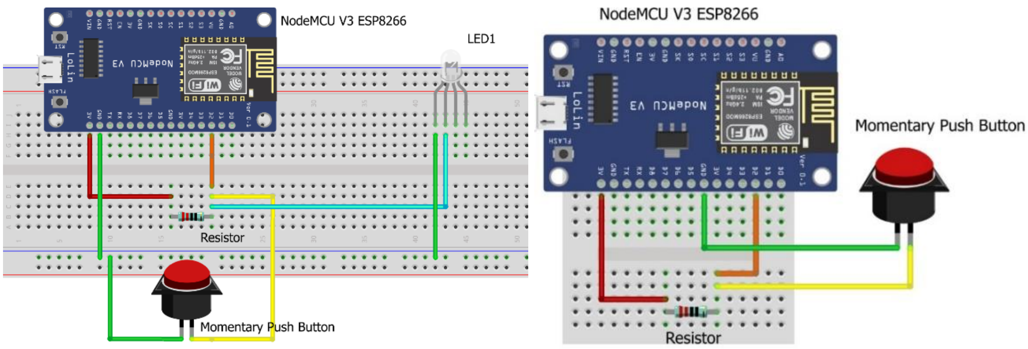
2.1 BRT measurement device

The BRT measurement device includes two main parts, the first one is the ESP8266 Wi-Fi module and the second part is the push button. There are two ESP8266 Wi-Fi modules used in this experiment, the server and the client. The server is used and placed in the car while the client is used and placed on the motorcycle. These Wi-Fi modules have been programmed using Arduino software to record the real-time clock in milliseconds and record the time gap between the push buttons being pressed. The LED is added to the server circuit for connectivity check; when the LED fades after the push button is pressed, the Wi-Fi modules are still connected. The client Wi-Fi module is powered by a power bank while the server is powered by a laptop. Figures 1 and 2 showed the BRT measurement device and its circuit diagram for each Wi-Fi module.



(a) (b)

Figure 1: BRT measurement device; (a)Server, (b)Client



(a) (b)

Figure 2: Circuit diagram of BRT measurement device; (a) Server (b) Client

Figure 3 displayed the coding of the Wi-Fi module using Arduino software. The system in Arduino software will keep printing time in milliseconds (ms) and only stop when the push button of the client is pushed and continue printing when the push button of the server is pushed.

Server

```
#include <ESP8266WiFi.h>
#include <WiFiUdp.h>
unsigned long myTime;

// Set AP credentials
#define AP_SSID "ServerEsp@TV2"
#define AP_PASS "nuruldayana"

// UDP
WiFiUDP UDP;
IPAddress local_IP(192,168,4,1);
IPAddress gateway(192,168,4,1);
IPAddress subnet(255,255,255,0);
#define UDP_PORT 4210

// UDP Buffer
char packetBuffer[UDP_TX_PACKET_MAX_SIZE];

void setup() {

  // Setup LED pin
  pinMode(4, INPUT);
 // pinMode(2, INPUT);
  pinMode(4, OUTPUT);

  // Setup serial port
  Serial.begin(115200);
  Serial.println();

  // Begin Access Point
  Serial.println("Starting access point...");
```

Client

```
#include <ESP8266WiFi.h>
#include <WiFiUdp.h>
unsigned long myTime;

// Set WiFi credentials
#define WIFI_SSID "ServerEsp@TV2"
#define WIFI_PASS "nuruldayana"

// UDP
WiFiUDP UDP;
IPAddress remote_IP(192,168,4,1);
#define UDP_PORT 4210

void setup()
{
  // Setup IO
  pinMode(4, INPUT);
  //pinMode(2, INPUT);
  // pinMode(4, OUTPUT);

  // Setup serial port
  Serial.begin(115200);
  Serial.println();

  // Begin WiFi
  WiFi.begin(WIFI_SSID, WIFI_PASS);
  WiFi.mode(WIFI_STA);

  // Connecting to WiFi...
  Serial.print("Connecting to ");
```

Figure 3: Coding of the Wi-Fi module in Arduino software

There is a push button used for each Wi-Fi module. Each push button is installed on the brake pedal and connected to the circuit using wires and connectors where they are being hidden inside the interior dashboard and through the body parts to minimize the disturbance for participants. These push buttons acted as the sensors upon pressing during the experiment. Figure 4 showed how the push button is installed on the brake pedal. BRT measurement devices are ensured to be connected before the experiment begins.

Figure 4: Push button attached to the brake pedal

2.2 Experimental Setup

The experiment is conducted in front of the Unitech Autowork Solutions workshop, inside the campus of University Tun Hussein Onn (UTHM) Pagoh. For the experimental setup, the car and motorcycle used are Perodua Myvi and Yamaha LC 135. The car is placed at 0 meters (m) or 'START' and the motorcycle is placed at the marked distances. The distance is described as x as shown in Figure 5. The experiment is conducted in static conditions to reduce the risk of any accident occur during the testing. The participants are seated inside the car at the driver side while the researcher is seated at the passenger side. The laptop and server Wi-Fi module is placed on the upper leg of the researcher to ease the recording of data, eliminate the obstacle between wires and participants and stabilise the Wi-Fi modules connection. The experimental setups can be seen in Figure 2.6. As shown in the figures, the experiment is conducted in night to increase the conspicuity of the motorcycle brake lamp.

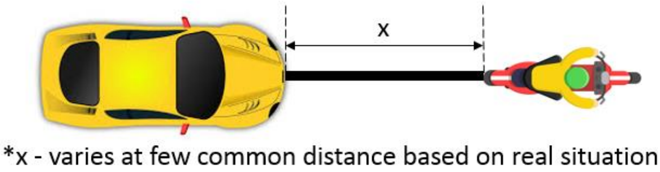


Figure 5: Distance between the car and motorcycle

(a)

(b)

(c)

Figure 6: Experiment setup; (a)Side view, (b)Front view, (c)Back view

Two sets of lamps are prepared and used in the experiment. Table 1 listed the details of the lamps and Figure 7 displayed the bulb used for the lamp sets.

Table 1: Details of brake lamps

Lamps	Conventional	Flashing
Type	P21/5W	1157/VYD15
Power (Watt)	21 W (Brake) 5 W (Tail)	1.5 W
Bulb	Dual-filament	COB LED
Brightness	440 lumens	2500 – 3000 lumens
Frequency	-	3 Hz

(a) (b)

Figure 7: Bulbs used in the experiment; (a) Conventional, (b) Flashing

2.3 Driver Classification and Distance Models

The experiment will involve 30 participants from UTHM students from different driving experiences and gender. The frequency of 30 participants is based on Morse [14], where he recommended 30 - 60 participants for a semi-structured questionnaire. In the questionnaire, the participant's willingness and availability for the experiment are also included. The participants volunteered will be grouped into three categories relative to their driving experience and gender. The first category is those who have 1 to 2 years of experience while the second category is those who have 3 to 4 years of experience and the last category are those who have 5 and more years of experience. Table 2.2 displayed the classification of drivers' driving experience. This classification is similar to Sohrabi study [12], where the target participants are mainly UTHM Pagoh students except the experience is based on years of driving instead of distance of driving. While the range of driving experience seems small but it is appropriate with the age range of the target participants since the age of the UTHM Pagoh students is ranged from 18 to 27 years old. The participants were deliberately chosen from answering the questionnaire via Google Form about their detailed information and also to be mindful of their conditions that may influence the result of the testing. The distance used in this experiment is based on the 2-seconds rule model of safe following distance [15] as shown Table 2.3. Since the test is in static conditions, 0 m cannot be used as the reference for the distance. Therefore, the distances between 10 km/h and 20 km/h are applied, where 6 m, 8 m and 10 m has been chosen.

Table 2: Classification of drivers' driving experience

Category	Driving Experience
Beginner	1 – 2 years
Intermediate	3 – 4 years
Experienced	≥ 5 years

Table 3: Safe following distance models [15]

	Safe Following Distance (m)			
Speed (km/h)	**Pipes'***	**Forbes'***	**Calibrated GM**	**2-second Rule**
0	5.00	5.00	0.00	0.00
10	8.13	9.17	31.52	5.56
20	11.25	13.33	36.70	11.11

30	14.38	17.50	4012	16.67
40	17.50	21.67	42.74	22.22
50	20.63	25.83	44.88	27.78
60	23.75	30.00	46.71	33.33
70	26.88	34.17	48.32	38.89
80	30.00	38.33	49.76	44.44
90	33.13	42.50	51.06	50.00
100	36.25	46.67	52.26	55.56
110	39.38	50.83	53.36	61.11
120	42.50	55.00	54.39	66.67
130	45.63	59.17	55.35	72.22
Assume average vehicle length of 5 meters.				

2.3 Experimental Procedure

The participants are divided into five groups of six people according to their availability for five sessions. The experiment is conducted for approximately two hours in each session, from 8.00 p.m. to 10.00 p.m. After the setup is done, a briefing about the experiment is given to the participants by the researcher. Then, the participant is seated inside the car calmly and get ready for the experiment. The feet must be placed at the accelerator pedal and the eyes focused on the rear lamp to imitate the real driving situations. An assistant rides the motorcycle and pressed the brake pedal at a random time after the starting signal. This is because the data collected need to be unbiased for the verification of the data. Each participant only needs to press the brake pedal once for each testing, except if some malfunctions or inconveniences distracted the participant's focus or ruined the accuracy of the data reading. The common problems that occurred during the experiment are connection loss between Wi-Fi modules and the participants cannot find the brake pedal due to nervousness. The experiment is conducted in three sets per lamp with a total of six sets per participant. Overall, the data collected will be 180 sets of BRTs for 30 participants.

3. Results and Discussion

The data collected will be calculated as the brake response time by finding the difference between two-time intervals. These BRT sets of data will be analysed using Microsoft Excel to find the mean BRT for the driving experience, distance, gender and types of lamps. The mean BRT discussed will be displayed in a graph for each variable.

3.1 BRT based on driving experience

Figure 8 is the analysis of BRT based on the participants' driving experience. Based on the figure, the mean BRT of conventional brake lamp and flashing brake lamp for the beginner category is 0.918 s and 0.795 s respectively. The mean BRT of conventional brake lamp and flashing brake lamp for the intermediate category is 0.677 s and 0.650 s respectively. The mean BRT of conventional brake lamp and flashing brake lamp for the experienced category is 0.653 s and 0.575 s respectively. The result shows a positive outcome on BRTs reduction for both lamps by 0.027 s to 0.123 s. The percentage improvement of the flashing brake lamp is 13.40 % for the beginner category, 3.99 % for the intermediate category and 11.94 % for the experienced category. A conclusion came for the reason on how the experienced drivers could achieve faster BRT is due to their competency and time spent on braking, which may have trained the muscle memories to react faster upon the signal activation. Conversely, the beginner drivers demonstrated the effectiveness of the flashing brake lamps better even though they do not spend enough time driving as experienced drivers.

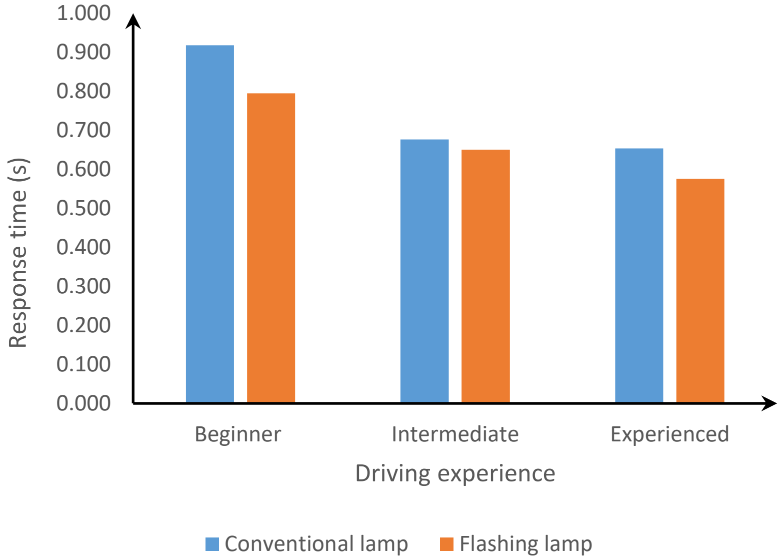


Figure 9: BRT versus driving experience

3.2 BRT based on distance between vehicles

Figure 10 is the analysis of the BRT based on the distance between the car and motorcycle. Based on the figure, the mean BRT of conventional brake lamp and flashing brake lamp for 6 m distance is 0.731 s and 0.691 s respectively. The mean BRT of conventional brake lamp and flashing brake lamp for 8 m distance is 0.735 s and 0.694 s respectively. The mean BRT of conventional brake lamp and flashing brake lamp for 10 m distance is 0.785 s and 0.643 s respectively. The result shows a positive outcome on BRTs reduction for both lamps by 0.04 s to 0.142 s. The percentage improvement of flashing brake lamp is 5.47 % for 6 m, 5.89 % for 8 m and 18.09 % for 10 m. The direct feedback from participants suggested that the BRT increased when the distance increased although the BRT for the flashing lamp at 10 m is decreased due to the drivers starting to adapt their response to the flashing brake lamp. The proof of that can be seen in the percentage improvement as their BRT reduction is increasing even though the distance is increasing.

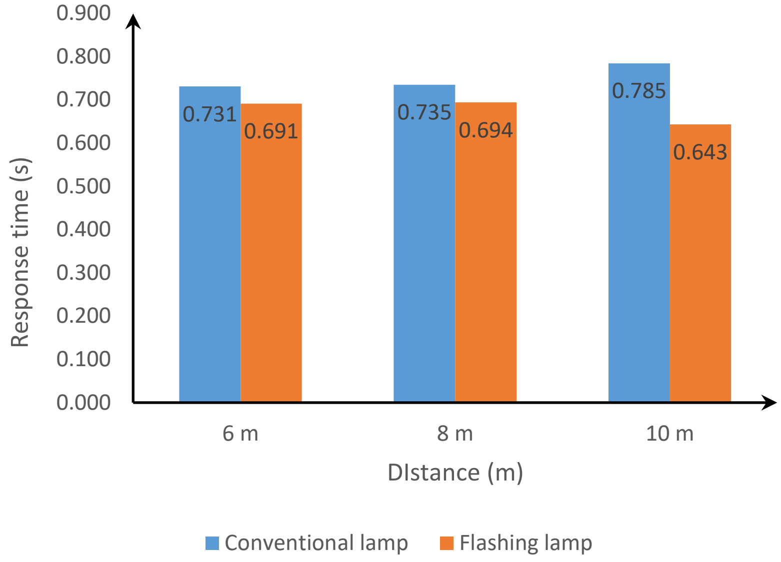


Figure 10: BRT versus distance

3.3 BRT based on gender

Figure 11 is the analysis of the BRT based on participants' gender. Based on the figure, the mean BRT of conventional brake lamp and flashing brake lamp for male is 0.693 s and 0.611 s respectively. The mean BRT of conventional brake lamp and flashing brake lamp for female is 0.906 s and 0.856 s respectively. The result shows the difference of mean BRT between female and male is 0.213 s and 0.245 s for both lamps respectively, which represented the percentage improvement of 23.51 % for conventional lamp and 28.62 % for flashing lamp. This shows that gender had an influential part in determining the BRT, as shown in [12] which parallel with the results that indicate that males have faster BRT than females.

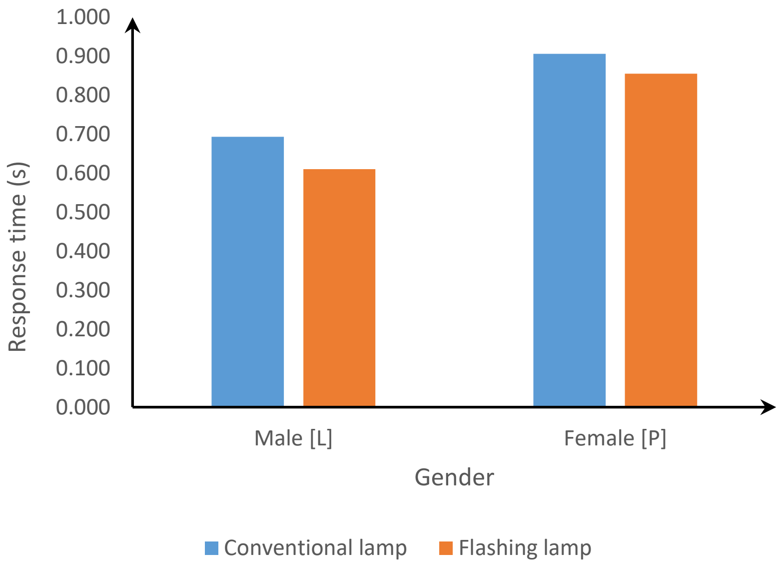


Figure 11: BRT versus gender

3.4 BRT based on types of lamps

Figure 12 is the analysis of the BRT on two types of lamps used in the experiment, which is conventional and flashing brake lamps. The figure represents the mean BRT from all of the participants.

The mean BRT of the conventional brake lamp is 0.750 s. While the mean BRT of the flashing brake lamp is 0.676 s. The result shows a positive outcome on BRTs reduction for both lamps by 0.074 s. The percentage improvement of flashing brake lamps is 9.87 %. The results may be quite small than expected but the improvement of BRT reduction on flashing brake lamp implementation is noteworthy and can be further improved in future studies.

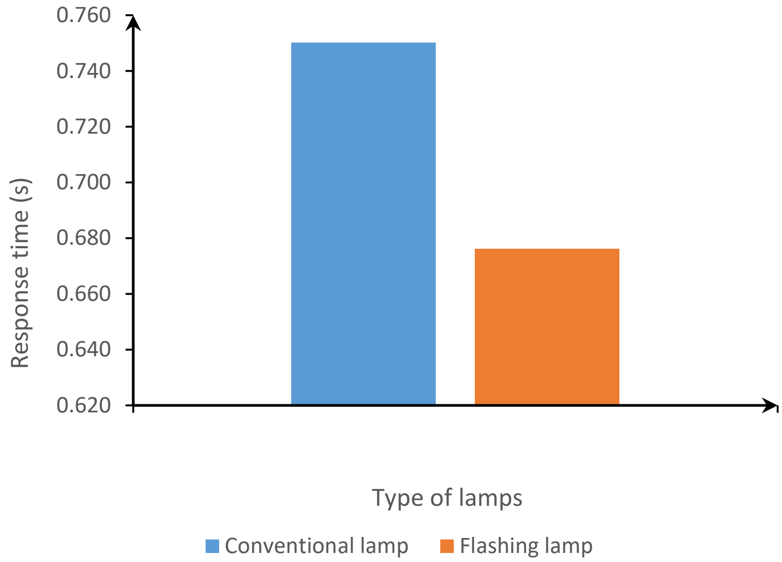


Figure 12: BRT versus type of lamps

Based on the results obtained in this study, it is indicated that the brake response time of the flashing brake lamp has improved as compared to the conventional brake lamp. The BRTs reduction for 6 m and 8 m of distance seems to be too small to be apt in lowering the rate of collisions, therefore it must be noted that some of the participants through direct feedback after the experiement, especially females mentioned their thought on flashing brake lamp which is something that unfamiliar to them. This can be considered as the adaptation of the brake lamp is still new to them and caused the mean BRT from 6 m and 8 m distances to be slightly smaller compared to from distance of 10 m. In addition, the distances tested demonstrate positive results as the BRTs reduction increased when the distance increased. This means that further vehicles can increase the BRT of a driver even for both brake lamps.

It was determined that driving experience also played important role in reducing the drivers' BRT. The graph illustrates how BRT for beginner, intermediate and experienced categories is becoming shorter when their driving experience increased. A deduction can be made on the effect of driving experience on the BRT of a driver where the more years of experience a driver has, the shorter BRT they will achieve. The gender group is also a factor in BRTs reduction. It can be seen that males have shorter BRT compared to females. In this experiment, it can be determined that gender presented the largest BRTs reduction compared to the other factors.

4. Conclusion

It is concluded that the implementation of the flashing brake lamp could be an improvement in reducing the brake response time, which affected the rate of rear-end collision that has been the main concern at the beginning of this study. The result from data collection has shown that the mean BRT of the participants is reduced in the graph when compared to the conventional brake lamp, which can be an indication of the significance of the flashing brake lamp usage in road safety. However, the BRT of drivers may vary depending on several factors such as driving experience, distance and gender. These prove that the flashing lamp can reduce the number of rear-end collisions and provides thorough insight into the potential of safety implications.

Overall, the flashing brake lamp is proven to have shorter BRT compared to conventional brake lamp. The conclusion also tallies with the objective of the project and have achieve the hypothesis and expectation from the start of the study. From the data analysed, the flashing brake lamps is more effective in reducing the BRT of the drivers compared to conventional brake lamps. That being said, flashing brake lamps are suitable for implementation on motorcycles, especially in ASEAN countries like Malaysia.

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