Safety Science 50 (2012) 371–377

Contents lists available at SciVerse ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Motorcyclist perception response time in stopping sight distance situations

Seyed Rasoul Davoodi [a,*], Hussain Hamid [b], Mahdieh Pazhouhanfar [a], Jeffrey W. Muttart [c]

[a] Department of Civil Engineering, Qeshm Branch, Islamic Azad University, Qeshm, Iran
[b] Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[c] Crash Safety Research Group, Post Office Box 261, Uncasville, CT 06382, USA

ARTICLE INFO

Article history:
Received 23 February 2011
Received in revised form 11 August 2011
Accepted 4 September 2011
Available online 25 November 2011

Keywords:
Exclusive motorcycle lane
Perception response time
Stopping sight distance
Motorcyclist behavior
Motorcycle crashes

ABSTRACT

One of the most effective engineering measures is the provision of an exclusive motorcycle lane that separates motorcycles from other mixed traffic to reduce traffic congestion and motorcycle crashes. Even though the existing exclusive motorcycle lanes in Malaysia reduced the incidents of motorcycle crashes with other vehicles, the design of this special motorcycle lane was based on a cross reference between a bicycle track and a highway. Thus, a suitable design guide is yet to be developed for the geometrical design of a proper and safer exclusive motorcycle lane. Safe stopping sight distance (SSD) has been recognized as a criterion for road design and should be taken into account. Motorcyclist perception response time (PRT) is the time from detection object until the rider reduces motorcycle speed in braking action is an essential component of motorcycle SSD. Two road experiments were conducted to obtain empirical values of motorcycle PRT to expected and unexpected objects. In the expected condition, 89 motorcyclists applied brake as quickly as possible following activation of a light beside the road. In the unexpected condition, 16 riders responded by braking in response to an obstacle that appeared suddenly in their lane. The mean PRT to expected and unexpected object is 0.71 s and 1.25 s respectively. The 85th percentile PRT to unexpected object is 2.12 s. This study found that most riders are capable of responding to an unexpected object along the roadway in 2.5 s or less. Therefore, PRT of 2.5 s is an appropriate value for motorcycle lane geometric design.

1. Introduction

There has been a large growth in motorcycling in many developed and developing countries in the last decade (Haworth, in press). In the majority of southeast Asian countries, the proportion of motorcycles vary from about 30% to 95% (Hussain et al., 2005; Lin and Kraus, 2009) which indicates that motorcycles are the major road users. Ibrahim et al. (2006) reported that affordability, reduced travel time in congestion, and maneuverability contributed to the significant growth in the number of motorcycles in developing countries.

On the other hand, the risk of death from a motorcycle crash is at least 20 times higher than from other motor vehicles for every kilometer traveled (Chang and Yeh, 2006; Department for Transport, 2008; Hussain et al., 2005). It was reported that motorcycle fatalities in the US increased in recent years as a result of increase in number of motorcycle riders and owners (IIHS, 2002, 2006). In Malaysia, more than 60% of all traffic fatalities are motorcyclists (MIROS, 2011). Thus, special attention is needed to tackle the safety of this vulnerable road user.

The provision of exclusive motorcycle lane to segregate motorcyclists from other mixed traffic is an effective engineering measure to reduce motorcycle accidents and fatalities (Tung et al., 2008). Radin Umar et al. (1995, 2000) proved that the introduction of a 30 km exclusive motorcycle lane in Malaysia reduced motorcycle accidents per year by 39%. Despite the effectiveness of segregation, motorcycle accidents still continue to occur along these exclusive motorcycle lanes in which fatalities result from multiple motorcycle crashes, single motorcycle crashes, and even collision of motorcycles into objects at the roadside (Tung et al., 2008). The occurrence of these motorcycle crashes may be due to the fact that the exclusive motorcycle lane in Malaysia was actually constructed based on the design criteria for cycle tracks (JKR, 1986) and not based on any scientific research in motorcycle traffic science, motorcycle characteristics and rider behavior.

In the design of a motorcycle lane, one of the most important factors that should be considered is the provision for adequate stopping sight distance at every point along the roadway (Davoodi et al., 2010). At least the sight distance should be such that a motorcycle traveling at or near the designated speed will be able to stop completely before hitting a stationary object along its travel path. The perception response time (PRT) which is the time measured from detection of an object to the time when brake is applied is an important component of stopping sight distance (Fambro et al., 1998). PRT is also the most commonly used measurement in crash avoidance research for the determination on the effectiveness of a system. It can show the accuracy and reaction time of a

* Corresponding author. Tel.: +98 9123375138.
E-mail address: davoodi76ir@gmail.com (S.R. Davoodi).

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doi:10.1016/j.ssci.2011.09.004

driver as a result of implementation of the system. As such, the PRT of motorcyclist is an important factor used to determine the horizontal and vertical curve lengths in providing the required stopping sight distance for exclusive motorcycle lanes. Although many studies about motorcycle safety are readily available (Di Stasi et al., 2010; Pai, 2009; Pai and Saleh, 2007; Yeh and Chang, 2009), only a few cover the design parameters of stopping sight distance for motorcycle lanes.

The current design standard by the American Association of State Highway and Transportation Officials (AASHTO) specifies a value of 2.5 s for driver PRT using a passenger car as the design vehicle (AASHTO, 2004). Meanwhile, by Fambro et al. (1998) confirmed that 2.5 s represents the most appropriate PRT for all passenger car drivers. Further, the AASHTO Guide for the Development of Bicycle Facilities assumes a value of 2.5 s for bicyclist PRT to provide a minimum stopping sight distance at various speeds for designed crest vertical curves or sag vertical curves in bicycle paths (AASHTO, 1999).

2. Literature review

The total time it takes for a driver to detect an object, recognize it as a hazard, and make a decision on an action, such as braking, is known as the PRT (Fambro et al., 1998). Drivers' reaction times have been examined in several studies, during which participants were alerted to the stimuli that were used to elicit a braking response in one scenario and left unalerted to the stimuli in another scenario. This is because the stimuli affected PRT values. In this section, PRT studies on the road are focused on passenger cars, bicycles and motorcycles in expected and unexpected scenarios.

2.1. Drivers aware that PRT is being measured (expected object)

In studies conducted with alerted drivers, drivers were told what stimuli to respond to with a braking response during the braking process. This basically means that the driver was informed of the measurement of his/her brake response time.

2.1.1. Passenger cars

Studies have been conducted in which participants driving a vehicle were told to initiate braking as soon as possible when lights or sounds were activated. A summary of the main studies on passenger car driver PRT in expected object conditions is presented in Table 1.

The most well-defined road study of brake application under low uncertainty was performed by Norman (1952). The study consists of drivers traveling on an airport taxiway at ''high speeds'' and braking on seeing an anticipated ''brilliant light'' 213 m ahead. The mean PRT was 0.73 s and the 95th percentile was at 0.89 s. In a study conducted by Johansson and Rumar (1971), drivers were stopped by police and asked if they could participate in the study. Those who agreed were asked to apply their brakes as quickly as they could after hearing a loud signal within the next 10 km of roadway. A median brake reaction time of 0.66 s was computed from the results of 321 drivers. The range of this brake reaction time varied between 0.3 and 2.0 s.

Fambro et al. (1998) carried out an experimental study in the field to determine the parameter values for stopping sight distance determination. During the study, some of their subjects performed braking maneuvers at a speed of 90 km/h under different conditions that involved the subjects using their own vehicle (study 3) and a test vehicle (study 2). Subjects stopped their vehicles the instant the windshield-mounted light-emitting diode signaled. Table 1 also showed the summaries of the observed results of their study. Considering all factors, results from many studies agree that a mean passenger car driver PRT of about 0.60–0.80 s is the best that can be expected on the road.

Table 1
Summary of studies on passenger car driver PRT in expected object.

Study	No. of subject	Mean (s)	Object/signal
Johansson and Rumar (1971)	321	0.75	Sound-horn
Olson and Sivak (1986)	64	0.72	Yellow foam
Norman (1952)	53	0.73	Brilliant light
Schweitzer et al. (1995)	45	0.53	Brake light
Sival et al. (1981)	12	0.73	Brake light
Fambro et al. (1998), test vehicle	26	0.60	Light-emitting diode
Fambro et al. (1998), own vehicle	11	0.62	Light-emitting diode

2.1.2. Bicycles

Landis et al. (2004) performed a complete study on the characteristics of emerging road and trail users in 2004. Bicycles and emerging devices were used to collect data in the field at 21 data collection stations at three shared-use paths across the United States. Part of their studies involved the measurement of PRT of emerging road and trail users. Subjects were video-taped from multiple camera positions within a segment of the shared path as they applied their brakes on seeing an expected stop sign. The computed mean for the bicycle PRT was 0.9 s while Kick Scooters had the maximum mean PRT of 1.2 s.

2.1.3. Motorcycles

A few experiments that concentrated on motorcycle riders have been carried out to determine the PRT of alerted riders (Davoodi et al., 2011; Ecker et al., 2001; Thom et al., 1985). Thom et al. (1985) and Davoodi et al. (2011) measured simple expected motorcyclist PRTs. Thom and his associates conducted studies on the front brake response time of motorcycle riders, in which each participant was asked to execute a reaction time test when sitting on the test motorcycle. They investigated the amount of time required to recognize a signal and initiate front wheel braking from two different rider hand positions. The mean response time for the experienced riders was 0.396 s while that for inexperienced riders was 0.444 s. Davoodi et al. (2011) conducted studies on the rear brake PRT of motorcycle riders using their own motorcycles. The motorcycle was kept stationary to allow the subject to sit in the normal riding position; then they waited for the activation of the brake lights of a passenger car positioned 8 m in front of them. The time between the activation of the passenger car brake lights and the onset of the brake lights of the motorcycle was measured. The mean and standard deviation of PRT was 0.44 s and 0.11 s respectively.

Ecker et al. (2001) employed an instrument-fitted motorcycle in a training facility for the investigation of PRT. They fitted the motorcycle with two digital timers for the measurement of brake reaction times on the brakes of both wheels. A red signal light was mounted on the instrument panel of the motorcycle, positioned on the peripheral visual field for the motorcycle operator. The participants were directed to ride at a speed of 60 km/h along the long straight test path and to make a full stop emergency brake when they noticed the brilliant red flare of the signal light. In this test, the measured mean reaction time of rear-wheel brake and front-wheel brake was 0.463 s and 0.423 s respectively.

2.2. Drivers unaware that PRT is being measured (unexpected object)

In this case, the drivers were not informed of the braking scenario, hence they were not aware that their brake response times were going to be measured. This element made the results from these studies more authentic than those for alerted drivers. A number of controlled studies for the estimation of passenger car driver response time in emergency situations have been conducted. A summary of the main studies on passenger car driver PRT in unexpected scenario is presented in Table 2.

Many experiments which focused on unalerted drivers have been carried out in the following car scenarios (Liebermann et al., 1995; McKnight and Shinar, 1992; Sivak et al., 1982). Liebermann et al. (1995) conducted a study to find out the response time of participants to the emergency braking of a vehicle ahead. Participants were told to maintain a specific headway (either 6 m or 12 m) from a lead vehicle at a specific speed (80 km/h or 60 km/h). In the real braking scenario, the fastest response time was recorded, which was 0.58 s at 80 km/h on the 6 m headway. Meanwhile, in the dummy braking scenario, the slowest response time was recorded, which was 0.83 s at 60 km/h on the 12 m headway.

Studies which investigated the effects of road stimuli on a driver's PRT have also been conducted (Triggs, 1987; Triggs et al., 1982). Triggs et al. (1982) investigated driver PRT to several road stimuli for drivers who were unaware that their PRTs were being measured. Sites were chosen that would allow easy identification of exactly when the stimuli came into the view of the driver (e.g. after a hill crest or after a horizontal curve). The PRT was measured using video cameras that recorded the time of appearance of the driver's brake lights in relation to the time the stimuli came into view. It was found that PRTs depended largely on the perceived urgency of the brake-initiating scenario and the vehicle speed. The higher the perceived urgency and speed of the vehicle, the earlier is the PRT. The authors also noted that many drivers would exceed the commonly accepted design value of 2.5 s for PRT.

Studies have also been conducted in which the PRT elicited by unexpected roadway hazards was measured (Hankey, 1996; Lerner, 1993; Olson and Sivak, 1986). The best study was shown by Hankey (1996) where a driver traveling at 55 mph on a country road were suddenly cut by another vehicle at an intersection, and his findings reported PRTs ranging between 1.55 s and 1.80 s, depending on time-to-collision.

Perhaps one of the most ecologically valid studies on passenger car driver brake PRT was done by Lerner (1993). He fitted instruments in 116 individuals' personal vehicles to conduct "roadway quality" drives in both older and younger drivers. After the participants had driven 0.7 miles on a new freeway section, a striking yellow barrel was projected from behind a bridge abutment and response times from braking and maneuvering were recorded. The mean PRT and the standard deviation of all participants were 1.5 s and 0.4 s respectively. A different study conducted by Olson and Sivak (1986) used an unexpected obstacle in the form of a piece of foam rubber which was positioned on the road over the crest of a hill. The average speed of drivers was 29 mph while the average visibility of the obstacle from the crest was 46 m. It was found that the 95th percentile PRT was 1.6 s.

As mentioned earlier, Fambro et al. (1998) conducted studies which consisted of four different research fields. Part A of studies 2 and 3 evaluated driver braking performance to an unexpected object scenario with a test vehicle and own vehicle respectively. Study 4 was carried out on an open-roadway, unlike studies 2 and 3 which were conducted in a closed course. The study was arranged such that when the subjects approached a particular location on the roadway, an unexpected object suddenly appeared in their field of vision. For this study, the measured mean passenger car driver's PRT to an unexpected object scenario under controlled and open-road conditions was about 1.1 s and the 95th percentile PRT under the same conditions was 2.0 s.

3. Purpose of the study and hypotheses

As stated earlier, many studies were conducted on PRT of passenger car drivers but very few were for motorcycle riders. Taking into account that motorcyclist PRT is an important factor in the determination of required stopping sight distance for motorcycle lanes, the objectives of this study were to determine the motorcycle riders' PRT in expected-object and unexpected-braking situations, and to recommend the suitable motorcycle PRT for use in geometric design of motorcycle lanes (both exclusive and non-exclusive types).

4. Methodology

4.1. Experimental 1(expected object)

4.1.1. Participants

Participants were recruited from the Universiti Putra Malaysia (UPM) and Selangor, Malaysia through newspaper advertisements and flyers. Interested riders were screened to verify whether they have valid motorcycle's licenses and to determine whether they were physically fit. A total of 89 (i.e. 56 males and 33 females) motorcycle riders were recruited, where 60 (i.e. 38 male and 22 female) riders were between 16 to 30 years old, with a mean age of 25.4. In addition, 29 (i.e. 18 males and 11 female) riders were 50–60 years old with a mean age of 54.7 years old.

4.1.2. Equipment

In this study, motorcycle braking test was conducted in one of UPM's campus roads considered suitable for this research. Safety was the first concern when selecting a test site with low traffic and without any obstacle. The path was flat, straight and spacious enough to represent the real motorcycle lanes in Malaysia. A station was designed to test the braking performance where a reference strip marker was placed on the road to be used as a scale in data collection (Fig. 1). The system of PRT measurement consists of the followings:

1. Settings of three camcorders (Sony HDR-XR 520) and one Samsung HMX 20C which were adjusted based on conditions as listed (Fig. 1): (A) the whole motorcycle is captured, (B) the participant was in the video, and (C) the light was captured as the detection mark. In addition, the Sony camcorder has the recording capacity at variable time-elapse rates of 240 frames per

Table 2
Summary of studies on passenger car driver PRT in unexpected object.

Study	No. of subject	Mean (s)	Object/signal
Johansson and Rumar (1971)	5	0.9	Sound-buzz
Olson and Sivak (1986)	49	1.1	Yellow foam
Summala and Koivisto (1990)	–	1.75	Police
Lerner (1993)	116	1.50	Barrel
Hankey (1996)	48	1.55	Car
Fambro et al. (1998), test vehicle	22	0.82	Fabric barricade
Fambro et al. (1998), own vehicle	10	1.08	Fabric barricade
Fambro et al. (1998), own vehicle (open road)	11	1.10	Large barrel

second and a large storage of 240 GB. On the other hand, the Samsung camcorder records at variable time-elapse rates of 300 frames every second.

2. There were three adjustable tripods used for flexible camera orientation.
3. Orange cones were used to define the lane of test site representing Malaysia's motorcycle lanes.
4. Power Director 6 was used in the study as it can read the video file frame by frame.

The motorcycles used in this study were modified to have their brake light turned on for both brakes: pedal and lever. The cameras were set up at different spots to obtain different angles of the motorcycles of different brake responses. One of the camera views determined the speed of motorcycle before and when the brake light was on. Other camera views captured the light that signaled the participants to start braking, participants' feet, and the taillight when it was turned on which was the duration between the time when the participant applied the brake and the motorcycle was slowed down.

4.1.3. Procedures

The test was conducted during ideal situations (i.e. daylight, good weather, etc.). Before the test, the participants were subjected to color-vision and visual-acuity tests. The selected participants had a minimum vision of 20/40 and did not fail the color-vision and drug/alcohol tests conducted through a medical questionnaire; therefore, they were fit for the riding test. At the check point, the participants were asked to familiarize with their motorcycles, i.e., checking the seats, mirrors, helmets, etc. as well as brake response.

The participants were briefed on the outline of the study and they were allowed to practice riding the motorcycles as directed. The participants were instructed to quickly apply the brake when signaled, and their actions were recorded in slow motion so that the motorcycle, the motorcyclist and the light could be seen from the main station. Therefore, the time between activation of the light and the initial onset of the activation of motorcycle brake light (i.e. stop light), was recorded.

All 89 test subjects performed braking maneuvers at an initial speed of 60 km/h and 80 km/h. Braking was also tested on wet and dry pavement conditions. Each session took between 10 and 15 min, and the participants were given petrol vouchers worth RM 20 for their participation.

4.1.4. Experimental Result 1

The analysis of riders' PRTs to the expected object scenarios (the onset of the light beside the test road) was limited in Experiment 1. Each participant performed a series of four braking maneuvers at 60 km/h and 80 km/h on wet and dry pavements. The braking maneuver was initiated when the test subject reacted to illumination of the light beside the pathway. This signal was an expected object, in that the test subjects knew the signal would be initiated, but not when it would be illuminated.

PRT is defined as the time that elapsed between the onset of the light to the onset of the brake lights of the vehicle, that is, PRT occurs when the vehicle is braking and its brake light is on (Gates et al., 2007; Mehmood and Easa, 2009; Triggs et al., 1982; Wortman and Matthias, 1983). Subjects were videotaped from multiple camera positions. The video files analyzed and measured the duration between activation of the light and the initial onset of the activation of the motorcycle brake light, using a synchronized time display on the video frames with PowerDirector 6 software.

All experimental data were sorted out and statistically analyzed using SPSS17.0. After investigating the movies, all participants completed the experimental test and provided valid expected PRT. The mean of all observations was 0.68 s with a standard deviation of 0.28 s. Fig. 2 illustrates the motorcyclist PRT in the expected object distribution. It showed that the range of observation data was 0.19–1.37 s. The 85th and 90th percentile values for motorcyclists PRT were 1.01 s and 1.10 s respectively.

4.2. Experimental 2 (unexpected object)

4.2.1. Participants

The participants were recruited from the UPM and Selangor, Malaysia through posters, local newspapers and word of mouth. Selected riders had legal motorcycles' licenses and were fit for the test. A total of 16 riders, including four males and four females age from 16 to 30 years were categorized as young riders, while another four males and four females of 50 years and older were categorized as elderly riders.

4.2.2. Equipment

The system for unexpected PRT measurement which was similar to Experiment 1 also included a fabric yellow obstacle (Fig. 3). The obstacle was carefully selected to be flexible and unbreakable if any possible collision with the motorcycle occurred. In addition, the obstacle should be noticeable by the riders to trigger sudden brake. As such, a piece of fabric barricade of width 1 m × 3 m was used as an obstacle. One side of the fabric is yellow while the other side is the same color as asphalt so that it is not noticeable to the riders until it the yellow side is suddenly flicked over to them.

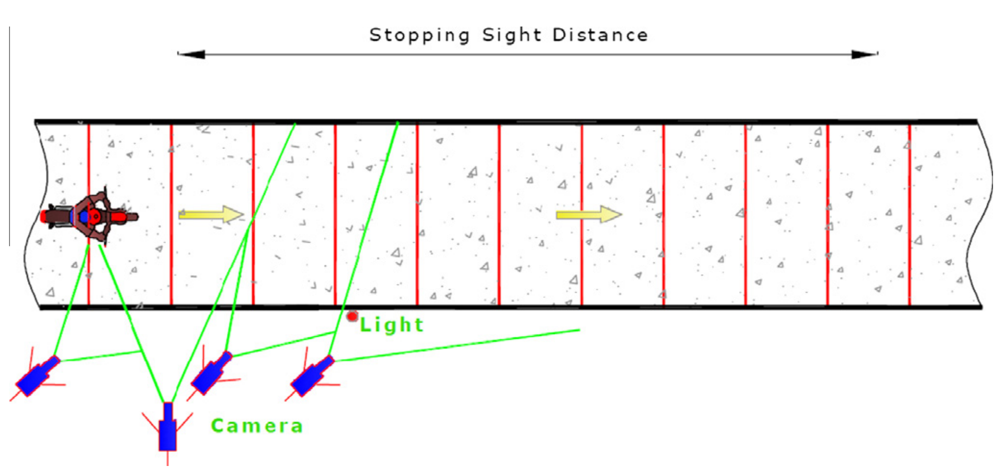

Fig. 1. The station for measuring motorcyclist PRT in expected object.

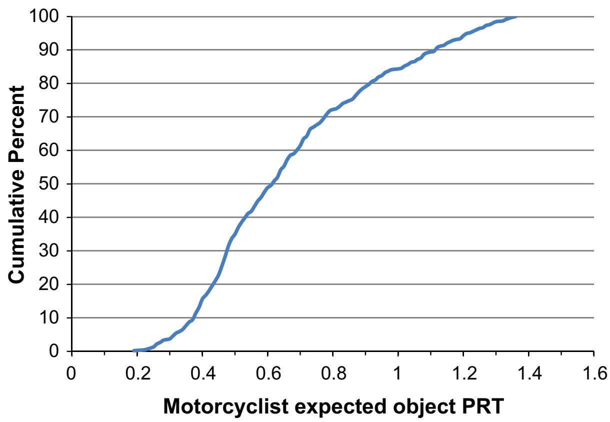

Fig. 2. Motorcyclist expected PRT distributions.

Fig. 3. The yellow fabric barricade suddenly appeared across the experimental route.

4.2.3. Procedures

Experiment 2 only focused on unexpected brake reaction time. In this experiment, the riders were not informed that their brake response times were going to be measured. The session started with directing the participants to their own motorcycles. The participants were told that they were going to participate in a research of an exclusive motorcycle lane evaluation. This protocol was undertaken to make sure that the participants did not foresee any braking scenario. The participants were asked to ride the motorcycle along an experimental route repeatedly until they became comfortable and familiar with the route. The main station of the experimental route is presented in Fig 4. All participants were asked to maintain a riding speed of 60 km/h. During the first round of riding along the experimental route, the yellow obstacle did not appear to prevent the participants from expecting any kinds of braking scenario. But during the second round of riding along the same experimental route, the yellow obstacle suddenly appeared and data was collected.

The videos were captured under a slow motion mode so that the motorcycle, motorcyclist and the obstacle could be observed. The time was recorded from the instant when the obstacle appeared until motorcycle brake light was activated.

At the end of Experiment 2, an explanation was given to the participants as to why the obstacle was hidden and only exposed later on in the experimental study. They were also asked to read and sign a new briefing form and agreed not to disclose any information for the next 2 months. Each experimental session took between 20 and 30 min and the participants were given petrol vouchers worth RM 50 as a token for their participations.

4.2.4. Experimental Result 2

In Experiment 2, riders' PRTs to unexpected object scenarios were analyzed. Each participant thought that he/she was not involved in a rider braking performance test, but rather in a motorcycle evaluation test. The braking maneuver was initiated when the unexpected object suddenly appeared on the test road.

PRT was defined as the time elapsed between the object appearing to the onset of the motorcycle brake lights. All experimental data were sorted out and statistically analyzed using SPSS17.0.

Fig. 5 shows the normal probability plots for the results of measured PRT in Experiment 2. PRT ranged between 0.55 s and 2.55 s with a mean of 1.29 s and a standard deviation of 0.6 s. A PRT of 2.12 s was noted for most of the riders (85%) in these studies. The results of the unexpected object PRT observations from study 2 showed that a PRT of approximately 2.5 s seemed inclusive of all test subjects.

5. Discussion and conclusion

Driver behavior has a significant place in urban roadway safety, signal control and traffic management; making it a key factor and a source of complexity in transportation science. Appropriate motorcycle rider behavior is fundamentally significant in bettering road safety performance in societies with a high number of motorcycles. The motorcyclist PRT can be considered the most representative figure of the road design constituents for rider behavior. Knowledge of driver perception response performance is essential

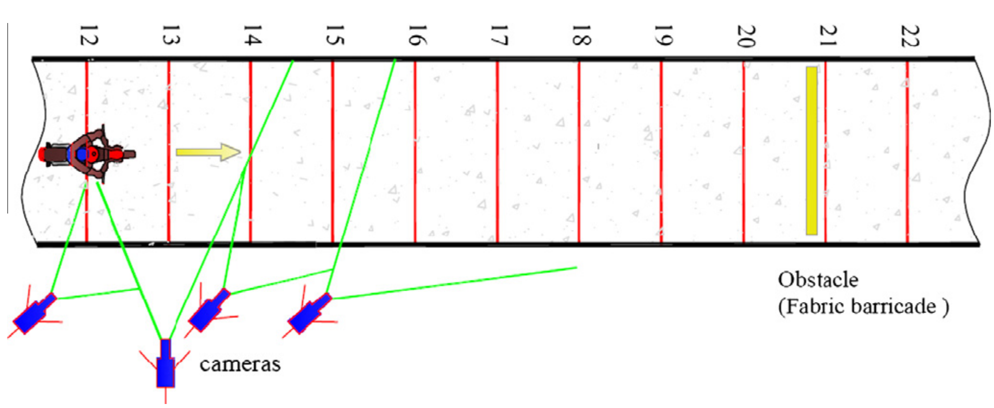

Fig. 4. The station for measuring unexpected object motorcyclist PRT.

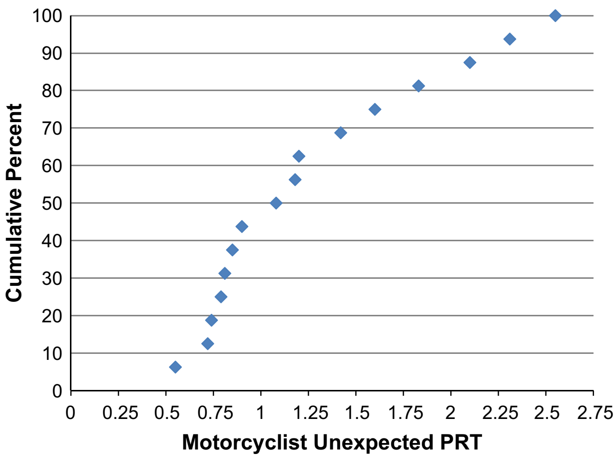

Fig. 5. Results of unexpected object PRT for motorcycle riders.

information for an effective design motoring environments. PRT is a significant design factor that is utilized widely in all categories of traffic engineering (Soobeom et al., 2003). This study acknowledged two limitations while carrying out the study which includes: the use of students from the Universiti Putra Malaysia and Selangor State in Malaysia as participants. Secondly, that the braking performance tests which was conducted at the university campus where the location was suited for the study purpose.

Experiment 1 measured the expected PRT where participants were informed that they will be subjected to a braking performance study. Using modern digital camcorders placed along the test road, motorcyclist PRTs to an expected object were obtained. The mean and standard deviation of the motorcyclist expected PRT were 0.68 s and 0.28 s respectively which were more than the PRT values obtained from past studies by Thom et al. (1985) and Davoodi et al. (2011). The difference could be that past studies measured PRT by using a simple method such as in a simulator, whereas this experiment was conducted on the road where the motorcyclist rode under real traffic conditions. PRT measurements from simulators are typically shorter than those measured in vehicles on the road because simulators have simplified visuals, smaller fields of view and no non-visual cues, etc. (Green, 2000).

This study found that the 85th percentile PRT to expected objects was 1.00 s. Further, the motorcycle braking performance also found that most riders are capable of responding to a PRT of about 1.00 s in expected scenarios. Thus, this is an appropriate value for geometric features of roads where riders are alerted, for example, in traffic signal design.

Experiment 2 measured unexpected PRT where riders were not informed that their brake reaction times were going to be measured. This experiment was the first study to measure the unexpected PRT for motorcyclists on the road. The level of stimuli was high since debriefing of participants showed that when the fabric obstacle suddenly appeared on the experimental route, they were confused and they did not foresee this would happen. The mean motorcyclist PRT to an unexpected object scenario under controlled road conditions was about 1.29 s. The 85th percentile PRT for this same condition was 2.12 s. Also, none of them were under the influence of drugs and alcohol. The findings from this study on motorcycle braking performance showed that all riders were capable of responding to a stopping sight distance situation in 2.5 s. According to this study, if consideration is given to factors such as fatigue and alcohol in real traffic conditions, the results showed that motorcyclist PRT of 2.5 s was an appropriate value for the geometric design of motorcycle lanes when stopping sight distance is the relevant control.

The results of this study showed that motorcyclist PRTs on the road in expected and unexpected scenarios were approximately the same as that for driver PRT in the same situation. This means that all roads can provide the required sight distance for motorcyclist, if it is in accordance with AASHTO guidelines and if motorcyclist deceleration is more than 3.4 m/s^2. Considering that the PRT of motorcyclist is mainly related to the height and visibility of an object along the line of sight of the rider, it is reasonable to state that the width of motorcycle lane does not influence the rider's PRT. As such, in the design of motorcycle lanes, the motorcyclist PRT value obtained from this study is not essential for traffic engineers to decide on the suitable lane width and eventually the capacity of motorcycle lanes.

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