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Differences of Drivers' Driving Performance in Simulated Driving

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Abstract: The statistics for a 10 years periods (1997-2007) shows an increasing number of road traffic accidents in Malaysia. Amongst, commuting accidents, which involved bus carsh are highest increased from year 2006-2007. Human errors have been identified as main reasons behind these fatal crashes compare to others. This study aims to determine the factors, which cause the differences of driving performance between two driving groups in related with environmental condition and road conditions in a simulated daytime and night-time driving. Fifty healthy male subjects, aged between 23-53 years old were divided into two groups and took part in one of the two different driving sessions (simulated daytime or night time driving). The total length of each simulated driving journey is 250 km. Outcomes were measured in terms of driver's driving performance (RORI and LSV index) in different of environmental and road conditions. The ambient temperature, Carbon dioxide (CO_2) level and lighting conditions were regulated throughout the experiment. The study showed that occupational drivers perform better rather than non-occupational drivers whenever the driving conditions and environmental factors considered. However, no difference of driving performance found between two driving groups in different of road types. Driver's age and driving experience was significantly correlated with both RORI and LSV index in an overall study. Occupational drivers perform better when considered the driving condition and environmental effect, indicating that drivers with extended age and prior experience tend to perform better.

Key words: Accidents, commuting, performance, RORI, LSV, occupational, age

INTRODUCTION

Road traffic accident, which involves cars, motorcycles and public transport is one of the major causes of death and injuries in Malaysia. A 10 years road traffic statistic showed that the total number of accidents had risen from 215,632 cases (1997) to 363,314 cases in 2007 (MIROS, 2007). Amongst, the rate of road accidents in Malaysia is one of the highest compared to other countries in the world. This is equivalent to 3.73 deaths for every 10,000 registered vehicles in year 2007. Recently, occupational vehicle accidents had recorded an alarming increase in serious injury and death. From the total number of occupational accidents reported to Social Security Organization (SOCSO, 2007), 17,682 cases (31%) were due to commuting accidents. Amongst, the most significant was the fatalities involving bus crash that had increased by 58% from year 2006-2007. Commuting accidents is occasionally defined as an accident where the employee suffers, while travelling to or from the workplace. It generally has, more serious consequences (permanent disabled or death) than ordinary occupational accidents and therefore, usually leads to higher costs in the form of compensation payments. In Malaysia, a total of RM 187,89 million was disbursed to workers as permanent disablement benefits in year 2007. Of that total, RM57.87 million was specifically disbursed for commuting accidents (SOCSO, 2007).

A simple deduction postulates that these incidents happened mostly due to human errors on the drivers' part (e.g., speeding, losing control over the vehicle, overtaking, fatigue and drowsiness), environmental condition as well as the vehicle conditions (Ng and Selva, 2003). For instance, speeding and careless driving are the two main causes of fatal road accidents which achieved 32.8 and 28.2% of total number of accidents (Ng and Selva, 2003), respectively. Dobbie (2002) determined that prolonged driving without rest can lead to increase the fatigue level and deteriorate the driving performance. Long duration of driving, inadequate sleep and other cumulative factors caused the sleep deprived drivers to make higher number of right edge-line crossings and other

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errors (Otmani *et al*., 2005; Philip *et al*., 2003). Apart from fatigue factors, studies had shown that working duration (Philip, 2005), tight working schedules (Biggs *et al*., 2006) and sleep deprivation, as a result of disruption of an individual's routine sleep cycle (Philip *et al*., 2003; Tippayanate, 2006), clearly contributed to the deterioration of driving performance. Reaction time was reported to have slowed by 18%, while stopping distance increased by 7.6% in sleep deprived individuals (Tippayanate, 2006). Driving behavior and performance is also shaped in part by road environments (Liu and Wu, 2009; Ting *et al*., 2008). Therefore, it is crucial to understand factors or determinants that will affect a driver's driving behavior, cognitive and driving performance.

Previous studies done had limited information on determining the root cause of commuting accidents which involved occupational drivers. Most of the studies done in Malaysia are prompt to investigate risk factors in commercial vehicles and overall planning for road system (Kareem, 2003; Law *et al*., 2005; Radin-Umar, 2005) rather than commuting accident. Also, very little research has been done to show the association between driver's ages with their driving performance. Perception on aging will deteriorate driver's alertness and therefore end out with poor performance is being unknown. Thus, this study aims to determine the factors which cause the differences of driving performance between two driving groups in related with environmental condition as well as road conditions in simulated daytime and night-time driving conditions in inducing the observed changes.

MATERIALS AND METHODS

Subjects: Fifty male drivers, aged between 23-53 and had driving experience for at least 2 years, were recruited in this experiment. They were assigned into two groups of 25 (occupational drivers, A) and 25 (non-occupational drivers, B) subjects of two driving conditions: daytime (A = 13; B = 12) and night-time (A = 12; B = 13). All drivers are healthy (evaluated through questionnaire) and free from simulator sickness. They used to drive regularly at day or night in daily life. Drivers were trained for 15 min on the driving simulator before the experiment began. The protocol of the study was accepted by ethics committee. General experimental conditions were explained to the subjects during the 15 min familiarization and learning period on the simulator. A simple self-administered questionnaire in Malay language was used to obtain the demographic data of the subjects. Written consent was obtained after they had agreed to volunteer for the trial.

Fig. 1: Driving simulator system

Apparatus: A custom made driving simulator system with modified vehicle instruments and controls was used in this experiment (Fig. 1). The video screen presented an in-car view and projected with a 24" LCD screen television located about 1 m from the driver. The display unit reproduced town area, trunk road and motorway scenery with computer-generated pictures simulating daytime and night time driving condition. A total of 5 laps driving journey (each lap = 50 km) was simulated with different scenery. All the simulated roadways were in two lanes. Drivers were allowed to overtake the in front vehicles. The traffic used along the driving task was light. The speed limit legalized in town area, trunk road and motorway was 50, 60 and 90 km h^{-1} accordingly.

Experimental procedure: Drivers were asked to complete a total of 250 km driving journey in full respect of driving rules within a given time limit. They were instructed to cover the journey within 3 h and the information of clock time was delivered to them. According to the group they were assigned to, each subject drove only one of the two driving simulation sessions, either daytime or night-time condition. All the drivers were told to restrain from smoking, caffeine, tea, alcohol and medicine 24 h before the test. They were asked to have a habitual amount of sleep the night without sleep deprivation. The lab temperature was maintained at 24±1°C to avoid influence of ambient temperature on physiological state of subjects.

Data collection

Driving measures: The method of calculating driving errors was described by Campagne *et al*. (2004). Running-of-the roads, RORI index is measured for each second by the amplitude of the exit. It consists of crossing over the Emergency Lane (EL) or the continuous white line limiting the left-hand hedge of the passing lane. When the vehicle

stays in traffic lanes, the score is 0. If the vehicle runs out the lane, it equals the distance between left front wheel and the EL for a RORI on the left-hand side and the distance between the right edge lines for a RORI in the Central Reservation (CR) (Fig. 2). The penalty is calculated for 1 min and corresponds to the square root of the sum of the RORI amplitudes squared and measured for each second.

$$\text{Running-off-the-road index: Penalty min}^{-1} = \sqrt{\sum \text{amplitude}^2} \quad (1)$$

For Large Speed Variation (LSV), a subject is penalized if an absolute difference between the vehicle speed and the highest speed authorized in the segment of road considered is calculated for each second. If the absolute difference is >20 km h^{-1}, the subject will get a penalty (per sec) proportional to the number of kilometers per hour above the speed authorized. The sum of penalty is made for each minute on the whole experiment:

$$\text{If}\Delta\text{speed} > 20, \text{ then penalty sec}^{-1} = \left(\frac{\Delta\text{speed}}{10}\right) - 1 \quad (2)$$

Statistical analysis: Datasets were analyzed using SPSS software, version 13. Differences in driving performance between two driving groups were compared by using independent sample t-test. Two-way between-groups ANOVA was employed to evaluate how driving conditions, weather and road conditions affected driving performance among two driving groups (occupational and non-occupational drivers). Pearson correlation coefficients was used to analysis the association between driver's age, driving experience and also driving performance.

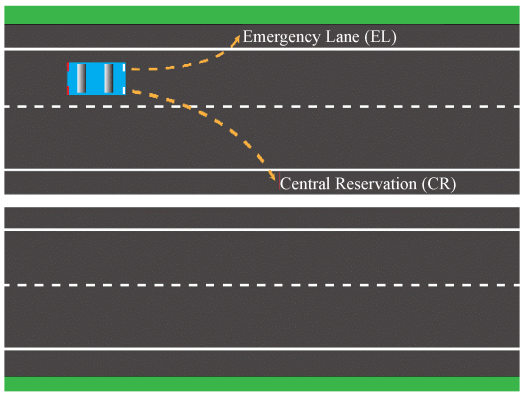

Fig. 2: RORIs

RESULTS

Comparison of driving performance among occupational and non-occupational drivers by driving conditions: Results showed that there was no difference of RORI index found between two driving groups, but the mean of LSV index among non-occupational drivers was significantly higher than professional drivers (Table 1).

When considered two driving conditions, RORI index shows no significant different ($p>0.05$) between occupational and non-occupational drivers. However, the result revealed that non-occupational drivers driving in night-time condition had committed higher LSV index compared to occupational drivers (Table 2).

Comparison of driving performance among occupational and non-occupational drivers by rain event: Considering all groups of drivers, a significant lower of RORI and higher LSV index was observed with the present of rain ($p<0.01$). In contrast, LSV index become lower, while RORI index was higher under no rain condition (Table 3). The difference of driving performance between two driving groups was then analyzed. Result revealed that non-occupational drivers had significantly higher RORI index compared to occupational drivers when it was raining ($p<0.05$). However, there was no difference of RORI index shown between occupational and non-occupational drivers in no rain condition. LSV index was higher among non-occupational drivers in both rain and no rain condition. Nevertheless, the difference of the LSV index between two driving groups was not significant under statistical analyse (Table 4).

Table 1: Mean of driving errors between occupational and non-occupational drivers

Errors	Occupational driver (N = 25)	Non-occupationals driver (N = 25)	t-value	p-value
RORI	38.40±4.80	40.10±5.40	-1.10	0.280
LSV	137.6±36.7	163.3±36.1	-2.50	0.016*

*p-value is significant at p<0.05

Table 2: Mean of driving errors between occupational and non-occupational drivers by two driving conditions

Errors	Driving condition	Occupational driver	Non-occupational driver	t-value	p-value
RORI	Daytime	38.60±4.50	37.70±6.10	0.39	0.698
	Night-time	38.30±5.30	42.10±3.90	-2.03	0.055
LSV	Daytime	139.1±30.1	148.0±42.1	-0.60	0.553
	Night-time	136.1±44.0	177.5±23.1	-2.98	0.007**

**p-value is significant at p<0.01

Table 3: Mean of driving errors by rain event

	Mean			95% CI of difference			
Errors	Rain	No rain	Mean difference	Lower	Upper	t-value	p-value
RORI	31.5	43.4	11.9	8.3	15.4	6.76	0.000**
LSV	160.7	144.2	-16.5	-26.7	-6.3	-3.26	0.002**

**p-value is significant at p<0.01

Table 4: Mean of driving errors between occupational and non-occupational drivers by rain event

				95% CI of difference			
Errors	Events	Driving group	Mean	Lower	Upper	F-stat (df)	p-value
RORI	Rain	Occupational driver	27.8	22.9	32.6	4.88 (1,41)	0.033*
		Non-occupational driver	35.1	30.4	39.9		
	No rain	Occupational driver	43.4	41.4	45.4		
		Non-occupational driver	43.4	41.4	45.3		
LSV	Rain	Occupational driver	149.7	130.4	169.1	0.23 (1,47)	0.632
		Non-occupational driver	171.7	152.4	191.0		
	No rain	Occupational driver	130.7	117.9	143.5		
		Non-occupational driver	157.7	144.9	170.5		

*p-value is significant at p<0.05

Table 5: Mean of driving errors by types of road

	Types of road (mean)							
Errors	Town	Trunk road	Highway (after toll)	Uphill and downhill	Road curve	Highway	F-stat (df)	p-value
RORI	7.6	10.9	19.3	54.4	46.8	54.3	423.30 (3,120)	0.000**
LSV	0.7	59.8	154.1	178.4	184.5	201.6	281.57 (3,146)	0.000**

**P-value is significant at p<0.01

Table 6: Mean of driving errors between occupational and non-occupational drivers by types of road

				95% CI of difference			
Errors	Driving group	Road event	Mean	Lower	Upper	F-stat (df)	p- value
RORI	Occupational driver	Town	7.126	5.932	8.321	0.877 (2,114)	0.436
		Trunk road	10.417	9.374	11.459		
		Highway (after toll)	17.136	12.796	21.476		
		Uphill downhill	52.571	47.339	57.802		
		Road curve	44.346	39.595	49.097		
		Highway	54.262	49.780	58.745		
	Non-occupational driver	Town	8.054	6.860	9.248		
		Trunk road	11.487	10.445	12.530		
		Highway (after toll)	21.384	17.044	25.724		
		Uphill downhill	56.302	51.070	61.533		
		Road curve	49.323	44.571	54.074		
		Highway	54.465	49.983	58.947		
LSV	Occupational driver	Town	0.087	-1.263	1.437	2.134 (3,138)	0.100
		Trunk road	59.950	43.003	76.897		
		Highway (after toll)	138.045	119.065	157.024		
		Uphill downhill	172.224	149.397	195.052		
		Road curve	169.208	148.982	189.434		
		Highway	192.382	173.332	211.431		
	Non-occupational driver	Town	1.223	-.127	2.573		
		Trunk road	59.710	42.763	76.657		
		Highway (after toll)	170.117	151.137	189.096		
		Uphill downhill	184.633	161.806	207.461		
		Road curve	199.867	179.641	220.093		
		Highway	210.815	191.766	229.864		

p-value is not significant at p>0.05

Comparison of driving performance among occupational and non-occupational drivers by road conditions: In the whole group studied, types of road conditions has significantly increase the RORI and LSV index (p<0.01). The mean of both driving errors index has increased by the changing from town, trunk road area till the monotonous highway. Amongst, the mean of RORI and LSV index were highest recorded when driving on uphill downhill and monotonous highway respectively (Table 5).

The effect of different road conditions on driving performance between occupational and non-occupational drivers was analyzed further. Although, the result showed that both driving errors was increased by the changing of road types from town to monotonous highway, but there was no significant difference found between occupational and non-occupational drivers (p>0.05). The mean of RORI and LSV index has slightly decrease during the road curve before achieved the highest value in monotonous highway (Table 6).

Correlations between age, driving experience and performance: Considering all groups of drivers, driver's age was inversely correlated with driving performance either in RORI or LSV index (p<0.01). Besides, a significant

Table 7: Correlation between socio demographic factors and driving errors

	RORI		LSV	
Variables	r	p-value	r	p-value
Age	-0.446	0.002**	-0.391	0.006**
Driving experience	-0.330	0.027*	-0.409	0.005**

*p-value is significant at p<0.05; **p-value is significant at p<0.01

Table 8: Correlation between driver's age and driving experience

	Driving experience	
Variable	r	p-value
Age	0.865	0.000**

**p-value is significant at p<0.01

inverse correlation was found between driving experience and driving performance in both RORI and LSV index ($p<0.05$) (Table 7).

In addition, result also showed that driver's age was significantly correlated with driving experience in an overall study ($p<0.01$). Amongst, the driver's age and driving experience both had notably high correlation coefficients exceeding 0.8 (Table 8).

DISCUSSION

It has long been observed that night-time driving is risky for drivers, particularly young and inexperience drivers. Aforementioned studies found that car travel at night carries a greater risk of being killed or seriously injured than does travel during the day (Ward *et al*., 2005). Similarly, study from (Rice *et al*., 2003) revealed that the rate ratios for injury crash with advancing of late night hours among young drivers aged between 16-17 years old, ranged from 1.3-10.6. A relevant result also showed that the hours of 10 pm to midnight has caused greater number of critical injured drivers than other time intervals. The study agreed with those findings. The only difference of the findings with previous researches was we do not carry out the experiment in real night-time condition. Instead, we only present the study in simulated day and night-time driving due to human ethics reason.

Non-occupational drivers performed higher RORI and LSV index compared to occupational drivers was highly attributed to the age difference shown between these two driving groups. In this study, the mean age of non-occupational drivers was around 22.4 years, while the occupational drivers were 32.4 years. The 10 years difference of age has really accentuated the possible changes of drivers' performance and behavior between them (Campagne *et al*., 2004; Makishita and Matsunaga, 2008; Roge *et al*., 2004). For instance, Campagne *et al*. (2004) discovered that some specific errors (i.e., speeding, running across the road) done by young and middle-aged drivers were more related to their driving attitudes rather than the vigilance level. Indeed, non-occupational drivers who were young and less driving experience preferred to test their vehicle to the speed limit, particularly when driving at night. This statement was supported by Ward *et al*. (2005) who mentioned that young drivers often engaged in risk taking behaviors at night. The situation become worsen due to some simulated areas was lacked of lamp pose, hence consequence as reduced visibility during the night-time driving. This explained what our study found. Furthermore, most of non-occupational drivers were egoistic which can lead to tendency to drive against the rules. Also, occupational drivers who are mentally more mature usually drove in a constant speed if no obstacle sudden happened. This explained the result of LSV index was lower among occupational drivers.

Looking from the effect of rain, drivers seem to perform better during raining, regardless occupational or non-occupational drivers. Owing to the visibility of road was reduced when raining, drivers drove extra careful and more alert. They started to reduce their vehicle speed or drove even slower than legal speed limit on highway. Thus, they commit less in RORI but high in LSV index. However, outcomes from (Siti and Law, 2004) showed that accidents involved heavy vehicle and motorcycle most likely to occur in good weather but rainy weather gave highest relative risk to cause fatality due to slippery of road and loss control of the vehicles. Hijar *et al*. (2000) agreed the fact, revealed that about 66.05% of traffic accident in Mexico happened in adverse weather. Nevertheless, the study done by simulator had neglected the effect of road slippery when rain present in real-life driving. That's why the chances of drivers to run across the road become less in this experiment. When comparing between two driving groups, non-occupational drivers tend to cross over the EL or CR lane and committed higher RORI index rather than occupational drivers when rain occurred. In truth, occupational drivers evidently drove in a more constant speed than non-occupational drivers along the trial. Also, occupational drivers with prior driving experience able to handle the vehicle more preferably when sudden obstacles happened. Thus, raining gave no much effect to their driving performance.

It seems obvious that a higher driving errors was occurred on the highway with uphill downhill (Table 5), but surprisingly we found no difference of driving performance between occupational and non-occupational drivers consequent by the changing of road environment. In fact, monotonous driving task provided little visual stimulation and make drivers gradually became drowsier and hence, ended with higher driving errors was evidently

proved (Liu *et al*., 2009). Also, we should bear in mind that changing of road environment from town, trunk road to monotonous highway was in sequence with time. Thus, we do not deny that there was a possibility of time effect causing drivers to feel weary and end out with making more errors on highway driving. Statement from (Liu and Wu, 2009) had mentioned that changing in road environment from complex to monotonous can cause drivers to feel a greater sense of monotony and making them less alert. Furthermore, the traffic density on highway was lighter compared to town or trunk road area, allowing the drivers tend to drive faster. The situation became worsen when drivers driving on uphill/downhill and cornering road with the extensive higher speed. This explained why the driving performance was deteriorated on town or trunk road area compared with highway. The study also supported by nearly 1 in five traffic crash resulted in driver casualty happened on state highway (Boufous and Williamson, 2006), while 68% of traffic crash which described as lose control of vehicle occurred in either straight or round the road corner (Kingshott *et al*., 2004).

However, we found no relevant statement mentioned that difference of driving groups (occupational or non-occupational drivers) has any significant effect to the driving errors made on town, trunk road, highway, road curve or even uphill downhill. The study shows that both driving groups have been exposed to the same driving condition in a controlled environment at temperature of 24°C and lighting condition. Also, all of them have not been exposed to drive in simulator before, thus there was no bias found between these two driving groups and gave no difference of result among them.

The linkage shown between these driving errors and driver's age has assured that occupational drivers able to perform better than non-occupational drivers in this simulator study. In truth, we found that age factor, as well as driving experience, were inversely correlated with both RORI and LSV index. This indicated that increasing of driver's age tend to deteriorate errors making. In this way, the result shows that occupational drivers who had older mean age rather than non-occupational drivers tend to perform better was significantly proved. A possible explanation could pertain to differences in driving behavior depending on age (Campagne *et al*., 2004). Moe (2008) also stated that students are the largest proportion of patients involved in road traffic accidents. Undeniably, all the non-occupational drivers who took part in this study were students from a local university. Thus, the findings were tallied with previous study (Moe, 2008).

CONCLUSION

Depending on driver's age, driving performance was better among the occupational drivers when considered the driving condition as well as environmental effect. As we knew, the significant differences among the occupational and non-occupational drivers in this study were age and driving experience. Thus, we concluded that occupational drivers with older age and prior driving experience able to perform better in this case. Indeed, most study found that young drivers tend to drive faster especially during night-time condition (Campagne *et al*., 2004). This consequence as age was inversely correlated with exiting the road on left and right sides (RORIs). Reduced in visibility during night-time driving also made older drivers drove extra careful. With better driving experience, older drivers able to control the vehicles more pronouncedly when sudden obstacles happened. In addition, night-time condition induced young drivers to involve in risk taking behavior such as speeding. The situations become worsen when they knew that driving in simulator would not bring any harmful effect to them. However, we could not from an ethics point of view to post the drivers to a more risky situation by making them drive in a real condition.

Similarly, raining condition brought positive effect to driver's performance. Surprisingly, we found that drivers tend to reduce their speed and commit fewer mistakes in adverse weather. Therefore, raining condition reduced drivers' visibility and therefore changed drivers' driving behavior to more cautious. Thus, raining make drivers become more alert and perform better. Monotony road environment with certain obstacles such as driving on road curve and uphill downhill cause more errors rather than driving in town area. However, we should consider that the time-on-task effect may interfere the changing of road conditions and making drivers feel drowsier and thus end out with higher driving mistakes.

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