Study of Driver Behavior as Motorcycles Mixed in Traffic Flow

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ABSTRACT

The population density in Taiwan is very high, especially in the metropolitan areas. The huge amount of motorcycles (532 motorcycles/1000 people) results in complicated traffic conditions and safety problems such as cars and motorcycles competing for lanes. Moreover, in-vehicle multimedia systems have become popular in Taiwan. A driver's workload increases when he or she watches or listens to a multimedia program.

The analysis of official accident reports shows that, among various types of crashes in which motorcycles involved, side collisions and side-swipe collisions account for about 50% of all collisions. Normally, drivers tend to look forward while driving. Therefore, car crashed could easily happen if drivers fail to notice their surroundings when motorcycles suddenly approach. In this context, Side-Collision Avoidance Systems (SCAS) could be capable of alerting drivers and enhancing safety. However, few studies and systems reflect on traffic conditions where motorcycles are mixed in the traffic. This study employed a driving simulator to assess the effects of using SCAS and in-vehicle multimedia on drivers' workload and driving performance (i.e., drivers' perception reaction times, the change in heart rate and eye blinks) while moving in traffic mixed with cars and motorcycles.

A primary finding of this study was that cars equipped with SCAS could decrease drivers' perception-reaction times effectively. The type of vehicle cutting in (car or motorcycle) had a significant influence on drivers' perception-reaction times—drivers displayed longer perception-reaction times when a car cut in than when a motorcycle cut in. This result indicates that drivers were more attentive in the traffic flow mixed with motorcycles. In addition, the change in drivers' eye blinks (from before a vehicle cut to after a vehicle cut in) were all negative--drivers blinked less frequently after a vehicle cut in. This finding indicates that drivers were more alert after vehicles cut in than before vehicles cut in.

INTRODUCTION

According to the traffic accident reports in Taiwan, side collisions, intersection collisions, side-swipe collisions and head-on collisions are the major types of crashes. Driver distraction and lack of caution are typical causes of crashes. In this context, Collision Avoidance Warning System (CAWS) shall be the focus of ITS development in Taiwan. The system is designed to alert drivers and therefore to prevent accidents. The population density in Taiwan is very high, especially in the metropolitan areas. The huge amount of motorcycles (532 motorcycles/1000 people) results in complicated traffic conditions and safety problems. Motorcycles mixing with cars in the traffic flow and competing for lanes are particular traffic conditions in Taiwan. Among various types of crashed in which motorcycles are involved, side collisions and side-swipe collisions account for about 50% of all crashes. Normally, drivers tend to look forward in the course of driving. Therefore, car crashed could easily happen if drivers fail to notice their surroundings when motorcycles suddenly approach. In this case, cars equipped with Side-Collision Avoidance Systems (SCAS) will be able to alert drivers and prevent accidents such as side collisions or side-swipe collisions. In particular, motorcycles relative to cars are small in size and aggressive in motion. The effect of motorcyclists on car drivers' driving performance may be quite distinct from that of other car drivers. However, few studies and systems reflect on traffic conditions where motorcycles are mixed in the traffic flow. This study aimed to assess the effects of using in-vehicle multimedia on drivers' workload and driving performance (i.e., drivers' perception reaction times, the change in heart rate and eye blinks). In addition, we also explored the volume of CAWS warning signals on drivers' perception-reaction times when an in-vehicle multimedia was used during driving.

In this study, a driving simulator was used to perform the driving simulation experiments in order to measure the following situations:

1. The effect on drivers' perception-reaction times and the change in heart rate with/without CAWS while moving in traffic flow of cars only and when moving

in traffic mixed with motorcycles;
2. The effect of collision warning sounds in various dB on drivers' perception-reaction times.
3. Drivers' eye blinks while watching a news program played by the in-vehicle multimedia device;

EXPERIMENTAL DESCRIPTION

Simulator and Tasks

The Institute of Transportation in Taiwan started developing a driving simulator in 1997. It is a six-degree-of-freedom hydraulically driven Stewart platform simulator. The horizontal front field-of-view is 135 degrees and vertical field-of-view is 36 degrees in the experimental scene. The simulated setting for this study was daytime roadways in downtown. There were three lanes in each direction, and each lane was 3.5 meter wide. The driver was asked to drive in the middle lane at normal speed (speed limit 50 km/hour). The driver was listening to a TV news program played by the in-vehicle multimedia device while driving. The participants were young men between the ages of 21 to 30. Totally, 12 men participated in this study. Accordingly, the selected programs played by the in-vehicle multimedia were those contents in which young men are interested, such as sports, informative or fantastic stories, entertaining information, etc. This was designed to measure the drivers' eye blinks when something interested him as well as his perception-reaction time when an unexpected incident (i.e., a car or motorcycle cutting in) arose.

Experimental Design

This study aims to explore the effect of SCAS on driver behavior while moving in the mixed traffic flow where cars are mingled with motorcycles. In the experimental setting, motorcycles would compete with cars for lanes. Pursuant to Australia statute [1], motorcycles have to keep at least 1 meter away from motorcars while driving. In this study, the alert range defined for the warning system was one-meter (see Figure 1 as the dotted line shows). When any motorcycle or car approached the alert range, the warning system would send a collision-warning signal to the driver. The speed limit of the downtown roadway was set to 50 km/hr. A traffic "incident" occurred when a motorcycle or a car would travel 60 km/hr, appear in either direction on the right side or left side of the subject vehicle, and then cut in and overtake the subject vehicle.

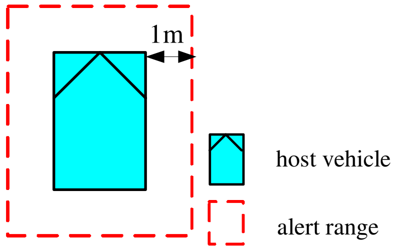

Figure 1. Alert Range

Pursuant to SAE J2400 [2], the Default Warning Intensity of audio signals should be less than 75 dB. Cheng [3] studied how the loudness of warning signals influenced driver behavior. Cheng used two different levels of loudness (68 dB and 78 dB) to sound the warning signals. The difference between the two volume levels was 10 dB. In respect of the audio frequency, Cho [4] and Cheng [3] in their findings concluded that 2000 Hz had better efficacy in the driving performance. The measured value that sounded from the driving simulator developed by IOT is 63 dB. Consequently, we set the loudness of warning signals in this study as 65 dB and 75 dB respectively. The sound frequency was set to 2000 Hz. The news program that drivers heard from in-vehicle multimedia was set to 65 dB.

In addition to a beep sound, the warning system also presented warning symbols on a Heads-Up Display (HUD). The driver could determine from which direction the vehicle (car or motorcycle) was approaching based on the diagram shown on the HUD. This study employed collision avoidance/warning symbols that Campbell [5] used in his study. For instance, the warning symbol shown in Figure 2 represents a danger on the right side of the vehicle, Figure 3 on the left side of the vehicle, and Figure 4 up front. The position of HUD makes reference to the research outcome of Green [6]. The ideal location to mount the HUD is 5 degree laterally to the right of the driver's horizontal vision.

Figure 2. A danger on the right side

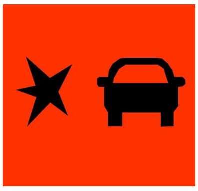

Figure 3. A danger on the left side

Figure 4. A danger up front

According to AAM [7] regulations, the display of any in-vehicle multimedia device shall be mounted in a position where the viewing angle is less than 30 degrees downward and up to 40 degrees laterally. The LCD used in this study was mounted 16 degrees downward and 21 degrees laterally to the right of the driver's vision (see Figure 5). Another position was placed 30 degrees downward and 27 degrees laterally to the right of the driver's vision (see Figure 6).

Figure 5. The LCD position (high)

Figure 6. The LCD position (middle)

The experiment designed in this study employed two blocks by the factors of "LCD position". The experimental factors and corresponding levels are shown in Table 1. When traffic flow consisted only of cars, only cars cut in front of the subject vehicle. In the mixed traffic flow (including motorcycles), two types of incidents occurred as both cars and motorcycles cut in from of the subject vehicle. Consequently, there were 9 simulative combinations of factor levels in each block.

Table 1.
Experimental Factors and Corresponding Levels

Factor	With/Without CAWS	Type of Traffic Flow	Type of Vehicle Cutting in
Level	Yes (Beeps - 65 dB)	Cars Alone	Car
	Yes (Beeps -75 dB)	Cars Mixed with Motorcycles	Motorcycle
	No		

Experimental Procedure

Each subject had eight trials to become familiar with the driving simulator in terms of operating the accelerator, the brake and so on. After a short break, the subjects were asked to perform the experiment and then to complete a questionnaire regarding the content of the news program played by the in-vehicle multimedia. On average, the subjects would take one hour to finish the whole experiment.

EXPERIMENTAL DATA ANALYSIS RESULTS

This study aims to explore the effect of SCAS on drivers' perception-reaction times. The SCAS used in the experiment is set to produce 3 kinds of auditory signals: (1) without any signal; (2) a warning signal in 65 dB; and (3) a warning signal in 75 dB. The experiment designed in this study employed two blocks by two positions to mount the LCD. News programs were played by the in-vehicle multimedia during the experiment. We examined drivers' perception-reaction times as well as the change in heart rate by variables such as the type of vehicle cutting in accidentally, the position of LCD, and the SCAS with/without auditory warning signals. In addition, we also examined the effect of the above variables on drivers' eye blinks.

Drivers' Perception-Reaction Times

Table 2 shows that, drivers' average perception-reaction time was 1.47 sec without any warning signal; 0.94 sec with a warning signal in 65 dB; and 0.74 sec with a warning signal in 75 dB. According to the Duncan multiple comparisons method, drivers displayed significantly longer perception-reaction times when no SCAS was provided than when warning signals appeared. There was no significant difference between the two levels of dB with respect to drivers' perception-reaction times. The volume of news program played by in-vehicle multimedia was 65 dB. Even though the volume of warning signal was the same as the volume of the news program (65 dB), the beep sound of the warning signal was effective at alerting drivers to be more attentive. Table 3 shows the results of a t-test for drivers' perception-reaction times by the type of vehicle cutting in. The type of vehicle cutting in had a significant influence on drivers' perception-reaction times (p = 0.05). On average, drivers displayed longer perception-reaction times when a car cut in suddenly (1.18 second) than when a motorcycle cut in (.72 second)—the former took 0.46 seconds longer than the latter. The findings suggest that drivers were more mindful in the traffic flow mixed with motorcycles and were more alert to unexpected motorcycles cutting in. Table 4 shows the results of a t-test for drivers' perception-reaction times by the position of LCD. The LCD used in the experiment was mounted 16 degrees downward and 21 degrees laterally to the right of the driver's vision. Another position was placed 30 degrees downward and 27 degrees laterally to the right. There was no significant difference between the two positions with respect to drivers' perception-reaction times (p = 0.6851).

Table 2.
Effect of SCAS on Perception-Reaction Time

SCAS Warning Signals	**Mean (sec)**	**Std Dev**	**Multiple comparison (Duncan, α=0.05)**
No	1.47	0.9	A
Yes (Beeps in 65 dB)	0.94	0.8	B
Yes (Beeps in 75 dB)	0.74	0.9	B

Table 3.
Perception-Reaction Time by the Type of Vehicle Cutting in

Type of Vehicle Cutting in	Mean (sec)	Std Dev
Car	1.19	1.03
Motorcycle	0.75	0.53
t-value=2.34 df =64.8 p-value =0.05		

Table 4.
Perception-Reaction Time by LCD Positions

LCD Position*	Mean (sec)	Std Dev
A	1.08	0.71
B	0.99	1.04
t-value=0.41 df =64.4 p-value =0.6851		

Note: * Position A is 16 degrees downward and 21 degrees laterally to the right. Position B is 30 degrees downward and 27 degrees laterally to the right.

Change in Heart Rate

The change in heart rate defined in this study refers to the difference of average heart rate (x_2 - x_1) 10 seconds after a vehicle cuts in (x_2) and 10 seconds before a vehicle cuts in (x_1). Table 5 shows the effect of SCAS on the change in heart rate by multiple comparisons. According to the findings, there is no significant difference in the change in heart rate between vehicles with and without SCAS. Table 6 and 7 show the results of t-tests for the change in heart rate by the LCD positions and by type of vehicle cutting in, respectively. There was no significant difference in change in heart rate with respect to the two positions (high/middle) (p = 0.3916) or with respect to the two types of vehicles cutting in (car/motorcycle) (p = 0.5205).

Table 5.
Effect of SCAS on the Change in Heart Rate

SCAS Warning Signals	Mean (beats/sec)	Std Dev	Multiple comparison (Duncan, α=0.05)
No	0.89	2.3	A
Yes (Beeps in 65 dB)	0.44	2.1	A
Yes (Beeps in 75 dB)	0.24	1.7	A

Table 6.
Change in Heart Rate by LCD Positions

LCD Position	Mean (beats/sec)	Std Dev
A	0.36	2.10
B	0.79	1.91
t-value=-0.86 df =68 p-value =0.3916		

Table 7.
Change in Heart Rate by the Type of Vehicle Cutting in

Type of Vehicle Cutting in	Mean (beats/sec)	Std Dev

Car	0.40	1.98
Motorcycle	0.73	2.14
t-value=-0.65 df =68 p-value =0.5205		

Eye Blinks

We also recorded drivers' eye blinks during the experiment. This is designed to measure drivers' eye blinks under the circumstance of different types of vehicles cutting in, the position of the LCD, and SCAS warning signals provided. The change in eye blinks defined in this study refers to the change in average blink frequency 10 seconds after a vehicle cuts in and 10 seconds before a vehicle cuts in. Table 8 shows the effect of SCAS on the change in eye blinks by multiple comparisons. There was no significant difference in the change in eye blinks among the three set-ups of warning signals. According to the findings in Table 9 and 10, the changes in drivers' eye blinks were all negative for all experimental conditions. This result indicates that drivers blinked less frequently after a vehicle cut in and were therefore more alert after this occurred (however, the changes in eye blinks from before the incident to after the incident were not significant ($p = 0.38$ and $p = 0.61$ for LCD position and for type of vehicle cutting in, respectively)).

Table 8.
Effect of SCAS on the Change in Eye Blinks

SCAS Warning Signals	Mean (times/sec)	Std Dev	Multiple comparison (Duncan, α=0.05)
No	-0.04	0.2	A
Yes (Beeps in 65 dB)	-0.06	0.2	A
Yes (Beeps in 75 dB)	-0.07	0.2	A

Table 9.
Change in Eye Blinks by LCD Positions

LCD Position	Mean (times/sec)	Std Dev
A	-0.08	0.21
B	-0.04	0.16
t-value=-0.88 df =52.4 p-value =0.38		

Table 10.
Change in Eye Blinks by the Type of Vehicle Cutting in

Type of Vehicle Cutting in	Mean (times/sec)	Std Dev
Car	-0.05	0.18
Motorcycle	-0.07	0.17
t-value=0.51 df =81 p-value =0.61		

V. CONCLUSIONS AND SUGGESTIONS

The huge amount of motorcycles in Taiwan has resulted in complicated traffic conditions and safety problems. Moreover, in-vehicle multimedia systems have become popular. This study employed a driving simulator to assess drivers' perception-reaction times as well as the change in heart rate and eye blinks as a result of the set-up of SCAS warning signals, the position of in-vehicle multimedia LCD and the type of vehicle that cut in suddenly. The conclusions and suggestions of this study are as follows:

1. Drivers in a car equipped with SCAS displayed shorter perception-reaction times than those without warnings. Even though the volume of the news program was the same as that of the warning signal (65 dB), the beep sound of the warning signal was effective at alerting drivers to be more attentive. In addition, according to our findings, there was no significant difference in the change in heart rate before and after a vehicle cut in between vehicles equipped with or without SCAS.
2. This study explored the effect of warning beeps only. It deserves further study of various auditory warnings such as voice messages and examination of their influence on driver behavior under circumstances of sound interference produced in the vehicle.
3. The type of vehicle cutting in had a significant influence on drivers' perception-reaction times. Drivers displayed longer perception-reaction time when a car cut in than when a motorcycle cut in. This result indicates that drivers were more attentive in the traffic flow mixed with motorcycles.
4. As for the relationship between the type of vehicle cutting and the change in heart rate, there was no significant difference in the change in heart rate with respect to the two types of vehicles cutting in (car/ motorcycle).
5. The LCD used in this study was mounted in two positions: 16 degrees downward and 21 degrees laterally to the right and 30 degrees downward and 27 degrees laterally to the right. There was no significant difference between the two positions with respect to drivers' perception-reaction times or with respect to the change in heart rate and eye blinks.
6. The change in drivers' eye blinks were all negatives with respect to the set-up of the warning signals, the position of the LCD (high/middle), and the type of vehicle cutting in (car/motorcycle). Based on the analysis results, drivers blinked less frequently after a vehicle cut in, indicating that drivers were more alert after a vehicle cut in than before (however, the changes in drivers' eye blinks were not significant).

REFERENCES

[1] VicRoads. "Driving in Victoria: Rules and Responsibilities, First Edition" 2002. Roads Corporation. Victoria. Australia.

[2] Society of Automotive Engineers. 2002. "Forward Collision Warning Systems: Operating Characteristics and User Interface Requirements Information Report (Draft)." SAE J2400. PA: Society of Automotive Engineers.

[3] Cheng, B., M. Hashimoto, and T. Suetomi. 2002. "Analysis of Driver Response to Collision Warning during Car Following." JSAE Review, Vol. 23, No. 2, pp. 231-237.

[4] Cho, M., K.Ku, Y. Shi, and Kanagawa. 2001. "A Human Interface Design of Multiple Collision Warning System." Paper presented at the International Symposium on Human Factors in Driving Assessment, Training and Vehicle Design. Aspen, Colorado.

[5] Campbell, J. L., D.H. Hoffmeister, R.J. Kiefer, D.J. Selke, P. Green, and J.B. Richman. 2004. "Comprehension Testing of Active Safety Symbols." SAE International.

[6] Yoo, H., O. Tsimhoni, H. Watanabe, P. Green, and R. Shah. 1999. "Display of HUD Warnings to Drivers: Determining an Optimal Location." Technical Report UMTRI-1999-9.

[7] Alliance of Automobile Manufacturers(AAM). 2003. "Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication Systems." PA: Alliance of Automobile Manufacturers.