

# THE STUDY ON THE INFLUENCE OF AUDIO WARNING SYSTEMS ON DRIVING PERFORMANCE USING A DRIVING SIMULATOR

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Paper Number 07-0170

## ABSTRACT

The traffic accident has been one of the first ten death factors in Taiwan for past years. The published statistical data showed that the number of casualties has gradually increased, and indicated that the main cause of traffic accident was the negligence by drivers, nearly twenty percent of the total amount of accidents every year in Taiwan. Many published researches about driving safety pointed out that the negligence is usually caused by driver's distraction and low level of alertness. In recent year, the Collision Warning System (CWS) providing visual, tactile and various audio signals to stimulate the driver's sense of hearing for warning purpose has been developed to assist drivers for a safe driving. Therefore, this study investigated the effect of various audio signals in the collision warning system on driving performance using a driving simulator. The driving performances in perception-reaction time, speed and lane-departure amount were recorded. In this study the driver encountered a sudden cut-in of an event vehicle from an adjacent lane, braking in front and speeding up. The design levels were no alert, speech and beep sound in the collision warning system. Thirty male participants ranging from 20 to 30 years of age were recruited. The experimental results showed that a car with warning system could make the driver be on alert earlier and thus reduce the perception-reaction time. In addition, the beep sound induced a shorter perception-reaction time than the speech did. The driver would reduce speed when the vehicle equipped with warning system. With respect to the amount of lane-departure, the data showed that the position deviation was small as

the driver did not change lane when the emergence happened in front.

## INTRODUCTION

The traffic accident has been one of the first ten death factors in Taiwan for past years and the number of casualties has gradually increased. The statistical data of traffic accident published by National Police Agency, Taiwan, indicated the urban, straight road was the location inducing the highest accident rate, and the main cause of traffic accident was the negligence by drivers, nearly twenty percent of the total amount of accidents every year. The negligence is usually caused by driver's distraction and low level of alertness. Therefore, the vehicle manufacturers have developed related safety devices to assist drivers for a safe driving. The Collision Warning System (CWS) is one of the devices warning the driver to take notice of traffic condition for avoiding accidents.

The collision warning systems provides various functions to prevent the crashes such as head-on collision, side collision, intersection collision and side-swipe collision. With various sensors equipped around the vehicle the collision warning system detects obstacles and gives various signals including voice or image at different levels to stimulate the driver's sense of hearing and vision for warning purpose. A product of collision warning system developed by General Motors Corporation and Delphi-Delco Electronics Systems incorporated the functionality of both Forward Collision Warning (FCW) and Adaptive Cruise Control (ACC). The system offered audio and visual warning to the driver

and displayed the visual warning signal for various levels of the alert on a head-up display [1].

Driving simulator (DS) is a very useful tool for pilot research and it has been applied in automobile industries and related projects for past years. With techniques of virtual reality, the DS creates a driving environment without threat for drivers. Some dangerous, abrupt traffic conditions that used to be simulated by real cars are now replaced by the driving simulator. The driving simulator has shown its great potential to study the influence of collision warning system on driving performance. Lee et al. [2] examined driver's response to evaluate the efficacy of a Rear-End Collision Avoidance System (RECAS) using the Iowa Driving Simulator. The experimental results showed that early warnings helped drivers react more quickly and reduce more time for drivers to release the accelerator than did late warnings or no warnings. Suetomi and Niibe [3] conducted the experiments to examine how beep sound characteristics influenced the driver reaction with a moving-base driving simulator, and the results validated that driver reaction time became faster against the beep sound, which has more than two frequency components and has higher repetition speed. The influence of the quality of the warning sound on the response time was analyzed by Cheng et al. [4]. It was indicated that there were statistically significant effects of the characteristics of warning sound on the brake response time, and that the characteristics of warning sound influenced the time of situation judgment of the subject was possible. Yamada and Wakasugi [5-6] used a driving simulator to evaluate the effectiveness of forward obstacles collision avoidance support system informing the driver of the traffic through the in-vehicle display and the roadside message board. To clarify the difference of effectiveness of each information type the vehicle speed at 100 m ahead the obstacle was examined, and the results indicated that the driver tended to reduce the vehicle speed to less speed when the combined information with in-vehicle and roadside information was offered than when the single information was offered.

Because a failure to notice a car in front is the most frequent cause of traffic accidents in Taiwan, the development of a collision warning system has been paid more attention. In this study, a driving simulator is applied to investigate the influence of various audio signals in the collision warning system on driving performance on urban roads in Taiwan.

## EXPERIMENTAL METHODS

The study employed a driving simulator to access the effect of collision warning system in various sound contents on driver's performance. The driving equipment, driving scenario, warning system, experimental procedure, and data analysis are described as follows.

## IOT Driving Simulator

The driving simulator, developed by the Institute of Transportation (IOT) in Taiwan, integrates a physical driving cabin, a six degree-of-freedom Stewart motion platform, a virtual reality-based visual and audio system, a vehicle motion simulation software, and a host computer system to simulate a virtual environment of urban area road. The driving cabin is a real car body mounted on hydraulic Stewart motion platform that supplies motion experienced in normal acceleration, braking and steering. The visual system consists of three screens providing 135° horizontal × 36.87° vertical field of view and the scene is updated at rates between 25 and 35 Hz. The audio system provides simulated noises from the engine, road tyres and street. Figure 1 shows the configuration of IOT driving simulator.



Figure 1. The configuration of IOT driving simulator.

## Driving Scenario

A straight road with intersections in urban area was simulated. It was a two-way two-lane road, 3.5 meters wide in each lane, with 1 meter wide pedestrian sidewalks. This road consisted of an accelerating section (300 m), an experimental section (5100 m), and a braking section (900 m). Eleven intersections were located every 400 to 600 meters in the experimental section. Event vehicles were distributed randomly along the road to avoid anticipation of the vehicle by participants. The event vehicle was defined as the vehicle which would overtake the host vehicle from either right side, cut into the lane that used by the host vehicle, brake, and then speed up.

## Warning System

The host vehicle (i.e., driving simulator) was equipped with a collision avoidance warning system. In case of urgent conditions, such as a driver tailgating, cutting in, or violating a traffic signal on

the other road at an intersection, the system would automatically send out a short voice message, 'bi-bi' or 'watch your front'. The participants were told that the CWS system would malfunction sometimes; thus, the system might not be able to sense emergent situations. The warning signal worked when the event vehicle cut into the lane that used by the host vehicle. The signal tone was a pure tone of 2 KHz with 70 dB of sound pressure level.

### Experimental Procedure

The subjects were first asked to fill in the personal information including gender, age, driving experience etc. Then, the experimental instructions of driving task and operation skill of driving simulator were introduced to participants by an assistant. After a 10~15 min practice at driving the simulator, the formal experiment was conducted. Each participant was asked to do his best in keeping a steady speed of 50 km/h in his own lane. At the end of the experiment the participants were de-briefed, paid \$10 (US) and thanked for participation. The period of experiment was about 45 minute.

### Data Analysis

The output of experimental data included system time, driving speed, steering wheel angle, normalized accelerator and brake position (i.e., scale of pedal depression ranging from 0-100 %), driving position, status of event vehicle, status of warning system and crash information. The data were collected at 30 Hz for the analysis of driving performance. Driver performance refers to the driver's perceptual and motor skills, or what the driver can do. The ability to judge the speed, control the vehicle at that speed, and react to hazards are all in the realm of driver performance [7]. The measures of driving performance were perception-reaction time, lane-departure amount and crash. The perception-reaction time was measured from the time when traffic event was happened to the time when driver released the accelerator. The lane-departure amount was measured from the time when traffic event was happened to the time when the event vehicle got away. All statistical analysis was conducted using SPSS for Windows (Ver 11.0), with significance accepted at  $p < 0.05$ .

## EXPERIMENTAL RESULTS

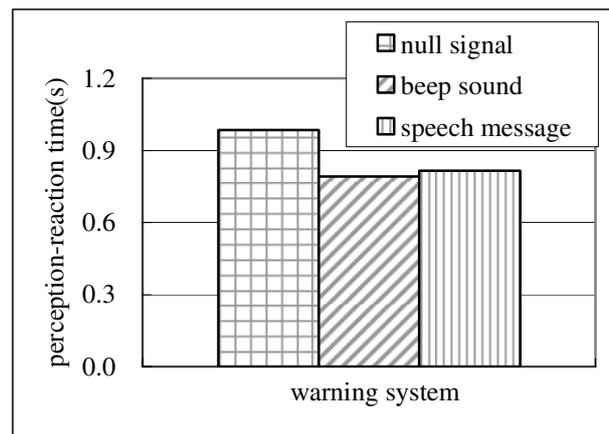
### Subjects

Thirty-three male participants ranging from 20 to 30 years of age, average age of 23.1, were recruited in this study. All participants held a valid driving license and had at least one years of driving experience. The data from two participants with improper driving behavior were deleted as the

participants simultaneously pedaled accelerator and brake while driving.

### Perception-reaction time

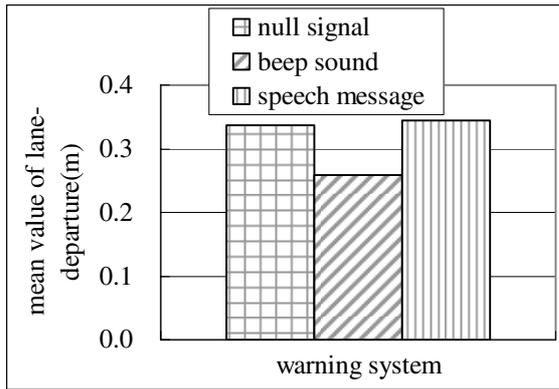
Figure 2 shows the perception-reaction time for various audio signals in CWS. The results showed that the longest perception-reaction time of 0.99 second was happened at the condition when the event vehicle braked in front without audio signal, i.e. CWS out of working. The perception-reaction time at the condition of beep sound was 0.79 second, while it was 0.82 second at the condition of voice message. The perception-reaction time decreased with the warning signals, there was a statistical difference ( $F=3.911$ ,  $df=2$ ,  $p=0.024$ ) among the three conditions. Significant differences were found between null signal and beep sound. However, there were no significant differences between null signal and speech message, and between the two audio signals. This indicated that the driver could respond more quickly to the emergency in front because of the working of CWS.



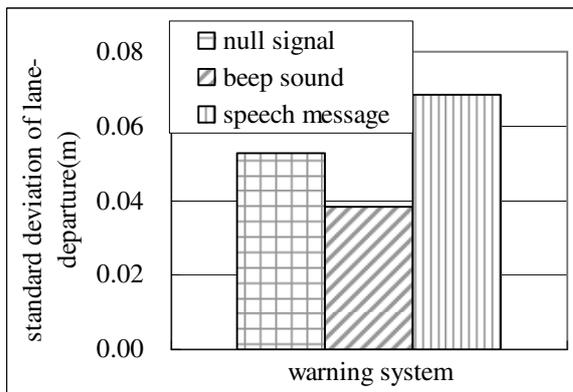
**Figure 2. The perception-reaction time for various audio signals in CWS.**

### Lane-departure amount

Figure 3 and 4 show the mean values and standard deviations of lane-departure amount for various audio signals in CWS. The results indicated that the drivers with beep sound CWS showed better performance because of less fluctuation in deviation value. However, the driving performance with speech message in lane-departure amount was not better than the performance without warning signal. The driving performances in standard deviation of lane-departure amount reached statistically significant difference among the three CWS conditions ( $F=3.783$ ,  $df=2$ ,  $p=0.026$ ), but the performances in mean value of lane-departure amount did not ( $F=1.706$ ,  $df=2$ ,  $p=0.186$ ).



**Figure 3. The mean value of lane-departure amount for various audio signals in CWS.**



**Figure 4. The standard deviation of lane-departure amount for various audio signals in CWS.**

### Crash

Only one collision happened in this study. It was because the driver wheeled too much when null warning signal, such that the car crashed into the vehicles in the next lane.

### DISCUSSION

With various sensors equipped around the vehicle the collision warning system detects obstacles and provides various levels and signals to simulate the driver's sense of hearing and vision and attract his attention. The driver would quickly respond to a dangerous traffic condition from surrounding vehicles after he receives the warning signal, and the driver's response is reflected in his driving performances. Driving performances, such as perception-reaction time and lane-departure amount, are the driver's abilities of controlling an automobile. The driving safety is usually indicated by the level of driving performance. For example, the low level of performance such as large lane-departure amount indicates great danger to the driver because it would increase the possibility of crashing into the vehicle

near by. The driving performance including perception-reaction time, average amount of lane-departure, standard deviation of lane-departure amount, and crash were recorded in this study. A straight road with intersections in Taiwan urban area was simulated in the study. To understand driver's reaction from the event vehicle braking in front. The perception-reaction time was measured from the time when the traffic event is happened to the time when driver releases the accelerator. The experimental results showed that the perception-reaction time taken by the driver in the condition of CWS with null signal was much longer than those in the conditions of CWS with audio signals, beep sound and speech message. It indicated that the driver could respond more quickly to the emergency in front because of the working of CWS with audio signals. In addition, the difference in the perception-reaction time between with and without audio signals was at least 0.2 second. It showed the CWS with audio signals could make the driver being on alert earlier and thus reduce the reaction time. The driving safety would be enhanced in such a condition. The perception-reaction time at the condition of beep sound was less than that at the condition of voice message. It indicated that the driver make a quicker response in the condition of beep sound and it can be inferred that the beep sound might be the directest stimulus to drivers and the speech message might take drivers more time to catch the message meaning. Besides, it did not reach a statistical difference in the perception-reaction time between the conditions of null signal and speech message while the difference was statistically significant between the conditions of null signal and beep sound. The previous published literature also showed positive view on CWS. Suetomi et al. [8] pointed out the driver's reaction with warning systems was at least 0.5 second less than that without warning systems. Lee et al. [2] showed the drivers who received a warning released the accelerator in only 1.03 seconds, compared with 1.73 seconds for the condition without collision warning device. The result shows that CWS can rapidly release accelerator, reduce accident rate and impact speed. This study indicated the driving performance was improved by CWS with audio signals and drivers have the shortest perception-reaction time with beep sound warning. According to results of lane-departure amount, the CWS with beep sound made drivers perform better, showing less mean value and deviation. However, the CWS with speech message showed a poorer performance as compared to drivers' response with CWS out of working. Although no crashing into traffic flow in the next lane, it still showed that the CWS with speech message made drivers perform worse in the control of steering. It might be inferred that the speech message interferes with drivers while driving. Moreover, this study showed that beep sound made drivers perform better in lane-departure amount

and perception-reaction time, and the differences were statistically significant.

Published research unanimously pointed out that a collision warning system could effectively reduce accidents. According to Suetomi's [8] research, around 18.6% of the participants in his study will encounter a vehicular accident without a collision warning system, while this figure will fall to 2.3% with a warning system. However, the accident resulting from the braking of the car in front, which is designed in this study, can be classified as a less emergent accident. Therefore, only one case crashing into traffic flow in the next lane.

## CONCLUSIONS

The influence of various audio signals in the collision warning system on driving performance is investigated in this study. A beep sound warning signal gives the directest stimulus to drivers focusing on the vehicle in front of them, and makes drivers perform better in steering control. However, a speech message does not bring any benefit when the car brakes in front, indicating that the beep sound is more effective in assisting a driver facing the car braking in front and does not give too much interference. This study focuses on the age group of 20 to 30, and thus further studies regarding this topic could be conducted in other age groups.

## ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance of Fu-Quan Wu for his help with the experiment in this study.

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