Effect of Auditory Intersection Collision Avoidance Warnings on Driving Behaviors in Different Distracted Driving Conditions

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ABSTRACT

In-vehicle information systems (IVIS) have become popular; IVIS could be used to provide drivers with a variety of information (e.g., en-route guidance information and collision warning information) via different in-vehicle devices. In Taiwan, some aggressive driving behaviors are observed such as tailgating and violating traffic signals. Intersection collision warning system (ICWS) provided by IVIS could be used for avoiding the accidents due to violating traffic signals. This study employed a driving simulator to investigate the influence of auditory collision warning messages on drivers' perception-reaction times and workload when the drivers were visually or audibly distracted by secondary tasks via different IVIS devices. The secondary task was to solve simple mathematical problems displayed to the driver three different formats: voice, numbers shown on a liquid crystal display (LCD) panel, and number shown on a heads-up display (HUD). The most important finding of the study was that the auditory collision warning message was capable of decreasing drivers' perception-reaction times when the drivers were visually distracted by the mathematical problems shown on the LCD panel or the HUD. However, when the drivers were distracted by an auditory task (i.e., hearing mathematical problems), the auditory collision warning message increased drivers' perception-reaction times.

INTRODUCTION

The traffic conditions in Taiwan are very congested, and some aggressive driving behaviors such as tailgating, speeding and violating traffic signals are observed. A collision avoidance warning system may help a driver to avoid a crash, but it could also contribute to an increase in driver distraction. Since driver distraction is always an important issue in driving safety, and analysis of accident reports shows that drivers violating traffic signals at intersections is the third leading cause of traffic accidents, this study focuses on whether or not an auditory ICWS could assist a driver in avoiding an imminent crash while he or she is visually and/or aurally and/or mentally distracted.

ICWS messages can be displayed in different formats via in-vehicle devices, such as auditory information and text or figure information shown on a heads-up display (HUD) or a liquid crystal display (LCD). An auditory display is a common means for providing collision warning messages. Several studies have found that an auditory display or multimodal display with auditory and visual warning information has positive effects on driving performance [1-4]. The major objective of this study was to investigate how auditory collision warning messages affect driving performance in the presence of other visual and auditory IVIS devices (i.e., distractions). A six-degree-of-freedom motion-base driving simulator was used for the experiment. The secondary task was to solve mathematical problems displayed using three different types of IVIS devices: (1) auditory voice from a speaker, (2) numbers shown on a LCD screen, and (3) numbers shown on a HUD. Driving performance was measured by measuring driver perception-reaction time. Additionally, heart rate variability was used as a measure of driver workload, and eye movements were used as a measure of driver eye distraction.

EXPERIMENT DESCRIPTION

The participants were asked to drive the simulator, which depicted scenes from an urban area. The road conditions were as follows: there were two lanes in each direction; the lanes were 3.50 meters wide; the traffic flow on the roads was 700 vehicles per hour per lane, and the speed limit was 50 km/hour. The participants were told before the formal experiment that the car (i.e., the host vehicle) was equipped with an auditory collision avoidance warning system (CAWS), and in case of urgent situations, such as a driver cutting in, the system would provide a short audio message, such as 'watch your left-hand side'. In addition, they were told that sometimes the CAWS system malfunctions, and thus, the system may not be able to sense all urgent situations. The purpose for telling the participants that the car was equipped with CAWS instead of

ICWS was to avoid participants' expectations of dangerous situations occurring at intersections. An urgent situation was defined as one in which a collision was likely to occur in less than 4 seconds. The short female prerecorded voice message, 'watch your right-hand side' or 'watch your left-hand side', was 1 second in Chinese. Therefore, the driver had 3 seconds left to respond to the urgent situation. Drivers' perception-reaction times were of interest to measure driving performance, and heart rate variability was used to determine driving workload. Heart rate variability was defined as the difference of average heart rate (x_2 - x_1) 10 seconds after the urgent situation (x_2) and 10 seconds prior to the urgent situation (x_1). In addition, glance frequencies and glance durations at a LCD display were analyzed to determine the effects of different types of mathematical problems on drivers' eye movements. The following factors were considered in the experiment: the provision of auditory ICWS, IVIS display formats, and complexity of mathematical problems (see Table 1).

Table 1.
Experimental Factors

Factor	Provision of auditory ICWS	Display format	Complexity of mathematical problem
Factor Level	yes	auditory	simple addition (e.g., 5+9)
	No	LCD	medium difficult addition (e.g., 24+35)
		HUD	repeating 3-digit number (e.g., 168)

For the secondary task, participants were asked to solve mathematical problems. The tasks included solving one-digit mathematical addition (e.g., 5 + 7), adding two-digit numbers less than 40 (e.g., 32 + 15), and repeating three-digit numbers (e.g., 254). Before a problem was presented by auditory display (voice), or shown on a LCD screen or a HUD, different short beeping sounds were presented to notify the subjects that a problem was going to be displayed. These three short sounds were easily distinguishable from each other. The locations of the 6-inch LCD and HUD are illustrated in Figure 1 and Figure 2, respectively, and the view angle from the eye to the center of the LCD display was 24.3 degrees to the right of center. There were three blocks in the experiment design representing the three display formats, and the sequence of the three display formats was random. The height of the numbers shown on the 6-inch LCD display was 6.5 cm, and the height of the letters shown on the HUD display was 31.5 cm.

Each subject had ten trials to become familiar with the driving simulator (e.g., using the steering wheel, the accelerator and the brakes). Then the subjects were asked to practice with the IVIS devices three times to become familiar with the devices and to make sure they could easily distinguish between the three short beeping sounds before a mathematical problem was displayed.

Young drivers were the focus of this study. The participants had to be licensed drivers between 20 and 30 years of age with at least three years of driving experience. Nineteen undergraduate and graduate students (10 male, 9 female) participated in this experiment.

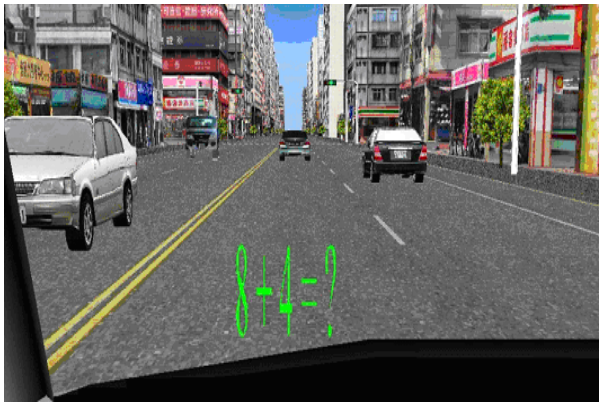

Figure 1. Heads-Up Display of a Mathematical problem

Figure 2. LCD Location

EXPERIMENTAL DATA ANALYSIS

This study aimed to explore the effect of different IVIS interfaces as well as with/without ICWS voice messages on driving behavior, including the drivers' perception-reaction times and the increase in hart rate while some unexpected imminent incident occurred such as a vehicle violating the traffic signal. Besides, this study also explored the drivers' glance frequencies and glance durations while viewing LCD. Duncan multiple comparison and t test methods were used to determine the significant factors.

Drivers' Perception-Reaction Times

Table 2 and Figure 3 show the effects of IVIS interfaces and provision of auditory warning

messages on drivers' perception-reaction times, and there is an interaction between these two factors. When drivers were engaged in solving mathematical problems displayed on a LCD or a HUD, their perception-reaction times were shorter if an auditory collision warning message alerted them to an urgent situation at the intersection. If drivers were watching the LCD, the perception-reaction times of drivers with an auditory collision warning message were 0.08 seconds shorter than the perception-reaction times of drivers without the auditory collision warning message. If drivers were watching the HUD, the perception-reaction times of drivers with an auditory collision warning message were 0.54 seconds shorter than the perception-reaction times of drivers without an auditory collision warning message. However, if the driver's were distracted by an auditory mathematical problems via voice interface, the perception-reaction times with an auditory collision warning message were 0.73 seconds longer than perception-reaction times without an auditory collision warning message. This is possibly due to drivers' sensory overload with two different voice messages (i.e., the collision warning message and the mathematical problem). Therefore, if ICWS warning messages are provided via voice interface, it is important to consider any other auditory distractions such as music or cellular phones. Drivers' perception-reaction times by sex are shown in Table 3. There was no significant difference between the perception-reaction times of the male and the female participants (p = 0.54111).

Table 2.
Effects of IVIS Interfaces and Provision of Auditory Warning Messages on Drivers' Perception- Reaction Times

Provision of warning message and types of IVIS interfaces	Mean (sec)	Std Dev	Multiple comparison[1] (Duncan, α=0.05)
Voice warning & voice Interface	1.77	0.81	A
Without voice warning & HUD interface	1.25	0.54	A B
Without voice warning & LCD interface	1.20	0.55	A B
Voice warning & LCD interface	1.12	0.83	B
Without voice warning & voice interface	1.04	0.64	B
Voice warning & HUD interface	0.71	0.39	B

Note: [1] The results in multiple comparisons with the same symbol indicate that the differences among the corresponding groups are not significantly different.

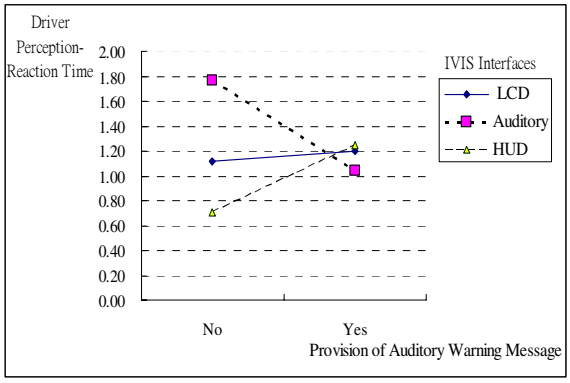

Figure 3. Interaction Effects of IVIS Interfaces and Provision of Auditory Warning Messages on Drivers' Perception- Reaction Times

Table 3.
Drivers' Perception-Reaction Times by Sex

Sex	Mean (sec)	Std Dev
Male	0.87	0.73
Female	1.01	0.59
t-value=-0.61 df =73 p-value =0.5411		

Increase in Heart Rate

Table 4 summarizes the effect of IVIS interfaces (i.e., distractions) and auditory collision warnings on the drivers' heart rate variability (i.e., difference of average heart rate (x_2-x_1) between 10 seconds after an urgent situation (x_2) and 10 seconds prior to (x1) an urgent situation. Although the multiple comparisons show that there was no significant influence of the IVIS interfaces or auditory warnings on heart rate variability, the table indicates that the increase in heart rate was the highest (6.08 beats/minute) when the driver was distracted by auditory mathematical problems and received an auditory collision warning message at the same time. The effect of heart rate by sex is shown in Table 5. There was no significant difference in increase heart rate between the male and the female participants (p = 0.1286).

Table 4.
IVIS Interfaces & Provision of Auditory Collision Warning Message on Increase in Heart Rate

Provision of warning message and types of IVIS interfaces	Mean (beats/ min)	Std Dev	Multiple comparison (Duncan, α=0.05)
Voice warning message & voice interface	6.08	5.46	A
Without warning message & HUD interface	4.79	3.89	A
Without warning message & LCD interface	4.47	4.59	A
Voice warning message & LCD interface	4.29	5.25	A
Without warning message & voice interface	3.31	4.95	A
Voice warning message & HUD interface	3.25	3.42	A

Table 5.
Increase in Heart Rate by Sex

Sex	Mean (beats/min)	Std Dev
Male	4.60	3.79
Female	6.24	4.94
t-value=-1.53 df =88 p-value =0.1286		

Eye Movements While Viewing LCD

Drivers' eye movements were recorded by a video-camera during the experiment in order to examine drivers' glance frequencies and glance durations when different types of mathematical problems were posed on the LCD. As shown in Table 6, the subjects glanced more frequently when required to repeat a 3-digit number or to solve more complicated mathematical problems than when posed with simple mathematical problems. In addition, the subjects took longer to repeat 3-digit numbers (1.87 sec) than to solve more complicated mathematical problems (1.40 sec) or simple mathematical problems (1.21 sec) (Table 7). Based on these results, the complexity of mathematical problems displayed on the LCD influenced drivers' glance frequencies and glance durations. The simple task of memorizing 3-digit numbers caused the most driver visual distraction (i.e., largest mean glance frequency and longest mean glance duration). A similar situation could occur when a driver views and memorized the route guidance information displayed on a LCD panel. However, more research is required with respect to drivers' information load and its effect on safety. Tables 8 and 9 show the results by sex in terms of glance frequency and glance duration, respectively. There was no significant difference between glance frequencies or glance durations by the male and the female participants (p = 0.8438 and p = 0.2514, respectively).

Table 6.
Drivers' Glance Frequencies by Mathematical Problems in Various Types

Complexity of mathematical problem	Mean (Frequency)	Std Dev	Multiple comparison (Duncan, α=0.05)	
repeating 3-digit number	1.47	0.51	A	
Medium-difficulty addition	1.42	0.72	A	
Simple addition	1.06	0.24		B

Table 7.
Drivers' Glance Durations by Mathematical problems in Various Types

Complexity of mathematical problem	Mean (min/one time)	Std Dev	Multiple comparison (Duncan, α=0.05)	
repeating 3-digit number	1.87	1.30	A	
Medium-difficulty addition	1.40	0.44	A	B
Simple addition	1.21	0.42		B

Table 8.
Drivers' Glance Frequencies by Sex.

Sex	Mean (Frequency)	Std Dev
Male	1.36	0.64
Female	1.33	0.58
t-value=0.20 df=73 p-value =0.8438		

Table 9.
Drivers' Glance Durations by Sex.

Sex	Mean (min/one time)	Std Dev
Male	1.74	1.33
Female	1.46	0.54
t-value=1.16 df =45.6 p-value=0.2514		

CONCLUSIONS

This study aimed to explore how the presence of IVIS information in a vehicle impacted driver workload (e.g., heart rate variability) and drivers' perception-reaction times with auditory ICWS information in a simulated urban driving environment. The experimental data analysis results

revealed that the auditory collision warning messages were capable of decreasing drivers' perception-reaction times when drivers were visually distracted by mathematical problems shown on a LCD panel or a HUD. However, when drivers were distracted by auditory mathematical problems, an auditory collision warning message increased perception-reaction times by 0.73 second. In addition, increases in heart rate were highest in this situation (although not significantly different from the other situations).

It was found in this study that the complexity of questions displayed on the LCD influenced drivers' glance frequencies and glance durations. The simple task of memorizing 3-digit numbers increased drivers' visual workload. This type of secondary task is similar to viewing and memorizing route guidance information from an IVIS. Further research is required with respect to drivers' information load and its effect on safety.

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