Effectiveness of Collision Avoidance Technology

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Executive Summary

This study aimed to assess collision avoidance capabilities of aftermarket products over the road evaluation. The MU research team from the Industrial and Manufacturing Systems Engineering (IMSE) department conducted a real-driving usability study for evaluating aftermarket Collusion Avoidance Technology (CAT) devices.

During the Phase 1 study, four CAT devices (Garmin Nuvicam, Audiovox LDWS100, Mobileye 560, and Safe Drive RD-140) were tested. Participants drove a vehicle along an open-course track in or around the area of Columbia Missouri. A total of 20 volunteers participated in the experiment. Every participant had a least two years of driving experience. The driving route was a set path through over 9.3 miles of open roads that featured parts of highways, an interstate, rural streets, and roads on campus. Each participant completed in four trials (about 20 mins per trial); the first trial was a control with no CAT device, while the next three experimental trials tested one of the CAT devices. The potential of driving performance, orientation of attention, and perceived workload were measured by using an HD video cam, an eye tracking device, EMG armbands, and NASA-TLX questionnaires. The result of the Phase 1 experiment included 1) eye-tracking data analysis, 2) electromyography (EMG) data analysis, 3) NASA-task load index subject workload analysis, 4) sensitivity analysis, 5) reaction time analysis, and 6) hierarchical task analysis. **The findings revealed that perceived workload appeared to be not significantly affected by the CAT devices. Mobileye and RD-140 were the best Advanced Driver Assistance Systems (ADAS) among four tested CAT devices. Both devices showed similar accuracy (72.5%) and false-positive responses (41.5%). The effectiveness of the lane departure warning (LDW) and the forward collision warning (FCW) marked 76% and 74.5%, respectively. The average reaction time of FCW was 2.81sec. The average reaction time of LDW was 1.20 sec.**

During the Phase 2 study, the MU research team designed and conducted a user perception and opinion survey for the Mobileye 560 device. The survey was conducted to the professional drivers from the Older Adult Transportation (OATS). The survey was designed to determine the following: whether the Mobileye device performed as expected, the likelihood of the driver to continue using the product (any annoyance), and any near misses or potential crashes avoided due to the use of the devices. **75% of drivers (3 out of 4) showed significant differences in driving behavior after they used a CAT device (Mobileye 560). 60% of drivers (3 out of 5) reported a positive feedback for the lane departure warning. 40% of drivers (2 out of 5) felt confident of the forward collision warning. However, most drivers disliked the pedestrian warning. The OATS drivers reported 69.28% of acceptance level of using the Mobileye 560 device.**

1. Introduction

Although vehicle manufacturers have striven to improve safety features, distracted-driving and fatigued-driving have accounted for 22% — around 500,000 people — of all car accidents and 31% — over 10,000 people — of all fatal car crashes in the U.S. in 2013 according to the National Highway Traffic Safety Administration. In 2014, 2.34 million people had suffered injuries and 32,675 people had died from vehicular collisions. Of these fatal car accidents, 10% involved distracted-driving, such as texting, eating, drinking, and talking, and another 21% or an estimated total of 10,000 deaths involved a fatigued driver (NHTSA, 2016).

Recently, the collision avoidance technology (CAT) had emerged as a key to reducing the number of vehicular injuries and deaths. CAT is likely to become accessible in new vehicles. In addition, many manufacturers offer various types of products, ranging from integrated systems to aftermarket kits and smart-phone applications. Numerous technologies are being explored to develop a better solution for collision avoidance. Breakthroughs in the development of collision avoidance technologies offer a promising future in vehicle safety and in saving human lives. These technologies should be thoroughly evaluated, in the context of driving, to understand how the collision avoidance technology may influence driving performance and safety. However, previous studies related to CAT evaluation were based on sensor-based analyses, such as the false-positive warning rate, the lane change test, and the turn signal warning prevention test (Hoover, Rao, Howe, & Barickman, 2014). It was only recently that the driver-centered perspective in the CAT had been studied. Conducting a usability study on CAT while driving is important for understanding the effectiveness of CAT, because the warning from the CAT system could cause the driving behavior to change. For example, according to the research done by Yan, Xue, Ma, and Xu (2014), drivers who received an auditory forward collision warning only crashed 16.5% of the time, while drivers who failed to notice the auditory warning crashed 66% of the time. In addition, Maltz and Shinar (2004) found that the effects of the collision avoidance warnings on driving performance could be influenced by the type of CAT system: visual, auditory, or a combination of both. These study results support that evaluating the driver's physiological and psychological impacts is vital to understand the benefits of using collision avoidance technologies when driving.

The CAT device warning could significantly influence driving behavior. According to the literature, there are several factors affecting driving behavior, such as personality, emotions, demographics, policy, and spatial and temporal elements (Ellison, Greaves, & Bliemer, 2013; Mesken, Hagenzieker, Rothengatter, & de Waard, 2007). These factors could also be influenced by inadequate mental workload, distractions, use of cell phones, stress, anxiety, and time pressure, which can affect driving performance (Haque, Ohlhauser, Washington, & Boyle, 2015; Palat & Delhomme, 2016). Hence, it is impossible to know whether or not implementing CAT could negatively influence one of these factors and impact driving behavior until we test them on an open track. For instance, if a CAT device continuously generates a high level of false alarms, it will influence the trustworthiness and reliability of the CAT device (Abe & Richardson, 2006). By conducting a usability study of CAT systems, the researchers can discover the benefits of using them to create a safer driving environment.

This report had several objectives. The first was to describe current CAT systems, and trials and evaluations of such systems. In this study, we chose the CAT devices which sense vehicles in the forward path and other lanes and generate warnings in response to a collision threat. The second objective of this report was to describe the testing of four different CAT devices and to provide the test results about the evaluated devices (Phase 1 study). The effectiveness of CAT devices was evaluated based on the drivers' physiological and psychological data. The third objective of the report was to estimate the potential benefits of implementing CAT in public transportation (Phase 2 study).

2. Market Research on the State of Industry for CAT Systems

CAT devices typically consist of multiple sensors that provide the vehicle with environmental information surrounding the vehicle. Many manufacturers offered collision avoidance system, ranging from integrated systems to aftermarket kits. Appendix A shows a list of 24 CAT systems that were considered for the Phase 1 study. Among them, we chose four CAT systems based on CAT system features, cost, and installation procedure. Below is a list of four selected CAT systems. All CAT devices provided both forward collision warning (FCW) and lane departure warning (LDW).

1. Garmin NuviCam LMTHD
2. Audiovox LDWS 100
3. Mobileye 560
4. Safe Drive System RD-140

2.1. Garmin NuviCam LMTHD

This device is originally designed for a navigation system. A built-in forward-facing camera detected road lines and cars in front of the device. By using the dash cam input and GPS information, the system calculated the safe distance and provided FCW or LDW. This device is portable; it can easily be taken out of the car. During the test, the device was placed on the dashboard near the center of the windshield. (Installation time: less than five mins; no need for a certified technician).

- FCW (> 30mph): beeping sound and visual signal (on the top of the screen)
- LDW (> 40mph): beeping sound and visual signal (on the right or left side of the screen)

Figure 2.1: Garmin NuviCam Camera (left), Recording view (right)

2.2. Audiovox LDWS 100

The system obtains an image of the front road and analyses the distance between lanes and the front vehicle. This device was connected to the turning signal to prevent false alarms from planned lane changes. The device also incorporated GPS information and was placed near the top center of the windshield. The device could be controlled by remote control (Installation time: 30 - 60 mins; no need for a certified technician).

- FCW (> 10mph): a series of short beeping sound
- LDW (> 35mph): solid tone beeping sound

Figure 2.2: LDWS100 – Camera and Controller (left), Lane Tracking Road Scene (right)

2.3. Mobileye 560

The device uses a combination of a vision sensor unit, a dynamic range camera, and an image processing board to detect signals. This combination allows it to better detect where the lines of roads are and to calculate the distance between vehicles. This system provides four different types of warning: FCW, Urban FCW, LDW, and Pedestrian Collision warning. A sensor camera was located near the top center of the windshield. The display unit was located at the top left corner of the car. This CAT device was also connected to the vehicle's turning signals. (Installation time: 1- 2 hours, certified technician needed).

- FCW (> 30mph): a high-pitched sound and red car icon on the display
- Urban FCW (< 30mph): similar to the FCW, but for low speed
- LDW (> 30mph): short beep sound and a lane indication light on the display
- Pedestrian Collision Warning (< 30mph): A red pedestrian icon on the screen and high-pitched sound

Figure 2.3: Mobileye 560 Camera (left), Overhead Windshield Mount View (right)

2.4. Safe Drive System RD-140

The RD-140 consists of a radar system (scans the road 20 times per second up to 500 feet ahead, detecting all types of metal objects) for FCW and a camera system for LDW. As part of a fusion system with radar in front of the vehicle, RD-140 performs functions related to longer distance detection and all weather conditions. It was also hooked up to the turning signal of the car. The display unit was on the dashboard, which is directly located in front of the driver. The camera sensor was located near the top center of the windshield (Installation time: 2 – 3 hours; certified technician needed).

Figure 2.4: RD-140 system components (radar and camera)

- FCW (> 15mph): different levels of sound and visual warning (proper distance: display light – green, no alert sounds; unsafe distance: display light – orange, no alert sounds; dangerous distance: display light – red, a loud and high beep sounds; risk of collision: display light – flashing and, rapid beeps)
- LDW (> 37mph): generate audio (a series of high-pitched beeping sound) and visual (flashing white sign on the display) alerts

3. Testing CAT Devices (Phase 1 Study)

3.1. Participant

Twenty students from the University of Missouri – Columbia participated in the phase 1 study. Every participant was male. The average age was 20.52 (StDev: 1.47), and the participants had at least two years of driving experience. They could not wear glasses during the study, so their normal or corrected visual acuity had to be at least 20/50. Compensation was $37.50 for approximately 2.5 hours of participation in the study.

3.2. Testing Vehicle

The vehicle used in this experiment was 2008 Chevy Malibu, the base model, shown in Figure 3.1.

Figure 3.1: CAT Fleet Vehicle – 2008 Chevy Malibu

3.3. Test Driving Route and Procedure

Participants drove the vehicle on an open track. The driving route was a set path through over 9.3 miles of open roads in and around the area of Columbia Missouri (See Figure 3.2). Although it is impossible to control every stressful event on the open road, the route was planned to take the driver through situations where standard levels of stress were likely to occur. The route was designed to reflect a typical driving task of the subject student population. The drive included periods of rest, Business Loop 70, and city driving that were assumed to produce low and medium levels of workload. The path included a multitude of driving environments, including Providence, a major road; Interstate 70; 63 Highway; and a campus road, Tiger Avenue.

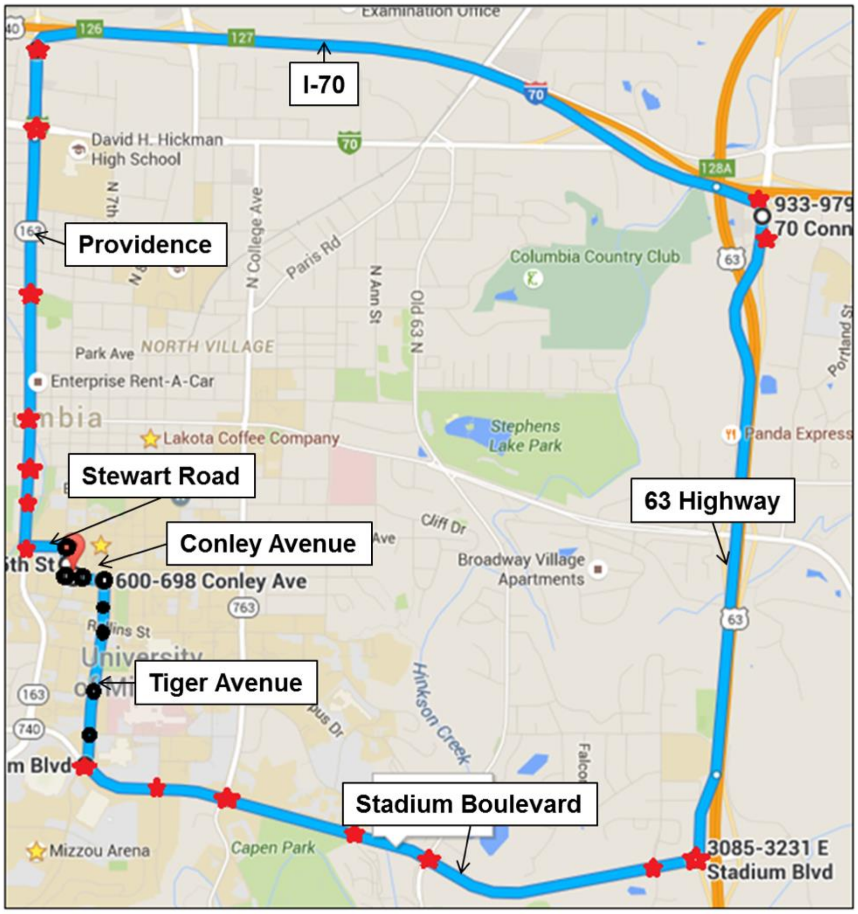


Figure 3.2: Overview of Driving Path

The path took roughly twenty minutes under light traffic conditions. The driving route was planned with several events to help us to test collision avoidance capabilities of selected CAT devices. The starting point of the testing route was the Conley Parking lots of Mizzou. Observers accompanied the driver in the car to support participant's questions during the experiment. All drives were conducted in mid-morning (10:00am-12:30pm) or mid-afternoon (2:00pm-4:30pm) when there was light traffic on the route. The total duration of one drive was 15 to 20 minutes, depending on traffic conditions.

The driver was given a set of instructions at the beginning of the trial. The instructions contained a brief overview of the route and where to place their hands on the steering wheel (see Appendix B). To participate in the experiment, the subjects must show their driver’s license (at least two years’ experience) and be able to drive without prescription lenses. Two research assistants rode in the back seat of the car to monitor participants’ driving behaviors and other events. Between trials, the participants were asked to fill out a NASA-TLX questionnaire to measure their workload levels during the trial. Four trials were conducted with each participant. In between trials the driver was given a 10-minute break. The first trial was conducted without warning signals from the CAT device. The next three trials were conducted with the CAT device. The test was designed for one-factor experiment with repeated-measure between subjects. The independent variable was the CAT device (n = 5 for each group). The test took about 2 – 2.5 hours per subject (briefing: 30mins; baseline data collection (without FCW and LDW): 20mins; 3 trials (with FCW and LDW): 1hour; total break time: 30 mins). Figure 3.3 shows the experimental setup.

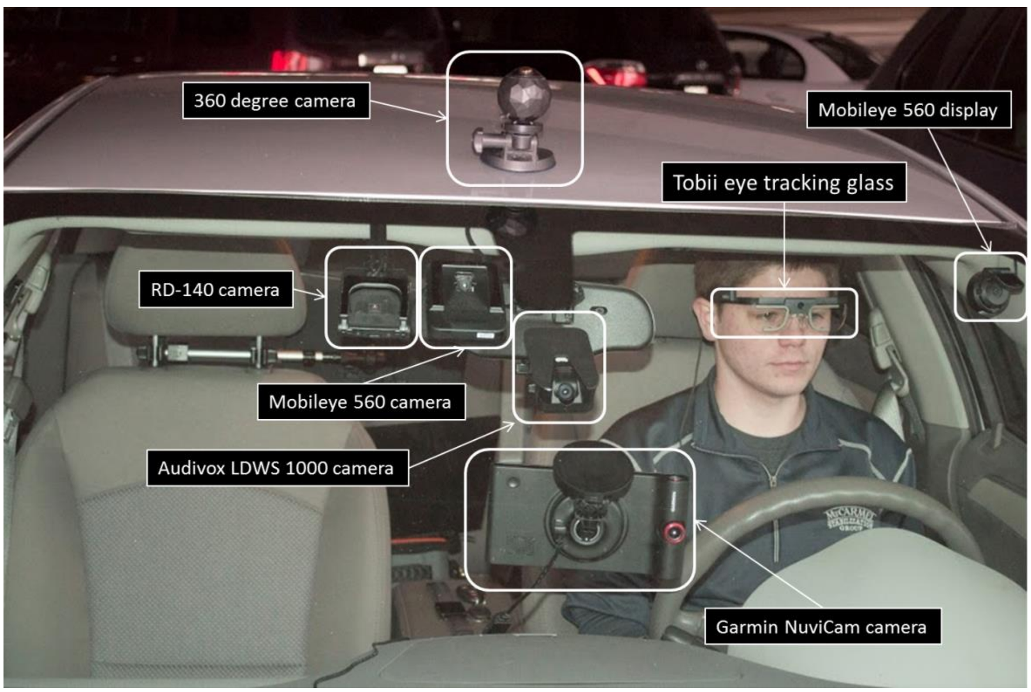


Figure 3.3: Experimental Setup

3.4. Equipment

Most of the vehicle accidents are caused by the physiological and psychological states of drivers (Matsuno et al., 2016). Data was collected from five different devices: electromyography (EMG) armband sensors, eye tracking glasses, a 360-degree video camera, a wide-angle video camera, and a forward facing HD cam with GPS data.

The EMG sensors were placed on the participant’s center of mass of forearm. The sensor with the blue light was placed in line with the participant’s thumb. Size clips can be used to help tighten this device on participants with thinner arms. The EMG armband sensors consisted of eight sensors per band. The sensors were connected through Bluetooth to a laptop. The EMGs and pitch (arm angle) data from the sensors showed the amount of arm muscle activity during the experiment. These data points helped us to understand how the collision avoidance warnings influenced driving behaviors on the open-road track environment. The eye tracking glasses recorded where the participants were looking at the moment of collision avoidance warnings. The glasses were connected through a Wi-Fi signal to a tablet. This data showed a driver's perceptual behavior in a dynamic driving environment and the effects of collision avoidance alerts on where driver's attention was pulled.

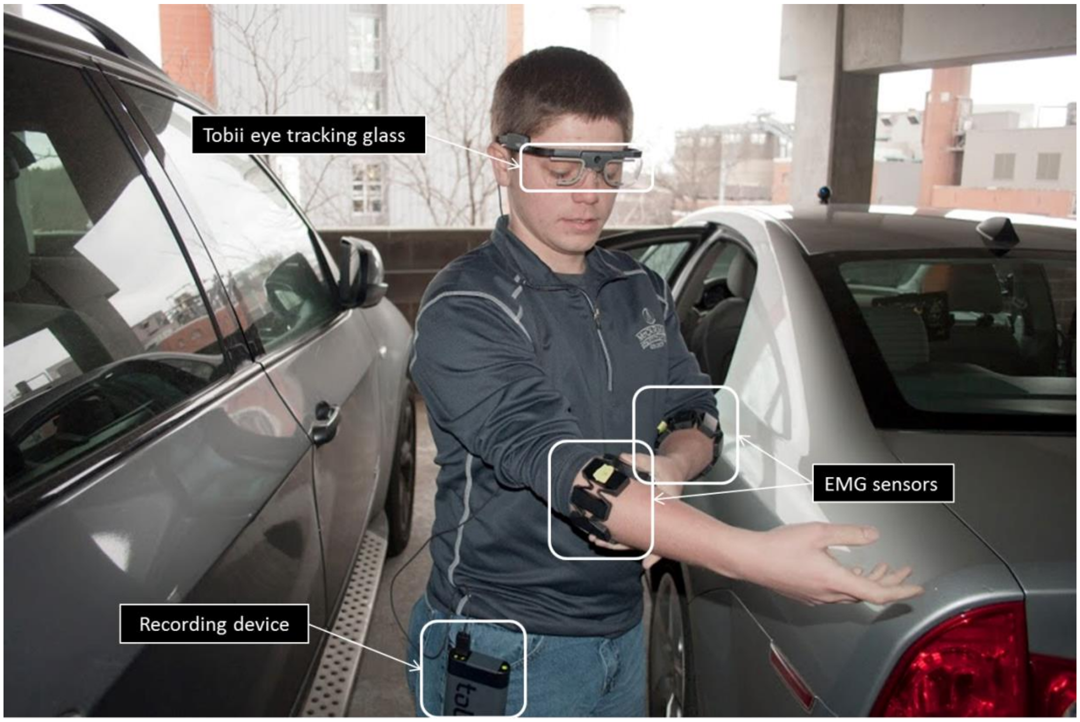
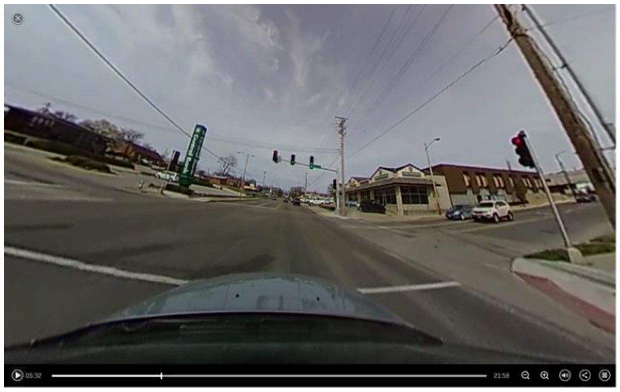


Figure 3.4: EMG armband and Eye Tracking Glasses

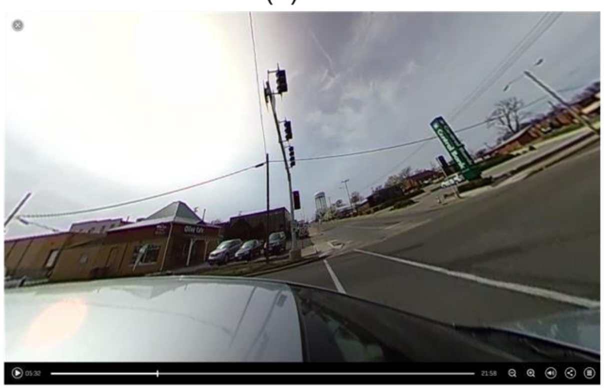
The 360-degree video camera was used to observe the external driving environment. This camera was placed on the roof of the vehicle and recorded a 360-degree view (see Figure 3.5). The recorded data revealed the traffic conditions at the moment of FCW and LDW. Also, the data was used to assess the driving conditions continuously. The wide-angle camera was also used to monitor the participant's driving posture (see Figure 3.6 (a)). The camera was placed on the passenger window and focused in on the driver. It captured the participants' arm and leg angles to analyze how FCW and LDW affect the drivers' physical demands during the experiment. The collected videos were used as a visual aid to analyze the arm and leg positions and driving behaviors. The HD cam-GPS was placed near the center of the windshield (see

Figure 3.6 (b)). This device provided the vehicle's position and speed during the test. The data allowed us to collect the reaction times of the participants related to the warnings from the CAT device.



(a)

(b)



(c)

(d)

Figure 3.5: 360-degree Camera: (a) front, (b) right, (c) left, (d) rear view

(a)

(b)

Figure 3.6: Screenshots from the Recorded Videos

3.5. Measure

3.5.1. Eye Gazing Points with Areas of Interest (AOI)

Visual attention was captured with the Tobii glasses (see Figure 3.4). This is a wearable eye-tracking unit that can be used in multiple research settings. The sampling rate is 100 Hz. The device consists of an ultra-lightweight and unobtrusive head unit to make sure that the participants feel comfortable and act naturally anywhere fitted with a high-definition scene camera. The resolution of the camera is 1920×1080 at 25 fps. It can track 82° horizontal and 48°vertical. The eye-tracking method is based on corneal reflection and binocular and dark pupil tracking. The system comes with analysis software to assess gaze locations and glance duration. The glasses recorded a series of eye-gaze data of the driver's visual attention within the driving environment. The software calculated the allocation of attention to different areas of interests (AOI). In this study, the driver's visual attention related to each AOI was calculated and compared between CAT devices. To analyze the eye gaze-points, we created the AOI map. This map is made by using three or four scene views of the left side, the windshield, the right side, and the panel. After the experiment, multiple 15-second time segment ($\pm$ 7 secs from FCW and LDW) videos with eye gaze points were created. These segments were run through the analysis software that marked a spot on the AOI map. After all of the segments had been mapped, 9 different AOIs were set to calculate the percentage of visual attention during the experiment (see Figure 3.7). These areas include: 1) a front view; 2) a Garmin display; 3) a left view; 4) a Mobileye display; 5) a vehicle panel; 6) an RD-140 display; 7) a rear view; 8) a right view; and 9) an unknown area. The outcome of mapping analysis showed how long participants were focused on each AOI in driving, and allowed us to understand the effects of FCW and LDW on the driver's visual attention.

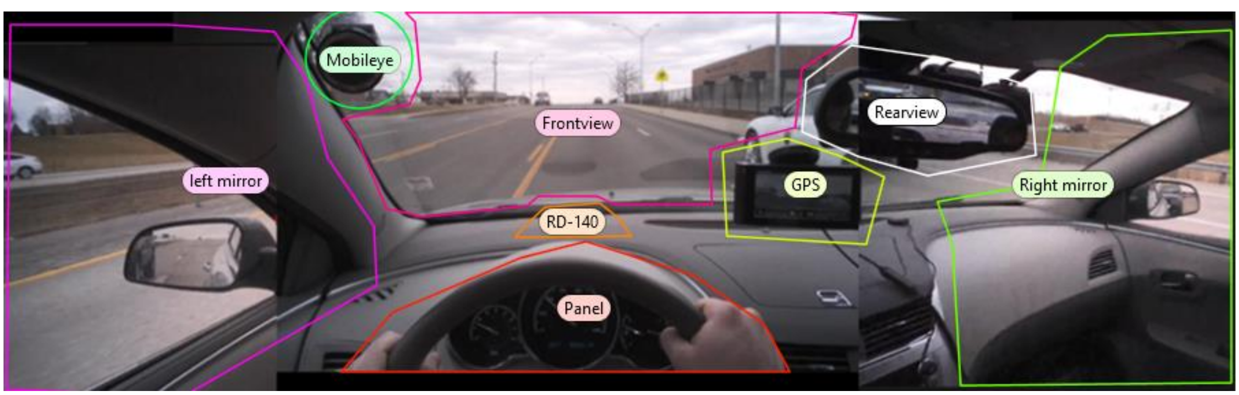


Figure 3.7: A screenshot of Areas of Interest (AOI) Map

3.5.2. Electromyography (EMG)

Electromyography (EMG) measures muscle activity and quantifies force levels. Two armbands recorded the changes in electrical potential around the muscle due to the depolarization of the cell muscle during muscle contraction. During the experiment, the EMG sensor was placed on both left and right forearm and used as an indicator of mental stress (see Figure 3.4). Each device contained 8 separate EMG sensors and 3 accelerometers. The drivers' muscle activity and posture of the forearm were collected during the experiment. By analyzing the forearm movement and EMG signals, we were able to find additional stress caused by FCW and LDW. Several studies support the relationship between mental stress or fatigue and EMG activity of muscle (Bansevicius, Westgaard, & Jensen, 1997; Brookhuis & de Waard, 2010; De Waard & Studiecentrum, 1996). For the data analysis, similar to the eye tracking analysis, we marked all time segments of the FCW and LDW ($\pm$ 7 secs from the warning). Then the average EMG value of the warning segment was compared to its baseline. If this average is significantly higher or lower than the baseline, then it indicates that the drivers experienced the additional stress because of the warnings from the CAT devices.

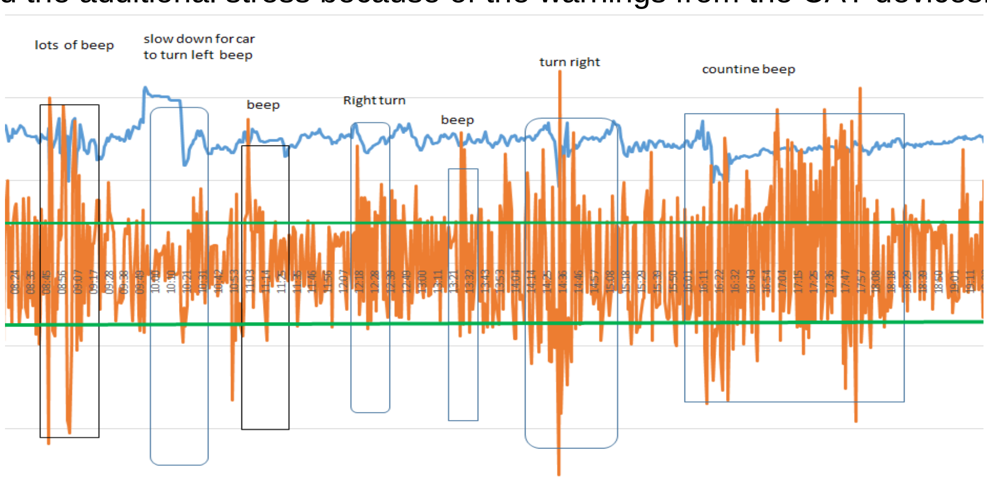


Figure 3.8: EMG Data Outcome

3.5.3. NASA-TLX Questionnaire

The NASA-TLX (NASA Task Load Index) is a multidimensional subjective workload rating technique. NASA TLX is commonly used to measure operators' workload (Cao, Chintamani, Pandya, & Ellis, 2009; Hancock, Williams, & Manning, 1995; Hart & Staveland, 1988). This technique considers the magnitude of six possible load types: mental demand, physical demand, and temporal demand, own performance, effort, and frustration. It weighs the six types of load through a series of 15 combinations (close to 100 – high workload; close to 0 - low workload). The NASA-Task Load Index ratings were collected after each trial. In order to obtain an overall workload estimate, a weighting procedure (Hart & Staveland, 1988) was used to combine the six individual scale ratings into a global score. After the experiment, the group average of six individual scale and overall weighted scores was compared to each CAT device group.

Table 3.1: NASA-TLX Rating Scale Description

Title	Endpoints	Descriptions
Mental Demand	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed or secure, gratified, content, relaxed, and complacent did you feel during the task?

3.5.4. Sensitivity Analysis using Signal Detection Theory (SDT)

Signal detection theory (Green & Swets, 1966) could provide a useful framework for comparing sensitivity between CAT devices. SDT framework has been used across a wide range of disciplines including psychiatry, engineering, medicine, and driving performance. Caley and Georgiou (2004) used signal detection theory as a tool to achieve a “consistent approach to audibility across diverse background noise conditions (for a locomotive) without leading to excessive alarm levels that may compromise function by inducing startle reactions or by generating unnecessary annoyance”. Wolf, Algom, and Lewin (1988) also used signal detection theory to test the decision of drivers in risky to drive between the spatial gap in different driving situations with a different level of frustrations. Burge (2015) used fuzzy signal detection theory to assess the impact of text messaging on drivers' hazard perception ability.

In the original form of SDT, a subject attempts to determine whether a signal has been seen or not (Nevin, 1969). The subject’s decision breaks down into four outcomes: hits, false alarms, misses, and correct rejections.

To understand the driving behavior related to warning signals, the hazard perception threshold of each driver should be analyzed. In this study, we used SDT framework as a tool to compare the sensitivity of the different warning signals from a CAT device. *d'* and *β* of each CAT device was calculated by using the video data from 360-degree and The HD cam-GPS cameras. The filmed footage of various traffic situations and their responses of detecting potential traffic hazards were examined to determine whether a warning signal has been responded or not. Although it was hard to understand the underlying cognitive mechanism of driver's decision-making process during the warning response, the participant's decision could break down into four outcomes: effective warning (EW), false warning (FW), aware warning (AW), and ignored warning (IW). Tables 3.2 and 3.3 show the details of response outcomes. In Table 3.2, the driver's response corresponding to the collision avoidance warning was categorized into the combination of physiological response and motor response. The existence of physiological response depended on the eye movement and EMG data. If the warning significantly influenced the driver's gaze pattern or EMG data, then we considered as the presence of the physiological response. On the other hand, the motor response is comprised of any actions related to breaking, accelerating, or steering wheel to change the vehicle speed or direction. By using the video data from the 360-degree camera, HD-cam, and GPS system, any motor actions related to acceleration, deceleration, and direction changes were observed. We analyzed every CAT warning based on the presence of the physiological response as well as the motor response.

Table 3.2: Four Possible Responses to the CAT Warning

		Physiological Response[1]	
		YES	NO
Motor Response [2]	YES	Effective Warning (EW)	Aware Warning (AW)
	NO	False Warning (FW)	Ignored Warning (IW)

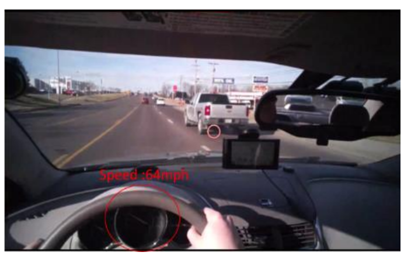
1) ***Effective Warning (EW):*** If the presence of at least one of the physiological responses (rapid eye-gaze movement or strong EMG signals) along with a motor response (breaking, accelerating, or steering wheel) existed, then the signal from the CAT device was categorized as the effective warning (EW). In this case, the driver seemed to trust the warning and take the appropriate action to avoid any potential danger. EW is considered as the most positive outcome compared to other responses since the warning helps drivers to be aware possible threats and give them an extra time to avoid a crash. For example, according to Table 3.2, after changing a lane, the CAT device generated a forward collision warning. The

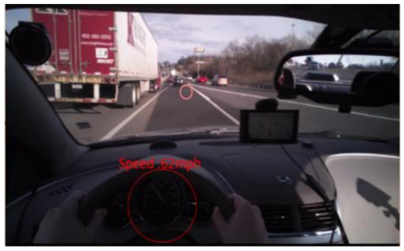
[1] Rapid eye-gaze movement between AOIs, a broad amplitude in EMG signals, or both of them
[2] Any motions related to breaking, accelerating, or steering wheel

participant responded to the warning by reducing the speed to avoid any collision. Before the driver executed breaking motion, both eye-gaze and EMG signal responses were detected.

2) ***Aware Warning (AW):*** If there was no physiological response and only a motor response existed, then this signal was considered as an aware warning (AW). In this case, drivers already detected the potential threats before the alarm occurred. Although the warning signal did not provide any additional information to drivers, it helped them to recheck their decisions regarding what kind of motor response should be performed to minimize a vehicle collision. In the example below Table 3.3, the driver reduced the vehicle speed when he heard a forward collision warning. However, he kept looking at the front view, and there was no significant difference in EMG signals between before and after the alarm.
3) ***False warning (FW):*** If there was no motor response about the warning (only physiological response existed), then it was classified as false warning (FW). In this case, the driver did not detect any potential hazards surrounding the vehicle after he heard the alarm. For that reason, he did not make any motor response. This is one of the negative outcomes, because FW may cause the sense of distrust. It could impede appropriate compliance and response on warnings.
4) ***Ignored warning (IW):*** In this case, the driver ignored the warning (no physiological and motor response). IW is considered as the most negative outcomes compared to other responses, because it creates a visible or auditory annoyance to drivers. In the example showed in Table 3.3, the driver completely ignored the warning after he experienced a high rate of false warning during the trial.

Table 3.3: Examples of Behavior Modification Caused by CAT Warning

Warning	Before Warning	After Warning
EW: Presence of physiological response and motor response		
AW: Presence of motor response only		

FW: Presence of physiological response only		
IW: No physiological and motor response		

To conduct the sensitivity analysis, EW rate and FW rate were measured by using the date from Phase 1 study. The rates of EW and FW were calculated by

$$ER = \frac{\text{total number of EW}}{total\ number\ of\ EW+AW} \tag{1}$$

$$FR = \frac{total\ number\ of\ FW}{total\ number\ of\ FW+IW} \tag{2}$$

Effective warning rate (ER) and false warning rate (FR) represents the effectiveness of CAT device to detect the collision warning while driving. The higher ER and lower FR are desirable to maximize the benefits of using CAT device. In this study, the relative frequencies of the driver’s responses related to CAT warnings were calculated by using the non-parametric signal detection analysis (Zhang & Mueller, 2005). It measured the difference between the average of the physiological response distribution and the motor-plus-physiological response distribution. It is denoted as *A’*, the sensitivity. The SDT model also considers the bias of the decision-maker towards minimizing FW versus AW. It is denoted as *b*.

$$A' = \begin{cases} \frac{3}{4} + \frac{ER - FR}{4} - FR(1 - ER) & if\ FR \le 0.5 \le ER; \\ \frac{3}{4} + \frac{ER - FR}{4} - \frac{FR}{4ER} & if\ FR \le ER \le 0.5; \\ \frac{3}{4} + \frac{ER - FR}{4} - \frac{1 - ER}{4(1 - FR)} & if\ 0.5 < FR \le ER; \end{cases} \tag{3}$$

$$b = \begin{cases} \dfrac{5-4ER}{1+4FR} & if\ F \leq 0.5 \leq ER; \\ \dfrac{ER^2+ER}{ER^2+FR} & if\ FR \leq ER \leq 0.5; \\ \dfrac{(1-FR)^2+(1-ER)}{(1-FR)^2+(1-FR)} & if\ 0.5 < FR \leq ER; \end{cases} \quad (4)$$

3.5.5. Hierarchical Task Analysis (HTA) and Reaction Time

The MU research team used hierarchical task analysis (HTA) technique to analyze the participants' driving behaviors. HTA is one of the standard methods to break down a human activity into a set of simple actions. The HTA technique is a central ergonomic approach to evaluating tasks (Stanton, 2006). In this project, the observed activities were decomposed into multi-level task elements. Each element had a measured time associated with the certain motor response. The overall HTA chart across multiple participants showed different driving behaviors based on their responses: effective warning (EW), false warning (FW), aware warning (AW), and ignored warning (IW).

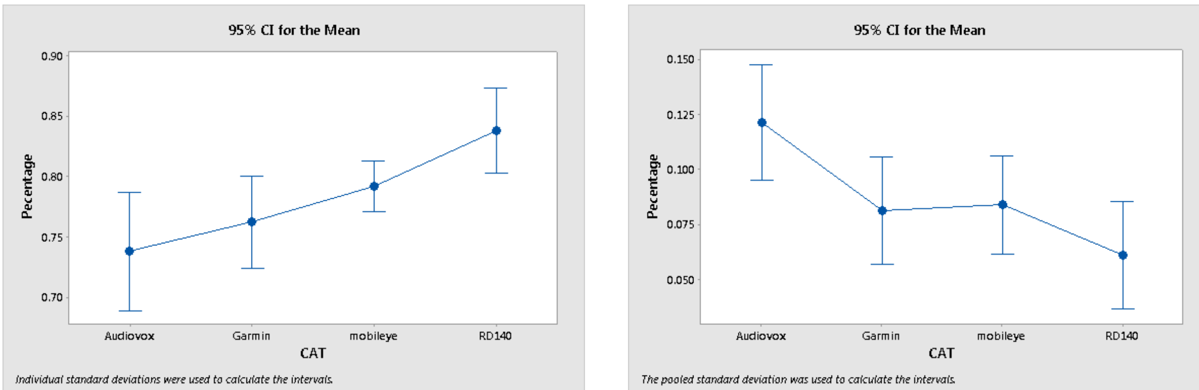
The team also conducted the reaction time analysis. According to the research done by McGehee, Mazzae, and Baldwin (2000), the early warning condition showed significantly shorter accelerator release reaction times, fewer crashes, and less severe crashes than both the baseline condition and the late warning condition. The results indicated that the timing of a warning is important in the design of collision warning systems." For that reason, it is essential to analyze the effect of driver's decision-making time caused by CAT warnings and other environmental factors, such as traffic and weather. For the reaction time analysis, we analyzed the motor response time based on the presence of the physiological response (effective warning).

4. Phase 1 Study Results

4.1. Eye-tracking Data

According to the eye-gaze data, there were significant differences between CAT devices regarding driver's visual attentions. One-way ANOVA test showed that their attentions on the AOI map (Front view, Garmin, Left view, Mobileye, Panel, RD-140, Rear view, Right view and Unknown part) were significantly influenced by the warnings from the CAT devices. For the front view (area #1), the drivers paid more attention when they used RD-140 compared to other CAT devices [F (3, 15) =6.55, P< 0.01]. Post hoc comparison using the Tukey HSD test indicated that the mean score for the RD-140 (M = 83.8%, SD = 6.3%) was significantly different than others (Mobileye 560: M = 79.2%, SD = 4.2%; Garmin: M = 76.3%, SD = 6.9%; Audiovox: M = 73.8%, SD = 8.1%). In addition, the eye gaze percentage of the RD-140 in the Unknown part (area #9) was significantly lower than others [F (3, 15) =3.90, P< 0.05]. Moreover, post hoc comparison using the Tukey HSD test indicated that the mean score for the Audiovox

(M = 12.15%, SD = 7.14%) was significantly higher than others (Mobileye 560: M = 8.39%, SD = 2.61%; Garmin: M = 8.15%, SD = 5.37%; RD-140: M = 6.1%, SD = 3.18%). These results showed that there might be an opposite pattern between the area #1 and the area #9. It means that the participants who paid attention more to the front view were looking less at other places such as inside vehicle environments.



(a) Front View Area (b) Unknown Area

Figure 4.1: Interval Plots for AOI results of the Front view and the Unknown area

For the AOIs around CAT devices (Garmin: area #2, Mobileye: area #4, and RD-140: area #6), the attention percentage of this AOIs area was increased when the CAT devices generated FCW or LDW. For example, the participants paid more attention to the area #4 when the Mobileye 560 was tested [F (3, 15) =22.22, $P<0.001$]. The drivers spent more time to check the area #2 when the Garmin's collision avoidance features were activated [F (3, 15) =25.51, $P<0.001$]. It was same for RD-140 [F (3, 15) = 6.18, $P< 0.01$]. For the Audiovox, the warnings attracted drivers more to look at the Panel (area #5) and Rearview (area #7). For the Right view (area #8), the trials with Garmin showed the highest attention percentage compared to others. However, for the Left view (area #3), there was no difference between CAT devices.

The AOI results indicated that visual signals from the CAT device significantly influenced the driver's visual attention to the front view. One of the differences between the Audiovox and other CAT devices was that the Audiovox system did not provide any visual warnings while others provided proper visual signals with sound warnings. For the Mobileye, Garmin, and RD-140, the participants checked the display unit if they heard FCW or LDW sound signals. However, the participants who were assigned to the Audiovox group checked the gauges on the vehicle panel or the radio display when they heard the sound warnings. In addition, the results showed that the location of the visual display was deeply related to the percentage of the driver's attention to the front view (area #1). During the experiment, Garmin, Mobileye, and RD-140 display were located at the right side, the top left corner, and the bottom of area #1 respectively (see Figure.

3.7). The AOI results showed that **the RD-140 marked the highest percentage of the area#1 compared to other devices**, because the display unit was on the dashboard which was directly located in front of the driver. It means the perceptual transition time could influence the driver's attention. In other words, depending on the distance between the foveal point of the front view and the CAT display unit, the participants could have different sensitivity levels of the warning signals from the CAT device.

Table 4.1: Descriptive Statistic Results of Eye tracking data

Area #	Name	Audiovox		Garmin		Mobileye		Rd-140		P-value
		mean	StDev	mean	StDev	mean	StDev	mean	StDev	
1	Front view	0.7382	0.0810	0.7627	0.0690	0.7920	0.0418	0.8383	0.0630	***0.001***
2	Garmin	0.0232	0.0108	0.0427	0.0220	0.0107	0.0101	0.0033	0.0037	***0.000***
3	Left view	0.0362	0.0094	0.0419	0.0326	0.0412	0.0262	0.0319	0.0212	0.637
4	Mobileye	0.0039	0.0063	0.0019	0.0019	0.0194	0.0128	0.0007	0.0007	***0.000***
5	Panel	0.0277	0.0171	0.0116	0.0126	0.0101	0.0059	0.0169	0.0139	***0.002***
6	RD-140	0.0044	0.0075	0.0019	0.0021	0.0018	0.0011	0.0117	0.0131	***0.001***
7	Rear view	0.0381	0.0120	0.0338	0.0236	0.0242	0.0120	0.0182	0.0126	***0.005***
8	Right view	0.0067	0.0050	0.0219	0.0129	0.0166	0.0133	0.0179	0.0141	***0.014***
9	Unknown	0.1215	0.0714	0.0815	0.0537	0.0839	0.0261	0.0610	0.0318	***0.013***

4.2. EMG Data

4.2.1. Comparisons between baseline and warning events

The warning events in trial 2, 3 and 4 were compared to the baseline events in trail 1 (see Figure 4.2). The baseline EMG data indicated the normal EMG data without any warnings. The warning EMG data pointed out the EMG signals during FCW and LDW events. By comparing the warning and baseline EMG activity between CAT devices, we found the impact of the psychophysiological stress caused by the warning signals. The results showed that FCW and LDW changed EMG signals significantly lower or higher compared to the normal EMG values.

For the Audiovox, Garmin and RD-140, the EMG signals under warning events were significantly smaller than the baseline events. However, for the Mobileye, there was no difference between the baseline and warning events. It means that the warning from Audiovox, Garmin and RD-140 made the drivers feel stressful, but the warnings from Mobileye did not. In other words, **the warnings from the Mobileye 560 did not contribute to increasing the driver's psychophysiological stress.** However, the warnings from other CAT devices influenced the drivers' stress.

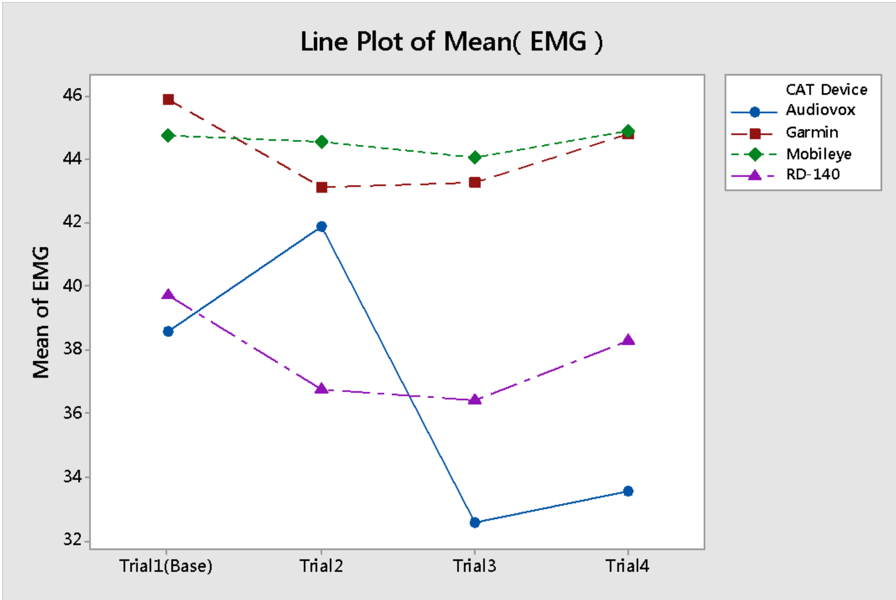


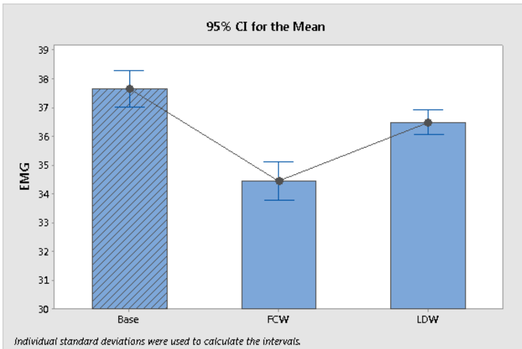
Figure 4.2: EMG Comparisons between baseline (Trial 1) and Warnings (Trial 2, 3, and 4)

Table 4.2: Descriptive Statistic Results of Baseline and Warning events

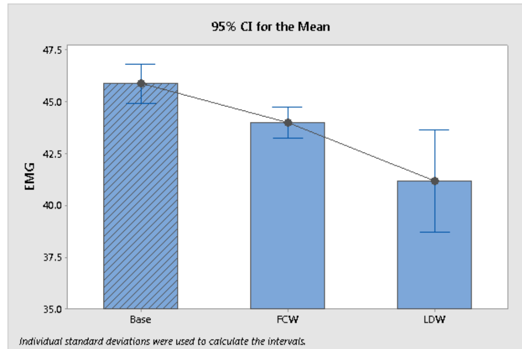
Event	Audiovox		Garmin		Mobileye		RD-140	
	mean	StDev	mean	StDev	mean	StDev	mean	StDev
Baseline	37.638	21.412	45.872	23.007	44.757	23.126	39.725	24.578
Warning	35.802	20.689	43.736	21.618	44.513	21.904	37.091	21.790
P-Value	**≤0.001**		**≤0.001**		0.535		**≤0.001**	

4.2.2. Comparisons between FCW and LDW

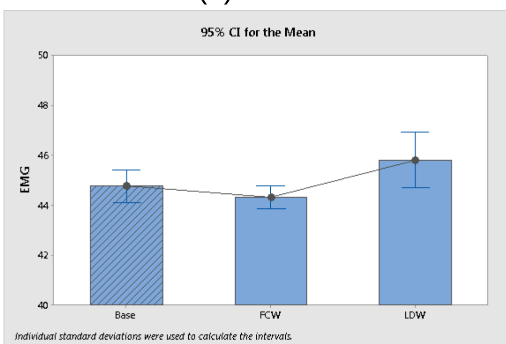
For the Audiovox (see Figure 4.3 (a)), the driver's EMG signals were significantly influenced by both FCW and LDW [$F(3,15) = 25.87$, $P < 0.001$]. Post hoc comparison using the Tukey HSD test indicated that the mean score for FCW (M = 34.44, SD = 21.87) was significantly lower than LDW (M = 36.48, SD = 20.04). It means that the drivers in this group felt more stress when they heard FCW compared to LDW. For the Garmin (see Figure 4.3 (b)), both FCW and LDW significantly influenced the driver's EMG signals [$F(3,15) = 8.81$, $P < 0.001$]. However, there was no difference between FCW (M = 43.98, SD = 21.54) and LDW (M = 41.17, SD = 22.23). **For the Mobileye 560 (see Figure 4.3 (c)), both FCW and LDW did not influence the driver's EMG signals [$F(3,15) = 2.78$, $P = 0.062$]**. For the RD-140 (see Figure 4.3 (d)), both FCW and LDW significantly influenced the driver's EMG signals [$F(3,15) = 89.07$, $P < 0.001$]. Post hoc comparison using the Tukey HSD test indicated that the mean score for LDW (M = 34.56, SD = 21.3) was significantly lower than FCW (M = 41.7, SD = 21.9). It means that LDW signals from the RD-140 contributed more stress than the FCW signals.



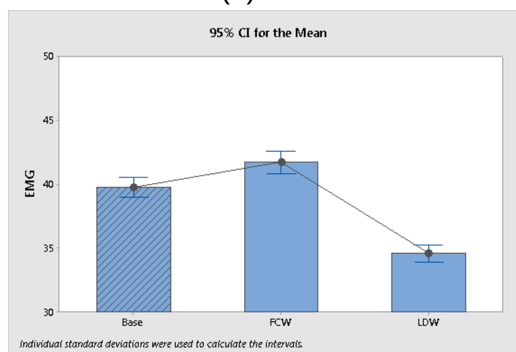
(a) Audiovox



(b) Garmin



(c) Mobileye



(d) RD-140

Figure 4.3: Interval Plots for EMG results

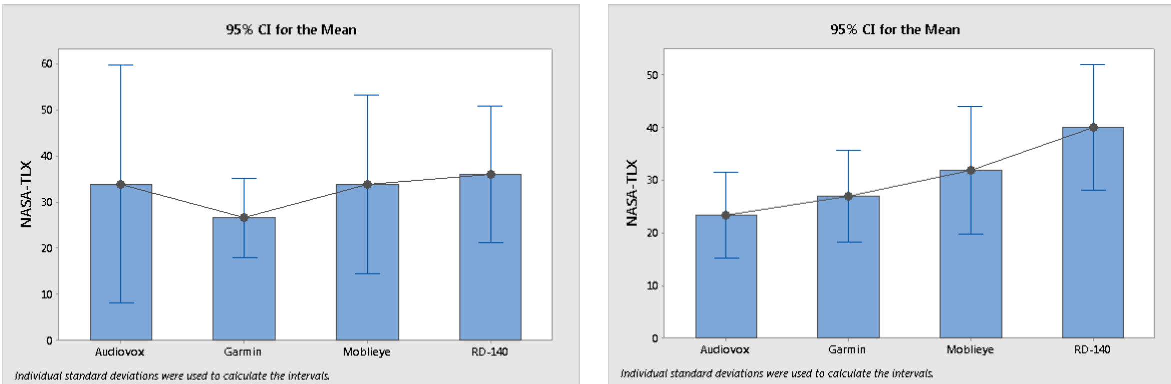
The EMG results pointed out that a sound signal from the CAT device significantly influenced the driver's psychophysiological stress. The participants showed different stress levels depending on a beeping sound. When the participants heard a series of high-pitched short beeping sounds (i.e., the FCW signal from the Audiovox and the LDW signal from the RD-140), their changes on the EMG were larger than with other beeping sounds.

Table 4.3: Descriptive Statistic Results of FCW and LDW

	Audiovox		Garmin		Mobileye		RD-140	
	mean	StDev	mean	StDev	mean	StDev	mean	StDev
(a) FCW	34.444	21.857	43.981	21.546	44.311	22.086	41.704	21.917
(b) LDW	36.480	20.047	41.17	22.23	45.810	20.664	34.565	21.303
(c) Base	37.638	21.412	45.872	23.007	44.757	23.126	39.725	24.578
Abs [(c) – (a)]	3.194	0.445	1.891	1.461	0.446	1.04	1.979	2.661
Abs [(c) – (b)]	1.158	1.365	4.702	0.777	1.053	2.462	5.16	3.275
P value	***<0.001***		***<0.001***		*0.062*		***<0.001***	

4.3. NASA-TLX Workload Data

After completing each experimental lap, participants received a questionnaire form to record their subjective ratings of perceived workload following the method specified for calculating NASA-Task Load Indices. The ratings were then averaged for each participant for each CAT device.



(a) Trial 1 (Baseline) (b) Trial 2, 3, 4

Figure 4.4: NASA-TLX Perceived Workload Average

The ANOVA model for NASA-TLX showed that there was no difference between trials and between CAT devices**.** It means that **the four selected aftermarket collision avoidance systems did not increase the driver's perceived workload.** Six rating scales assessed mental/physical/temporal demand, performance, effort, and frustration following each CAT device. For the mental demand, performance, and frustration, the participants felt more stress when they heard the warnings from RD-140 [Mental: $F(3, 15) = 2.77$, $P<0.05$; Performance: $F(3, 15) = 8.39$, $P< 0.001$; Frustration: $F (3, 15) = 3.26$, $P<0.05$]. For the physical demand, Mobileye and RD-140's workload were significantly higher than Audiovox and Garmin [$F(3, 15) = 4.39$, $P < 0.01$]. However, there were no significant differences in the temporal demand, effort between CAT devices.

Table 4.4: Descriptive Statistic Results of NASA-TLX

Event	Audiovox		Garmin		Mobileye		RD-140	
	mean	StDev	mean	StDev	mean	StDev	mean	StDev
Trial 1	33.80	20.77	26.47	6.89	33.68	18.46	35.93	12.00
Trial 2,3,4	23.29	14.84	26.91	15.67	31.83	24.27	39.91	21.48
P-Value	0.229		0.952		0.867		0.701	

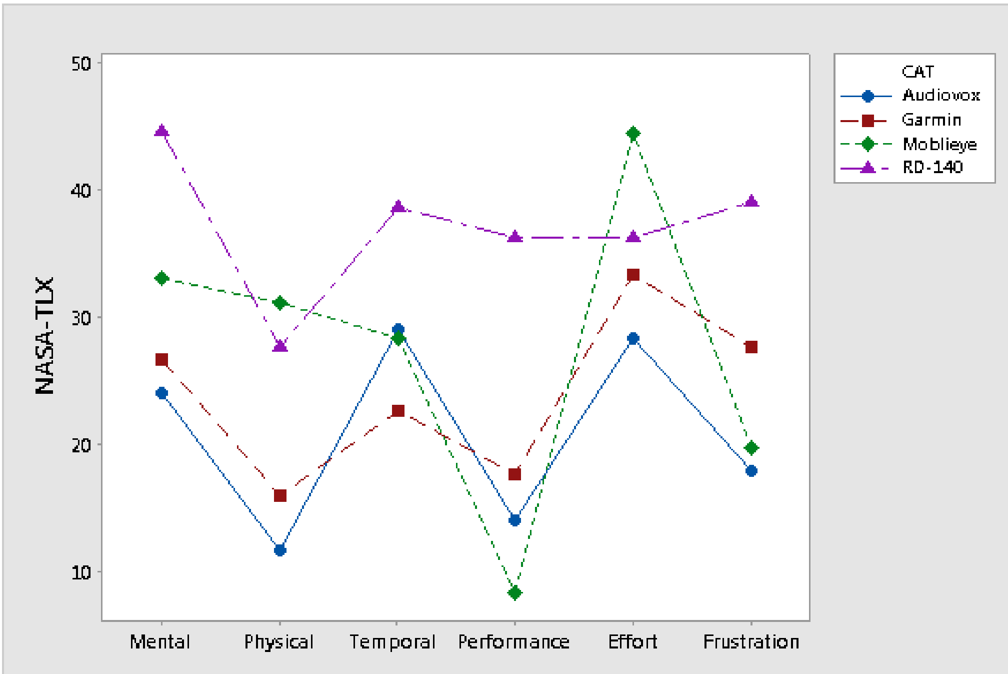


Figure 4.5: NASA-TLX Comparisons between Six Ratings

Table 4.5: Descriptive Statistic Results of NASA-TLX Six Ratings

NASA-TLX	Audiovox		Garmin		Mobileye		RD-140		P-value
	mean	StDev	mean	StDev	mean	StDev	mean	StDev	
Mental	24.00	15.26	26.67	13.58	33.06	27.77	**44.67**	24.01	**0.049**
Physical	11.67	10.63	16.00	10.72	**31.11**	28.52	**27.67**	10.15	**0.007**
Temporal	29.00	17.24	22.67	11.63	28.33	24.85	38.67	15.75	0.131
Performance	14.00	12.42	17.67	14.25	8.33	7.48	**36.33**	27.15	**0.000**
Effort	28.33	23.43	33.33	28.58	44.44	32.71	36.33	21.91	0.392
Frustration	18.00	16.99	27.67	18.50	19.72	23.29	**39.00**	23.16	**0.028**

4.4. Performance Analysis using SDT

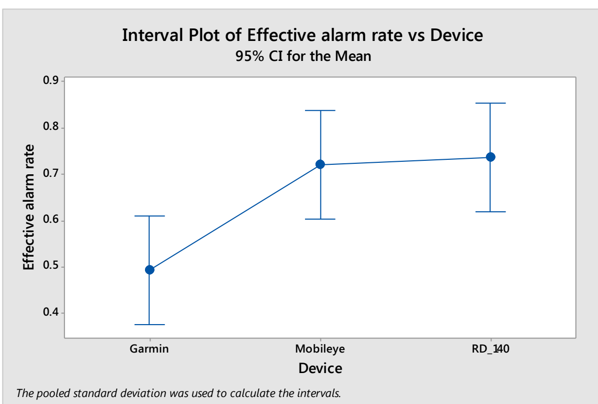
The accuracy and effectiveness of the CAT devices can be determined by the effective warning rate (ER) and the false warning rate (FR). If the test results show the high level of ER and the low level of FR, it indicates that the tested device is trustful and effective to reduce the risk of vehicle accidents. In this performance analysis, we assumed that the threshold to discern an effective warning and false warning is based on the drivers' physiological and motor responses in the video data.

According to the results from the eye-tracking, EMG, and NASA-TLX data, Audiovox showed the worst performance compared to other CAT devices. **Based on the feedback from the participants who experienced the Audiovox system, they**

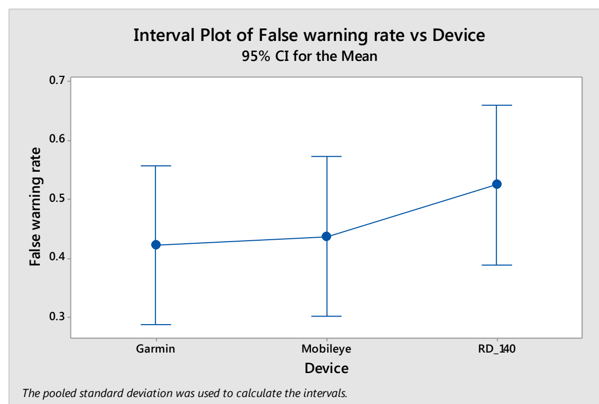
lost confidence in the system over the time and adjudged the alarms from Audiovox as a nuisance. Eventually, they ignored the warnings from Audiovox. Hence, we did not include Audiovox in the performance analysis.

4.4.1. Effective warning Rate(ER) vs. False warning Rate (FR)

The effective warning rate (ER) and false warning rate (FR) were compared between CAT devices: Garmin, Mobileye, and RD-140. ER and FR on the CAT system were calculated by using a general linear model. According to the results, there was a significant difference in ER between the CAT devices [F (2, 42) =5.49, $P<0.05$]. However, there was no significant difference in ER between trials [F (2, 42) = 0.80, P =0.445], in FR between the CAT devices [F (2, 42) =0.68, P= 0.497], and in FR between trials [F (2, 42) = 1.31, P=0.282]. The post hoc Tukey comparison test showed that the ER mean of RD-140 (M= 0.7367 SD =0.2351) and Mobileye (M=0.7201, SD= 0.1602) was significantly higher than Garmin (M= 0.4928, SD =0.2669). **The results showed that RD-140 and Mobileye were significantly better than Garmin. However, there was no performance difference between RD-140 and Mobileye.**



(a)



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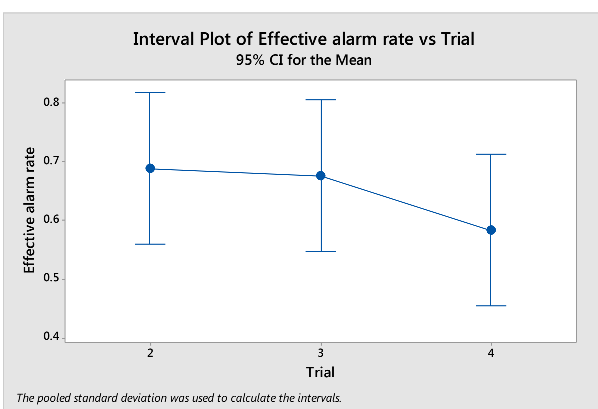
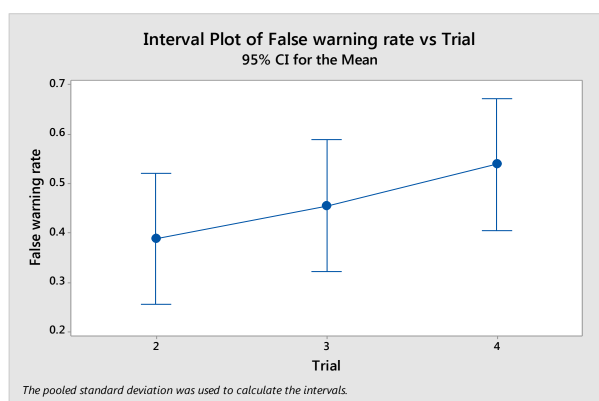


(c)



(d)

Figure 4.6: ER and FR Mean Comparisons between Garmin, Mobileye, and RD-140

4.4.2. False Warning Rate Comparisons between FCW and LDW

False warning rate (FR) is related to the reliability of the CAT device. When FR is higher, the driver ignores a warning more often. FR could be influenced by the type of warning and device. Table 4.6 showed the FR between the type of warning (LDW and FCW) and between CAT devices (Mobileye and RD-140).

Table 4.6: Descriptive Statistic Result of FR

Event	Mobileye		RD-140	
	mean	StDev	mean	StDev
LDW	0.2879	0.3059	0.6171	0.023
FCW	0.5170	0.2751	0.2619	0.3081
P-Value	0.072		**<0.001**	

Although RD-140 is the best CAT device for FCW, there was a significant FR difference between LDW and FCW. On the other hand, Mobileye did not show any significant FR difference between LDW and FCW (see Table 4.6), and Mobileye is the best CAT device for LDW. According to the result of the false FCW rate, there was a significant difference between Mobileye and RD-140 [F(3,15) = 7.04, P < 0.001]. The mean of the false FCW rate for Mobileye (M=0.5170, SD= 0.2751) was much higher than RD-140 (M=0.5170, SD= 0.2751). **It means that RD-140 showed the best performance for the FCW compared to other tested CAT devices.** For the LDW, there was a significant difference between Mobileye and RD-140 on the FR [F (3, 15) = 10.94, P<0.001]. The mean of false LDW for RD-140 (M= 0.6171, SD =0.2023) is much higher than Mobileye (M= 0.2879, SD =0.3059). **Hence, we can conclude that Mobileye is the most effective device for LDW among the tested CAT devices.**

4.4.3. Sensitivity Analysis between Mobileye and RD-140

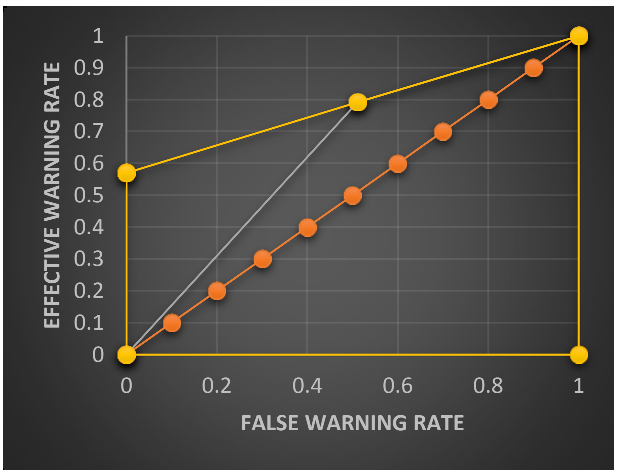
CAT system should be designed to maximize the detectability of any potential collision while driving. Hence, it is desirable to use the CAT system with the high sensitivity level, which means the high level of ER and the low level of FR. Satisfying one of them does not guarantee a safe design (Sullivan 2015).

The effective warning rate (ER) and false warning rate (FR) were used to calculate the sensitivity (A') and bias (b) and were compared between Mobileye and RD-140 (see Table 4.7). **According to the results, there was no significant difference between Mobileye and Rd-140 regarding the level of sensitivity A' (P = 0.636) and bias (P = 0.124).**

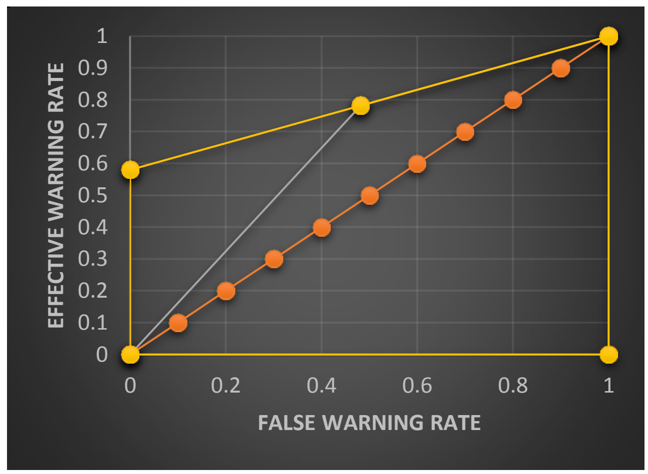
Table 4.7: Sensitivity and Bias Comparisons between Mobileye and RD-140

	Sensitivity (A')		Bias (b)	
	mean	StDev	mean	StDev
RD-140	0.6991	0.1429	0.7518	0.245
Mobileye	0.6751	0.1319	1.095	0.719
P-value	0.636		0.124	

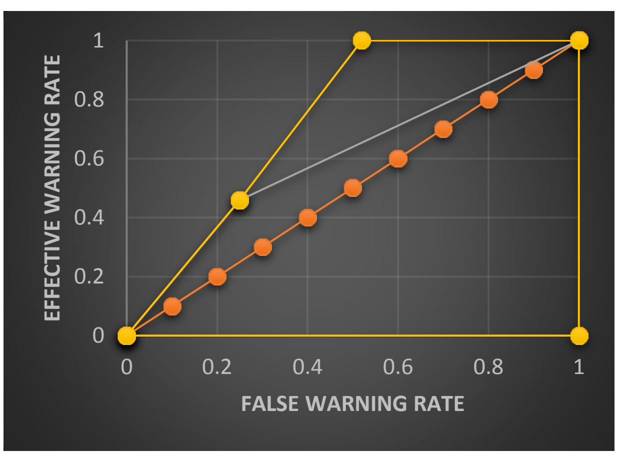
By using the ER and FR results, we were able to develop the receiver operating characteristic (ROC) curves regarding LDW and FCW for Mobileye and RD-140. These ROC curves show the tradeoff between sensitivity and specificity. Hence, in this study, the area under the curve was used as a measure of the effectiveness of the warning. **According to the rough guide[3] for classifying the test results, both Mobileye and RD-140 systems are in a fair group (area between .70 – .80).**



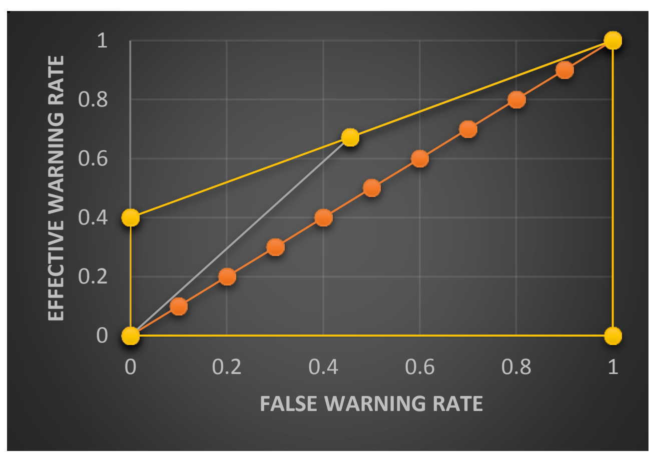
(a) LDW for RD-140 (area: 0.78)



(b) FCW for RD-140 (area: 0.79)



(c) LDW for Mobileye (area: 0.74)



(d) FCW for Mobileye (area: 0.7)

Figure 4.7: Receiver Operating Characteristic (ROC) Curves for RD-140 and Mobileye

[3] Excellent (0.9 – 1); Good (0.8 – 0.9); Fair (0.7 – 0.8); Poor (0.6 – 0.7); Fail (below 0.6)

4.5. Reaction Time Analysis

Reaction time analysis was conducted by using eye-tracking and HD-cam video data. The reaction time is commonly defined as the time taken by the driver to respond to the warning. In this study, we observed two types of responses: 1) physiological response, 2) motor response. The eye-tracking data measured the reaction time corresponding to the physiological response. After a driver heard a CAT warning sound, the duration time from the initial eye fixation point to the next fixation point was considered as a reaction time for the physiological response. The reaction time related to the motor response was calculated by using HD-cam videos. From the video data, we found the motor actions, such as reducing the vehicle speed, pressing a brake pedal, or turning the wheel. In this analysis, we assumed that the driving path and experimental time remained constant. According to Table 4.8, the results showed that there was no significant reaction time difference between Mobileye and RD-140 for FCW (Effective Warning [$F(1,79) = 1.23$, $P = 0.271$]). However, for LDW, the drivers showed faster response time when they used Mobileye device compared to RD-140 (Effective Warning [$F(1,42) = 11.09$, $P < 0.01$]). **The drivers took 0.87 sec for Mobileye and 1.542 sec for RD-140 to response lane departure warnings. They also took 2.989 sec for Mobileye and 2.639 sec for RD-140 to react forward collision warnings. It supports that Mobileye system is the best CAT system for the lane departure warning.**

Table 4.8: Reaction Time Comparisons between RD-140 and Mobileye (unit: sec)

Warning type	LDW		FCW	
(Effective Warning)	mean	StDev	mean	StDev
Mobileye	0.873	0.740	2.989	1.610
RD-140	1.542	1.215	2.639	1.113
P-Value	**0.002**		0.271	

4.6. Hierarchical Task Analysis (HTA) Charts for Driving Behavior

HTA is one of the best ways to analyze human behavior in a dynamic control environment. The main purpose of developing HTA charts in this study is to understand the patterns of the driving behavior in response to the CAT warnings. The task is divided into three main sub-processes: 1) perception, 2) cognition, and 3) motor process. The perception and cognition processes could be reflected by using the physiological response. The motor process was analyzed by using the motor response. The results of HTA revealed the sequence of perception, cognitive, and motor processes corresponding to drivers' warning responses. According to the HTA result, the process pattern was significantly influenced by the driver’s decision. Hence, in this analysis, we focused on the process sequence of the effective warning (EW), aware warning (AW), and false warning (FW).

Plan 0: Responding to the CAT device warnings

This is the overall goal of the task. The aim of Plan 0 is to response the alarms from the CAT device. Each driver responded LDW and FCW differently. The driver's reaction was also significantly influenced by traffic and weather conditions. The goal of Plan 0 was achieved by accomplishing three sub-goals: 1) collecting information from the driving environment, 2) evaluating the gathered information, 3) executing the motor system. Figure 4.8 shows the overall HTA regarding the driver's response to the CAT warnings. For the effective warning (EW), the drivers executed Plan 1 and Plan 2 in loops until they decide to perform an appropriate motor response (Plan 1 ←→ Plan 2 → Plan 3 → END). If the driver noticed any emergency situations during Plans 1 or 2, then the driver moved to Plan 3 immediately. For the aware warning (AW), since the drivers were already aware of the potential hazards before the warning occurred, they performed actions without any cognitive process (Plan 1 → Plan 3 → END). For the false warning (FW), the drivers evaluated the meaning of warnings and concluded that no motor response was necessary in this case (Plan 1 → Plan 2 → END).

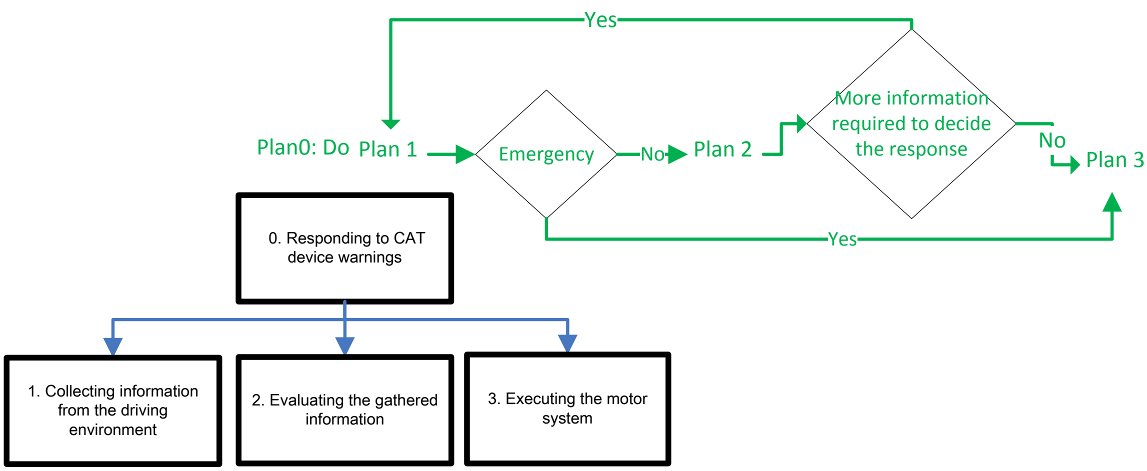


Figure 4.8: Plan 0 – Overall HTA Chart for Driving Behavior

Plan 1: Collecting information from the driving environment

The main goal of Plan 1 is to collect the information from all surrounding environments to identify any potential hazards. Continuous monitoring is required without any distractions during the plan 1process. Figure 4.9 shows the detailed map of the plan 1.

Plan 2: Evaluating the gathered information

After drivers gathered the information, they need to interpret the meaning of the information and understand the consequences caused by these possible threats that might lead to vehicle accidents. This is the most important plan to prevent any erroneous judgments while driving. Figure 4.10 shows the detailed map of the plan 2.

Plan 3: Executing the motor system

Depend on the drivers' decision; they chose different motor responses, such as reducing the vehicle speed, pressing a brake pedal, or turning the wheel for their response.

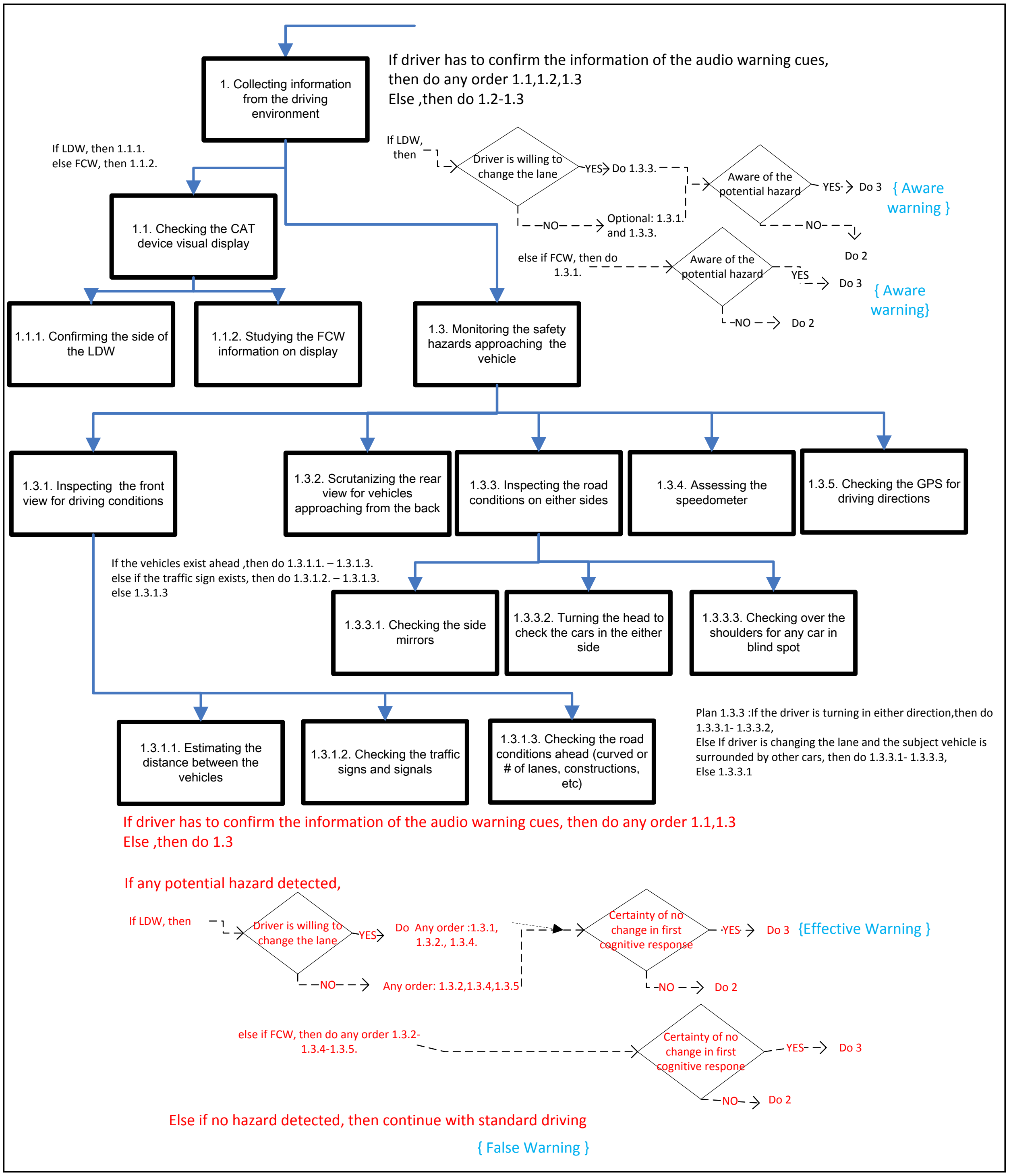


Figure 4.9: Plan 1 – HTA for Collecting Information from the Driving Environments

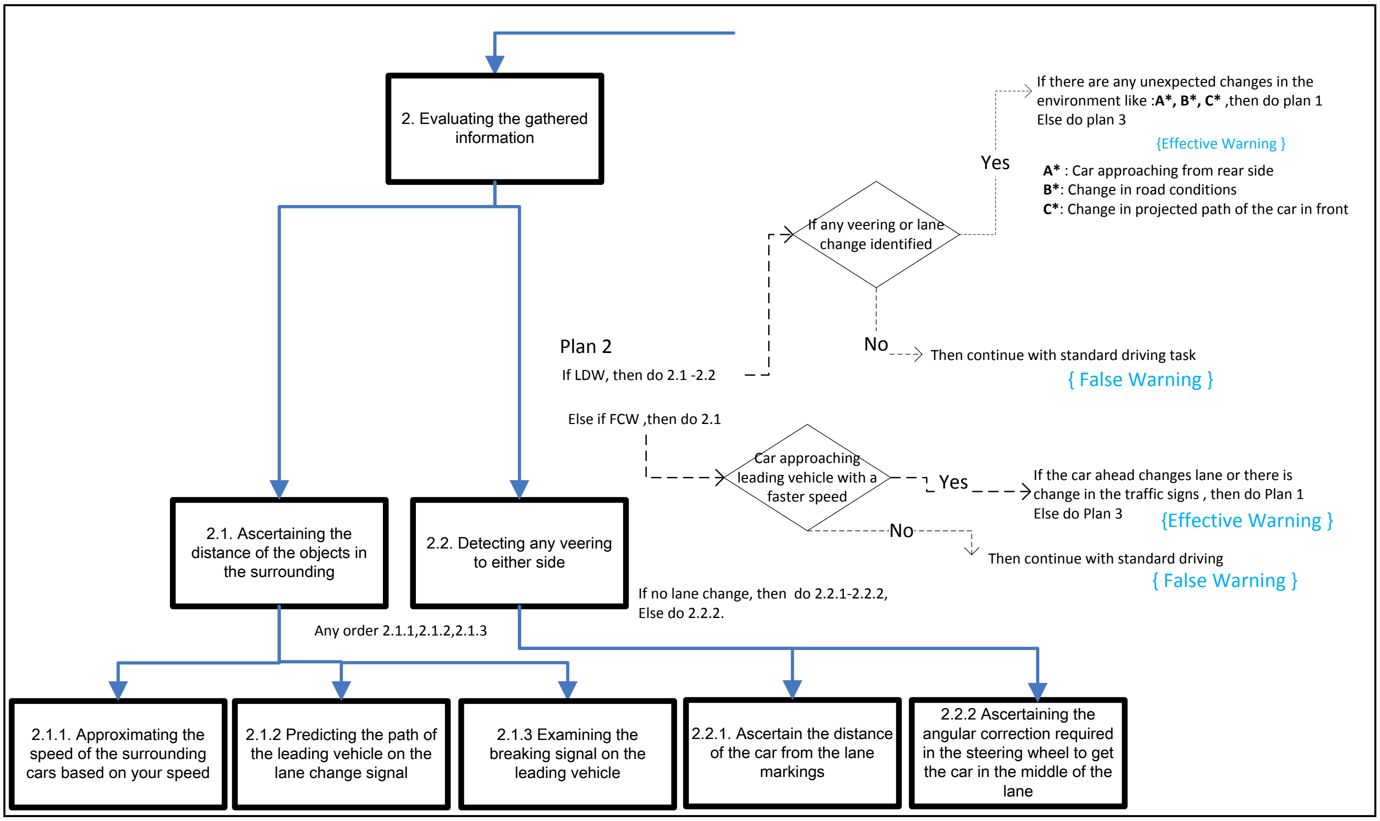


Figure 4.10: Plan 2 – HTA for Evaluating the Gathered Information

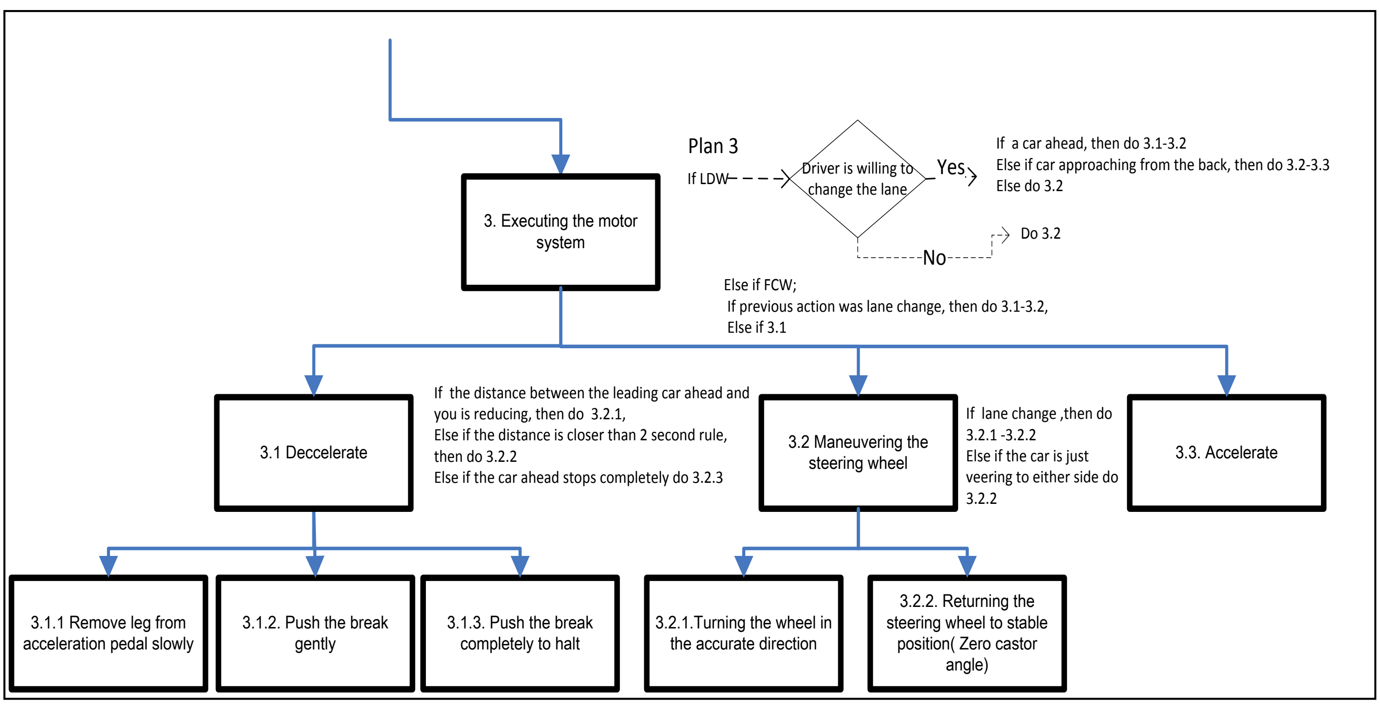


Figure 4.11: Plan 3 – HTA for Executing the Motor System

5. Mobileye Pilot Program (Phase 2)

According to the results of Phase 1 study, we concluded that Mobileye system was the best CAT device among the tested CAT devices. To investigate the benefits of using the Mobileye system in a commercial vehicle, we conducted the Mobileye pilot program as the Phase 2 study. Five professional drivers from OATS tested the Mobileye 560 device for 3 weeks.

The Mobileye's pilot program is designed to monitor the benefit of using the Mobileye system in real-world driving environments. The results of this pilot program showed how the drivers perform differently after the Mobileye system was installed. If there is the impact on Mobileye's solution, the total number of alarms including lane departure, headway monitoring, and forward collision warning, should be reduced significantly. If there is no impact on the driving habits, then the total number of alarms might remain in the same level. The MU research team also conducted the survey to the drivers. The survey was designed to gather their perception and feedback of the Mobileye system. The process of Phase 2 experiment was conducted with two modes: 1) stealth mode, and 2) active mode.

For the stealth mode, the Mobileye unit was installed in the vehicle without any audio or visual alerts. The drivers were not trained at this point. The participants were asked to drive their vehicle as they had in the past without any knowledge that the Mobileye program was going to record the alerts. A black box was also installed which sends the alerts to Mobileye for monitoring. The alerts were recording while the driver was driving without the Mobileye program or training. The experiment was conducted for three weeks as the stealth mode. After first three weeks, we brought the drivers back in to train them, all types of warnings and how the Mobileye system works. During the week of the training, the Mobileye data was collected and marked as training week data. After that, the Mobileye system was placed in active mode. The audio and visual systems were turned on so the driver has a functioning system.

Active mode is done after the driver has driven the vehicle for 3 weeks. At the end of the active mode, we asked them questionnaires about the Mobileye system and their feedback of using the CAT system in a commercial vehicle.

5.1. Participant

Five professional drivers (4 males and 1 female) from Older Adults Transportation Service (OATS) participated in the Phase 2 study. All subjects had enough driving experience to be considered as expert drivers to participate the Mobileye pilot program. The average age of male driver was 70.25 (StDev: 6.495), and the only one female driver is 39 years old. The average driving experience of male driver was 55.5 years (StDev: 7.297), and the female driver has 22 years old driving experiment. All five participants had at least one years of working experience in this current position of

OATS. They are all professional drivers and familiar with the driving path of daily working.

5.2. Apparatus

Five Ford E350 bus were used as testing vehicles for the Phase 2 experiment (see Figure 5.1). These vehicles were operated by the OATS center in Columbia, Missouri. Since the drivers provide a transportation server to customers, the driving path was totally based on the clients' need during the Phase 2 experiment.

Figure 5.1: Phase 2 Study Vehicle

For the Phase 2 study, Mobileye 560 was installed in all testing vehicles. Figure 5.2 shows the location of Mobileye display and camera.

Figure 5.2: Phase 2 Mobileye Pilot Test Setup

5.3. Measure

5.3.1. Warning Report

After completing the stealth mode and active mode, the warning report, which contained the total number of alarm for each week, was provided as the result of the pilot program. This report helped us to see the effect of the Mobileye system while driving. Comparison between the stealth mode warning data and the active mode warning data showed a measurable outcome, such as normalized alerts/ 100 miles and a total number of warnings per day.

5.3.2. Questionnaires

The MU research team designed and conducted a user perception and opinion survey for the Mobileye 560 device. The survey contained 30 questions, including demographic information, driving experience and perceptive measures scale. We visited OATS center three times to hand out the questionnaires. The drivers were asked to answer the questions and provided feedback. All the questions were related to user's feeling and experience of Mobileye 560 during the pilot program. In addition, some questions were designed to analyze user's acceptance and willingness of driving with the Mobileye 560 device. The measuring scale was from point 1 to 7. The larger rating score represented a better user experience.

5.3.3. User Acceptance Model

In the questionnaires, some questions were designed to calculate the user acceptance level of the Mobileye system. Based on the research done by Son and Park (2015), the drivers were asked for their feeling about the system in terms of 'safe,' 'desirable,' 'pleasant', and 'comfort.' In the user acceptance model, '*Safe'* represents the level of feeling safe while using the system. '*Desirable'* denotes the rate of driver's interest to use the system after the test. '*Pleasant'* reflects the driver's preference level of this technology. '*Comfort'* reflects the level of tranquility about the technology. Among these four subjective experiences of feeling, '*safe'* and '*desirable'* represent positive responses, while '*unpleasant'* and '*annoying'* indicate negative feedback. The Technology Acceptance Model (TAM) was also used to quantify the computer-related technology acceptance behaviors (A) of the user. It consists of perceived usefulness (U) and perceived ease of use (EOU).

$$A = U + EOU \tag{5}$$

The usefulness (U) is based on 'safe' and 'desirable' rating scale from the participant's response.

$$U = (S_{safe} + S_{desirable})/2 \tag{6}$$

Where S_{safe} is the subjective score of safety rating. $S_{desirable}$ is the subjective score of desirable rating from the survey reslt.
The ease of use (EOU) term is calculated by using the subjective rating of '*pleasant'* and '*comfort'* in the questionnaires:

$$EOU = (S_{pleasant} + S_{comfort})/2 \quad (7)$$

Where $S_{pleasant}$ is the subjective score of pleasant rating. $S_{comfort}$ is the subjective score of comfort rating.
Finally, the user acceptance of the Mobileye system is measured by the average of the usefulness (U) and the ease of use (EOU).

$$A = \left(\frac{U+EQU}{2*C_{Ratingscale}}\right) * 100\% \quad (8)$$

Where $C_{Ratingscale}$ is the subjective rating scale (from 1 to 7).

6. Phase 2 Study Results

6.1. Warning Data Analysis

Table 6.1 showed the normalized number of weekly warnings. Because of a failure in a data collection device in vehicle #183, the warning data from four testing vehicles (1841, 1830, 1840, and 2075) were used in this analysis. According to the result, we could clearly see the decrease of the number of FCW when the data was compared between stealth mode and active mode [$F(1, 17)=7.934$, $P=0.012$]. It means that FCW from the Mobileye system significantly influenced the driving behavior related to a forward vehicle collision. In addition, there was a weak significant difference on LDW [$F(1, 17)=4.78$, $P=0.044$]. However, there was no difference on PCW [$F(1, 17)=2.65$, $P=0.123$]. According to Table 6.2 and 6.3, three subjects showed significant difference on LDW between stealth mode and active mode (subject 2 [$F(1,6)=10.63$, $P=0.004$], subject 1 [$F(1,24)=24.55$, $P< 0.001$],and subject 5 [$F(1,22)=12.5$, $P=0.002$]). For HDW, only one subject showed a significant difference between stealth mode and active mode ($F(1,24)=16.03$, $P=0.001$).

Table 6.1: Comparison of Normalized Weekly Warning

	LDW		**FCW**		**PCW**	
	Mean	Std	Mean	Std	Mean	Std
Stealth Mode	45.49	21.38	54.02	33.92	0.3778	0.4604
Active Mode	27.01	13.66	19.00	15.54	0.0889	0.2667
P-value	**0.044**		**0.012**		0.123	

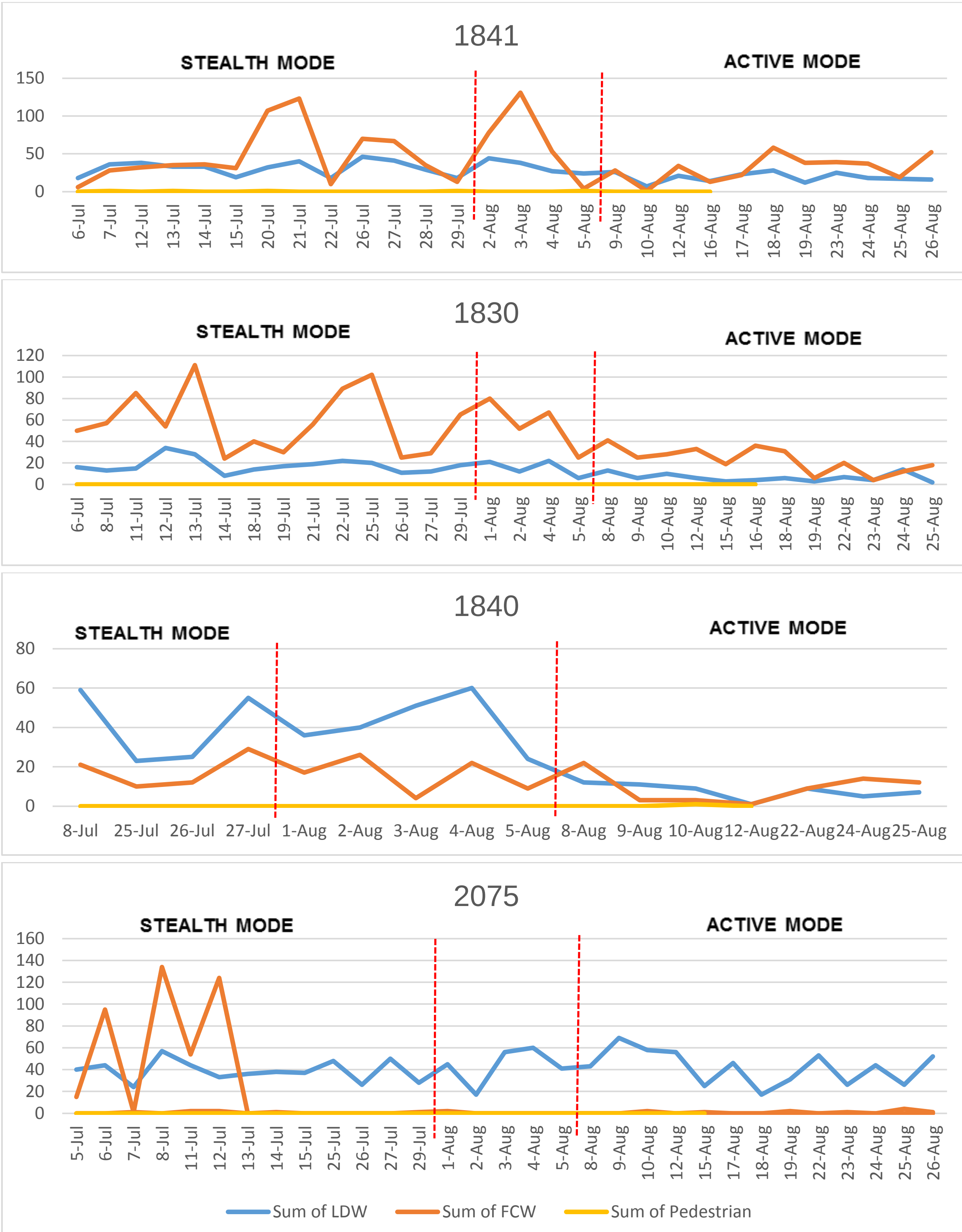


Figure 6.1: Tendency of warning number during the Mobileye Pilot Program

Table 6.2: Number of LDW in different mode

Vehicle #	2075		1840		1830		1841	
Subject #	3		2		1		5	
Mode	**mean**	**StDev**	**mean**	**StDev**	**mean**	**StDev**	**mean**	**StDev**
Stealth Mode	37.78	8.32	34.333	17.926	18.167	7.309	31.545	9.730
Active Mode	42	15.73	7.714	3.773	6.50	3.92	18.818	6.462
P-value	0.472		**0.004**		**<0.001**		**0.002**	

Table 6.3: Number of FCW in different mode

Vehicle #	2075		1840		1830		1841	
Subject #	3		2		1		5	
Mode	**mean**	**StDev**	**mean**	**StDev**	**mean**	**StDev**	**mean**	**StDev**
Stealth Mode	20.44	43.66	17.333	10.116	61.08	30.86	51.73	36.50
Active Mode	0.85	1.21	11.429	9.554	24.25	11.40	31.82	16.69
P-value	0.118		0.403		**<0.001**		0.116	

6.2. Questionnaires

According to the survey results (see details in Table 6.4), the average condition of driving in heavy traffic was 5.4 out of 7, with around 50% on highway while 30% urban driving. In addition, the rating of path familiarity was 5.4 out of 7. Both results indicated that the drivers had experienced medium-high level of workload during the Mobileye 560 driving test. Regarding the attention paid to the Mobileye system, the warnings from the system influenced their visual attention and checked the Mobileye display after they acknowledged an alarm signal. Based on the driver's experience during the pilot program, they felt that both LDW and FCW had a similar accuracy level [F (1, 4) =2.08, P=0.187]. The accuracy of FCW and LDW from user' perspective rating were 4.8 and 5.8 out of 7, respectively.

According to drivers' feedback, three drivers (subjects 1, 3, and 4) reported a positive feedback for the lane departure warning. Two drivers (subjects 1 and 3) felt confident of the forward collision warning. However, most drivers disliked the pedestrian warning. Subjects 1 and 3 (one male and one female) recommended using the Mobileye system in an OATS vehicle. They said that the Mobileye device helped them to maintain lane position and to be aware of measuring the distance from a leading vehicle. Although it took a time to be familiar with both LDW and FCW, both drivers had no problem with using the Mobileye device after they were getting used to it. The user acceptance level of subject 1 and 3 were 80% and 78%, respectively. However, subjects 2 and 4 expressed negative feedback of using the Mobileye system. Subject 2 said that the warnings distracted and annoyed him due to a lot of false warnings (user acceptance level: 20%). He would prefer to use the Mobileye device in a personal car rather than a commercial vehicle because passengers got nervous due to the warnings. Alarm sound sometimes made him change his visual attention away from the road. When he drove in a city with heavy traffic congestion, he was often frustrated by the forward collision warnings. Subject 4 also mentioned several negative comments about using the Mobileye system. Among them, he experienced that the lane departure warning did not work accurately when there were heavy rains. He also felt the forward collision warning function should be improved further, because the device was not effective in larger cities. Subject 5 were medium. He was fine with keeping the Mobileye system in a vehicle. For the pedestrian warning, most drivers wrote negative comments. They said that the pedestrian warning was ineffective and inaccurate.

Table 6.4: Phase 2 Survey Results

Question	**Scale**	**Mean**	**SD**	**Min**	**Max**
Age	-	64	13.78	39	80
General driving experience (year)	-	48.8	14.90	22	65
Working experience of OATS (year)	-	5.5	4.898	1	15
Familiarity of driving path	1 to 7	5.4	1.2	4	7
How often met with heavy traffic	1 to 7	5.4	1.496	3	7
Percentage of highway driving	0 to 100%	50%	29.15%	15%	100%
Percentage of urban driving	0 to 100%	30%	18.97%	15%	60%
Attention on Mobileye system	1 to 7	4.8	1.6	2	6
Frequency of checking Mobileye display	1 to 7	5.8	1.94	2	7
FCW accuracy from drivers' experience	1 to 7	4.8	1.16	3	6
LDW accuracy from drivers' experience	1 to 7	5.8	0.748	5	7
Improvement in driving behavior	1 to 7	5.4	1.02	4	7
Effectiveness of Mobileye system	1 to 7	5.8	0.748	5	7

6.3. User Acceptance Level

Table 6.5 showed the average score of the user acceptance level of the Mobileye 560. According to the five drivers' responses, their acceptance level of the Mobileye system was about 69.28 out of 100. Comparison of user acceptance level between FCW and LDW showed that there was no significant difference [$F(1, 4) = 0.05$, $P = 0.824$].

Table 6.5: Acceptance Level (Scale 0 – 100%)

Item	Mean	SD	P-Value
Overall User Acceptance	**69.28**	24.91	
User Acceptance of FCW	**70.71**	24.26	0.824
User Acceptance of LDW	**74.28**	19.351	

7. Discussion and Conclusion

7.1. Overview

This study investigated the likely effect of collision avoidance technology (CAT) systems. During Phase 1, the effects of various styles of CAT systems were tested. Several field trials of CAT systems were conducted in order to understand drivers' responses regarding the lane departure warning (LDW) and the forward collision warning (FCW). Twenty students from the University of Missouri – Columbia participated in this experiment.

According to the results of the Phase 1 study, the Mobileye system was decided as the best choice for the Phase 2 study. The objective of the Phase 2 study was to estimate the potential benefits of implementing a CAT system for public transportation. Five professional drivers from OATS participated in this study and tested the Mobileye 560 device for several weeks.

The results of Phase 1 and 2 studies showed that a CAT system was generally accepted by drivers and appeared to have positive effects on their driving behavior. The overall effectiveness of a CAT system was about 75%, and the acceptance was about 69%. However, we found several factors that could influence the effectiveness of a CAT system. First, the drivers' reliability was subjected to change over a period of time. After the participants had repeatedly been exposed to warning signals, their responses to the warnings were different from their initial reaction. Some participants became more positive while others were not because they felt it as a nagging critique of their style of driving. Secondly, the participants adjusted their reliability of a CAT system based on the level of the false warning rate. During the Phase 1 experiment, after the drivers experienced a high level of the false warning rate, they trusted the system less and ignored the warnings more often. After the drivers continuously experienced a high false warning rate, they considered warnings as a nuisance. Eventually, it significantly reduced the effectiveness of the CAT systems. Third, it is more efficient to provide the warnings through multiple cognitive channels instead of using a single cognitive resource. According to the EMG data, we found that the drivers who used Audiovox system (auditory alarm only) experienced a high level of psychophysiological stress compared to others who tested the CAT device with the combination of visual and sound alarm. Finally, the effectiveness of a CAT system could be significantly influenced by weather and road conditions. Based on our data, the participants' responses to LDW were significantly different between rural and highway driving. Also, one of the OATS drivers reported that he was unpleasant to use a CAT system while driving in heavy rain conditions.

All our findings indicated that it was extremely important to understand how drivers set their threshold on whether to accept the warning signal. In addition, a CAT system must be designed to minimize any potential distractions caused by the warning.

7.2. Main points

- The results of Phase 1 and 2 studies detailed in this report predict significant crash reductions with the introduction of a CAT system.
- Eye tracking analysis showed that the existence of a visual warning and the location of a visual display are very important to optimize the warning perception and to minimize the distraction caused by the warnings from CAT systems.
- The device that provided only auditory warnings (e.g., the Audiovox LDWS 100), is not recommended for a collision avoidance system. EMG data results revealed that the warnings became a nuisance and distracted drivers.
- NASA-TLX results showed that none of the tested CAT devices increased the driver's perceived workload during the Phase 1 experiment.
- A radar sensor with expansive fields of view (the RD-140) provided greater results for detecting a forward collision, but it also increased the false-positive responses.
- The best CAT systems marked 72% (the Mobileye 560) and 73% (the RD-140) of effective warning acceptance and 40% (the Mobileye 560) and 43% (the RD-140) of false-positive responses.
- According to the sensitivity analysis results, the effectiveness of LDW and FCW were 76% and 74.5%, respectively.
- The average reaction time of FCW (2.81sec) was slower than the average reaction time of LDW (1.20 sec). According to the research done by Sivak, Post, Olson, and Donohue (1981), the recommended reaction time is 1.25 ($\pm$ 0.6) seconds to properly respond unpredicted events.
- As many as 75% of drivers (3 out of 4) showed significant differences in driving behavior after they used a CAT device (the Mobileye 560).
- Sixty percent of drivers (3 out of 5) reported a positive feedback for the lane departure warning. Forty percent of drivers (2 out of 5) felt confident of the forward collision warning. However, most drivers disliked the pedestrian warning.
- The OATS drivers reported a 69.28% of acceptance level of using the Mobileye 560 device.

7.3. Limitations

While this study successfully quantified the effectiveness of a CAT system, there are several identified limitations. First, this study only considered a limited age group of drivers. According to the research done by Son et al. (2015), an advanced driver assistance system is more effective to older drivers over age 70. Future research should consider recruiting the entire age group. Second, although we were able to estimate the benefits of using a CAT system through analysis of survey and experimental data, it was impossible to predict the reduction rate of vehicle crashes without simulations or closed-course driving experiments. Hence, for future study, we need to simulate the near crash and crash scenarios in different traffic and weather conditions to understand the important form factors that increase the effectiveness of a CAT system. Third, other collision avoidance technologies, such as LIDAR, autonomous emergency braking, traffic jam assist, super cruise, free space detection, and animal detection, should be tested. Finally, it is recommended that future research evaluate the CAT systems for longer duration of time to see if the acceptance and effectiveness of the systems change over time.

7.4. Conclusion and Recommendations

This study investigated the acceptance and the effectiveness of CAT systems through on-road field operational tests using eye tracking, EMG, HD-cam 360 degree video, and survey data. The Phase 1 study involved an open-course driving experiment in a passenger vehicle, and the Phase 2 study was conducted on OATS drivers in a public transportation service vehicle. The results have conclusively shown that CAT systems are effective in improving driving behavior. However, there is still room for improvement in terms of the effectiveness and the user acceptance level.

In general, a CAT system senses other road users and intervenes if the system detects possible crash conditions. According to the study, the greatest benefit was predicted to result from systems that combine auditory and visual alarms, with a user-friendly UI display unit, and wide angle system. The CAT system should be designed to minimize the probability of false warnings and to increase the effective warning rate. Moreover, many drivers are subject to distraction. Hence, the warnings should not create any distractions to drivers. Visual distraction is one of the key factors that affect driving behavior (Bakowski, Davis, & Moroney, 2015). Since driver distraction contributes to approximately 43% of motor-vehicle crashes, the warnings should be designed to avoid any visual distractions.

It can be concluded that it is essential to evaluate how a driver uses new in-vehicle technology to avoid unexpected negative impacts and provide appropriate safety parameters. Encouragement should be given to drivers in installing the CAT systems as doing this shows satisfactory effectiveness and acceptance level. Finally, we recommend several points to improve the effectiveness of the CAT system.

- Encourage the creation of performance standards for the device’s reliability measuring the effectiveness of the CAT system.
- Design the CAT system to maximize the effective warning rate and minimize the false warning rate.
- For the lane departure warning, it is highly recommended to test another cognitive stimulus instead of an auditory alarm. When people drove in heavy traffic, the alarm sound often annoyed and distracted them. According to the

research done by the Insurance Institute for Highway Safety (IIHS), 65% of drivers turn off the lane departure warning. Based on feedback from the drivers, they were more likely to turn off the CAT system if it used audible warning. They also did not like having their passengers hear it.

- For the forward collision warning, it is highly recommended to test the vibrotactile stimulus to reduce the average reaction time. It has been proven that the reaction time of drivers is much less with tactile warnings compared to other forms of warning (Scott & Gray, 2008).
- To make a driver aware of the circumstances beyond his capability to detect, a series of warnings could be used instead of a single warning, with an adjusted level of sensitivity.

8. Future Collision Avoidance Technology

Collision avoidance technology (CAT) systems have been implemented in many new passenger vehicles. Six of the most common CAT systems are forward collision warning, auto brake, lane departure warning, lane departure prevention, adaptive headlights, and blind spot detection. These technologies are based on hardware sensors (e.g., LIDAR, ultrasonic, infrared, cameras, GPS, lasers, and short- and long-range radar) and computer algorithms to monitor what is going on around the vehicle (see Figure 8.1). Although there are issues related to the acceptance and the effectiveness of the CAT systems, as we discussed in the previous section, most researchers agree that there is a net benefit in using a CAT system, regardless. To make these advanced safety systems better, many researchers and vehicle manufacturers are developing and testing other new technologies. In this section, we address some of the new, upcoming CAT systems in the passenger vehicle market.

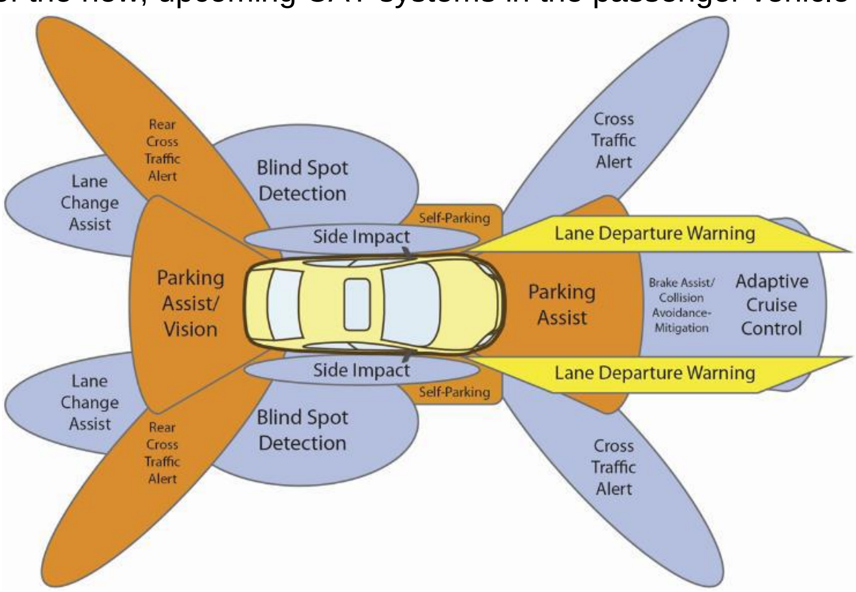


Figure 8.1: Driver Assistance features

- *Vehicle-to-everything (V2X) Communication*: V2X technology is the next step in the advanced safety systems. V2X is vehicular communication between both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I). Many automobile manufacturers, such as BMW, Audi, Honda, General Motors, Volvo, and Daimler, are working on this technology. V2V is known as VANET (vehicular ad hoc network). It allows vehicles to communicate to each other directly by using dedicated short-range communications (DSRC) devices. Through V2V communication, the vehicles can exchange speed and real-time location data with other vehicles. By using V2I communication, the system could request current traffic information from a traffic management system and access the best possible routes. It can also provide advisories to in-vehicle systems on the timing of traffic signals to optimize fuel efficiency and time-saving driving habits. Vehicles with V2X communication systems should be able to tell drivers how many seconds they have left before a vehicle crash. Hence, V2X is required for the parallel development of self-driving technology. To develop the turnkey self-driving system for V2X communication, Delphi Automotive and Mobileye are doing research together. Up to now, the most well-known fully autonomous vehicles is the Google Driverless car. Since Google announced its first fully functional driverless car, they had tested their fleet of vehicles a total of 1,725,911 mi.
- *Advanced Rear Cross-Traffic Alert*: The current real cross-traffic alert (RCTA) comes with plenty of limitations. For example, if a vehicle is stuck between two large objects, then the RCTA system does not interpret the rear scene accurately. According to the research done by AAA, the system showed 48% and 30% of the failure rate of motorcycles and passing vehicles, respectively. However, the advanced RCTA system can interpret full rear view vision by using multiple high-resolution camera sensors (Trifocal + multiple cameras: at least one camera covers any segment of the field of view). The warning consists of an auditory and visual cue in either the outside mirror or the rear camera. This technology is beneficial if the drivers do not have clear visual perception.
- *Adaptive Forward Collision Warning Algorithm*: It provides early warnings for collision avoidance without noticeably increasing the risk of false alarms in real traffic. The algorithm is designed to provide an adaptive threshold for triggering the forward collision warning by using the predicted steering threat number (STN) and the braking threat number (BTN).
- *Distraction and Drowsiness Detection*: According to Linkov (2015), “Mercedes-Benz pioneered one of the first, which uses a computer algorithm that compares a driver’s steering behavior with those recorded at the start of the trip”. He also said that some track the driver’s eye movements with an in-car camera, noting rapid or prolonged eye blinks. By using the eye tracking technologies from Tobii, SMI, and Smart Eye, researchers can gain insight into driving behavior and detect drowsiness and distracted driving. Volvo is one of the companies that conducting research into driver

sensors to create cars that get to know their drivers. According to the article ("Volvo Cars Conducts Research into Driver Sensors to Create Safer Cars,"), “through systems that can recognize and distinguish whether a driver is tired or inattentive, the eye tracking technology can detect closed eyes or what the driver is looking at. By placing a sensor on the dashboard to monitor aspects such as in which direction the driver is looking, how open their eyes are, as well as their head position and angle, it is possible to develop precise safety systems that detect the driver’s state and can adjust the car accordingly. This means that the car will ensure that it does not stray out of the lane or get too close to the car in front when the driver is not paying attention, as well as being able to wake a driver who is falling asleep”.

- *Driver Alcohol Detection System:* This system prevents alcohol-impaired driving in a transparent manner. Researchers developed two different technological approaches (breath-based and touch-based systems) to measuring driver alcohol level. A touch-based approach detects alcohol in human tissue. For a breath-based approach, it allows assessment of alcohol concentration in the exhaled breath.
- *Vibrotactile System*: It consists of several vibrating elements or tactors mounted in a driver’s seat, wheel, or wearable display. The tactile feedback can significantly reduce the driver’s workload compared to visual or auditory feedback, particularly in the high traffic condition. Recently, General Motors is testing a new lane departure warning system that sends vibrations to the driver’s seat when he or she unintentionally begins to depart from the current lane. They are also testing a wearable vibrotactile display for automotive route guidance.
- *Evolution of Sensing*: the improvement of sensing technology could also increase road safety as well. The current mono front-facing camera can detect up to a 50-degree angle. The engineers from Mobileye Company predict that the angle will be wider (The year 2018: 75 degree, The year 2019: 100 degree). In addition, the resolution of camera sensor will go up to 7 megapixels with a low light sensitivity function in Year 2020.

In conclusion, there are many others developing high-end safety functions to improve the effectiveness of collision avoidance technologies, such as semi-autonomous highway driving, called Super Cruise, free space detection path delimiters, animal detection, and traffic jam assistance. However, we need to understand about these systems to make sure that all technologies are working as expected, not only on test track performance but also on open road effects.

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Appendix A: List of CAT Systems (double click to open the table below)

Company	Product	Product Display	Active/Passive	Technology	FCW	LDW	HMW	PCW	TSR	SLI	DVR	Eye tracking	Blind spot detection	Autonomous braking	Alert data is stored?	Website	Description
Mobileye	Mobileye 560		A	Camera	Y	Y	Y	Y	Y	Y					Y	http://www.mobileye.com/products/mobileye-5-series/mobileye-560/	Mobileye® 560 allows you to receive critical real- time warnings straight to your personal Smartphone, in addition to the existing EyeWatch™ display. Mobileye® 560 is a safety solution for collision prevention and mitigation. The system includes a smart camera located on the front windshield inside the vehicle. It utilizes Mobileye's vehicle, lane, traffic signs and pedestrian detection technologies to detect traffic signs, measure the distance to vehicles, lane markings and pedestrians, providing the driver with life saving alerts.
Mobileye	Mobileye C2-270		A	Camera	Y	Y	Y	Y		Y						http://www.mobileye.com/products/mobileye-c2-s	C2-270 includes a "smart" camera located on the front windshield inside the vehicle. It functions as a "third eye" on the road, utilizing Mobileye's vehicle, lane, speed sign and pedestrian detection technologies to measure the distance to vehicles, lane markings, speed signs and pedestrians, providing the driver with life saving alerts.
Mobileye	Mobileye Shield +		A	Camera (4)	Y	Y	Y	Y		Y					Y	http://www.mobileye.com/products/mobileye-shie	Mobileye Shield + only alerts drivers if a collision is imminent with vulnerable road users, not inanimate objects. In addition, this solution includes a full telematics system which tracks the vehicle and reports all warnings made by the Mobileye System to your fleet management system, providing fleet managers with valuable information about their drivers' daily driving behavior.
Safe Drive Systems	RD 140		A	Radar/Camera	Y	Y	Y									http://safedrivesystems.com/rd140/	Safe Drive Systems uses advanced radar and camera technologies to constantly monitor your distance to vehicles ahead of you as well as help keep you from drifting from your lane. The real-time analysis and warning of the potential dangerous driving conditions can help prevent serious or fatal injuries to you and your family
Seeing Machines	Driver Monitoring Systems		A	Camera								Y				http://www.seeingmachines.com/solutions/autom	Seeing Machines' real-time fatigue and distraction detection technology helps organizations prevent incidents before they happen.
Smart Drive	Safety		P													https://www.smartdrive.net/smartdrivesafety.aspx	SmartDrive focuses on driving skills. We pinpoint specific driving maneuvers and how to personally improve the driver's performance. Our expert analysts review, analyze, categorize and prioritize the most relevant events to coach, so you don't have to. Then, drivers are coached and improve driving skills—reducing fuel wasting maneuvers. Fleets experience reduced risk and significant tangible savings.
PLK Technologies	Optian		A	Camera	Y	Y					Y					http://plktech.trustpass.alibaba.com/product/1675	FCW function is intended to assist the driver in avoiding or mitigating the impact of rear-end collisions. LDW is driver's convenience function; a warning sound is issued when OPTIAN detects an unintentional lane departure. Beep & Watch can detect the movement of a vehicle in front while waiting for the traffic light to change and will inform the driver of any front movement through a warning tone, and DVR function can record accident video data through the Full-HD front camera and the VGA rear (if equipped) camera.
PLK Technologies	Roadscope XG		A	Camera		Y					Y					http://plktech.trustpass.alibaba.com/product/1148	It can warn the driver when the vehicle drifts from its lane and can automatically record events in cases of accidents. Also it can detect the movement of the front objects while waiting in the traffic jam or in front of the traffic light. If any movement such as the departure of the front vehicle is detected, it will inform the driver with the auditory warning.
PLK Technologies	ROADSCOPE LX		A	Camera	Y	Y										http://plktech.trustpass.alibaba.com/product/1237	The Roadscope LX can help drivers to avoid / mitigate potential driving accidents by providing drivers with the audible alarming or haptic vibration in advance . can monitor the distance and the speed between the host car and the front car. If there are any potential risks of collision, it will warn the driver by using its warning system. It can generate noticeable warning sound and vibration if the system detects an unintentional lane departure. And can detect the movement of the front objects while waiting at traffic lights . It will inform the driver of any front vehicle movement .
MOVON CORPORATION	MDAS-10		A	Camera		Y					Y					http://mdas.co.kr/eng/product/product1_1.php	MDAS-10 has been developed as Advanced Driver Assistance System (ADAS) based on a single camera to help motorists drive safely. MDAS-10 includes major functions such as Lane Departure Warning (LDW) and Car Digital Video Recorder (DVR). Additionally, MDAS-10 provides Digital Tachograph (DTG) and can be expanded with a two-channel camera for Back-Up Aid (BUA) (an extra rear camera is needed for BUA).
MOVON CORPORATION	MDAS-20		A	Camera	Y	Y					Y					http://mdas.co.kr/eng/product/product1_6.php	MDAS-20 has been developed as Advanced Driver Assistance System (ADAS) based on a single camera to help motorists drive safely. MDAS-20 includes major functions such as Forward Collision Warning, Lane Departure Warning (LDW) and Car Digital Video Recorder (DVR). Additionally, MDAS-20 provides Digital Tachograph (DTG) and can be expanded with a two-channel camera for Back-Up Aid (BUA) (an extra rear camera is needed for BUA).
MOVON CORPORATION	OEM		A	Camera	Y	Y					Y					http://mdas.co.kr/eng/product/product1_4.php#lir	MDAS-B4 is developed for commercial vehicles such as trucks, buses for driver assistance system based on monocular camera. MDAS-B4 provides Lane departure warning(LDW), forward collision warning(FCW), high-beam assist(HBA), and one-channel driving recorder
MOVON CORPORATION	MDAS-MLF1		A	Camera	Y	Y										http://mdas.co.kr/eng/product/product1_7.php#lir	MDAS-MLF1 Module is the solution to feature LDW(Lane Departure Warning) and FCW(Forward Collision Warning). MDAS-MLF1 captures the image from CMOS image sensor and runs LDW&FCW algorithms using that images, sends LDW&FCW results to other processors through UART interface. It is a co-processor system which can be integrated with other system such as Car Navigation, Black-Box, Car Audio and other car components.
MOVON CORPORATION	MDAS-3LF		A		Y	Y					Y					http://mdas.co.kr/eng/product/product1_9.php	
Smartmicro	UMRR-0A (Type 29 long ranage)		A	Radar	Y											http://www.smartmicro.de/automotive-radar/prod	The Smart Microwave Sensor radar is an after-market device fitted to trucks that record, warn and identify near miss and dangerous driving scenarios.
Meritor Wabco	OnLane		A	Camera		Y										http://www.meritorwabco.com/Product,1,36,2,OnL	OnLane™ Lane Departure Warning System with SafeTraK technology by Takata is a camera-based warning system that helps your vehicle avoid unintentional lane drifting. The system utilizes a camera mounted near the top center of the vehicle windshield to monitor and calculate the vehicle's position within the lane. When OnLane detects the vehicle crossing lane markings without the turn signal being activated, the system sounds a audible warning. This alerts the driver to take a corrective action to prevent potential collisions or run-off-road accidents.
Meritor Wabco	OnGaurd		A		Y											http://www.meritorwabco.com/product/OnGuard-CMS	
Goshers	Blind Spot Detection System		A	Radar									Y			http://www.goshers.com/BSDS	An Aftermarket Blind Spot Detection System includes 2 sensors which can detect any objects in the most common blind spot areas.Will alert the driver anytime any type of object is detected by either sensor (including curbs, walls, posts and other objects)This unit is limited to a maximum range of approx. 10 feet per sensor. Uses reliable, Sonar technology with detection in less than 120ms.
Vox electronics	LDWS100		A	Camera	Y	Y					Y					http://www.voxxtechservices.com/advent/lane-de	The LDWS100 recognizes traffic lane markings as well as vehicles in front of you and warns a driver with an audible tone when the vehicle begins to move out of its lane (unless a turn signal is on in that direction) on freeways and arterial roads when traveling at or above 35mph or vehicles that suddenly are too close for safety in front of you when driving at or above 15mph.
Garmin	NuviCAM LMTHD		A	Camera	Y	Y					Y					https://buy.garmin.com/en-US/US/on-the-road/aut	With a built-in dash cam that continuously records your drive, plus features that enhance driver awareness, nüviCam LMTHD takes GPS auto navigation to a whole new level.
Open XC	Nighttime Forward Collision Warning		A	Camera + Android system	Y											http://openxcplatform.com/projects/nightvision.ht	This Nighttime Forward Collision Warning is an Android app that uses OpenXC and a standard USB webcam to add "night vision" to a car with off-the-shelf parts. The webcam faces forward from the dashboard and uses edge detection to detect objects on the road in the path of the vehicle (i.e. deer). **OpenXC™ is a combination of open source hardware and software that lets you extend your vehicle with custom applications and pluggable modules.** It uses standard, well-known tools to open up a wealth of data from the vehicle to developers, even beyond OBD-II.
Autoliv	Vision Systems		A	Camera	Y	Y		Y						Y		http://www.autoliv.com/ProductsAndInnovations/	Autoliv's pioneering work with camera-based vision systems virtually gives the driver an additional pair of eyes, scanning the road ahead for danger. Advanced algorithms allow the camera to "see" and track other vehicles, speed signs and lane markings, warning the driver when the car is in danger of colliding with pedestrians or other vehicles.
Gentex Corporation	Driver Assist		A	Camera	Y	Y		Y	Y							http://www.gentex.com/automotive/products/forw	Driver Assist systems that offer features like lane departure warning, forward collision warning, traffic sign recognition, and pedestrian detection also use a miniature camera-on-a-chip integrated into a Gentex auto-dimming mirror combined with algorithmic decision-making. Gentex is in development of Driver Assist systems in conjunction with Mobileye®, the global pioneer in the development of vision-based driver-assistance systems.
Banner Engineering	R-GAGE QT50R-AFH		A	Radar												http://info.bannerengineering.com/cs/groups/publ	High sensitivity radar-based sensors ideal for collision avoidance on board mobile equipment, like reach stackers, forklifts, and mining vehicles. The sensor is able to detect a proper object (see Detectable Objects) from 1 to 24 m (3.3 to 78.7 ft), depending on target

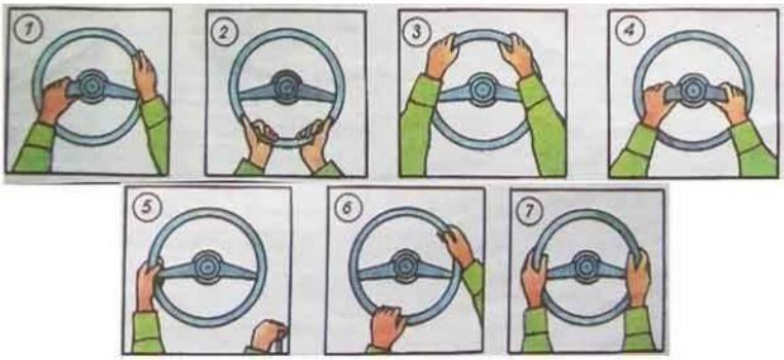
Appendix B: Arm Posture during the Phase 1 experiment

To reduce noise EMG signals and collect valid data, the participants must hold the wheel with specified postures:

1) Keep two hands on the steering wheel and maintain a same height during the experiment. The recommended positions are 3 o'clock (right hand) and 9 o'clock (left hand) or 2 o'clock (left hand) and 0 o'clock (right hand)

2) Do not use palm for turning the wheel
3) Make one hand over 90 degree when you turn left or right

(Question)
Which posture is the most appropriate posture during the test? (Answer: 7)



Appendix C: NASA-TLX survey form

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Appendix D: Phase 2 Survey Questions

Please answer the following questions regarding your background experience. This information will not be used to evaluate you personally. We are asking for this information so we are in a better position to understand how the findings may relate to operator experience or other demographic characteristics.

1. Age: ___________

2. Gender: Male Female

3. Driving experience (years): ___________

4. How long have you been work as this driving position (years)? __________________

5. What is the starting date of using this collision avoidance system?

(MM)	(DD)	(YEAR)

6. Are you familiar with the work path when you use the collision avoidance system?

Very unfamiliar	1	2	3	4	5	6	7	Very familiar

7. How often did you experience heavy traffic with collision avoidance system?

1	2	3	4	5	6	7

Never Sometimes Always

8. How often did you drive on highway?

1	2	3	4	5	6	7

Never Sometimes Always

9. How often did you drive on urban road?

1	2	3	4	5	6	7

Never Sometimes Always

10. How do you think the collision avoidance system has helped you reform your driving habits?

a. Yes, very helpful
b. Helps a bit
c. No help at all (Please move to Q#12)

10.1 Do you feel that the system helps you improve your signal habits while changing lanes, and driving habits in maintaining the lanes**?**

a. Yes, very helpful
b. Helps a bit
c. No help at all
d. Lane departure warnings are very troublesome, and I have no need for them.

10.2 Do you feel that the system helps you improve your habits in keeping a safe distance from the vehicle in front of you when driving?

a. Yes, very helpful
b. Helps a bit
c. No help at all
d. Warnings are very troublesome, and I have no need for them.

11. How often do you pay attention to the collision avoidance system?

1	2	3	4	5	6	7
Never			Sometimes			Always

12. How often did you check the collision warning display when you heard a warning sound?

1	2	3	4	5	6	7
Never			Sometimes			Always

13. Do you monitor the display of the system (seconds / distance) to maintain a safe distance?

a. I often stare at the screen, using the data to maintain a safe distance, and try to avoid warnings.
b. I rarely look at the monitor, using mainly the acoustic signal to keep a safe distance.
c. I do not stare at the screen and can keep a safe distance by intuition, but it is useful to have the system just in case.
d. I do not need the monitor and I have no need for alerts.

Please indicate how you feel:

14. Did you feel safe driving with this collision avoidance warning compared to driving without it?

Very unsafe	1	2	3	4	5	6	7	Very safe[4]

15. Did you feel safe driving with this **forward collision warning?**

Very unsafe	1	2	3	4	5	6	7	Very safe

16. Did you feel safe driving with this **lane departure warning?**

Very unsafe	1	2	3	4	5	6	7	Very safe

If you feel unsafe, please explain why:

17. Would you desire to drive with the collision avoidance warning?

Very undesirable	1	2	3	4	5	6	7	Very desirable[5]

18. Would you desire to drive with this **forward collision warning?**

Very undesirable	1	2	3	4	5	6	7	Very desirable

19. Would you desire to drive with this **lane departure warning?**

Very undesirable	1	2	3	4	5	6	7	Very desirable

If you feel undesirable, please explain why:

[4] Help drivers to get more safety driving, instead of bothering them
[5] You are very interested that the system remain in your vehicle after the test

20. Did you feel unpleasant driving with this collision avoidance warning compared to driving without it?

Very unpleasant[6]	1	2	3	4	5	6	7	Very pleasant

21. Did you feel unpleasant driving with this **forward collision warning?**

Very unpleasant	1	2	3	4	5	6	7	Very pleasant

22. Did you feel unpleasant driving with this **lane departure warning?**

Very unpleasant	1	2	3	4	5	6	7	Very pleasant

If you feel unpleasant, please explain why:

23. Did you feel annoying driving with this collision avoidance warning compared to driving without it?

Very annoying[7]	1	2	3	4	5	6	7	Very comfortable

24. Did you feel annoying driving with this **forward collision warning?**

Very annoying	1	2	3	4	5	6	7	Very comfortable

[6] Drivers might think the system is keeping judging them even sometime the warning is helpful

[7] Feeling about the warning sound and sensitive level if they feel like the warning is the noise

25. Did you feel annoying driving with this **lane departure warning?**

Very annoying	1	2	3	4	5	6	7	Very comfortable

If you feel annoying, please explain why:

26. Which type of warning you think influenced you a lot?

a. Visible warning on display
b. Sound warning
c. Equally influenced
d. Neither influenced

27. Do you think the collision avoidance system provides the accurate[8] **forward collision warning**?

1	2	3	4	5	6	7
Never			Sometimes			Always

28. Do you think the collision avoidance system provides the accurate **lane departure warning**?

1	2	3	4	5	6	7
Never			Sometimes			Always

29. Did you make any changes of driving after you saw or heard a warning from the system?

1	2	3	4	5	6	7
Never			Sometimes			Always

[8] Accurate means if the system provides correct warning or not. Sometime, the system might give the waring though there is no dangerous situation and wrong behavior of driver

30. Please choose which condition you think you were in when there was a warning:

a. Ignore the warning and continuously driving in the same way as before.
b. Take a glance of the warning system but without driving behavior changed
c. Change the driving behavior

30.1. If you choose **option a**, how often did you ignore the warning?

1	2	3	4	5	6	7
Never			Sometimes			Always

30.2. If you choose **option c**, how often do you change driving behavior because warning reminds you something you have not noticed?

1	2	3	4	5	6	7
Never			Sometimes			Always