

## **ABSTRACT**

DENG, YULIN. Effect of Levels of Automation and Vehicle Control Format on Driver Performance and Attention Allocation. (Under the direction of Dr. David Kaber).

Enabled by recent technological advances, automated and “autonomous” driving systems are being developed and put into service. Previous research studies in this area have shown that the role of drivers has changed due to higher levels of vehicle automation. Although the effect of automation on driver distraction has been examined, few studies have assessed effects of various levels of automation (LOAs) on driver performance, particularly under hazard conditions. Moreover, a recent vehicle survey revealed that many major automobile manufacturers are developing novel control formats for accessing automation functionality, including touch screens along with traditional manual controls; however, no prior research has made direct comparison of these designs when driver make use of different vehicle LOAs.

The objective of this study was to conduct a driving simulator-based assessment of driver visual behavior and hazard negotiation in use of manual and touch screen control interfaces, under manual driving or while using adaptive cruise control (ACC; i.e., an automated assistance system that controls the longitudinal motion of the vehicle). Twenty-two participants (9 females and 13 males) each completed six simulated driving trials presenting a rural environment with half the participants using ACC (and the other half driving manually). Participants were informed of the possibility of hazard exposure during test trials. One hazardous situation was presented in each scenario, and hazard negotiation (reaction time) was analyzed for successful avoidance trials. While driving, participants also performed music selection tasks using one of the three control formats,

including: (1) touch screen only; (2) manual control only; or (3) a combination of manual and touch screen control (the participant could use any function from among the manual and touch screen controls). All participants experienced all three types of control formats. Data on driver visual behavior during secondary task performance (fixation frequency and longest glance duration on a media control panel) were collected using an eye tracking system. Driver secondary task performance measures (task completion time and number of errors) were also recorded.

Results revealed automated-driving to produce significantly shorter hazard reaction times than manual driving. A significant number of drivers using automation placed their feet over the brake pedal while driving in order to quickly avoid any possible hazard. Regarding vehicle control format, secondary task completion time with the touch screen and combination format was significantly longer and produced more errors in comparison to manual control use. Furthermore, while using the touch screen, drivers exhibited significantly greater visual workload (higher fixation frequency, and longer glance duration on the media panel) as compared to the other control formats. When given the option of using both touch screen and manual controls, the majority of drivers demonstrated (through actions) a preference for manual controls over the touch screen.

Findings indicate that when the possibility of hazard exposure is communicated to drivers prior to driving tasks, an automated-driving condition allows for greater attention allocation for hazard detection and avoidance. Regarding the effect of control format, findings suggest that touch screen controls leads to greater visual workload and degraded secondary task performance, possibly due to the lack of haptic and kinetic feedback.

Study results also demonstrated that the redundancy of control formats (the combination of touch screen and manual controls) was associated with degraded secondary task performance, which might be related to user confusion and hesitation when posed with multiple available formats.

Results of this research are expected to enhance understanding of driver behavior under automated and manual driving, and provide applicable guidance for in-vehicle control format design, ultimately supporting increased driver safety. Caveats include the using of a driving simulation as well as a convenience sample for testing.

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Effect of Levels of Automation and Vehicle Control Format on Driver Performance and  
Attention Allocations

by  
Yulin Deng

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## **BIOGRAPHY**

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# 1. Introduction

## 1.1 Levels of vehicle automation

Enabled by technological advances, the recent years have seen an increasing number of automobile driving tasks being automated. To provide common terminology for automated driving, the Society of Automotive Engineers (SAE) identified six levels of vehicle automation (SAE, 2016), from complete manual driving (level 0) to full automation (level 5). The SAE definitions have also been adopted by the Department of Transportation for defining driving automation in on-road motor vehicles (SAE, 2016).

According to SAE, the Level 0 automation, which is no automation, requires the human drivers to manually control all aspects of the dynamic driving tasks (SAE, 2016). At this level, full time performance of steering, speed control and environment monitoring are expected of human drivers. Some warning systems may be provided as driver aids.

The SAE Level 1 automation is defined as “driver assistance”, where a driver assistance system performs mode-specific execution of either steering or speed control. All other aspects of the dynamic driving task are expected to be performed by the human driver. Common technologies, as part of Level 1 automation, include adaptive cruise control (ACC) and lane keeping assistance (LKA).

The SAE Level 2 automation is defined as “Partial automation”, where the driver assistance system automatically executes both the steering and acceleration/deceleration functions, while the human driver performs all other aspects of the dynamic driving task.

The SAE Level 3 automation is defined as “Conditional Automation”. At this stage, the system performs all aspects of the dynamic driving tasks, including steering and speed control. The human drivers are only expected to respond to requests to intervene. The major difference between level 3 and level 2 automation is that drivers are relieved of driving environment monitoring under level 3 automation.

The SAE Level 4 automation is “High Automation”. The system performs all aspects of the dynamic driving task, and the driver assistance system execution is expected even when the human driver does not respond to requests for intervention. The system capability is limited in terms of driving modes (e.g., parking, driving on motorway, driving on freeway) and geographical locations. (SAE,2014).

The SAE Level 5 automation is “Full automation”, where all roadway and environmental conditions are expected to be managed by the driver assistance system, and the system capability includes all driving modes.

Among the vehicle automation levels identified by SAE, Level 1 automation has been extensively deployed in commercial vehicles (Christensen et al., 2015). For example, ACC systems, which control the longitudinal speed of a vehicle and automatically maintain a constant safe headway to a lead vehicle (SAE, 2016), represents a Level 1 vehicle automation feature, if used alone. Many major automobile manufacturers, including Tesla, Volvo, BMW, Acura, Chevrolet, Dodge, Audi and Ford, have made the ACC capability available in their commercial vehicle models (Trimble et al., 2014). Given the wide application of Level 1 vehicle automation in commercial

vehicles, and the extensive utilization of ACC capability on the road, this study focused on the effect of Level 1 automation, particularly ACC, on driver performance in comparison to the manual control (Level 0 vehicle automation). In addition, this comparison represents a conservative approach to determining whether any automation whatsoever causing differences in driver behavior in terms of dealing with critical roadway events.

## **1.2 Vehicle automation and on-road hazards**

Due to the increasing number of automated vehicles operating on public roads, the total number of crashes involving automated vehicles has been significantly increasing as well (Schoettle & Sivak, 2015). This situation has raised some public concern regarding safety issues associated with vehicle automation. From implementation through October 2015, the Google Self-Driving Car has been involved in 16 crashes (Blanco et al., 2016).

Although the total number of crashes involving automated vehicles is low, according to current published data, the fact that automated vehicles are driven mainly in limited and less demanding driving conditions (Schoettle & Sivak, 2015), as well as the relatively low public exposure (Blanco et al., 2016), makes the actual safety implication of such automated vehicles uncertain.

Based on automated vehicle crash rate statistics, much uncertainty still exists about the effect of automation on driver safety under hazard conditions. Further research on automated driving complications is necessary to reveal the safety implication of vehicle automation and to provide a basis for making recommendations regarding effective

automation design for supporting driver safety.

### **1.3 Studies of effects of vehicle automation on driver performance**

As previously identified, ACC can partially automate vehicle control tasks; however, drivers are still required to play an active role in critical traffic situations (Nilsson, 1996). Limitations of ACC sensor systems require drivers to takeover vehicle control in order to avoid collisions (Nilsson, 2013), which makes driver performance capability under hazardous conditions crucial to safety.

While some researchers believe that automation can potentially provide automatic vehicle control, as well as support driver attention and response in imminent crash conditions (Rau et al., 2015), previous studies have raised concerns about the effects of automation on driver hazard negotiation. Endsley and Kiris (1995) reported that following a breakdown of an automated system, driving decision time was longer than when operators used a fully manual system. To further understand driver behavior under automated driving conditions, a literature review was conducted on driver performance with Level 1 types of vehicle automation (e.g., ACC and LKS) with a focus on those studies making comparison with manual driving. Keyword searches on the terms “driver”, “vehicle automation”, and “performance” using databases, including Web of Science (Science Direct), IEEE Xplore digital library (IEEE) and Sage Journals, revealed several studies focused on comparison of driver performance under ACC with manual driving. Six studies attempted to compare driver performance under manual and automated (ACC) driving in terms of driving task performance, mental workload,

situation awareness and hazard negotiation (Shanton et al., 1997; Young & Stanton, 1997; Rudin-Brown et al., 2003; Ma & Kaber, 2005; Flemisch et al., 2008; Gold et al., 2013). Two studies investigated driver hazard negotiation performance under critical conditions (Rudin-Brown et al., 2003; Gold et al., 2013). The findings of these studies are summarized in Table 1, which identifies the driving mode (manual or automated) that produced superior driver performance under specific driving conditions.

Table1: Summary of Previous Research on Driver Performance under Manual and Automated (ACC) Conditions

<b>Studies</b>	<b>Performance of primary driving tasks</b>	<b>Performance of secondary driving tasks</b>	<b>Mental workload level</b>	<b>Situation awareness</b>	<b>Hazard Negotiation</b>
<b>Shanton et al., 1997</b>	Comparable	Automated	Automated	Manual	—
<b>Young, &amp; Stanton, 1997</b>	Comparable	Comparable	Comparable	—	—
<b>Rudin-Brown et al., 2003</b>	Manual	Automated	Automated	Manual	Manual
<b>Ma &amp; Kaber, 2005</b>	Automated	—	Automated	Automated	—
<b>Flemisch et al., 2008</b>	—	Automated	Automated	—	—
<b>Gold et al., 2013</b>	Manual	—	—	Manual	Manual



Regarding primary driving performance, contradictory results have been reported. Two studies indicated that automated driving resulted in less smooth acceleration (Gold et al., 2013) and degraded lane keeping performance (Rudin-Brown et al., 2003), as compared to manual driving. In contrary, Ma and Kaber (2005) observed less deviations in headway distance, less deviation in following speed, and superior lane maintenance performance under ACC control. Two other studies reported that manual and automated driving produced comparable lane and speed maintenance performance (Shanton et al., 1997; Young & Stanton, 1997).

As with performance, mental workload assessment has also revealed some conflicting findings. Lower mental workload in automated driving was observed by four studies (Ma & Kaber, 2005; Shanton et al., 1997; Rudin-Brown et al., 2003; Flemisch et al., 2008). However, Young and Stanton (1997) reported comparable workload among manual and automated driving. Although lower mental workload is seemingly desirable, researchers have argued that a low level of mental load could deteriorate driver performance (Young & Stanton, 1997). The rationale for this argument is that significantly low driver mental workload would lead to a rapid increase in demand when they are posed with a hazardous situation. The researchers speculated that this would make it difficult for drivers to cope with and avoid collisions (Young & Stanton, 1997). Therefore, driver “underload” may substantially affect driver performance, especially if in a hazardous situation.

Regarding secondary task performance, it was generally reported that automated driving led to better secondary task performance (Rudin-Brown et al., 2003; Young, & Stanton, 1997; Flemisch et al., 2008). This finding was attributed to the likelihood of low mental workload associated with automated driving.

Lower levels of situation awareness in automated driving, as compared to manual driving, was observed in three previous studies (Rudin-Brown et al., 2003; Young & Stanton, 1997; Gold et al., 2013). Young and Stanton (1997) explained that under the automated driving condition, drivers were put out-of-the (control) loop, which degraded their attention to environments. Drivers were also found to be more likely to be inattentive and distracted when driving under automated conditions (Rudin-Brown et al., 2003; Gold et al., 2013). However, Ma and Kaber's (2005) findings are counter to these observations, revealing that the use of Level 1 automation (ACC) reduced operator workload and, consequently, led to greater driver SA on the driving task and roadway conditions.

Two studies were found to directly compare driver hazard negotiation under manual and automated driving. Results of these studies suggested that automated driving led to deteriorated hazard negotiation performance, relative to manual driving. Degraded performance under automated driving was indicated by longer reaction time and an increase in collisions (Rudin-Brown et al., 2003; Gold et al., 2013). Researchers have attributed these observation to driver inattention and distraction under automated driving conditions (Rudin-Brown et al., 2003; Gold et al., 2013).

It is important to note that in both of the above studies of driver performance under critical roadway conditions (Rudin-Brown et al., 2003; Gold et al., 2013), participants were not warned of the possibility of automation failures. Given the increasing level of public knowledge of automated driving systems, it is likely that drivers are now more aware of functional limitations of such technology and may exhibit a greater level of suspicion of effective operation. According to previous research, unwarned hazards can deteriorate driver performance; whereas, when driver assistance systems effectively communicate hazards, drivers may demonstrate their full potential to handle critical situations (Beller et al., 2013). Therefore, based on this literature review, there remains a need to examine driver potential to cope with hazardous situations when they are aware of the possibility of occurrence of hazards.

#### **1.4 Survey on vehicle control formats**

In addition to vehicle automation, another trend has been observed in commercial vehicles. Many major automobile manufacturers have implemented multiple novel control formats along with traditional manual controls in their vehicle models, as revealed by a vehicle survey (Table 2). Multiple control formats (touch screen, single function manual control, multi-function manual control) are available in a variety of vehicle models (e.g., Ford Flex 2016; BMW 7 Series 2016; Jaguar InControl Touch, 2016; Nissan Juke 2016; Chevrolet Corvette 2016), and it is common for these control formats to have overlapping functions. This vehicle survey examined models from five major manufacturers. The survey described the available control formats in the five models as

well as the functions that can be controlled with each format (Table 2). In general, single-functional controls can only control one vehicle function. Such controls usually take the form of a button (e.g., a defrosting button controls the window defrost function).

Universal functional manual controls, on the other hand, can control multiple functions (e.g., a control knob can scroll display menus and be used to select different functions).

As shown in Table 2, some functions are available in both manual and touch screen control formats. These overlapping functions are categorized as redundant functions. The most common overlapping functions are the vehicle climate and audio controls (e.g., radio, CD, etc.). Images of the vehicle control panels are presented in Appendix A.

Table 2: Control Format Summary for Vehicle Models Developed by Major Manufacturers

<b>Control format</b> <b>Vehicle</b>	<b>Touch screen</b>	<b>Manual (Single function)</b>	<b>Manual (Universal function)</b>	<b>Redundant functions: Touch screen &amp; manual</b>
<b>BMW 7 Series (iDrive; 2016)</b>	Communication, Media/Audio, Navigation, Vehicle setting, Driving information,	Climate, audio	Media/ Audio Navigation, Scrolling the menu	Climate Media/ Audio Navigation, Scrolling the menu
<b>Chevrolet Corvette (2016)</b>	Phone, Audio, Navigation, Vehicle settings, Climate, Information, Entertainment	Climate, Audio	Scrolling the menu	Climate, Audio Scrolling the menu

Table 2 Continued

<b>Control format</b> <b>Vehicle</b>	<b>Touch screen</b>	<b>Manual (Single function)</b>	<b>Manual (Universal function)</b>	<b>Redundant functions: Touch screen &amp; manual</b>
<b>Ford Flex (2016)</b>	Phone, Navigation, Climate, Vehicle Settings, Information, Entertainment	Climate, Audio		Climate Audio
<b>Jaguar (InControl Touch; 2016)</b>	Camera, Web browser, Vehicle settings, Communication, Navigation, Information, Entertainment	Climate, Audio		Climate Audio
<b>Nissan Juke (2016)</b>	Entertainment, Phone, Navigation, Information, Vehicle settings	Audio, Menu selection, Navigation, Climate, Camera		Audio, Menu Selection, Navigation

### 1.5 Studies of effects of vehicle control format on driver performance

Several earlier studies have addressed the effects of in-vehicle single control format on driver performance. Contradictory results have been found regarding comparisons of manual control and touch screen control. Three earlier studies reported that touch control posed a higher visual demand on the drivers, as compared to manual control (Pitts et al., 2012; Burnett & Porter, 2001; Stevens et al., 2002). The researchers explained that manual control provided both haptic and kinesthetic feedback while touch screens

provided neither, as sources of information to drivers for confirming inputs. Wang et al. (2010) investigated the effect of touch screen, keypad and rotational controls on driver's secondary task performance and visual attention. Their driving simulation and field study showed no meaningful differences between the touch screen and keypad entry methods on task completion time; however, more glances and longer glance durations were involved in using the touch screen. In contrast, some studies have argued that touch screen controls produce superior performance, as compared with manual control, because touch screens typically have a lower interface density and customized appearance of the display (Jaegar et al., 2008).

Few driving simulation studies have actually examined the effect of redundancy of in-vehicle control formats on driver performance. However, some earlier non-driving simulation studies have provided some insights into this issue. Repetition of content in different formats has been found to be beneficial for novice or new users, but detrimental to users with high prior knowledge (Vetere & Howard, 2002; Sweller, 2002). Considering the availability of vehicle user instructions, drivers tend to have high prior knowledge of in-vehicle control systems. Therefore, it is possible that the redundancy of control formats might be detrimental to driving performance.

According to the above survey, there are conflicting results on the effect of single in-vehicle control format on driver performance. Moreover, although combinations of multiple control formats have been extensively used by major automobile manufacturers, few studies have examined effects on driver performance. Therefore, more research is

necessary to identify the effect of single vehicle control formats and the redundancy of vehicle control formats on driver behavior.

## **1.6 Motivation**

With the potential for deteriorated driver performance in hazardous situations with use of automated driving systems, and with the effect of vehicle control format uncertain, the present work assessed the impact of levels of automation and vehicle control format on driver performance. The ultimate objective was to provide a basis for making recommendations regarding effective vehicle automation and control design towards enhancing driver performance.

The first research question was whether driver performance in hazardous situations would vary among manual and automated driving conditions, given that the drivers were informed of the possibility of hazard occurrences prior to driving. Driver ability to maintain vehicle control under hazardous situations is essential for safety. Based on the literature review, there remains uncertainty of driver hazard negotiation performance under automated driving. This study focused on driver reaction time in coping with hazardous situations, which is especially important to minimizing potential crashes and bodily and vehicle damage.

The second research question was whether driver performance would vary with different vehicle control formats. It is important for drivers to successfully and efficiently perform in-vehicle secondary tasks (e.g., climate and information systems control), and to be able to stay attentive and maintain vehicle control during task performance. It is

possible that different vehicle control display formats can affect driver visual behavior, ability to control the vehicle and secondary task performance. This study aimed to reveal the effect of single vehicle control formats and redundancy of vehicle control formats on driver visual behavior and in-vehicle task performance.

## **1.7 Hypotheses**

Based on the findings of the existing literature, the below hypotheses (H) were formulated.

Regarding hazard negotiation performance, automated driving was expected to lead to mental disengagement in the driving task and thus increase brake reaction time to hazard situations (H1) across all control format types.

In terms of secondary task performance, it was expected that the haptic and kinetic feedback associated with manual control would result in the shortest task completion times (H2) and fewest errors (H3). Furthermore, related to confusion caused by control format redundancy, the combination of touch screen and manual control was expected to lead to the longest task completion time (H4) and greatest errors (H5).

Regarding visual behavior, the manual control format was hypothesized to lead to reduced visual demand due to haptic and kinetic feedback and, therefore, would result in the lowest off-road glance frequency (H6) and reduced average off-road glance duration (H7). It was also expected that the combination of touch screen and manual control would increase off-road glance frequency (H8) and increase average off-road glance duration (H9) relative to manual control and touch screen control.



## 2. Methodology

### 2.1 Apparatus

To present simulated driving scenarios to participants, the experiment made use of the North Carolina State University Ergonomics Lab static driving simulator, which is a STISIM Drive Model 400 driving simulator, developed by System Technology, Inc. (Hawthorne, CA). The driving simulator integrates three 37" HDTV screens, a surround sound audio system and a realistic cab and vehicle controls (see Fig. 1).



Figure 1: Driving Simulator Setup

To collect real-time data on glance duration and fixation frequency, this study made use of a FaceLAB 5.1 eye tracking system from Seeing Machines (Australia), integrated with two cameras and an infrared light source (see Fig. 2). Eye movements were recorded at 60 HZ with an accuracy of 0.5° to 1° of rotational error.



Figure 2: Eye-Tracking System Hardware

The scenarios presented with the driving simulator were designed to represent a normal rural driving environment. All aspects of the roadway environment design, including signage, followed guidelines from the North Carolina Department of Transportation (NCDOT) and the Manual of Uniform Traffic Control Devices (MUTCD) (FHWA, 2009).

In order to present vehicle media system control interface prototypes, a 13-inch touch-screen notebook computer was also integrated with the driving simulator setup. The touch screen computer was positioned to the right side of the driver's forward-view and a keypad was positioned below the touch screen to represent a manual vehicle media system control interface. The location of the computer and its display angle were based on a survey of positions of vehicle media displays in actual vehicles (see Fig.3).



Figure 3: Vehicle Media System Setup

To represent an in-vehicle media system control interface, a prototype was developed based on the control interface as part of the current Ford Sync 3 in-vehicle entertainment system (Ford, 2017; see Figure 4). The design of the prototype included features commonly found in commercially available touch screen interfaces, and it matched manual control formats. Consequently, the touch screen allowed for task performance in exactly the same manner as the manual control format. The prototyping storyboard for the secondary music selection task is presented in Appendix B.



Figure 4: Vehicle Media System Control Interface Prototype

The touch screen as part of the computer allowed users to directly interact with the interface display. To manually control the vehicle information system, participants used a keypad directly adjacent to the display screen. The makeup of the keypad was based on common button panel designs of vehicles investigated in the earlier vehicle survey (Figure 5). Since the prototype media system only made use of 14 adjacent keys as part of the keypad, unused keys were concealed under a black cover to avoid visual distraction.



Figure 5. Layout of Manual In-Vehicle Control Format

A camera with video recording function was utilized to record participant’s hand movement during secondary task performance. The recorded videos were later examined to extract data on secondary task completion time, number of errors and participant preference of control format (based on actions/control use).

## 2.2 Participants

Twenty-two participants with age from 18-64 were recruited for the study, including 13 males and 9 females. Eleven participants (6 male and 5 female) drove under the automated driving mode. Eleven participants (7 male and 4 female) drove under the manual driving mode. The average ages of participants within each driving mode group, as well as counts of participants in young, “middle” and senior age groups (Zahabi et al., 2017), are presented in Table 3. In general, the samples represented younger and active driver groups. All participants held a valid driver’s license, and had 20/20 vision (either naturally or with corrective lenses) at the time of experiment participation. All participants were recruited online or by flyers posted on North Carolina State University campus. Each participant was compensated at a rate of \$20.00 per hour. The experiment lasted approximately 2.5 hours for each driver.

Table 3: Participant Age information

		<b>Counts of Participants in Age Groups</b>		
<b>Driving Mode</b>	<b>Average Age</b>	<b>Young (18-22)</b>	<b>Middle (23-64)</b>	<b>Senior (65+)</b>
<b>Automated</b>	25	4	7	0
<b>Manual</b>	28	5	6	0

### 2.3 Task Description

Participants were asked to drive in 6 trials presenting a rural highway with two lanes and three interchanges. The road was designed to have logo signs and road signs to represent a realistic driving environment. Level A traffic (2 cars/lane/min) was simulated in the highway.

Half of the participants (11) were randomly assigned to drive under the manual driving condition. All drivers were instructed to drive in the right lane of the freeway and conform to the posted speed limit (65 mph). Other than that, drivers drove in their normal manner, and they followed the 3-second rule recommended by the Division of Motor Vehicles (DMV; Driving Etiquette & Safety Tips, n.d.) by keeping a constant headway time of no less than 3 seconds between the driver's vehicle and a lead-vehicle. During driving, one hazardous situation was presented in each scenario, in which a vehicle in front of the driver's vehicle performed an abrupt lane incursion (see Figure 6). This type of hazard was included in the test scenarios because it was identified as one of the most common maneuvers of vehicles prior to crashes (NHTSA, 2008; Martinez, 1997).



Figure 6. Example of Lane Incursion Hazard Event

Locations of the hazard events were randomized in order to reduce any learning effect for drivers from one test trial to the next. In addition, no hazard occurred within the first 5 minutes of driving, in order to allow enough time for initial secondary task performance. The hazard events also occurred while participants were performing secondary tasks to represent driver hazard negotiation under distracting conditions. The experiment trials ended shortly after the hazard exposure. Since the location of hazard events varied across trials, the length of experiment trials could vary from 6 to 12 minutes. Prior to driving, participants were informed of the possibility of occurrence of hazards, and they were instructed to avoid the hazard events in their own manner (through speed control or steering maneuvers).

The remaining half of participants (11) drove with the use of adaptive cruise control. The driving simulator automatically controlled the speed of the vehicle and maintained a constant headway distance to a lead-vehicle. In this experiment, the speed was kept at 65mph and the leading distance was 286 ft., conforming with the 3 second rule (Driving Etiquette & Safety Tips, n.d.). Drivers were instructed to control the vehicle in the lateral direction and drive in the right lane of the freeway at all times. Hazard events occurring during automated driving were same as those presented under manual driving. The automated driving participants were also informed of the possibility of hazard exposure before test trials. At the time of a hazard, drivers could take over longitudinal control of the vehicle and react to hazards in their own manner, by steering or braking.

While driving, participants also performed music selection tasks using one of the three control formats: (1) touch screen only; (2) manual control only; or (3) a combination of manual and touch screen control (the participant could use any function from among the manual and touch screen controls). Participants used one control format in each trial, and they were informed of which control format to use prior to the trials. Each music selection task required participants to search for a target song with the in-vehicle media control interface. The secondary tasks mimic operating CD players while driving, which has been identified as one of the most common and most distracting in-vehicle tasks (Singh, 2010; Young et al., 2007; NHTSA, 2008). The participants were instructed by audio messages when they needed to begin secondary task performance. The audio messages also informed participants of the names of target songs to be selected during driving. The timing of the secondary task was random but there was at least a 3 minute time interval between occurrences of secondary task demands. Each trial produced two observations on secondary task performance: the first one took place under normal driving conditions, and the second one took place during exposure to the hazard condition.

#### **2.4 Independent variables**

Two controlled manipulations were assessed in the present study, including: level of vehicle control automation and the format of in-vehicle control interfaces. The levels of automation included manual driving (Level 0) and use of ACC (Level 1). The control interface configurations as part of the embedded secondary task, included the manual



control interface, the touch screen control interface, and the combination of manual and touch screen control interfaces.

## **2.5 Dependent variables**

There were three types of response measures captured in this study, including: hazard negotiation performance, secondary task performance, and visual behavior during secondary tasks.

Driver reaction time to the occurrence of a roadway hazard has been extensively used to measure driver hazard negotiation performance in previous studies (e.g. Gold et al., 2013; Rudin-Brown et al., 2003). In an earlier study investigating driver reaction to unexpected ACC failure, Nilson et al. (2013) measured the time elapsed between initiation of ACC failure and when the brake pedal or the on/off button was pressed by a driver. In the present study, hazard negotiation (reaction time) was analyzed for successful avoidance trials. Reaction time started when the hazard vehicle initiated movement and elapsed until participants initiated a conscious hazard avoidance maneuver. The thresholds for identifying conscious hazard avoidance maneuver included turning the steering wheel more than 2° (Louw et al., 2017; Gold et al., 2013) or depressing the brake pedal (Louw et al., 2017).

The secondary task performance measures included task completion time and errors. Task time was the time elapsed between participant movement towards the vehicle control interface and completion of the music selection task. Previous studies (e.g. Rudin-Brown et al., 2003; Young, & Stanton, 1997; Flemisch et al., 2008) also used this

definition of task completion time. Only the tasks that were successfully completed by participants were included in the analysis of task time. An error in secondary task performance was defined as an unsuccessful attempt to press a specific button or selecting a wrong control for the task. This definition was applied in an earlier study of in-vehicle control interfaces (Jaegar et al, 2008). In the current study, errors could be, for example, a failed attempt to press a button (a participant did not press the “CD” button but pressed an adjacent keyboard area instead) or an incorrect selection of a control (a participant selected the “Climate” button for CD control). Total error count for each secondary task was recorded as an indicator of performance.

The visual behavior measures included longest glance duration and fixation frequency to various areas of interest (AOIs). Glances to the vehicle media system interface were within an “off-road” AOI. The off-road glance frequency was calculated as ratio of the number of off-road glances over the total number of on-road and off-road glances during secondary task performance periods. A glance was defined as the total time the focus of attention remained within the AOI. A fixation was defined as when a participant’s gaze traveled for longer than 100 ms at a velocity less than 100 degrees/s (Holmqvist et al., 2011).

## **2.6 Experimental design**

The present study followed a 3 x 2 between-within mixed factor experiment design with the two levels of driving automation and three levels of control interface format. The level of automation was a between-subject factor and the control interface format was a within-

subject factor. All participants were exposed to all three levels of control format and each specific control format was replicated for a participant. Each participant completed 3 training scenarios (with one level of control format in each training scenario) and 6 test trials. The test trial order for each participant was randomized. Consequently, the following statistical model was applied to the response measure data as part of the study:

$$Y = \mu + V_i + P(V)_{j(i)} + S_k + VS_{ik} + SP(V)_{kj(i)} + T_l + \epsilon_{ijklr}$$

where  $\mu$  = Grand mean;  $V$  = Driving Mode ( $i=1,2$ );  $P$  = Participant ( $j=1, \dots, 11$ );  $S$  = Control Format ( $k=1,2,3$ );  $T$  = trial number ( $l=1,2,3,4,5,6$ );  $VS_{ik}$  = interaction effect driving mode and control format;  $SP(V)_{kj(i)}$  = interaction effect of the control format and participant nested within the driving mode;  $r$  = replication ( $r= 1,2$ ); and  $\epsilon$  = error term.

## **2.7 Procedures**

### ***2.7.1 Consent and Demographic Questionnaire***

At the beginning of the experiment, the participants were presented with an informed consent form. If they agreed to participate, they were asked to complete a brief demographic questionnaire (see Appendix C). Participants were asked to provide their age, gender, visual acuity, driving history, and experience with vehicle automation and vehicle control interfaces.

### ***2.7.2 Simulator Sickness Questionnaire***

After completion of the demographic questionnaire, participants were asked to complete a simulator sickness questionnaire (SSQ; Kennedy et al., 1993). The questionnaire included 16 different symptoms, and participants were requested to provide ratings from 0 to 4 for

each one of the symptoms, where 0 represented no symptom and 4 represented severe symptoms at the time of completion of the survey (see Appendix D). During the experiment, this questionnaire was administered after every two test trials. In case a participant presented simulator sickness symptoms, a 20-minute break was provided. If the symptoms persisted, his or her participation was terminated, and the participant was compensated for any time provided. In the present study, none of the participants exhibited simulation sickness symptoms, therefore, it is unlikely that any symptoms influenced experiment results.

### ***2.7.3 Training Scenario***

After completing the study forms, participants were asked to sit in the driving cab and were introduced to the driving simulator controls (i.e., steering wheel, turn signal, foot pedals), media system control interfaces, and the eye-tracking system. Following this setup introduction, participants complete a training session, including three 5-min driving scenarios. The training scenarios were designed to ensure that participants were familiar with the control interfaces and capable of controlling the driving simulator.

The scenarios involved negotiating a simulated rural environment with manual control or use of ACC (similar to the virtual driving environment to be presented during experiment trials). Participants were also required to use the in-vehicle control interfaces to perform a sample secondary task. Training scenarios also included hazard situations, which required participants to perform emergency vehicle maneuvers. The hazard events presented during the training were similar but not identical to those presented in

experiment trials.

The manual driving training scenario tested whether participant speed control, lane maintenance, and headway distance control met established criteria. Under manual driving mode, participants were required to produce 1.0 mph or less average speed deviation, 1.37ft or less average lane deviation (Horrey & Wickens, 2006), and 44ft or less average headway deviation. Under the automated driving mode, participants were required to produce 1.37ft or less average lane deviation. If this criterion was not satisfied, the participant repeated the training scenario. If participant training performance remained unacceptable after three trials, his or her participation in the experiment was terminated.

#### ***2.7.4 Experiment***

Once the training session was complete, and a participant felt comfortable driving while performing an in-vehicle task, the Facelab eye tracking system was configured.

Participants were then given instructions for test trials. When ready, participants began the driving task, as described in Section 2.3. During the 5-minute breaks between trials, participants were required to rest outside of the simulator cab. Lastly, participants filled out a payment form and were escorted out of the lab.

#### **2.8 Statistical Data Analyses**

After extraction and exclusion of incomplete trial results and trials that did not meet the data analysis criteria, 116 observation periods were available for hazard negotiation analysis, and 186 observation periods were available for secondary task performance and

visual behavior analysis. Outliers and abnormal data were removed prior to data analysis by application of Cook's D Method. This method identifies highly influential points with Cook's D value above  $4/n$ , where  $n$  is the number of observations on a response measure. These influential points were further examined, and all data points associated with equipment problems or failure of participants to follow experiment instructions were removed.

Diagnostics were conducted on all response measures to ensure that the data met analysis of variance (ANOVA) assumptions of homoscedasticity and residual normality. The diagnostics and follow-on data analysis procedures were conducted on the sanitized data set with outliers removed. Residual normality was examined with normal probability plots and the Shapiro-Wilk's normality test. Variance homoscedasticity was assessed using Bartlett's tests.

ANOVA models were developed to test the effect of the driving modes and vehicle control formats. A significance level of  $p \leq 0.05$  was used to identify statistical significance of any effect. As mentioned previously, the driving mode was a between-subject variable. The vehicle control format and the interaction with driving mode was included in the model as well. Trial number was also included in the model as a co-variate. If trial number did not have a significant effect on a response measure, it was removed from the statistical model for the final analysis. For experiment manipulation with more than two levels (i.e., control formats), Tukey's post hoc test was conducted to identify differences among the levels.

Among all responses measures, the data sets for hazard reaction time and fixation frequency satisfied the parametric test assumptions. Secondary task completion time was subjected to a square root transformation to meet the ANOVA assumptions, and longest gaze duration was subjected to a log transformation. The number of secondary task performance errors failed to meet parametric test assumptions and transformations of the data set was unsuccessful; therefore, the number of errors was subjected to average rank transformation and submitted to the ANOVA procedure to yield a non-parametric analysis.

### 3. Results

Table 4 presents the descriptive statistics on the three dependent measures across the settings of the independent variables of driving mode and interface control format.

Table 4: Descriptive Statistics of Performances across Manipulations

Driving Mode	Control Format	Hazard reaction time(ms)		Secondary task completion time(s)		Number of error		Fixation frequency (relative to total fixation)		Longest Gaze Duration (ms)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Manual	Manual	1187	265	16.45	5.59	0.10	0.30	0.25	0.22	851	1049
	Touch Screen	1241	238	17.39	6.85	0.29	0.53	0.39	0.18	1228	820
	Manual+ Touch Screen	1275	233	18.81	6.56	0.32	0.70	0.25	0.19	822	800
Automated	Manual	766	323	14.79	4.75	0.21	0.74	0.27	0.19	746	735
	Touch Screen	709	273	19.00	5.88	0.65	0.91	0.39	0.22	937	740
	Manual+ Touch Screen	761	229	18.80	5.05	0.67	1.15	0.29	0.17	753	689

### 3.1 Hazard Negotiation Performance

Regarding the hazard reaction time analysis, trial number was insignificant in effect and was, thus, removed from the statistical model. The main effect of driving mode was found to be highly significant ( $F(1,106) = 47.49, p < 0.0001, 1-\beta > 0.999$ ). However, the main effect of control format ( $F(2,106) = 1.68, p = 0.1992, 1-\beta = 0.199$ ) and its interaction with driving mode ( $F(2, 106) = 1.39, p = 0.89, 1-\beta = 0.116$ ) were both insignificant. Results revealed that participants under the automated-driving condition exhibited significantly shorter hazard reaction time than manual driving. For visual interpretation, a graph of the hazard reaction time across driving modes is presented in Figure 7. Error bars in the graph represent  $\pm 1$  standard deviation of the response measure.

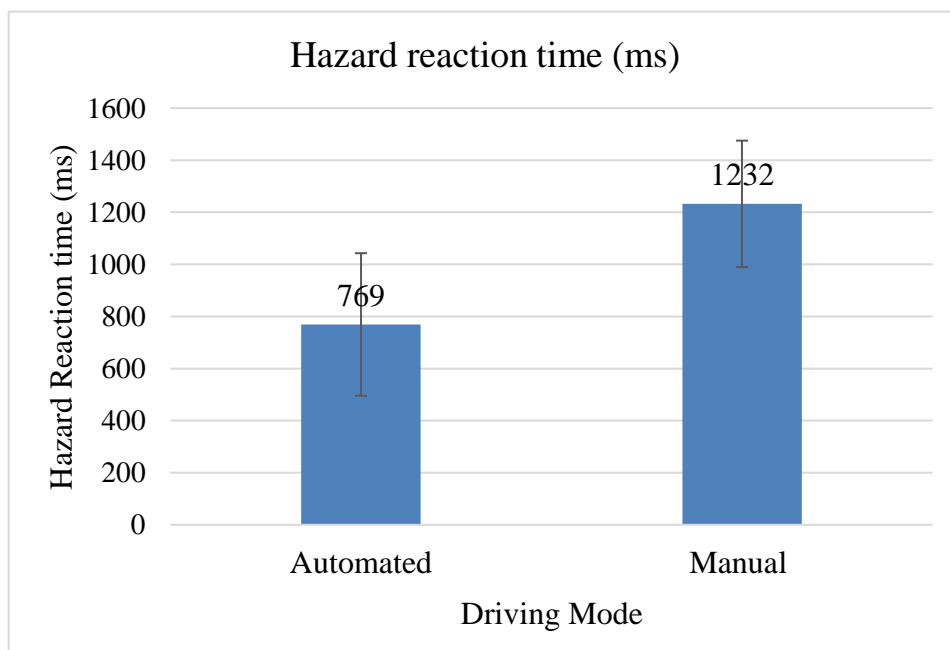


Figure 7: Effect of Driving Mode on Hazard Reaction Time ( $\pm 1$  SD)



With respect to driver maneuvers in response to hazard events, in 88.78% of successful hazard avoidances, participants used the brake rather than steering to avoid the vehicle lane incursion. Drivers were also more likely to use the brake under the manual driving condition than automated control. Results showed that braking was applied in 98.28% of successful hazard avoidances under manual driving, as compared to 77.55% of cases under automated driving. The proportion of driver hazards negotiation maneuvers under each driving mode are presented in Figure 8.

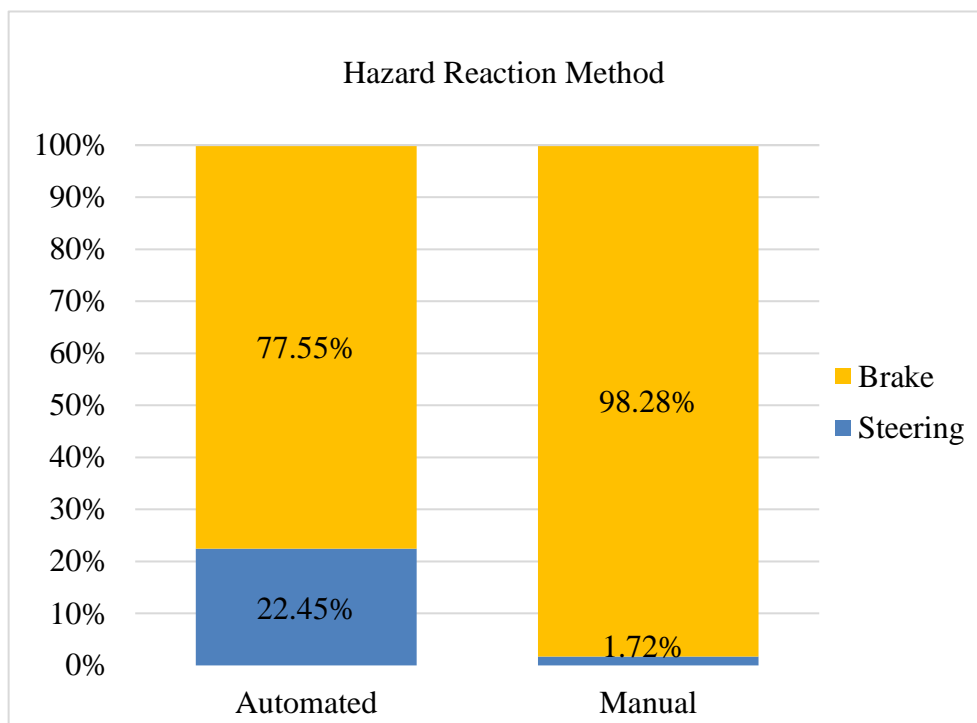


Figure 8: Hazard Negotiation Methods under Manual and Automated Driving

### 3.2 Secondary Task Performance:

Regarding secondary task completion time, the trial number effect was found to be insignificant in the model and was, therefore, removed for the final statistical analysis.

The main effect of control format ( $F(2, 183) = 5.67, p = 0.0068, 1-\beta = 0.734$ ) was found to be significant in secondary task completion time. The driving mode ( $F(1, 183) = 0.04, p = 0.8527, 1-\beta = 0.059$ ) and its interaction with control format ( $F(2, 183) = 0.49, p = 0.6177, 1-\beta = 0.108$ ) were insignificant. Tukey's post-hoc test was conducted on the control format effect. Results revealed the task completion time for the touch screen and combination format to be significantly longer than manual control. Figure 9 presents the trend of the response measure across control formats.

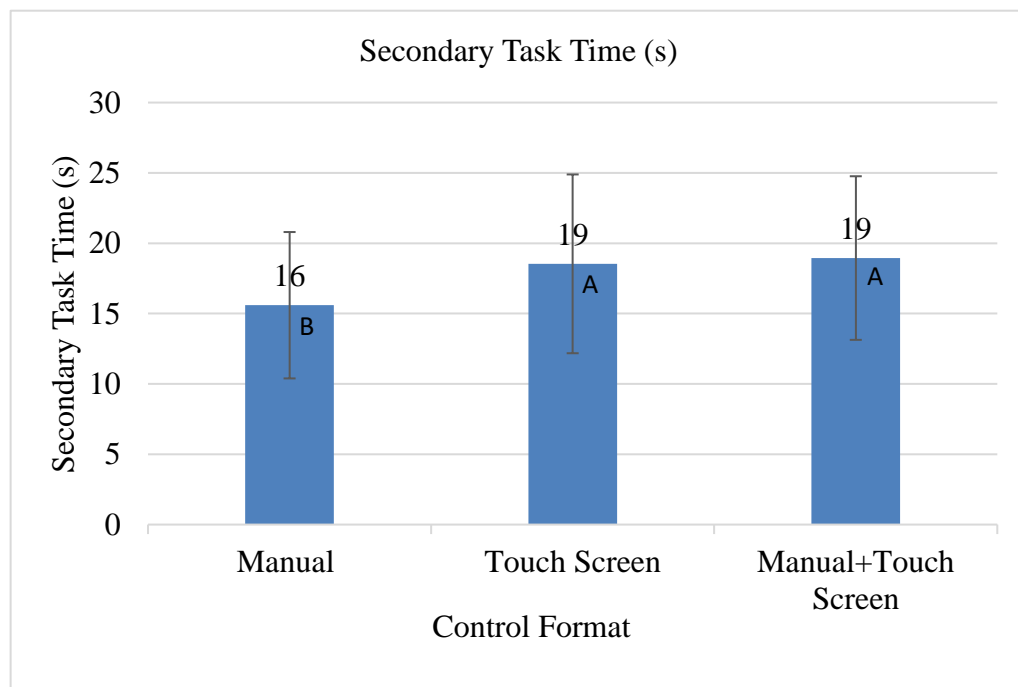


Figure 9: Effect of Control Format on Secondary Task Completion time (+/- 1 SD)

Although the task error response did not satisfy the assumptions of parametric analysis, the results of the non-parametric and parametric ANOVAs were identical, and the parametric results are reported here. The trial number effect was found to be

insignificant and removed from the model. The main effect of control format ( $F(2, 183) = 4.65, p = 0.0153, 1-\beta = 0.864$ ) was found to be significant on the number of errors in use of the media device. The driving mode ( $F(1, 183) = 1.5, p = 0.235, 1-\beta = 0.486$ ) and its interaction with control format ( $F(2, 183) = 0.4, p = 0.6715, 1-\beta = 0.107$ ) were insignificant. Tukey's post-hoc test was conducted on the control format effect. Results revealed users to produce more errors per task when using the touch screen and combination format as compared with manual control. Figure 10 presents the trend of the response measure across the control formats.

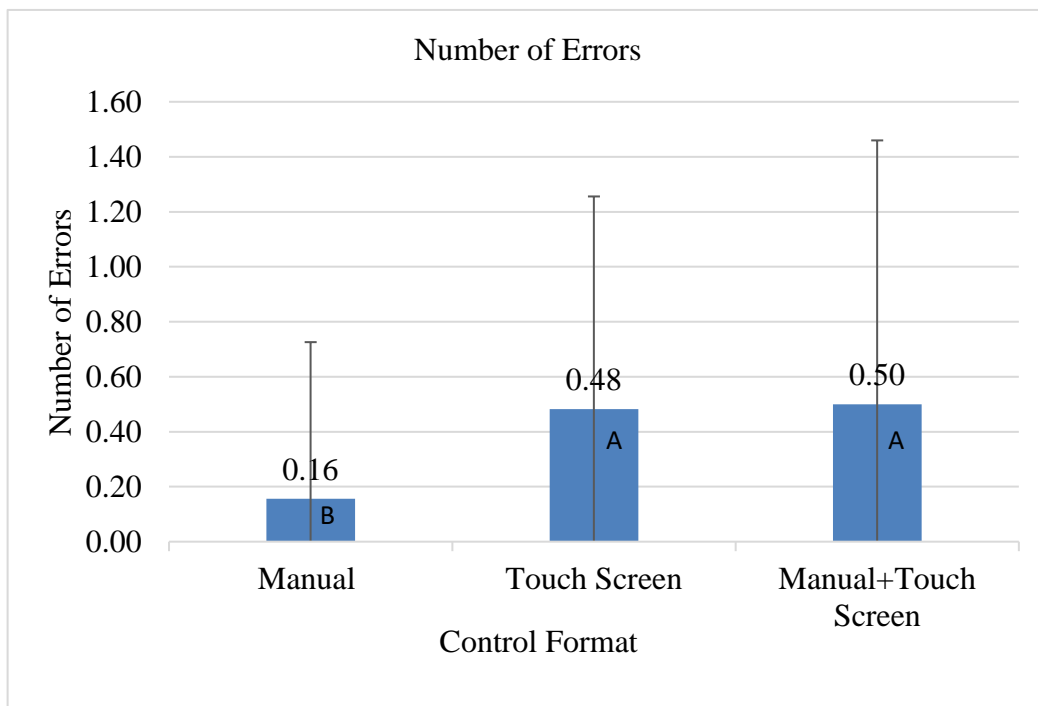


Figure 10: Effect of Control Format on Number of Errors Per Task (+/- 1 SD)

### 3.3 Visual Behavior during Secondary tasks:

With respect to the fixation frequency response, the trial number was also found to be insignificant and was removed from the statistical model. The main effect of control

format ( $F(2, 165) = 11.74, p = 0.0001, 1-\beta = 0.912$ ) was significant in the frequency of fixations to the off-road AOI or media device. The driving mode ( $F(1, 165) = 0.16, p = 0.6935, 1-\beta = 0.142$ ) and its interaction with control format ( $F(2, 165) = 0, p = 0.997, 1-\beta = 0.05$ ) were insignificant. Tukey's post-hoc test was applied to the control format effect. Results revealed drivers to exhibit a higher fixation frequency when using touch screen, than manual control or the combination format. Figure 11 presents the trend of the eye-tracking response across the control formats.

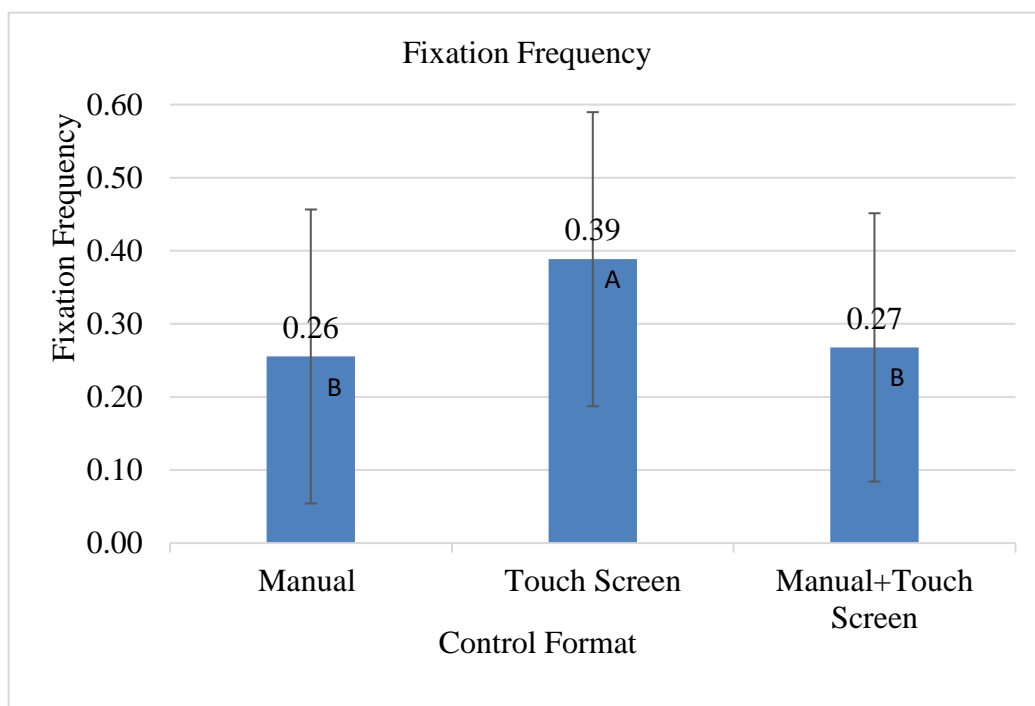


Figure 11: Effect of Control Format on Fixation Frequency (+/- 1 SD)

Regarding the longest glance duration response, the trial number effect was found to be insignificant and was removed from the statistical model. The main effect of control format ( $F(2, 166) = 10, p = 0.0003, 1-\beta = 0.724$ ) was found to be significant in the “off-road” glance duration. The driving mode ( $F(1, 166) = 0.06, p = 0.807, 1-\beta = 0.87$ ) and its

interaction with control format ( $F(2, 166)=0.05, p=0.3586, 1-\beta=0.119$ ) were insignificant. Tukey's post-hoc test was conducted on the control format effect. Results revealed the users exhibited longer off-road glance durations when using the touch screen vs. manual control or the combination format. Figure 12 presents the trend of the eye-tracking response across the control formats.

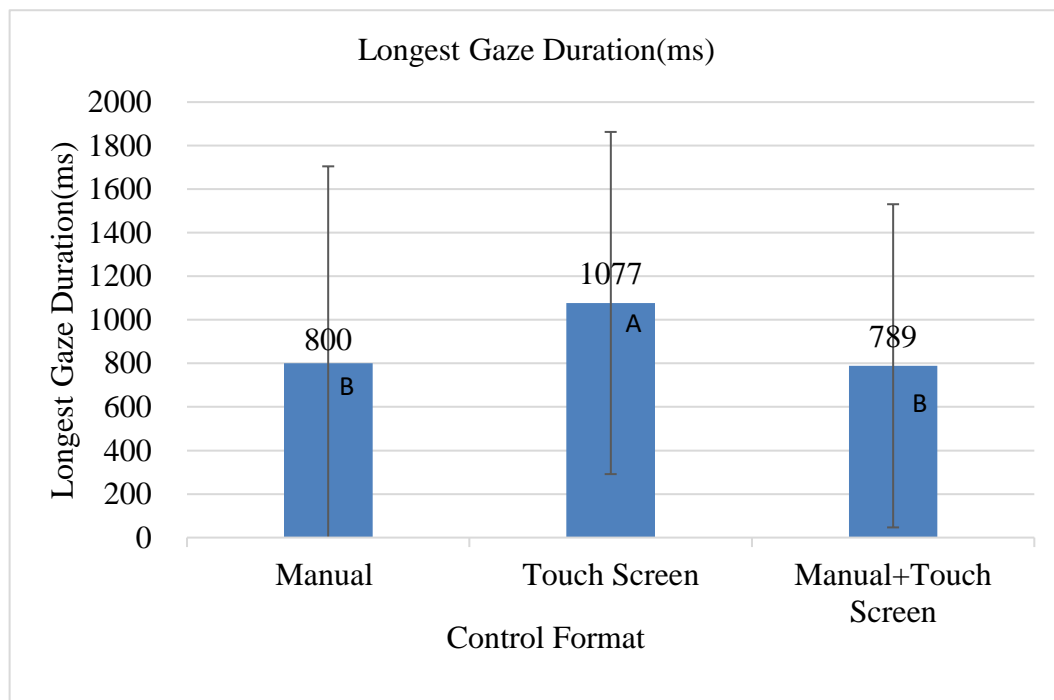


Figure 12: Effect of Control Format on Longest Gaze Duration on Media Panel (+/- 1 SD)

### 3.4 User preference of control format

Beyond the above analyses, the video recordings of the experiment test trials were analyzed in order to determine driver preferences for particular control formats based on overt behavior/observed actions. It was found that when the participants were given the option of using any function from the combination of manual and touch screen controls,

in the majority of use cases (60.6%), drivers applied manual controls to complete secondary tasks. Only in 19.7% of use cases were secondary tasks completed with exclusively with the touch screen. In the exact same percentage of use cases did drivers apply both control formats for secondary tasks. The percentages of user choice of control formats are presented in Figure 13.

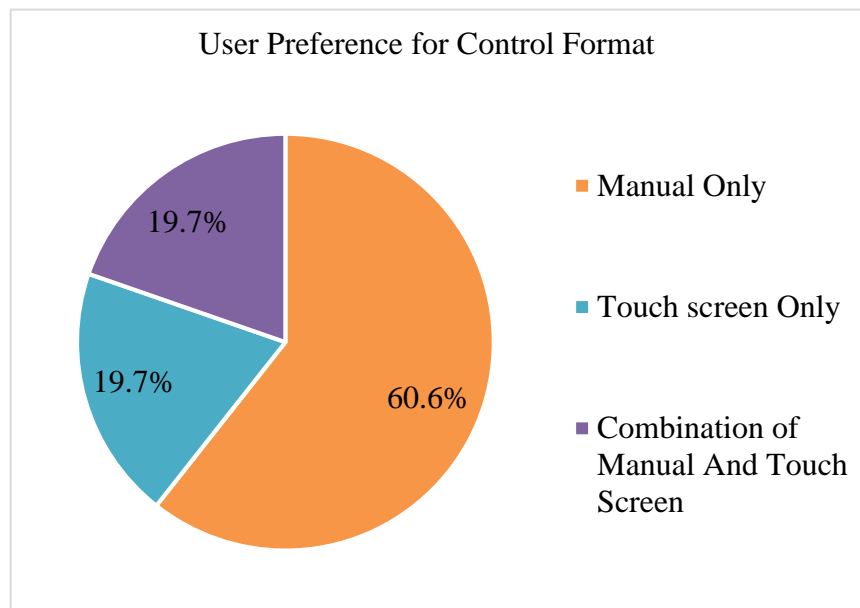


Figure 13: User Preference of Control Format

#### 4. Discussion

Returning to the hypotheses of the study, automation was expected to result in greater driver reaction time to hazards, due to mental underload and potential loss of roadway awareness. However, the findings of this experiment indicated that when the possibility of hazard exposure was communicated to drivers prior to driving tasks, drivers using automated vehicle control exhibited superior hazard negotiation performance. This result appears to contradict some findings from other studies on hazard negotiation performance

under automated driving (Gold et al., 2013; Rudin-Brown et al., 2003), which have reported that manual control led to superior hazard negotiation. However, in these investigations, drivers were not warned in advance of the possibility of hazard occurrence. In the present study, we informed drivers that roadway hazards may occur, as in real freeway driving, and the training they received prior to the start of the experiment included hazard avoidance maneuvers. Consequently, the mental underload and lack of roadway awareness with automated driving, as reported by previous studies, were not observed in this investigation. We observed that drivers were actively involved in hazard identification and that drivers using automated control were able to attend more to the roadway for avoidance maneuvers than with manual control. The automated driving condition offloaded the speed and headway maintenance tasks from drivers to the ACC. Moreover, it was observed during experiments that a significant number of participants under the automated driving condition placed their foot over the brake pedal during the course of driving, while drivers using manual control mostly placed their foot on the acceleration pedal to control speed. Therefore, under automated driving, the participants could more quickly initiate braking than in manual driving.

The findings of this experiment also showed that braking was a preferred hazard negotiation strategy across driving modes. It was also revealed that under automated driving mode, drivers were more likely to use steering as a hazard negotiation method than under manual driving. This finding is consistent with findings from an earlier study (Nilsson et al., 2013). Drivers expected the ACC to control acceleration or deceleration

and perceived takeover to be necessary in the event of an emergency condition (Nilsson et al., 2013).

In terms of secondary task performance, we hypothesized that manual control would result in the shortest task completion time (H2) and fewest errors (H3). Hypothesis 2 and 3 were supported by the study results, which showed that manual control led to significantly superior secondary task performance as compared with the touch screen and the combination of manual and touch screen control. There have been few prior studies directly comparing in-vehicle control formats. With relevance to the present investigation, Pitt et al. (2012) examined a novel visual-haptic touch screen technology and pointed-out a lack of haptic and kinesthetic feedback from touch screens, as compared with manual controls, could degrade performance. Hoggan et al. (2008) directly compared user performance in use of a mobile phone touch screen and physical keyboard, and reported a trend of superior task performance with the physical keyboard. Still other studies (Rogers et al., 2005; Greenstein, 1997; Taveira & Choi, 2009) have observed difficulties in touch screen use due to the level of precision that must be achieved in selecting screen options with an outstretched arm. Furthermore, the typical posture position assumed in touch screen use can cause muscle fatigue while performing option selection tasks (Greenstein, 1997; Taveira & Choi, 2009).

Beyond the above hypotheses, redundancy of control formats was expected to lead to the greatest task completion times (H4) and errors (H5). Hypothesis 4 and 5 were partially supported by the results of the experiment. It was found that redundancy of



control formats (the combination of manual and touch screen controls) resulted in poorer performance, as compared with manual control, but it produced performance comparable to touch screen use.

No previous study has examined the redundancy of vehicle control formats and its effects on driver secondary task performance. However, some research has examined redundant information presentation using numerous formats. Sweller (2002) and Vetere and Howard (2000) showed that repetition of information content using different formats benefited new users, but was detrimental to users with higher *a priori* knowledge. In this study, participants had prior knowledge and experience with both manual in-vehicle controls and the touch screen technology and their task performance was degraded by redundancy of controls. This outcome was likely due to user hesitation and confusion in control use. However, it is worth noting that a significant number of tasks were performed with manual control only, even when users were given the option of using either manual or touch screen control formats. It is also possible that the observed negative effect of redundancy of controls might have been diluted due to the substantial proportion of tasks performed with manual control only.

Regarding driver visual behavior during secondary task performance, manual control was hypothesized to lead to reduced visual workload, or the lowest off-road glance frequency (H6) and reduced average off-road glance duration (H7). Hypotheses 6 and 7 were supported by the study results. Previous research by Pitts et al. (2012) has also shown a trend of higher visual workload posed by touch screen displays. These findings

can also be explained in terms of the haptic and kinesthetic feedback afforded by the manual controls. Wang et al. (2010) compared driver visual responses during an address entry task using a keyboard vs. touch screen. They reported higher fixation frequency and total glance duration for touch screen users in the absence of haptic and kinesthetic feedback. The high level of visual demand posed by touch screens may also increase the likelihood of safety risks (Pitts et al., 2012), making manual control a more suitable control format in situations of limited attention, such as driving.

It was also expected that the combination of touch screen and manual control would increase off-road glance frequency (H8) and increase average off-road glance duration (H9) relative to manual control and touch screen control. However, the study results did not support hypothesis 8 and 9. In fact, while using the combination of touch screen and manual control, drivers exhibited visual workload comparable to manual control, which was much lower than the fixation frequency and glance duration for the touch screen display. Although it was previously observed that information redundancy could be detrimental to task performance by knowledgeable users (Sweller, 2002; Vetere & Howard, 2000), results from this study showed that redundancy in control formats did not pose additional visual demands for drivers. This is possibly due to participants performing the majority of secondary tasks (70.3%) with a single control format when they were presented with the redundant control condition, including 60.7% of tasks being performed with manual control.

Previous studies (Young & Stanton, 1997; Rudin-Brown et al., 2003; Flemisch et al., 2008) reported superior secondary task performance under automated driving. However, this trend was not observed in the present study. It is possible that driver knowledge of the possibility of hazard occurrence caused them to allocate additional attentional resources to the roadway for hazard detection and avoidance vs. allocation for secondary task performance. Since there was no time pressure for participants to complete the secondary task, it is possible that they prioritized hazard negotiation.

### **5. Limitations**

During the present experiment, participants were not allowed to use their cell phones or other personal devices while driving, which are now common distractions in real life vehicle use. The use of personal data devices would likely increase the level of driver distraction and decrease the level of situation awareness when posed with other secondary tasks under manual or automated driving. Since automation partially freed drivers of driving task, it is possible that they will be more engaged in use of personal devices than manual driving. Therefore, use of automation in conjunction with distraction by personal data devices could lead to worse performance than manual.

Although the touch screen design in this study was common among commercial vehicle media receivers, the representativeness of the touch screen design might be limited due to the wide variety of available designs on the market. The usability of the prototype interface might have had influenced the experiment results as well.

Furthermore, according to the demographic statistics, the majority of persons (82%), who participated in this research, had manual control interface installed in their personal vehicles. Therefore, it is possible that participant proficiency in using manual controls and the observed action preference for manual control use may stem from driver control familiarity.

## **6. Conclusions**

In conclusion, this study provided a driving simulator-based assessment of the effect of vehicle automation and control formats on driver visual behavior and hazard negotiation. Two levels of vehicle automation, including manual driving (SAE Level 0) and use of ACC (SAE Level 1), were examined along with and three types of in-vehicle control formats, including touch screen only, manual control only and a combination of manual and touch screen control.

On the basis of the findings of the study, drivers under automated conditions exhibited significantly superior hazard negotiation performance, when drivers in both vehicle automation groups were informed of the possibility of hazard exposure. It was explained that an automated-driving condition may allow for greater attention allocation for hazard reaction and quickly initiation of hazard avoidance.

Regarding the effects of vehicle control format, findings suggest that manual controls lead to reduced visual workload and superior secondary task performance, as compared to touch screen use, which is possibly due to the haptic and kinetic feedback provided by manual control. Although the redundancy of control formats (the

combination of touch screen and manual controls) does not result in greater visual load than manual control, it leads to degraded secondary task performance, comparable to touch screen performance. One explanation for this finding is confusion and hesitation experienced by users when posed with multiple available control formats. Regarding user preference of control formats, users tend to perform secondary tasks with a single control format even when multiple formats are available. They also tend to prefer manual control over touch screen use.

The study provides support for introducing of automation (level 1) in vehicle, which has the potential benefit of enhancing driver hazard negotiation performance, when adequate information on system limitations are communicated to drivers prior to driving. On the basis of this study, and prior conflicting research results, it is possible that higher SAE levels of vehicle automation might produce similar benefits, up until a certain level at which drivers may experience vigilance issues and losses in situation awareness. Therefore, this study highlights the need for further research concerning the impact of higher SAE levels of vehicle automation on driver hazard negotiation performance. It is necessary for future studies to conduct a more complete mapping of the impact of vehicle automation and driver situation awareness. Future research should also explore other possible problems related to vehicle automation, for example, automation use and the potential for driver drowsiness.

Implications of the study also include the need for further driver education on automated driving. Drivers should be provided with education programs relating to the

role of drivers in automated driving, as well as functional limitations of vehicle automation. It is also necessary for drivers to receive training on effective vehicle maneuver techniques to handle possible automation failure scenarios, or hazardous conditions beyond automation system's hazard avoidance capability. Further empirical work is necessary to identify other factors that may be influential in system limitation communication and driver hazard negotiation performance.

The findings of the study also provide an applicable guide for in-vehicle control format design. Manufacturers should consider driver visual workload, in-vehicle task performance, and driver preferences when designing vehicle control formats in order to support in-vehicle secondary task efficiency and driver safety.

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## APPENDICES

**Appendix A: Pictures of Vehicles Involved in the Survey on Vehicle Control Format**

**Control panel 1: An example of MyFord Touch control panel in Ford Flex 2016**

(Ford, 2016)



**Control panel 2: An example of 2016 BMW 7 Series control panel (BMW, 2016)**



**Control panel 3: An example of Chevrolet Corvette 2016 control panel (Chevrolet, 2016)**



**Control panel 4: An example of Nissan Juke 2016 control panel (Nissan, 2016)**



**Control Panel 5: An Example of Jaguar Incontrol Touch Control System (Jaguar, 2016)**





## Appendix B: Virtual Storyboard for Music Selection Task

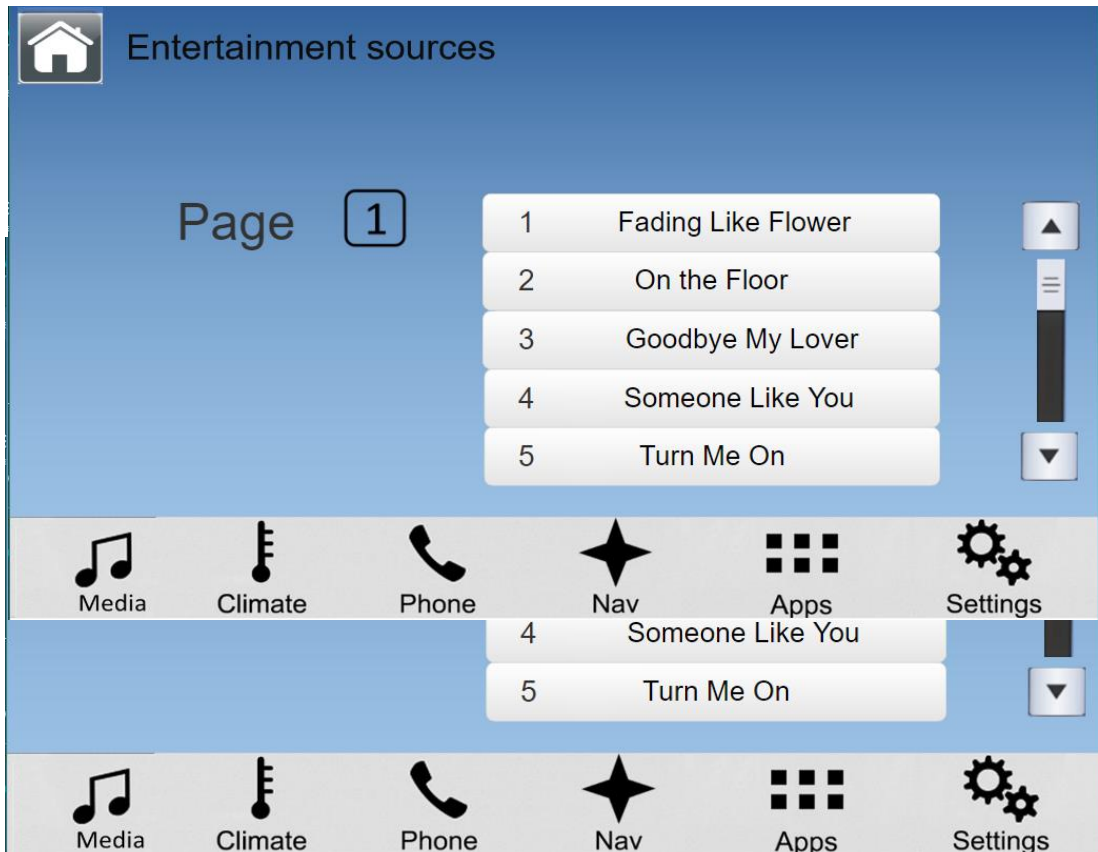
### Step 1: Select Media



### Step 2: Select CD



**Step 3: Use “Page up” or “Page down” buttons to go to target page**



**Step 5: Use “Home” button to go back to home page**



## Appendix C: Driver Background Questionnaire (DBQ)

### Driver Background Questionnaire (DBQ)

Please check one box only (for multiple choice questions) unless otherwise indicated.

#### **Section A: Demographic**

1. Name (e.g., first last): \_\_\_\_\_
2. Please write your age in years: \_\_\_\_\_
3. Please select your gender:     Male      Female
4. Please write your current corrected vision (e.g., 20/20):  
Left \_\_\_\_\_ Right \_\_\_\_\_

#### **Section B: Driving Experiences**

5. About how many days per week do you drive?
  - a. 1-2 days per week
  - b. 3-4 days per week
  - c. 5-6 days per week
  - d. Everyday
6. During the last 3 years, how many minor road accidents have you been involved in?(A minor accident is one in which no-one required medical treatment AND any cost of damage to vehicles and property were \$1,000 or less).  
Number of minor accidents \_\_\_\_ (if none, write 0)

7. During the last 3 years, how many major road accidents have you been involved in? (A major accident is one in which EITHER someone required medical treatment OR costs of damage to vehicles and property were greater than \$1,000, or both).

Number of major accidents \_\_\_\_ (if none, write 0)

**Section C: Automated driving Experience**

8. Please provide the following information of your current vehicle (necessary to establish level of technology exposure):

a. Type (e.g. sedan/ truck) \_\_\_\_\_

b. Make \_\_\_\_\_

c. Model \_\_\_\_\_

d. Year \_\_\_\_\_

9. Have you used adaptive cruise control before?

Yes  No

If yes, please answer the following questions (10-13):

10. How often do you use adaptive cruise control?

\_\_\_\_\_ hours per week.

11. Please state which of these types of roadways you use frequently when driving

with adaptive cruise control (check one or more boxes as appropriate):

- a) Freeways
- b) Other main roads
- c) City streets
- d) Country two-lane roads

12. During the last 3 years, how many major road accidents have you been involved in when driving with adaptive cruise control? (A major accident is one in which EITHER someone required medical treatment OR costs of damage to vehicles and property were greater than \$1,000, or both).

Number of major accidents \_\_\_\_ (if none, write 0)

13. During the last 3 years, how many minor road accidents have you been involved in when driving with adaptive cruise control?  
(A minor accident is one in which no-one required medical treatment AND cost of damage to vehicles and property were \$1,000 or less).

Number of minor accidents \_\_\_\_ (if none, write 0)

**Section D: Vehicle control interface Experience**

14. Please state which of these types of control interfaces are available in your vehicle

(check one or more boxes as appropriate):

a) Manual controls (buttons, control knobs)

b) Touch screen

15. If you checked both boxes above, which type of control format do you use

more frequently? (check one box as appropriate):

a) Manual controls (buttons, control knobs)

b) Touch screen

16. About how often do you use a car CD player when you drive

a. < 1 day per week

b. 1-2 days per week

c. 3-4 days per week

d. 5-6 days per week

e. Everyday

f. My car does not have a CD player

17. What type of control format do you mostly use to play CDs in your vehicle

(check one or more boxes as appropriate):

a) Manual control (buttons, control knobs)

b) Touch screen

c) My car does not have a CD player

## Appendix D: Simulation sickness questionnaire (SSQ)

### Post-exposure Simulator Sickness Questionnaire

#### SYMPTOM CHECKLIST (Post-exposure)

Post-exposure instruction: Circle below if any of the symptoms apply to you now.

- |     |                                      |      |              |          |          |
|-----|--------------------------------------|------|--------------|----------|----------|
| 1.  | General discomfort                   | None | Slight       | Moderate | Severe   |
| 2.  | Fatigue                              | None | Slight       | Moderate | Severe   |
| 3.  | Boredom                              | None | Slight       | Moderate | Severe   |
| 4.  | Drowsiness                           | None | Slight       | Moderate | Severe   |
| 5.  | Headache                             | None | Slight       | Moderate | Severe   |
| 6.  | Eyestrain                            | None | Slight       | Moderate | Severe   |
| 7.  | Difficulty focusing                  | None | Slight       | Moderate | Severe   |
| 8.  | Salivation increase                  | None | Slight       | Moderate | Severe   |
|     | Salivation decrease                  | None | Slight       | Moderate | Severe   |
|     | (as compared with normal salivation) |      |              |          |          |
| 9.  | Sweating                             | None | Slight       | Moderate | Severe   |
| 10. | Nausea                               | None | Slight       | Moderate | Severe   |
| 11. | Difficulty Concentrating             | None | Slight       | Moderate | Severe   |
| 12. | Mental depression                    | No   | Yes ( Slight | Moderate | Severe ) |
| 13. | "Fullness of the head"               | No   | Yes ( Slight | Moderate | Severe ) |
| 14. | Blurred vision                       | No   | Yes ( Slight | Moderate | Severe ) |
| 15. | Dizziness eyes open                  | No   | Yes ( Slight | Moderate | Severe ) |
|     | Dizziness eyes close                 | No   | Yes ( Slight | Moderate | Severe ) |
| 16. | Vertigo                              | No   | Yes ( Slight | Moderate | Severe ) |
| 17. | Visual flashbacks*                   | No   | Yes ( Slight | Moderate | Severe ) |

18.	Faintness	No	Yes (	Slight	Moderate	Severe )
19.	Aware of breathing	No	Yes (	Slight	Moderate	Severe )
20.	Stomach awareness	No	Yes (	Slight	Moderate	Severe )
21.	Loss of appetite	No	Yes (	Slight	Moderate	Severe )
22.	Increased appetite	No	Yes (	Slight	Moderate	Severe )
23.	Desire to move bowels	No	Yes (	Slight	Moderate	Severe )
24.	Confusion	No	Yes (	Slight	Moderate	Severe )
25.	Burping	No	Yes (	Slight	Moderate	Severe )
26.	Vomiting	No	Yes (	Slight	Moderate	Severe )
27.	Other	No	Yes (	Slight	Moderate	Severe )