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Investigating the Impact of In-car Communication on Law Enforcement Officer Patrol Performance in an Advanced Driving Simulator

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Project Abstract

Law enforcement officers must process and respond to a variety of information sources to effectively and safely patrol the environment. These demands on attention, such as dispatch radio calls, are necessary for the officer to perform the patrol and thus cannot be eliminated without compromising the officer's effectiveness. This project evaluated law enforcement officers' driving, visual attention, and situation awareness during patrol driving. We varied conditions to determine the impact of information presentation format on officers' ability to execute patrols. In addition, we were interested in how the growing number of in-vehicle technologies may be able to provide additional support to the officer and reduce the impact of information overload.

Fourteen municipal law enforcement officers, recruited from local law enforcement agencies, performed patrols using a driving simulator under general patrol conditions: baseline patrol driving, patrol driving with radio calls, and patrol driving with radio calls and an in-car data terminal. We anticipated that the need to process information over the radio would lead to changes in driving behavior (e.g., steering and lane position variability), visual attention deployment (e.g., eye movements), and situation awareness (e.g., current status of self and other officers). We also expected that the provision of redundant information via an in-car terminal would reduce the impact of this additional demand on the officer's attention. Finally, we were interested in the structure of information transmitted to the officers during patrol. We presented radio calls in both ten-codes (e.g. 10-20 = location) commonly used in police departments or in a more natural language structure (e.g., "What is your location?") Ten-codes are brief but sacrifice transparency of the message. Whereas natural language structure may be easier to understand, it can require a longer transmission time. We presented information in both formats during simulated patrols to determine if one type of transmission type has a lower impact on officers' driving, visual attention, and situation awareness.

Analysis of variance plus post-hoc planned comparisons were used to evaluate the impact of information format and language structure on driving behavior, visual attention, and situation awareness measures. Our results indicate that when ten-codes are paired with a display echoing communication with dispatch or when natural language is used without such a display, accuracy on a test of situation awareness was similar to a baseline condition without distraction. This provides evidence that police departments should be made more aware of how certain technologies and practices interact.

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A. PURPOSE, GOALS, AND OBJECTIVES

The purpose of the research presented here was to provide an objective evaluation of law enforcement officer driving behavior, visual attention, and situation awareness under standard patrol conditions. The goal of the research was to understand whether and how law enforcement officer effectiveness during patrol tasks is impacted by dispatch communication and in-vehicle devices. In order to achieve this goal, we identified two general objectives.

The primary objective was to evaluate the impact of the processing of dispatch-provided information on officer driving and patrol behaviors, officer visual scanning patterns, and officer situation awareness during simulated patrol activities. Achievement of this objective provided an understanding of how the combination of the driving task and patrol tasks affects overall officer performance. The secondary objective was to evaluate how increased information availability, such as that supported by in-car computer terminals and other technological devices, impacted officer performance.

To achieve these objectives, we conducted a simulator based experimental study that manipulated the information provided to law enforcement officers and measured the impact not only on driving behavior but also on the officers' attention to the environment. We investigated the impact of information, both auditory (dispatch calls and other radio traffic) and visual (information provided by mobile data terminals and other in-vehicle devices), on law enforcement officer driving and monitoring of the environment under normal patrol situations. Because we placed the officer in an attentionally demanding situation that at extreme levels could impair driving, for safety considerations, this study was well-suited for simulator-based investigations. The current project resulted in insights about officer performance that can be applied to future research and technological support endeavors.

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B. REVIEW OF RELEVANT LITERATURE

1. Law Enforcement Driving

Driving is a complex task; several component tasks (e.g., visual scanning of the driving environment, monitoring vehicle speed and position, manipulating the vehicle controls) interact to produce 'driver performance' (Hole, 2007; Salvucci, 2006). However, the law enforcement driver has even greater attentional demands due to several factors including high speeds, the need to anticipate the behavior of suspects and other drivers, and a high potential for distraction from numerous, but necessary sources (Crundall, Chapman, Phelps, & Underwood, 2003). To prepare law enforcement recruits for such demands, law enforcement academies include specialized driving training as part of the standard curriculum. However, law enforcement driver training primarily focuses on vehicle dynamics, high-speed maneuvers, and other driving-specific factors rather than on the potential interactions between driving and other tasks (e.g., monitoring dispatch communications, patrolling a residential area). All of these other tasks could influence the effectiveness of the officer's patrol behavior and his or her safe operation of the vehicle.

Law enforcement driving is encompassed in three general categories of driving situations (Crundall et al., 2003). The first category of driving is standard patrol, in which all driving regulations are followed appropriately, including speed limits. The other two categories include instances requiring exceptions to general speed and right-of-way regulations: emergency response and vehicular pursuit. Emergency response driving occurs when a call for service is received requiring immediate assistance, such as reporting to the scene of an accident. Pursuit driving involves engagement of a fleeing suspect who may be disregarding driving regulations in an active attempt to evade law enforcement. Although high-speed pursuits do occur and receive a

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great deal of media attention, these events are relatively infrequent, and many law enforcement agencies already have specific pursuit policies in place to help reduce liability concerns due to vehicular pursuits (MacDonald & Alpert, 1998). The focus of the current study was on the type of driving that law enforcement officers spend most of their time doing: patrolling.

While on patrol, officers are required to manage the driving task as well as additional tasks including communication with dispatch and other officers, route planning, and preparing for what is necessary once they have reached their destination. These additional demands on the officers' attention are necessary and vital components of the officers' primary task of maintaining public safety and, thus, cannot be eliminated. For example, communication with dispatch provides critical instructions and information for response to a call for service. The information that is provided by dispatch must be processed and comprehended by the officer to determine if he or she is to respond, all while continuing to drive the patrol vehicle safely. Previous research (e.g., Recarte & Nunes, 2003) has found that these additional demands on a driver's attention impact driving, even when the additional tasks involve only the manipulation of cognitively held information without any interaction with a physical item or device. Thus, the simple demand of processing the information impacts the drivers' abilities even outside the operation of a handheld device such as a radio microphone or cell phone. In the current study, we investigated the distracting effects of task-relevant communications – information from dispatch affecting both the officer in the experiment and other simulated vehicles in the environment – on driving behavior, attentional deployment, and situation awareness, and whether in-vehicle support mechanisms (e.g.. mobile data terminals) may be effective in limiting the negative effects of the cognitively demanding monitoring and response to dispatch calls.

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2. Visual Attention in Driving

Although there is no precise estimate available for how much information for driving is gathered by the visual system compared to other systems, vision is clearly important for driving performance. One of the critical aspects of vision is the allocation of attention to parts of the visual environment for specific processing. Attentional control is generally considered from two viewpoints: directed by individual goals (i.e., top-down processing) and in response to salient stimuli in the environment (i.e., bottom-up processing) (Yantis, 1998). General consensus is that the two processes interact to direct attention across a visual scene (e.g., Torralba, Oliva, Castelhano, & Henderson, 2006; Yantis, 1998). For example, a driver may check their mirrors prior to signaling a lane change (top-down); the same driver may respond rapidly to a salient stimulus in the environment (e.g., a suddenly appearing car; bottom-up). Characteristics that may result in a salient stimulus (e.g., one that captures attention) include motion, sudden onset (appearance of an object in the visual field), or distinctiveness from the environment background.

Two common methods of measuring visual attention include response time measures and eye movement recording (Wolfe, 1998). Response time measures rely on the fact that additional time is necessary to select things to process and to move attention. Although it is effective in many situations, response time measures tend to aggregate several attentional selections in a single measure making it impossible to determine individual selection decisions. On the other hand, because the visual system has a limited locus for high-acuity viewing (the fovea, about two degrees of visual angle in diameter; Rayner 1998), attention to a specific spatial location or object is reflected in eye movements, so that, as the eye shifts, the location or object image falls on the fovea, providing greater visual detail (Posner, 1980). By measuring what objects or

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locations the eyes are pointing at, researchers can obtain a good indication of what is being attended in the environment. Attention and eye movements are not obligatorily tied; one can attend to information peripherally, as when drivers maintain lane position (Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003). However, visual attention and eye movements are closely linked under most natural circumstances, and attention must deployed to the location or object to provide information about how the eyes need to move to process that location or object (e.g., Deubel & Schneider, 1996; Henderson, 1993; Hoffman & Subramaniam, 1995; see Rayner, 2009 for recent review). Thus, where the individual is looking is a good marker for what is being attended in the environment. In the current research, the driver's tracked eye movements were used to infer the focus of the driver's visual attention.

3. Visual Attention in Law Enforcement Driving

Although law enforcement driver training focuses on vehicle dynamics, one of the focus areas of law enforcement driver training is expanding the breadth of visual scanning across the environment in order to support better situation awareness and reduce 'tunnel vision' (Bondurant & Sanow, 2000; Crundall et al., 2003; D. W. Halliday, personal communication, July 25, 2007; see also Underwood, Crundall, and Chapman, 2011). Although training to move the eyes broadly is common practice, the available empirical research on law enforcement driving, eye movement control and attentional deployment is sparse. Two studies, originating in the United Kingdom, evaluated gaze patterns during police driving situations. Crundall et al. (2003) asked three participant groups (students, experienced drivers, and police officers) to view actual law enforcement driving footage from one of the three categories of driving tasks described previously (patrol, emergency response, and pursuit). While viewing the video footage, participants continuously (i.e., in real-time) rated the hazard level of the environment on a sliding

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scale. The viewing task was not interactive; participants could not change the view or modify the actions of the vehicle. For example, the participants could not change the perspective to look through the side window of the vehicle when moving through intersections. Because the viewing task was not interactive, the hazard rating task was used to engage the participants, so that they would be more likely to maintain attention on the presented video. Participant eye movements were recorded throughout the session.

The results of the Crundall et al. (2003) study indicated that law enforcement officers, regardless of the category of driving task, demonstrated a wider breadth of scanning compared to control subjects. In addition, Crundall, Chapman, France, Underwood, & Phelps (2005) further analyzed the data from Crundall et al. (2003) and found that, although law enforcement officers and controls viewed the suspect vehicle for the same amount of time during a pursuit, officers were better able to use their remaining time to attend to other areas of potential hazards (e.g., parked vehicles), presumably due to their specialized training and experience.

Although the research of Crundall and his colleagues has provided valuable insight into potential differences between law enforcement drivers and other drivers, one could question whether the results would be similar if the driver was responsible not only for identifying hazards but also responsible for control of the vehicle (see Land & Lee, 1994; Pollatsek, Fisher, & Pradhan, 2006 for non-law enforcement studies of driving and eye movements). Research investigating eye movements during natural task performance indicates that eye movements and actions are highly dependent on the visual and motor requirements of the task (Hayhoe, Shrivastava, Mruczek, & Pelz, 2003). Thus, in order to accurately evaluate law enforcement officer visual attention during driving, the research must include vehicle control and require driver performance.

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4. Evaluating Driver Performance

The research conducted by Crundall and colleagues (Crundall et al., 2003, 2005) evaluated gaze patterns for law enforcement and control drivers while viewing video footage of police driving. It did not evaluate actual driving performance (law enforcement or otherwise) or the impact of additional tasks on eye movements and attention. It would also not be surprising to find that eye movements follow a different pattern during patrol activities than during an active pursuit or emergency response, but the Crundall et al. (2003, 2005) research does not extend to consider these differences. The current project builds on the Crundall et al. results by extending them to patrol activities and by including measures of driving performance in addition to visual attention.

Driver performance with respect to vehicle dynamics can be considered for additional measures of interest and can be compared to the patterns of eye movements during a driving task. Driving research is conducted using a variety of methods, including instrumented vehicles on public roadways or test tracks as well as driving simulation systems. The current project used a medium- to high-fidelity driving simulator (Figure 1). The driving simulator supports approximately 180° of forward visual angle, and an additional screen and built-in LCD monitors for viewing behind and to the sides of the vehicle. The driving simulator also supports detailed control for scenario design that would not be available in an instrumented vehicle on a roadway. Participants sit in a standard full-size sedan cab (Nissan Maxima) and interact with the virtual environment using the standard vehicle controls.

Sometimes there is a concern that driving simulator data lacks ecological validity. Although there is not an exact match between simulated driving and driving in a real vehicle, previous research evaluating the validity of driving simulation has determined that simulators

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have good *relative validity*, in that the patterns within data collected in actual and simulated driving are similar (Kaptein, Theeuwes, & van der Horst, 1996; Underwood et al., 2011). In our current study, we compared baseline driving against driving and monitoring auditory or auditory + visual display-based communication and use of natural language or ten-codes. The relative impact of these manipulations on law enforcement officer driving should be similar in the simulator and in the real world.

Figure 1. *The CAVS Driving Simulator*

In addition, for in-depth analyses of driver performance, the advantages of using driving simulation cannot be discounted. A key benefit of using a driving simulator is the ability to study behavior and performance in driving situations that would be hazardous to the driver or others on the road. Safety concerns, particularly with regard to hazardous situations, are greatly reduced by using a simulator rather than an actual vehicle. A second benefit of simulators is the degree to which the experiment environment can be controlled to investigate the scenarios of interest.

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Multiple drivers can be placed into the same infrequent but critical situations that would be difficult to replicate or control during normal driving. Additionally, driving simulators allow for the recording of high-quality data on how the driver interacts with the vehicle controls, and along with the use of integrated and time-synched video and eye movement recording, adds to the high level of detail available for measuring and evaluating driver performance.

All of these advantages of simulator studies were important to the current study because officers were required to patrol in novel and distracting environment while communicating with dispatch and monitoring the environment for potential violations. The officer during the patrol also had to interact with simulated actors in the environment. The ability to precisely measure aspect of vehicle handling and eye tracking without concern for the safety of the various actors allowed this project to investigate situations that would be dangerous otherwise while maintaining an element of realism to the patrol. By using an immersive environment we could allow officers to make their own decisions about how to perform the patrol safely. For example, officers were not required to take the same path to call for service, and thus they could execute the patrol in a more realistic manner. This ability to allow officers freedom of choice in how to patrol, however, does have the consequence that each officer might act differently in the environment. Although this might be seen as a disadvantage of the current design, it is more realistic to allow officers freedom of choice in how they would respond to a call especially in the path that they take to the location.

5. Evaluating Officer Performance

The previous discussion has centered on visual attention in driving performance, but a law enforcement officer's tasks extend well beyond that. Previous research supports the prediction that primary (driving) and secondary (communication and more) tasks interact to

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significantly impact visual attention and eye movements. The situation is even more extreme for law enforcement officers who are expected to simultaneously scan the local environment, monitor dispatch communications, and maintain safe driving practices.

The current research evaluated officer performance, including driving performance, eye tracking, and situation awareness measures, during a simulated patrol task. As already mentioned, driver performance measures were recorded by the simulation system, and eye tracking equipment was integrated with the simulation system to record synchronized gaze information. The gaze information collected combines elements of driving-related and patrol-related tasks. As for the final set of measures, we used an established definition for situation awareness (Endsley, 1995a). Endsley defines situation awareness as an integral part of complex task performance wherein multiple stimuli are perceived and integrated to determine a situation's current and projected (future) status. Situation awareness requires individuals to process and comprehend information from their environment and combine it with their knowledge and expertise into an overall understanding of the situation and how it may change.

Technology can impact situation awareness by making relevant information more easily obtainable, or by adding complexity or ambiguity that increases demands on the operator (Lee, Lee, & Boyle, 2007; Ma & Kaber, 2007). Ma and Kaber presented navigation information to participants using either a cell phone or a laptop interface; the navigation information was either 100% reliable, as measured in the fewest number of turns to be made, 80%, or 60% (in which two additional turns were required as 'corrective' actions). Situation awareness was measured by recall of aspects of the driving environment as well as general estimates of time required to complete the drive, immediately following each trial. The reliability of the information was

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found to impact situation awareness scores more dramatically than the format of the information (i.e., cell phone or laptop).

Other factors that may impact situation awareness include current task goals, stress, situation complexity, and fatigue, all of which can be viewed as relevant to officer performance. The current research included an assessment of situation awareness that provided a deeper understanding of the impact of communication type and content on officer comprehension of and performance during simulated events.

Numerous previous studies have found decreased performance on at least one task during multitasking; these include cellular phone conversations (Strayer, Drews, & Johnston, 2003), text messaging, use of a GPS system, and mental processing tasks (Recarte & Nunes, 2003). Because law enforcement officers are frequently required to maintain multiple goals in demanding situations, the potential for distraction or mental overload leads to safety concerns, both for the officer and the general public (Anderson, Courtney, Plecas, & Chamberlin, 2005). Previous research on novice and experienced civilian drivers has found that cellular phone conversations not only negatively impact driving performance measures, but also driver situation awareness (Kass, Cole, & Stanny, 2007). Although novice drivers show lower performance and situation awareness overall, the impact of cognitive distraction is similar across the two groups – This has significant implications for law enforcement driving, as it suggests that drivers cannot easily 'learn' to multitask successfully (e.g., Cooper & Strayer, 2008).

Most of the focus in research on driver multitasking has focused on the potential for distraction. However, there is also a possibility that adding a redundant source of information can support officer performance; for example, an in-car display that repeats information provided by dispatch may allow the officer to focus more on driving and preparation because he or she no

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longer is forced to maintain the details of the call for service in memory. The additional support may improve performance over and above the potential distraction effects of having a visual display in the vehicle.

In addition, law enforcement officers are 'advanced drivers' (Walker, Stanton, Kazi, Salmon, & Jenkins, 2009) in that they have received additional specialized training. It is possible that due to this additional training, law enforcement officers may have improved situation awareness and improved ability to anticipate information needs, both from the driving environment and from their equipment, compared to civilian drivers; researchers have found that specialized training can improve officers' recall for domain-relevant information (Page, Thibeault, Page, & Lewinski, 2008). This training may in turn mitigate the potential distraction effects. Such an analysis of the cost and benefits of these devices for law enforcement officers has not, to our knowledge, been evaluated at this level of detail. However, this issue has received national interest as evidenced by a recent *New York Times* article entitled "Driven to Distraction: Gadgets in Emergency Vehicles Seen as Peril" in which anecdotes of potential dangerous use of in-vehicle devices are described (Richtel, 2010). Concern about officers interacting with in-car technology has even led some departments to 'lock out' interactions with the terminal once the vehicle reaches a certain speed (Rose, 2012; see also Driver Focus Telematics Working Group, 2006, for more general guidelines from the Alliance of Automobile Manufacturers). Because of the potential for both positive and negative effects of in-vehicle devices, a better understanding of how these new technologies impact officer safety and performance is necessary for officers and policymakers to make informed decisions, particularly given the financial constraints of most agencies.

C. RESEARCH DESIGN AND METHODS

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The current project explored the impact of communication with officers by using eye tracking technology, driving simulation, and situation awareness assessment to investigate officer performance during simulated patrol activities. We investigated both the communication format (ten-codes vs. natural language) and the presence of support technology (a text display repeating information from a call for service vs. no repetition of the call for service information). These factors could influence the ability of the officers to focus on their patrol driving.

Our manipulation of the type of communication was motivated by the different challenges of using a coded communication format versus a more natural communication type. Many police departments in the United States rely on coded communications between dispatch and officers and among officers. These communications are efficient (e.g., in one department in the current study the code 10-78 J1 represents a suspicious person). However, to effectively use this communication type, the officer must have memorized what the codes mean and must retrieve that information at the time of the call for service. In contrast, some police departments are making a transition to natural language communication type. In this type of communication, the dispatch operator uses natural language when describing the call for service (e.g., “there is a suspicious person”) rather than relying on a code. This type of communication has the advantage that there is no need for the officer to decode the information, it is in the correct format already. In addition, this communication type does not require the learning of new codes or different codes for different departments. However, natural language may be less efficient over a radio especially after years of experience. Thus, our manipulation of the dispatch format investigates if and how communication type impacts patrol driving and attentional deployment and whether the additional demands of one type of communication affect performance.

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The second factor that we manipulated was the presence of technology that repeated the information that the dispatch operator had given over the radio. We were interested in whether or not the demands of attending to radio communications while driving could be mediated by providing an “external memory” of the information received. In our dynamic display condition, when officers received a call for service such as "We need you to 10-22 at 318 East Main Street", the information would be displayed in the vehicle on a mobile data terminal (MDT) simulator (see Figure 2 and below for description). During that call for service, the officer could refer to the display to aid in remembering the necessary details of the particular call. Thus, the repeated information on the MDT decreased the need to rely on the officer’s own memory of the call. In a separate condition, the MDT did not repeat the call for service and thus the officer had to rely on his or her on memory of the call. This latter condition should be more cognitively demanding that the condition that did not provide the additional information.

1. Simulator

The driving simulator that was used for the project provided standard vehicle controls in a full sedan-style cab (see Figure 1). The simulator is housed at the Center for Advanced Vehicular Systems (CAVS) on the Mississippi State University campus. The driving environment in front of the driver is projected onto three large screens, providing a full 180-degree field of view from the driver’s perspective. Additionally, the side mirrors include LCD monitors and there is another screen located behind the vehicle to provide rear views, resulting in what is functionally an immersive, 360-degree driving environment. All driving scenarios were designed using the scenario development tool SimVista and were run using SimCreator (Real-Time Technologies, Inc.; Royal Oak, MI). The CAVS simulator had previously been used for research investigating impact of hands-free cellphone conversation on driver attention (Garrison

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& Williams, 2013) and performance and for development of human-in-the-loop simulator tools for the US Army Tank Automotive Research, Development, and Engineering Center.

The simulated environment was designed to be similar to the environments participating officers regularly patrol as part of their jobs, although it was not designed to directly reflect any specific area of the cities represented by participating officers. There were a number of reasons for this. Recruiting from three jurisdictions would have required three separate terrain models, and differences among terrains would complicate comparisons across departments. Although it is possible to import LIDAR-scanned terrain models into the simulation system, this would be cost- and time-prohibitive for the current project. Simpler modeling (e.g., constructing terrains that were roughly comparable to actual areas of the participating jurisdictions) may have been possible, but also extremely time-intensive. In addition to simplifying technical requirements, the use of a single generic environment put all participating officers in a similar situation – no one was familiar with the environment they were patrolling. Thus, all officers began the experiment with a similar level of knowledge of the patrolled environment.

To simulate mobile data terminal communications, a Sony Vaio© VGN-T260P mini notebook computer (Screen size -- 10.6 in, 27 cm) was mounted to the right of the gear shift in the cab of the simulator (see Figure 2) 91 cm from the driver head rest with the seat in the position that most officers used. At that distance, 27 cm subtends 16.88° of visual angle. As can be seen from Figure 2, the screen was divided into two panels. The right panel contained an overhead map of the simulated environment. This map was visible at all times while the officer was driving the vehicle, but the officer's location was not indicated on the map. The other panel contained the area where text "echoes" of service calls were displayed in the dynamic display experimental conditions (See Table 1 for conditions in the experiment). In those conditions, the

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text that would be displayed was a repetition of the dispatch call for service. For example in the ten-code display condition, the text “We have a 10-78 J1 on the 200 block of Oak Drive” would be presented on the display following a dispatch call for service using the same language. In the natural language condition, the text “We have a reported vehicle burglary in progress at 205 Ginger Street” would be displayed following that particular call for service. In the baseline and static display conditions, the map was visible, but the text display panel remained blank. Critically, although the notebook screen contained data relevant to the patrol, the officer was not required to interact with the device to retrieve information.

Figure 2. *In-car mobile data terminal setup*

The notebook computer was also used to collect data following a stop in the simulation at a call for service or a normal patrol stop. The simulation would pause and be removed from the projection screens. At this time, both the map and the display panel would be removed from the notebook’s screen and a series of questions about the current situation would be presented to the officer. The questions were in a multiple choice format and the officer would input his or her

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answers to the questions using the keyboard. Critically, this interaction with the laptop only occurred while the simulator was in “park” and thus the vehicle was not moving. Once the series of questions were completed, both the notebook screen and the projection screens returned to the normal simulation information and the officer proceeded with the patrol.

Another aspect of this design was the collection of gaze patterns to indicate attentional deployment during the patrol. Gaze patterns were recorded using a faceLAB 4.6 stereo video-based eye tracker and software (Seeing Machines; Canberra, Australia). The faceLAB 4.6 system incorporates eye and head tracking in a compact portable system that was installed in the driving simulator. Because this type of eye tracker is mounted on the dashboard in front of the driver and does not use any head mounted hardware to track the eyes, the system allowed a participant to move his or her head freely during the tracking episode. The freedom of movement allowed for a more natural interaction with the patrol environment. The sampling rate for the faceLAB system is 60Hz, and running in precision mode, it can localize the point of gaze to within 1 degree of visual angle. However, the functional sampling rate of the eye tracking data analyzed is 30 Hz, due to the dependence on the context of the driving simulation and the limitations of the integrated video recordings in Data Distillery (Tumokinetic, LLC; Fort Collins, CO). In addition, the mounting of the eye tracker on the dashboard limited the eye tracking overlay to the 30 degrees forward of the driver (+/-15 degrees from the center line). In contrast, the in-car terminal was located to the right of the center console, more than 45 degrees from the center line. For these reasons, the video was used as the primary source of eye, gaze, and head tracking data, with the pixel and screen coordinates from faceLAB used for gaze dispersion analyses.

2. Participants

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A total of 24 sworn law enforcement officers were recruited to participate in the experiment. Of these, 14 law enforcement officers completed the experiment. All participants who completed the experiment received a monetary payment of $50 as compensation for a single 2.5-hour time commitment, and all participants were recruited from local law enforcement agencies: Starkville Police Department, Columbus Police Department, and Tupelo Mississippi Police Department. Officers from the Columbus and Tupelo Police Departments were also compensated a set amount based on round-trip travel mileage at a rate of $0.50/mile ($23 for Columbus [2 officers]; $64 for Tupelo [3 officers]). The participants were recruited via notices approved by the Mississippi State University Institutional Review Board (IRB) and the relevant departmental agencies, which were posted at department headquarters and/or made available via department intranet. All officers provided written informed consent prior to participation in the experiment.

Ten officers provided written consent to participate but failed to complete the experiment. These individuals either withdrew voluntarily or were impacted by simulator sickness to the degree that the experimenter terminated the experiment. In the latter case, individuals were made comfortable in the laboratory (away from the driving simulator itself) and monitored until they reported a return to baseline condition. In either instance, participants were paid for their time spent in the laboratory ($25/hour, rounded to nearest half-hour) plus any mileage, as defined in the previous paragraph (Starkville [5 officers], Columbus [3 officers], Tupelo [2 officers]). This rate of attrition far exceeded previous experiments using this driving simulator and negative interactions of some officers with the driving simulator likely impacted our substantial efforts to increase the sample size of the experiment.

3. Experimental Design

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The experimental design is presented in Table 1. The project used a within-subjects experimental design where each participant participated in a baseline condition (baseline patrol driving – no additional information) and the experimental conditions that manipulated communication format and technology (e.g., patrol while monitoring natural auditory + static display, ten-code auditory + static display, natural auditory + dynamic display, or ten-code auditory + dynamic display). A within-subjects design is more powerful for detecting differences between conditions than standard between-subjects experimental designs (where each participant serves in only one condition). In essence, each participant served as his or her own matched control group and thus the design examines only changes between conditions. Regardless of the individual's baseline performance, if an experimental condition had an effect the difference between an individual's performance in the experimental condition and a different condition isolated the experimental effect.

3.1. Independent Variables

The independent variables investigated included the format of information from dispatch communications (auditory + static display or auditory + dynamic display presenting information), the format of dispatch communications (natural language or ten-codes), and the type of event (call for service from dispatch or an event observed during patrol).

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Table 1. *Experimental Design*

Scenario	Patrol Type[a]	Information Presented[a]	Communication Type[a]
1	Familiarization	Not Applicable	None
2	Baseline	Not Applicable	None
3	Patrol	Auditory + Static (No) Display	Ten-Codes
4	Patrol	Auditory + Dynamic Display	Ten-Codes
5	Patrol	Auditory + Static (No) Display	Natural Language
6	Patrol	Auditory + Dynamic Display	Natural Language

[a] Scenarios 2 through 6 are presented in a counterbalanced order including each combination of information type and communication type.

The first factor that we manipulated was the type of information that was presented to the officer during a patrol. Officers patrolled a simulated environment according to their standard patrolling behaviors. Officers were expected to follow speed limits and observe right of way, given that none of the presented events required a high-priority response (e.g., responding with lights and siren activated). In the baseline patrol, the officer patrolled the environment without any radio or dispatch auditory information being presented to the officer. In the auditory + static display conditions, the officer executed all aspects of the baseline patrol but had to attend to dispatch calls and other radio traffic (i.e., other simulated vehicles). The officer was required to attend to, process, and respond to calls relevant to his/her patrol. The auditory + dynamic display conditions included all of the auditory information of the previous condition but the officer was

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also given access to a mobile data terminal simulator that provided visual information that supported the auditory information provided.

A second factor that was manipulated in this study was the structure of the additional information that was provided to the officer. In one set of patrols, the officers heard 'ten-codes' that are common in their department (e.g., 10-8, 'in service'; 10-4, 'message received, understood'; 10-20, 'location'). This type of information is rapid and succinct, which can lead to faster reactions by the officer, but, to be effective, ten-codes must be memorized and easily recognized by officers or they may lead to confusion. In the other set of patrols, the officer heard communications in natural language. This information, though less succinct, is more transparent in meaning and may be less likely to cause confusion when interpreted by the officer. By presenting both auditory only and auditory plus visual information in both ten-codes and natural language (in separate patrols), we were able to examine the impact of information type on patrol behaviors, attentional deployment (i.e., eye movements), and an officer's situation awareness. We manipulated both the type of information (none, auditory + static display, auditory + dynamic display) and the form that the additional information took (police ten-codes or normal conversation).

The final factor that was manipulated was the type of event that the officer responded to during a patrol. During each patrol, there were events that required a response from the officer. The events included situations that arose during the patrol itself as well as calls for service from dispatch (only in the auditory + static display and auditory + dynamic display conditions). Examples of *patrol events* are erratic or careless driving by a simulated vehicle, suspicious behavior, or violations of the law. Participants were asked to respond to events 'at their discretion'; the scripted patrol events were designed to draw attention. However, in an effort to

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maintain the appearance of standard patrol, there were no additional cues that indicated to officers that patrol events were of interest. In practice, officers responded to 'distractor' vehicles parked along the side of the road and occasional anomalies in the automated traffic behavior. In these cases, officers were presented with a generic situation awareness assessment and reviewed and scored by an experimenter.

An example of a dispatch call would be that a security alarm has sounded and the officer is directed to proceed to that location to evaluate the situation. Officers interacted with the simulated environment up until the point that they would exit the vehicle to address a situation. When the officer stopped and placed his/her vehicle in Park, the event ended. At that point, the situation awareness assessment was given in lieu of actually simulating the stop/response. The simulation did not end and was not interrupted; however, the simulator screens were blacked out to remove cues from the environment and dispatch radio traffic was not present during the assessment. Following the situation awareness assessment, the patrol simulation continued with the event-triggering suspect removed from the environment. Critically, we evaluated the officer's situation awareness when responding to these various events. Specific details about the situation awareness assessment format are provided in the following section.

3.2 Dependent Variables

The dependent variables that were collected included driving performance measures, eye movement behaviors, and situation awareness during the patrol drives. Dependent measures of driving performance included control inputs, measures of longitudinal control (e.g., speed) and measures of lateral control (e.g., lane position). Driving measures were analyzed twice: 1) all samples in which the vehicle was in motion, and 2) straight-line segments of driving for lane offset measures. The officers were allowed to navigate the environment freely in order to more

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accurately reflect the patrol activity. That said, events (both calls-for-service and environmental events) occurred at regular intervals throughout the drives. Although the freedom to navigate the driving environment at will introduced additional noise into the analyses, it is important to note that the order of conditions was counterbalanced and participants were not aware of the order. Thus, any adaptation to the simulator or changes in patrolling strategy by the participating officers should be distributed across all of the conditions, rather than apparent in any specific condition.

Eye and head movement patterns (e.g., breadth of gaze, looks to mobile data terminal) were recorded via an eye tracking system and accompanying recorded video. Officer performance was measured through the integration of eye movement and driving performance data and with the situation awareness measures (described next).

Five measures of driving performance were analyzed: Two of the measures of interest involved vehicle control inputs (throttle and brake pressure) and were used for comparisons across information availability and communication conditions (Hancock, Simmons, Hashemi, Howarth, & Ranney, 1999). The third measure addressed longitudinal (speed) control via changes in velocity. The fourth and fifth measures were the variability in lateral control as reflected by the degree of deviation from the center of the lane (Cnossen, Meijman, & Rothengatter, 2004) and steering input as measured by the angle of the steering wheel. When considered together, these measures permitted the examination of the officer's ability to maintain the vehicle within standard driving rules. While patrolling, the officer was expected to follow all of the normal rules of the road. By examining speed changes and variability in lane position, the authors were able to examine the impact of distracting information on the officer's basic driving

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behavior. These measures have been used previously in the CAVS Driving Simulation Laboratory as an indication of the effects of cell phone usage on driving behavior.

The next three measures of interest considered eye movement patterns: gazes to the mobile data terminal, gaze location in the driving environment, and gaze duration. Due to the dynamic nature of the driving environment, the video overlay of eye movement recordings was used to determine targets of participants' gazes rather than defining generic areas of interest. For the purpose of the project, a 'gaze' was defined as three video frames (approximately 100ms), at the same location, once apparatus noise was taken into account. Gaze location (whether to the mobile data terminal, Figure 2, or to the driving environment) and duration were rated independently by at least two raters, with initial discrepancies settled through discussion between raters if needed. Visual gaze location was used to determine if a potential hazard or object of interest was fixated and processed by the participant. The extreme angle of the in-car terminal in relation to the eye tracking cameras further complicated the eye tracking analyses. Because the device was outside the effective range of the eye tracker, we were required to use head turns along with the gaze to estimate looks to the computer.

Situation awareness was measured by an assessment presented on the in-car terminal each time a participant responded to one of two types of event: a call for service or an environmental event (see Figure 2). A call for service required the officer to drive to a specific location provided by dispatch. An environmental event required the officer to identify a suspicious activity in the environment and respond. The assessment asked for basic information about the call or event, similar to information that may be included in a report or in communication with dispatch and other officers. Participants selected their responses to the assessment questions from four alternatives provided via the in-car terminal (i.e., a four-

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alternative forced-choice recognition task). Each assessment required participants to respond to three questions before returning to the simulated patrol task.

Assessing situation awareness by requesting basic information about the situation from the participant is a commonly used technique; although the assessment resulted in a brief interruption in the simulation, previous research indicates that it is neither obtrusive nor disruptive to participant performance (Endsley, 1995b; Ma & Kaber, 2007). Officers input responses to questions probing the first two of the three levels of situation awareness as defined by Endsley and Garland (2000): Perception and Comprehension (information presented on the terminal simulator in the visual information conditions was removed prior to asking the officer these questions). By examining situation awareness across the different types of distraction and communication types, we more fully captured the impact of the distracting information on what the officer was or was not aware of at the time. Also, by evaluating the presence of supporting visual information on situation awareness, we determined if the provision of such information is advantageous for law enforcement officers.

There is a distinction to be made between the situation assessment measures used by Ma and Kaber (2007) and those used here. In the Ma and Kaber study, the goal was to measure *driver* situation awareness; for instance, did drivers effectively follow the directions provided by the navigation aid (whether the most efficient or reliable route or not). In contrast, the current study aimed to evaluate *officer* situation awareness; that is, how much information about the current event did the officers perceive, and can thus recognize in a forced-choice assessment. In essence, the difference is that officers are required to report on many details after the fact in a police report. The goal of the officer situation awareness questions was to evaluate if the different types of communications impacted the awareness of the perceptual and comprehension

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details that require memory (e.g., vehicle type involved in the accident). The questions did not probe information about irrelevant details that occurred during the drive. Officers were asked about event-related details and details regarding other officers in the area. These are relevant details for officers and our interactions with local officers indicated that these questions were reasonable.

3.3 Demographic Questionnaire

All participants were given the demographic questionnaire provided in Appendix C Form A. Demographic measures were used to characterize differences in driver performance based on age, training, education, or experience.

4. Procedure

The experiment took no more than 2.5 hours to complete. The study was divided into 2 main components: Familiarization Driving and Patrol Scenarios. Upon consenting to participate in the experiment, participants were seated in the simulator and given a brief introduction to the particulars of the vehicle controls and the eye tracking system. Any questions that the participants had about the vehicle controls and eye tracking system were answered prior to any data collection. The purpose of the familiarization drive was for participants to be given time to drive freely through a simulated environment to acclimate to the dynamics of the driving simulator. This portion of the study was not analyzed. The familiarization drive took approximately 8 minutes.

Once participants had been given an opportunity to acclimate to the driving simulator environment and the presence of the eye tracking equipment, the experimenter calibrated the eye tracking system for the participant. Participants might have noticed a set of dimly lit LEDs on the eye tracker frame when the eye tracker was recording, but these LEDs did not interfere with

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the ability to see the simulated environment. Once eye tracker calibration had been completed, participants received instructions to begin the first driving scenario. The experimenter checked the eye tracking system calibration prior to each scenario run and gave participants instructions for each of the scenarios.

To screen for potential adverse effects of simulation, e.g., simulator sickness, participants also completed the motion sickness/simulator sickness questionnaire (MS/SSQ; Kennedy, Lane, Berbaum, & Lilienthal, 1993; see Appendix C, Form B) after each scenario and were given a short break. Based on their responses to the MS/SSQ, participants may have been reminded of their rights to withdraw from the experiment at any time; a total of ten participants did so, either following the familiarization drive or during the first patrol drive, in addition to the fourteen participants who completed the experiment. Each patrol scenario plus MS/SSQ questionnaire took approximately twenty minutes to complete.

Each participating officer performed up to five types of patrol drives (baseline, natural language + static display, ten-code + static display, natural language + dynamic display, ten-code + dynamic display). The order of types of patrols was counterbalanced across participants with participants randomly assigned to presentation order. Two of the fourteen participants only completed four drives due to time constraints.

Within each type of patrol drive, the officer was asked to perform normal patrol behaviors and to respond to 3-4 situations (approximately one every 3 minutes) as they normally would while on patrol. For example, during a patrol, the officer might have witnessed an individual driving erratically. During patrols, officers were expected to follow normal traffic behavior (e.g., speed limits, stops, etc.), and each officer was expected to respond according to his or her own training in all situations.

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When performing the patrol with distracting/additional information, the officer was expected to monitor and respond appropriately to dispatch radio calls (in the auditory + static display conditions) or dispatch radio calls plus text-based information on the mobile terminal (in the auditory + dynamic display conditions) in addition to performing all normal patrol behaviors. Depending on the experimental condition, the information was presented in natural language or using ten-codes.

The additional information provided in the auditory conditions simulated multiple patrol vehicles in the area and occasionally required the officer to respond to a call (e.g., a security alarm sounding somewhere in the environment). While the officer was patrolling, he or she needed to ignore or disregard information that was not relevant to his or her specific patrol, but needed to respond when the dispatcher indicated that the officer should proceed to a specific location. In practice, very little of the presented information could be disregarded because the dispatch information provided related to either other officers in the environment or to the participant him/herself. Questions regarding the participant's situation awareness of other officers' locations were asked on occasion, in addition to questions about the circumstances of the current call. This was to gauge the participant's engagement in the current task, and his/her acceptance of the task as a simulation of patrol activities that might include possibilities when an officer may be called on to provide backup, or may be required to call on other officers for backup.

The experimenter was present throughout the experiment to answer any questions that arose. Following completion of the patrols, the participant completed the demographics questionnaire, was debriefed, and received compensation for his or her time.

4.1 Data Analysis

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All analyses was performed using SAS 9.2 statistical software and findings were considered significant at α=0.05. Repeated-measures analysis of variance (ANOVA) plus post-hoc planned comparisons were used to compare measures across the five patrol conditions. Driver performance was evaluated based on vehicle control (e.g., speed maintenance, lane position, steering stability) dependent measures. Eye movements recorded by the eye tracking system were overlaid onto the presented scene and were coded by at least two raters prior to analysis. Eye movement patterns were then compared across scenarios and events, based on the independent variables, to determine how task demands impacted visual attention allocation. Participant responses to situation awareness assessments were scored and compared across the conditions to evaluate impact of auditory communication, auditory communication + visual support, of natural language and ten-codes, and of event type.

D. RESULTS

1. Forms and Demographics

The fourteen participating officers (13 male) ranged in age from 26 to 45 years (mean = 33.8 years, standard deviation (*SD*) = 7.6). All but one reported having completed a 10-week police academy program; one reported having completed a 22-week (military) police training program. Five officers also reported additional training involving simulated driving (3 officers), pursuit management, and/or defensive driving (1 officer for each). Officers averaged 14.4 years of education (*SD* = 1.8 years), 9.1 years of experience as a law enforcement officer (*SD* = 7.1 years), and 7.1 years on patrol duty (*SD* = 5.6 years). Two officers were with a department that has used only natural language in dispatch communications since 2007; both officers reported that they were familiar with ten-codes and had used them in the past. All officers were given the

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opportunity to briefly review a ‘cheat sheet’ of ten-codes for their respective departments prior to the first experiment (patrol) drive.

In addition to the Demographic Questionnaire, participants completed a Motion Sickness/Simulator Sickness questionnaire (MS/SSQ) following each drive in the simulator, as well as one immediately following the informed consent procedure for a baseline measure (i.e., prior to any exposure to the simulated environment). Simulator sickness impacted some participants, with the most common complaints being slight fatigue (37% of responses, across all drives), slight eyestrain (33%), and blurred vision (32%). The most common ‘moderate’ complaint was ‘burping’ (7%).

2. Outcomes from the simulator experiment

2.1. Driving Performance Measures

Figures 3 through 7 present the means (a) and standard deviations (b) for the driving measures. Repeated-measures ANOVAs were conducted on the five driving measures, for both mean values and standard deviations (variability) across the five conditions, with the exception of steering angle. Only standard deviation was considered for steering angle, given an interest in the variability of lateral control (e.g., maintaining a consistent lane position) and given that mean steering angle is dependent on the route chosen by the participant, which was neither manipulated nor controlled. The following paragraphs only include descriptions for significant (or marginally significant) results. Additional analyses were run to include only straight-line driving segments, but there was insufficient power to result in any significant findings for any of the driving measures (All Fs < 2.18; all ps >.08). Analyses were also conducted after removing the two officers who were with a department that no longer uses ten-codes for communication. The resulting ANOVAs were all non-significant; however, the data patterns are substantively the

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same as the entire data set (means and standard deviations are presented in Appendix C for comparisons to Figures 3 through 7).

The first measure of interest was steering angle variability. Although there were slight differences (see figure 3), the differences did not reach significance ($p > .20$) and thus will not be discussed further.

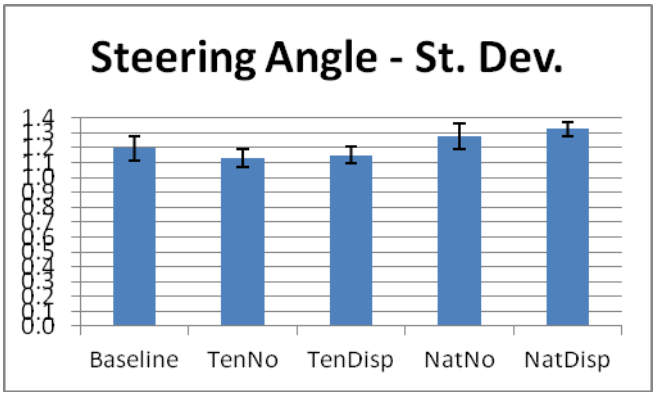

Figure 3. *Standard Deviations for steering angle (in radians) by condition.*

Mean lane offset (Figure 4a) was marginally impacted by patrol condition, $F(4, 44) = 2.38$, $p = 0.07$; this was no longer significant following Greenhouse-Geisser correction (corrected $p = .10$) for violation of the sphericity assumption. More interestingly, the standard deviation of lane offset did vary significantly across conditions, $F(4, 44) = 3.31$, $p < .05$ (see Figure 4b). Lane offset in the ten-codes + static display condition was significantly less variable than the baseline condition, $t(12) = 2.44$, $p < .05$ (only 13 participants completed the baseline drive), and lane offset in the ten-codes + dynamic display condition was marginally less variable than in the baseline condition, $t(11) = 2.07$, $p = .06$. Comparing across conditions with dispatch communications, lane offset in the ten-codes + static display (no additional information) condition was less variable than in the naturalistic + static display condition, $t(13) = 3.74$, $p < .01$. Similarly, lane offset in the ten-codes + dynamic display condition was marginally less

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variable than the naturalistic + dynamic display condition, $t(12) = 2.05$, $p = .06$ (Note that only 13 participants completed the ten-codes + dynamic display drive). No other conditions differed significantly in lane offset variability. It is interesting to note that the ten-code conditions demonstrated the least variability in lane offset even compared to baseline driving; this result will be considered more fully in the Discussion that follows.

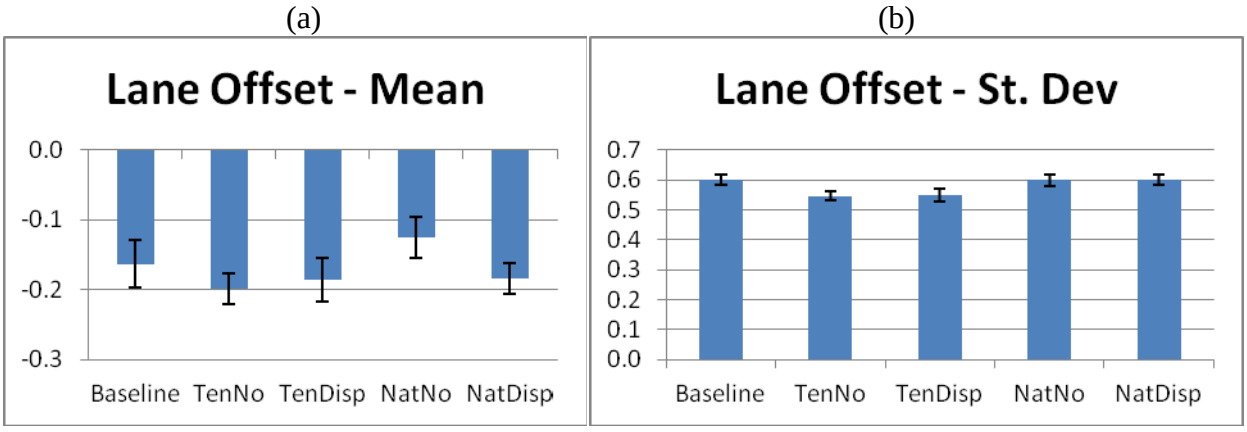

Figure 4. *Means (a) and Standard Deviations (b) for lane offset (in meters) by condition.*

Mean throttle pressure was marginally impacted by patrol condition, but was no longer significant following correction (corrected $p = .11$). Throttle pressure standard deviations were impacted by condition, $F(4, 44) = 3.94$, $p < .01$ (see Figure 5b). A second ANOVA excluding baseline found no differences among the display format or communication format conditions, $F(3, 36) = 0.41$. Therefore, throttle input was less variable in the baseline condition than in the other conditions. No other driving measure results were significantly different across conditions.

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(a) (b)

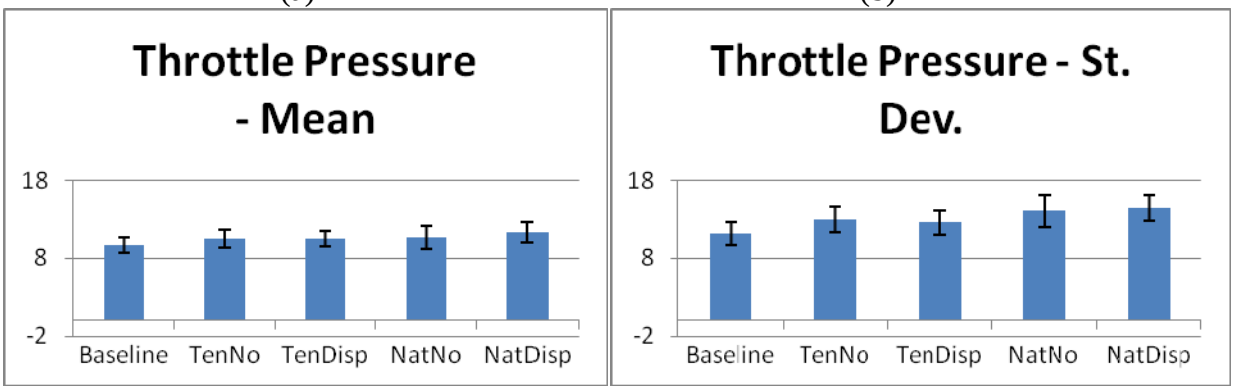

Figure 5. *Means (a) and Standard Deviations (b) for throttle pressure by condition.*

(a) (b)

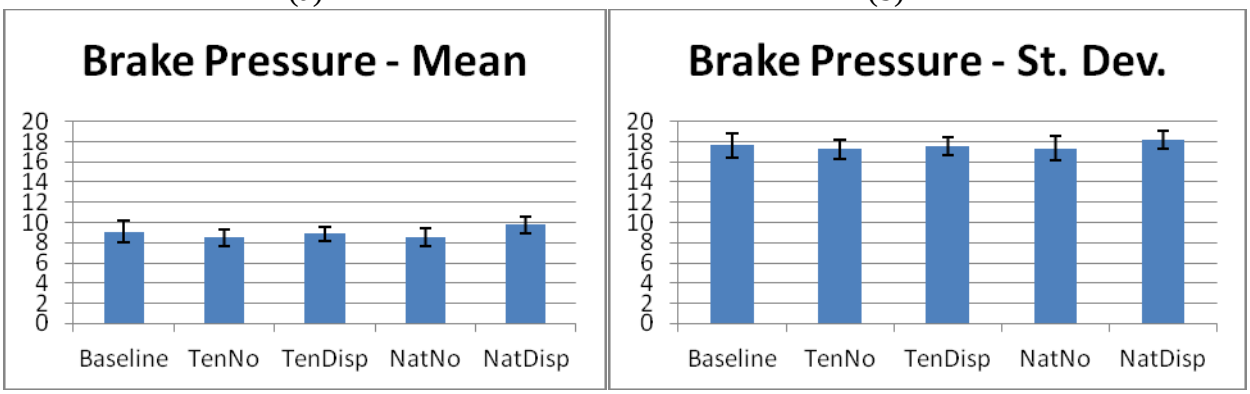

Figure 6. *Means (a) and Standard Deviations (b) for brake pressure by condition.*

(a) (b)

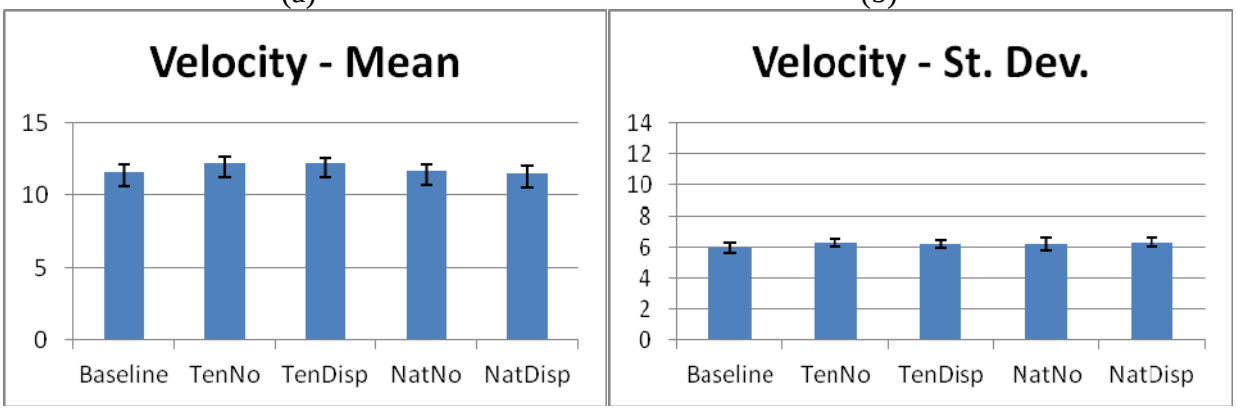

Figure 7. *Means (a) and Standard Deviations (b) for velocity (m/s) by condition.*

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In addition to the separate conditions, repeated-measures ANOVAs were also conducted on the order of drives to evaluate any potential impacts of the simulator system or fatigue over time. Mean brake pressure was impacted by drive order, $F(4, 44) = 3.05$, $p < .05$. Brake pressure was significantly higher in Drive 2 than in Drive 1, $t(13) = 2.17$, $p < .05$. Drives 3 through 5 were not significantly different from Drive 2. The variability (standard deviation) in brake pressure was also impacted, $F(4, 44) = 2.61$, $p < .05$. Brake pressure was significantly more variable in Drive 2 than in Drive 1, $t(13) = 3.55$, $p < .01$, but there was no further differences beyond Drive 2. The increase in both mean brake pressure and variability is most likely attributed to participants adapting to the stiffness of the brake pedal in the simulator.

Mean lane offset varied across drives, $F(4, 44) = 2.96$, $p < .05$. Lane offset did not differ for Drives 1 and 2, but participants drove closer to the center line starting in Drive 3, $t(13) = 2.95$, $p < .05$ and continuing through Drives 4 and 5, which were similar to Drive 3. No other order effects were apparent in the driving measures. Recall that conditions were counterbalanced in presentation order, and any potential impacts of drive order on specific conditions should be distributed across conditions, although this may result in reduced statistical power.

2.2. Eye Movement and Gaze Measures

Repeated-measures ANOVAs were conducted on gaze analyses at two levels: overall gaze dispersion and glances to the in-car terminal while the vehicle was in motion. There were no significant differences in overall gaze dispersion for either the horizontal or vertical dimension. When considering only gazes to the in-car terminal, only the baseline condition differed from the other patrol conditions, $F(4, 44) = 5.56$, $p < .001$, with the baseline condition, and $F(3, 36) = 2.20$, $p = .10$, excluding baseline. The gaze dispersion analysis was repeated without the two officers who did not currently use ten-codes. Gaze dispersion was marginally

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more variable in the vertical dimension, $F(4, 32) = 2.53$, $p = .06$, but this dropped to a probability of $p = .13$ once corrected for violations in sphericity.

Although there was no difference in the overall looks to the in-car terminal, an additional analysis was performed to examine those glances to the terminal that exceeded two seconds while the vehicle was in motion. Looks away from the road for greater than two seconds are considered particularly dangerous (Green, 1999). Given that the in-car terminal contained information that was critical to the patrol (both the map of the environment and in the dynamic display conditions, calls for service), we analyzed whether patrol condition affected these long glances (Figure 8) regardless of whether the participant viewed the map or the text (given technical constraints, it was impossible to distinguish glances to the text area or the map). Similar to all glances to the in-car terminal, there was a main effect of condition on the number of long glances, $F(4, 44) = 4.12$, $p < .01$, but as above, this effect was the result of the baseline condition being statistically different than the other conditions. When the baseline condition was removed, $F(3, 36) = 1.90$, $p > .10$, or when the ratio of long glances to the in-car terminal to the total number of glances to the terminal was considered (including the baseline condition), $F(4, 44) = 1.11$, $p > .10$, no differences were found. When the long-glance data were analyzed without the two officers whose department no longer used ten-codes, the pattern was the same. It should be noted that even given the demands of the task, long glances accounted for less than 31% of the looks to the screen across conditions (ranging from 20% in the baseline condition to 30.1% in the ten-code static condition).

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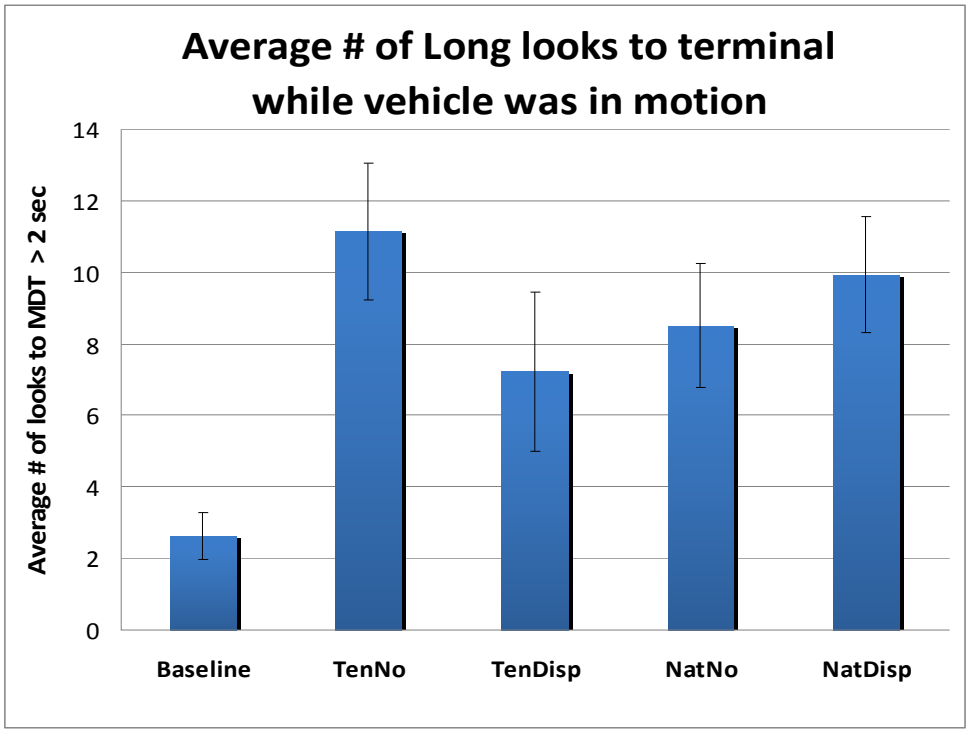

Figure 8. *Mean number of glances to the terminal that exceeded 2 seconds while the vehicle was in motion.*

2.3. Situation Assessment Measures

The final measure of interest was an assessment of participants' situation awareness, based on responses to a four-alternative forced-choice recognition test. A total of 63 questions were developed across a set of categories (12 per drive, 5 drives, plus 3 generic questions for officer-initiated events). Three questions were presented for each event. Categories included suspect and victim characteristics (race/gender/clothing), vehicle characteristics (type/color), location, and status of other officers (patrolling, responding to incident). Attempts were made to balance the types of events and questions across the conditions. Two individual questions (one each for ten-codes + static display and natural language + dynamic display) and one event (a motor vehicle collision in the natural language + dynamic display) were answered correctly by few, if any, of the officers and thus, they were judged as confusing and were eliminated from the

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analysis. Given that officers responded to events at their own discretion (e.g., officers may choose not to respond to a scripted event, or may respond to unscripted vehicle or character behavior), the number of events responded to per drive varied. Error rates are thus given as percentages (See Figure 9). A repeated-measures ANOVA was conducted on the five patrol conditions. Situation assessment scores were significantly impacted by condition, $F(4, 44) = 2.80$, $p < .05$. Post-hoc comparisons revealed that the ten-codes + static display condition, $t(12) = 3.03$, $p < .05$, and the naturalistic + dynamic display condition, $t(12) = 2.25$, $p < .05$, had higher error rates than baseline. None of the other conditions, including naturalistic + static display ($t(12) = 1.56$, $p = .14$), differed significantly from the baseline condition. A similar pattern of results occurred when the two participants who did not currently use ten-codes on patrol were removed from analyses (see Appendix C, Figure 9C).

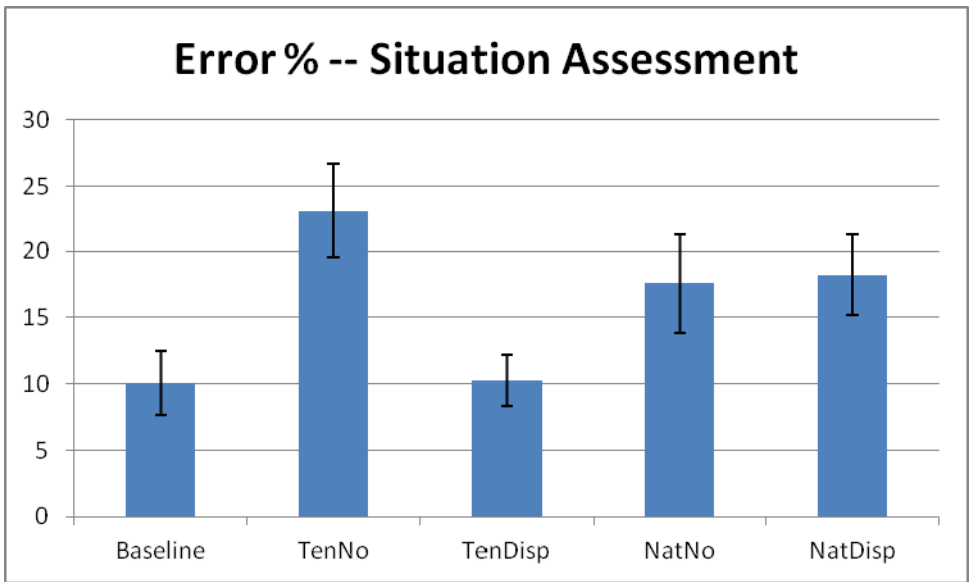

Figure 9. *Mean error rates on the situation assessment test, by condition.*

Within the communication format conditions, participants made significantly more errors in their situation assessments in the ten-codes + static display condition than in the ten-codes +

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dynamic display condition, $t(12) = 4.22$, $p < .01$; however, there were no differences among the display conditions for the natural language format, $t(13) = 0.14$.

E. DISCUSSION

The current project was designed to investigate the impact of two aspects of in-vehicle technology in law enforcement patrol: 1) the availability of dispatch information on the display and 2) dispatch communication presented in either coded (i.e., ten-codes) or naturalistic language format. In two of the conditions (ten-codes + dynamic display, naturalistic + dynamic display), dispatch information was presented next to the environment map on the display, and in the other two primary conditions, there was no additional information presented on the (static) display.

The results indicate that the most demanding condition for participants was the ten-codes + static display condition, based on decreased lane offset variability and high situation assessment error rates. The decrease in lane offset variability is important because it may indicate a shift from automated control of lane monitoring to conscious control (e.g., Kubose, Bock, Dell, Garnsey, Kramer, & Mayhugh, 2006), shifting attention away from other aspects of the driving task.

The combined evidence showing ten-codes + static display to be the most difficult condition is a surprising result because none of the participating departments actually use a mobile terminal in their patrol vehicles, and also because two of the three departments, and most of the participants in this study, use ten-codes for their dispatch communications. However, the apparent improvement in performance in the ten-codes + dynamic display condition indicates that the presence of mobile technology in the vehicle does not necessarily result in increased risk for officers on patrol. For example, there were numerically *fewer* long (> 2 seconds) glances to the terminal in ten-codes + dynamic display condition compared to the ten-codes + static display.

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The improvement in performance found between the ten-codes conditions was not present in the naturalistic conditions. This dichotomy could indicate that the mental workload of remembering multiple similar codes is challenging, but when available at all times it provides efficient and effective communication. In other words, although they are challenging for the officer to work with, if able to be perceived at any time, rather than relying on memory, this information is easy to work with. Ten-codes, from a cognitive processing point of view, do require one to both remember information in working memory (what one is doing at the moment) and match it to a long-term memory representation of what the coded information means. This cognitive effort, especially with calls that are very perceptually similar, appears to be more difficult. However, because the code itself does provide information, if it is available, it can aid processing. On the other hand, naturalistic language does not have the same demands on mental processes, and thus, the need to perceive that information again is not as critical.

The project also produced some potential trends of interest for targeted follow-up research and highlighted some of the distinctions between traditional, 'civilian' driver distraction research and law enforcement driving demands. As an example, a future project may include a more active display that provides navigation cues to participants. Provided that an analogous task can be found for civilian drivers, we can hypothesize that civilian drivers will be more greatly impacted by increased demands to attend to information outside the vehicle than are patrol officers, based on results such as Chan, Pradhan, Pollatsek, Knodler, and Fisher (2010), who found that novice and experienced drivers were 'equally bad' (p. 351) at maintaining attention to driving maintenance when gazing at objects outside the vehicles – a primary component to the law enforcement patrol task.

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There are a number of caveats and limitations to the current project. First, although the presentation order of the conditions was counterbalanced, the events that participants responded to within each condition were not counterbalanced. Although the original assignment of events to conditions was randomized, there is the possibility that some events were more difficult to find or respond to than were others. In addition, the environment navigated by participants was unfamiliar to them, which is unlikely to be the case for actual officers on patrol. This was a necessary limitation because officers from three municipalities participated, but it may have impacted the dependence of the participants on the mobile terminal display. A majority of the available screen space was dedicated to this static map on an otherwise very simple display. The simplicity of the display may factor in to the relative lack of impact of the display on officer performance, in contrast to other studies (e.g., Ma & Kaber, 2007, Victor, Harbluk, & Engström, 2005). The display had only a static map for aiding in navigation, and this map always presented reliable and accurate information. More dynamic systems will provide more challenges in maintaining reliability in system performance, which is known to impact driver situation awareness and performance (Ma & Kaber). Actual mobile terminal displays are likely to differ from the version used here.

Although mobile data terminals are being replaced in many jurisdictions with fully functional laptop computers, the current project used a very simplified terminal interface. Our goal by presenting a simplified version was to examine effects of even minimal distraction resulting from a device in the vehicle. If there was an effect of this simplified display, one can assume that a more complex display will have a greater impact. However, as we noted earlier, the display presented here did not substantially decrease (and in some cases improved) performance. In addition, the shift to in-car computers has not reached many municipalities in

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the local area (i.e., northeast Mississippi), so even improvements in the ecological validity of the interface might have been undermined by the lack of familiarity for the participating officers.

F. IMPLICATIONS FOR POLICY AND PRACTICE

Given the limited population available and the technological constraints, the considerable convergence across measures and conditions in this project permits some basic conclusions on the implications of mobile technology use on officer performance. Law enforcement officers are required to operate in a cognitively demanding situation. Previous demonstrations of the impact of distraction on driving in "civilian" populations clearly show that attention demanding tasks lead to worse driving performance. However, officers are trained extensively in driving and departments are adding technology to patrol vehicles to aid on these cognitively demanding situations. Given the increasing number of devices present in the law enforcement vehicle, there is significant concern regarding the costs and the benefits of such devices. This research aimed to determine whether and how in-car communications are affecting law enforcement officer performance in a manner similar to the impact of cellular phone conversations. In addition, our evaluation of the use of a mobile data terminal for computer-aided dispatch in the auditory + dynamic display conditions offers insight into whether the external memory benefits of the device mitigate any reduction in performance due to in-car communication and whether the addition of the mobile data terminal itself actually impairs performance. The results of the current study did not indicate that there was a substantially negative impact of the type of in-vehicle devices we were testing on either driving performance or on situation awareness. In fact, when communications were presented in the most demanding fashion (ten codes), the dynamic display condition was led to better performance. Given these data, one can support the use of in-vehicle technology that can be used by officers to help remember the current situational data.

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On a second issue, the content of the information processed by the officers, we manipulated the type of information broadcast to the officers. The current study quantitatively assessed the costs and benefits of ten-codes in terms of officer attention and situation awareness. In the end, we found that ten-codes appeared to be most cognitively demanding communication type as indicated by both driving and situation awareness measures. However, this demand was also mediated by the implementation of in-vehicle technology. Thus, the current results do not favor one type of communication over another when officers are provided technological support. However, in the absence of this support, the current results indicate that there may be a slight advantage to using natural language communication rather than the more memory intensive ten-codes. This recommendation will need to be studied more completely before being implemented.

G. DISSEMINATION OF RESEARCH FINDINGS

In order to disseminate the results to the law enforcement community, several methods are being used. First, details of the project have been presented at the NIJ Conference in 2011 and 2012. Preliminary situation awareness results were also presented at the Applied Ergonomics Conference 2012 and at a meeting of the National Officer Safety and Wellness meeting held at the Office of Justice Programs. The project was the basis of a presentation on officer safety to the International Association of Law Enforcement Planners (IALEP) in September of 2012. Another presentation was given at the Cognitive Load Workshop at the International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI ’12), focusing on the analyses of gazes to the in-car display. Presentations at these conferences are desirable since they allow for dissemination of the results to national, and some international, participants representing law enforcement officers and policymakers, researchers, and industry professionals. Feedback received from simulator trainers and risk management personnel at these

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presentations indicated that the research was of interest despite known limitations, particularly with regard to the inclusion of free driving in long, demanding scenarios. A submission to a peer-reviewed law enforcement or criminal justice journal (e.g., Journal of Criminal Justice) will follow.

Another avenue that will be used to disseminate the results will be publication in a peer-reviewed journal such as Human Factors or Ergonomics. This will ensure the results are disseminated to the research community, even those outside law enforcement. By focusing on a peer-reviewed publication with a broader audience, other researchers with similar interests or applicable expertise can be targeted. A manuscript focusing on patrol officer performance is being prepared for publication. All manuscripts will be submitted for approval by the NIJ prior to public release if desired.

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APPENDIX B: PARTICIPANT QUESTIONNAIRES

Form A
Demographic Data

Participant Number _____

Age: _____ Gender: _____

Ethnicity: (please check one)

_____ Hispanic or Latino _____ Not Hispanic or Latino

Race: (please check one)

_____ American Indian or Alaska Native _____ White

_____ Native Hawaiian or Other Pacific Islander _____ Black or African American

_____ Asian _____ Other, please specify below

_____

Did you attend a police academy? Yes No

If so, how long was the training? _____

Have you received any additional formal training in police driving since the academy?

Yes No What kind?_____

_____

Excluding a police academy, Highest Level of Education: (please circle)

Grade School:	5	6	7	8	
High School:	9	10	11	12	
College:	13	14	15	16	
Graduate:	17	18	19	20	21
Other:	_____				

Years experience as a police officer: _____

Years served as primary patrol officer: _____

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Form B
Motion Sickness/Simulator Sickness Questionnaire

Participant Number

Pre-exposure/Post-exposure Simulator and Motion Sickness Questionnaire

Please circle the appropriate items below according to your CURRENT feelings with respect to the symptoms listed.

You will be asked to answer this questionnaire again after each scenario.

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
9.	Sweating	None	Slight	Moderate	Severe
10.	Nausea	None	Slight	Moderate	Severe
11.	Difficulty Concentrating	None	Slight	Moderate	Severe
12.	Mental Depression	None	Slight	Moderate	Severe
13.	“Fullness of the Head”	None	Slight	Moderate	Severe
14.	Blurred Vision	None	Slight	Moderate	Severe

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15. Dizziness (eyes open)	None	Slight	Moderate	Severe
Dizziness (eyes closed)	None	Slight	Moderate	Severe
16. Vertigo	None	Slight	Moderate	Severe
17. Visual Flashbacks	None	Slight	Moderate	Severe
18. Faintness	None	Slight	Moderate	Severe
19. Aware of Breathing	None	Slight	Moderate	Severe
20. Stomach Awareness	None	Slight	Moderate	Severe
21. Loss of Appetite	None	Slight	Moderate	Severe
22. Increased Appetite	None	Slight	Moderate	Severe
23. Desire to Move Bowels	None	Slight	Moderate	Severe
24. Confusion	None	Slight	Moderate	Severe
25. Burping	None	Slight	Moderate	Severe
26. Vomiting	None	Slight	Moderate	Severe
27. Other (please describe)	None	Slight	Moderate	Severe

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APPENDIX C: FIGURES FOR DEPARTMENTS USING TEN-CODES ONLY

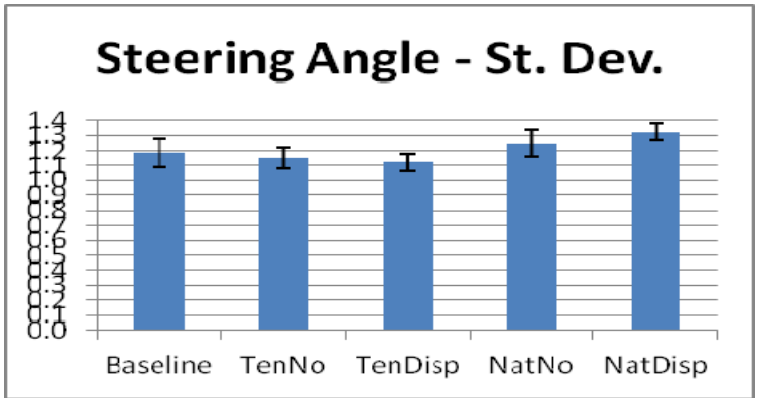

Figure 3C. *Standard Deviations for steering angle (in radians) by condition.*

(a) (b)

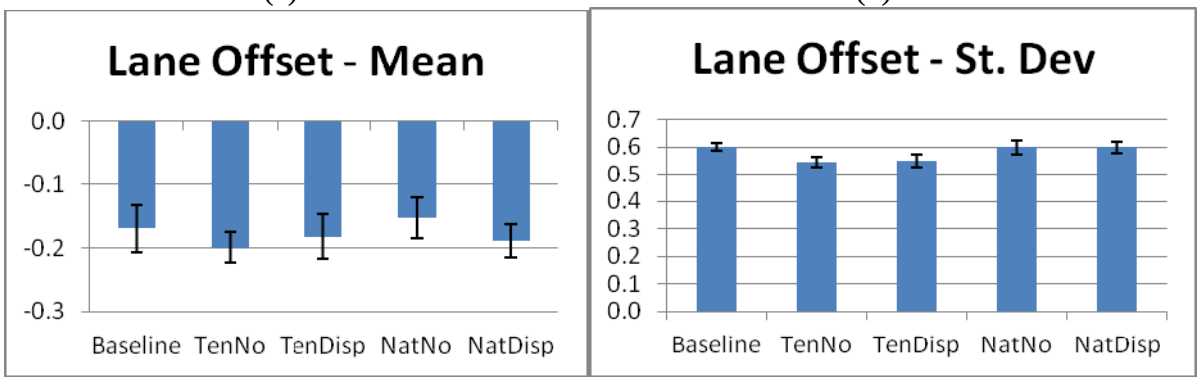

Figure 4C. *Means (a) and Standard Deviations (b) for lane offset (in meters) by condition.*

(a) (b)

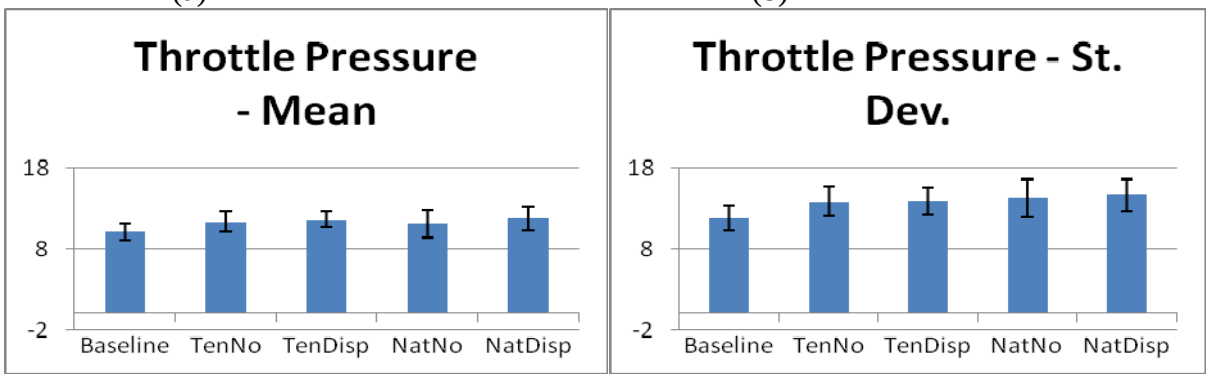

Figure 5C. *Means (a) and Standard Deviations (b) for throttle pressure by condition.*

(a) (b)

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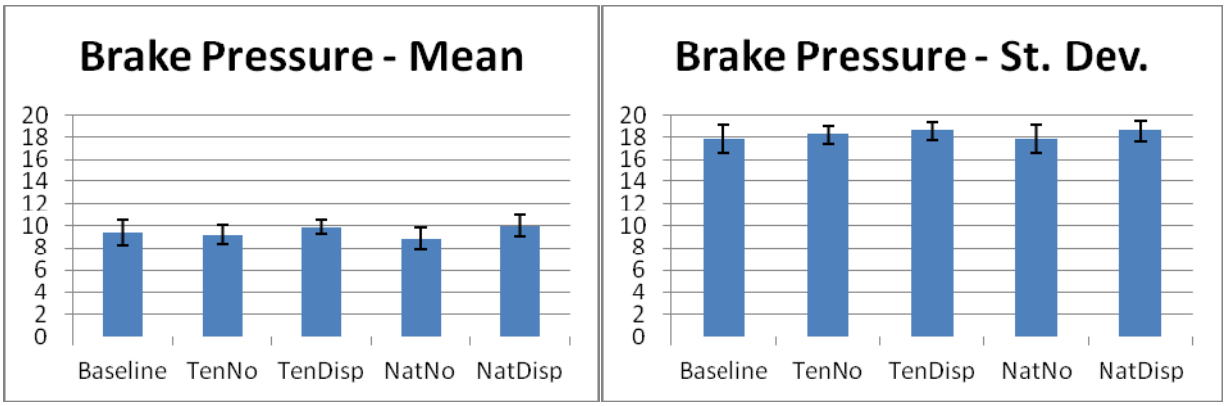

Figure 6C. *Means (a) and Standard Deviations (b) for brake pressure by condition.*

(a) (b)

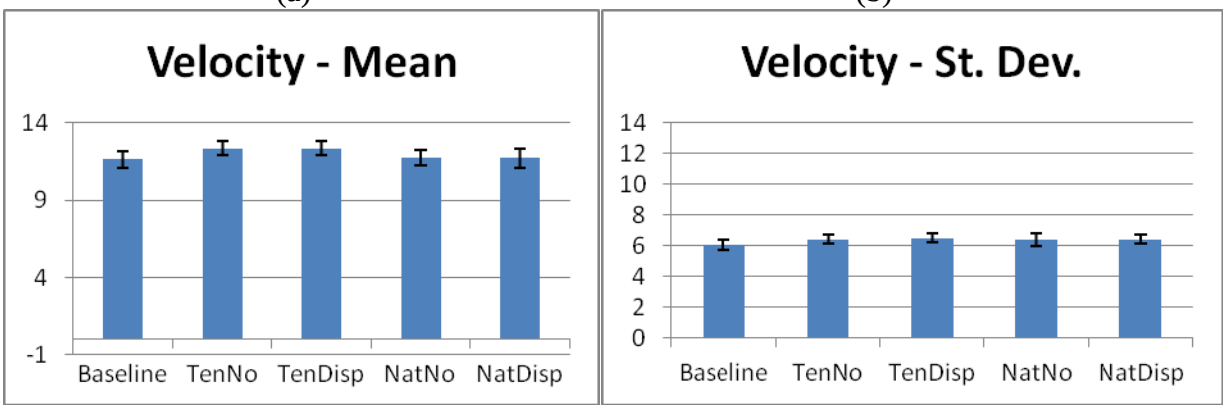

Figure 7C. *Means (a) and Standard Deviations (b) for velocity (m/s) by condition.*

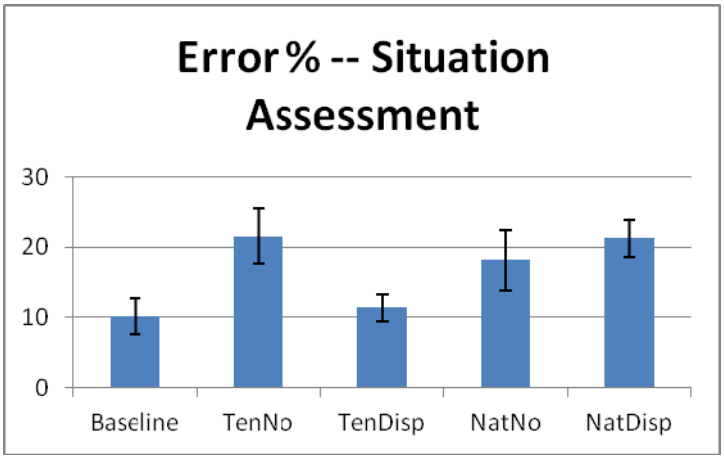

Figure 9C. *Mean error rates on the situation assessment test, by condition.*

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APPENDIX D: DATA ARCHIVING STRATEGY

A. DATA SETS

1. Simulator Data

Original Data. The RTI medium-fidelity driving simulator's scenario authoring tools, SimCreator and SimVista, allow researchers to collect many different variables during simulated driving. The simulation updates at 60 Hz. For each simulated driving scenario, we will collect acceleration, deceleration, lane deviation, steering angle, and the vehicle coordinates in the environment. The raw data is then synchronized with the video recording (30 fps) via SimObserver. Thus, the actual synchronized sampling rate is a maximum of 30 Hz.

Intermediate Data. Synchronized data and video from SimObserver is processed through Data Distillery, which allows frame-by-frame analysis of the integrated data and video. Files can then be exported from Data Distillery in a standard text-based format to be aggregated for additional analyses. Video files are available independently from Data Distillery, but removing of all identifiers must be completed prior to release.

SAS 9.2 was used to transform and reduce the raw data for analysis using SAS scripts. Initial data sets prior to transformation and reduction were saved as SAS data sets along with the participant data sets after transformation and reduction is complete. Intermediate data files for participants will include average lane deviation, min/max acceleration/deceleration values, abrupt changes in steering angle, and corresponding standard deviations for each scenario or event (as defined from the Data Distillery review). Intermediate participant data sets will be aggregated into an intermediate aggregate data file.

Final Data. An intermediate aggregate data file containing performance data on the simulator scenarios will be analyzed to compare driver performance across the simulated scenarios.

2. Driver Point of Gaze

Original Data. Driver point of gaze will be recorded by a Seeing Machines faceLABv4 system during simulator and test-track scenarios. Point of gaze information will be available in two formats: video (see below) and pixel location. For the simulator scenarios, RTI and Seeing Machines have an API that integrates faceLABv4 data with the simulator's recorded driver performance data in real-time, via the SimCreator and SimObserver software products. SimObserver generates a single data file that synchronizes records of the driver's point-of-gaze, fixations, and gaze-object intersections with the driver performance data outlined in Section 1.1.

Intermediate Data. The driver's gaze data will be reduced to a sequence of fixations in Data Distillery, including an overlay of gaze location on the central channel screen (i.e., the road scene). Additional gaze locations beyond this central region can be extrapolated by head and gaze position, as recorded by the faceLABv4 system and the SimObserver video recording. For each fixation, the point-of-gaze of the fixation, the duration of the fixation, and the focus of the fixation were determined and recorded in an intermediate data file. Intermediate participant data was saved and aggregated into intermediate aggregate data files for the simulated driving scenarios.

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Final Data. The final aggregate data files include data for breadth of gaze pattern and duration of fixations (either on all objects of interest [6 participants] or mobile-data terminal only [8 participants]) by scenario for each participant.

3. Situation Awareness Assessment

Original Data. Participant situation awareness assessment measures were collected using a custom program. Each response was coded based on the event. Resulting data files were in a standard text-based format suitable for aggregation and analysis in SAS 9.2.

Intermediate Data. The participant's responses to each event were combined with the corresponding video data to verify the situation at the time the participant responded. Participant responses to questions were then reviewed based on their overall performance during the simulation to highlight potential effects of distraction or support from information reliability on situation awareness.

Final Data. The final aggregate data include an assessment of each participant's overall performance across events, based on the type of information available and the type of event (witnessed or call for service). Overall performance scores were averaged across participants and conditions in order to evaluate the general impact of information availability and load on simulated patrol performance.

B. DOCUMENTATION

All manipulations of original data recorded by the RTI driving simulator were transformed, reduced, and analyzed in the SAS 9.2 statistical analysis package. Face and eye tracking data recorded in the faceLABv4 system were reduced by Data Distillery or in the SAS 9.2 statistical analysis package. All exported text files, SAS scripts and documentation detailing the application of scripts to the original data will be provided as part of the final report for the project.

C. DATA FILE DELIVERY

For the simulator experiments, an archive will be prepared containing a folder for raw and intermediate data files as well as the SAS 9.2 output files for each participant. In addition to the participant folders, there will be a folder containing all of the intermediate and final aggregate data files as well as any SAS 9.2 related output files. A folder containing all of the SAS 9.2 scripts and accompanying documentation will also be placed in the archive to permit transparency in the data reduction techniques used. Text-based files exported from Data Distillery will be provided in lieu of the proprietary Data Distillery format to promote transparency. Video files may also be included if required, but these will require editing prior to delivery.

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