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The effects of visual-manual tasks on driving performance using a military vehicle on a dirt road

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ABSTRACT
Driver distraction is deadly. In the United States alone, approximately 25 percent of all automobile accidents and 21 percent of all fatal accidents occur as a result of driver distraction in civilian settings.[1] However, it is more difficult to estimate the impact of driver distraction on military personnel. One similarity between civilian and military operating environments is the increasing proliferation of in-vehicle information systems. The purpose of this study was to examine the effects of three different visual-manual secondary tasks on participants' driving performance. All tasks required participants to interact with touch screen technology. The results indicated that participants' performance was significantly impaired during conditions when they executed a secondary task.

Categories and Subject Descriptors
H.1.2 [**User/Machine Systems**]: Human factors, human information processing

General Terms
Measurement, Performance, Experiments, Human Factors

Keywords
Distraction, driving, touch screen technology, military

1. INTRODUCTION
Traffic related fatalities are one of the leading causes of death in both civilian and military settings. In the United States, 32,261 civilians died and another 2.3 million were injured in motor vehicle accidents in 2008. Among military personnel, motor vehicle crashes are the leading cause of death and are ranked in the top five leading causes of hospitalization among warfighters.[7] In fact, the United States Army reported that approximately 40 percent of the total number of noncombat deaths were caused by combat vehicle or motor vehicle accidents since the beginning of the War In Iraq in 2003.[10]

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Indeed, root cause analyses of these accidents indicated that their leading cause was "human error".

In the driving domain, human error may result from a variety of factors which include but are not limited to failures in perception or comprehension of environmental cues and the failure to project those environmental cues into the near future.[3] One precursor of the aforementioned factors is distraction. In fact, distracted driving accounts for an estimated 25 percent of all automobile accidents and 21 percent of all motor vehicle fatalities in the United States.[1]

Moreover, numerous experimental and epidemiological studies indicate that distractions negatively affect drivers' performance in civilian settings.[2,14] However, it is more difficult to estimate the impact of driver distraction in military settings for several reasons: Firstly, military motor vehicle crash rates are not widely published. Of the studies that examine crash rates, few distinguish crashes that involve personally owned vehicles (POV) from those that involve military motor vehicles (MMV). This means that frequently, reported crash rates are based on a combination of the two types of vehicles, and thus, may have very different characteristics. Similarly, the causes of military accidents are not widely published. Although "human error" has been cited as a contributing factor, the nature and impact of this factor on military crash statistics is relatively unknown.[4]

Moreover, military operational driving environments differ from civilian driving environments. Military drivers operate under risky conditions, in both on and off-road contexts, in convoys, and in combat settings while wearing heavy gear, which may limit drivers' physical mobility, hearing, and vision.[7] Thus, performance measures and interventions suitable for drivers operating POVs in civilian settings may not be applicable to drivers operating military owned vehicles in combat settings.

In addition, laboratory studies that simulate military environments may not capture essential characteristics of both MMVs and their operating environments. Thus, performance observations resulting from a simulated environment may not translate to the actual operational context, thereby affecting external validity.

Although differences between civilian and military driving environments exist, their in-vehicle context does share one similarity: in-vehicle informational systems (IVIS). These include but are not limited to global positioning systems (GPS), music applications, wireless communications technology, gaming systems, and even televisions. Albeit highly unlikely that military drivers would interact with gaming or music systems during combat situations, they often interact with particular IVIS systems including those that relate to command and control operations and GPS. Thus, the potential for driver distraction does exist within this context.

1.1 Types of Distractions

Although distraction has not been extensively studied in MMVs, some tenets of previous studies conducted in civilian settings may be extended to these environments. According to the National Highway Traffic Safety Administration (NHTSA), there are three main types of distracted driving: visual, manual, and cognitive. Visual distractions occur when drivers avert their eyes from the driving scene. This may occur when drivers dial a number on their cell phone. Manual distractions occur when drivers remove their hands from the wheel. Examples of manual distractions are eating, grooming, or changing the radio station. Cognitive distractions occur when drivers' attention is shifted from the driving task to the contents of their mind. These distractions occur even when drivers' eyes are directed at the roadway and even when their hands are located on the steering wheel.[8,12] Examples of cognitive distractions include cell phone conversations, thinking about tasks or goals, and daydreaming.

There have been several attempts to rate the level of distraction that each task poses. Nakayama, Futami, Nakamura, and Boer (1999) parsed distractions into the categories of conversations, thinking, eye diversions, and the operation of equipment and reported that drivers' distraction increased in that order.[11] Research conducted by the National Highway Traffic Safety Administration was congruent with this categorization.

1.2 Purpose

It is well documented that distracted driving is a major contributor to vehicle accidents in civilian setting. Past research performed in driving simulators has shown that distraction impacts a number of performance measures including reaction time, steering entropy, acceleration, brake reaction time, lane maintenance, speed, heading, and crash rate.[5] However, as mentioned previously, the impact of distracted driving in military environments is relatively unknown. Thus, one purpose of the current research is to extend the prior research on distracted driving to an environment that shares some salient features with military environments.

During the current study, participants drove a Humvee equipped with performance measurement equipment on a closed, off-roading test course. All participants completed the test course 1) without performing a secondary task (i.e., during an attentive driving condition) and 2) while performing three different visual-manual secondary tasks using touch screen technology (i.e., during distracted driving conditions). We predicted that participants' performance would suffer more in the distracted driving condition compared to the attentive driving condition.

2. METHOD

2.1 Participants

Sixty-seven male and female employees from Sandia National Laboratories in Albuquerque, NM, ages 22-50, participated in this experiment. All drivers reported possessing a current driver's license and normal or corrected to normal vision.

Apparatus and Materials

2.1.1 HMMWV

The Army Research Laboratory Human Research and Effectiveness Directorate provided an instrumented military HMMWV for this research. The vehicle was an automatic and provided a range of inherent sensors that collected driving performance data.

2.1.2 Cameras

There were four cameras that recorded various driving views from within the vehicle. Two of these were forward looking, giving a view of the road in front and to the side of the driver. Another camera recorded the driver's face and additional camera recorded the controls over the driver's right shoulder. All camera views were combined into a composite video stream.

2.1.3 Laptop

The software ran on a ruggedized laptop with a solid state drive running the Vista operating system. It was connected via Ethernet to the data acquisition equipment where it periodically (4Hz) received a data packet with sensor data in it. In addition, the laptop interfaced to an I/O box to present the subject with experimental tasks and record their behavioral responses (i.e. button presses). At the end of each trial, the video files and data files were downloaded from the vehicle.

2.1.4 Experimental Setting

Experimental testing was conducted on unimproved dirt roads near the Robotic Vehicle Range at Sandia National Laboratories. The course consisted of three roads and was approximately 6.6 miles long. The speed limit on the course was 20 mph.

2.1.5 Simulated Braking Task

Throughout all experimental trials, participants responded to an LED light that was mounted in the front window of the vehicle by pressing a button that was located on their right index finger. This light turned on and off randomly throughout the experiment. This task was meant to simulate the braking of a lead vehicle.

2.1.6 Experimental Tasks

2.1.6.1 Short-glance Task

During the short-glance task, participants monitored a series of circles on a touch screen. Participants' task was to indicate which circle was highlighted immediately before all circles turned red. Participants accomplished this by touching the last-highlighted circle on the touch screen. This task required the driver to share visual attention between the road and the task, glancing back and forth for short periods. The overall distraction (involving approximately 10 responses) lasted approximately one minute per block. There were 13 blocks during the 30-minute experimental driving loop.

2.1.6.2 Long-glance Task

The long-glance task used the same dot row previously discussed, with the exception that 4 dots were randomly presented for 500ms. This task required participants to remember the sequence of dot presentations, and when prompted, to touch the circles in that sequence in order to score a correct answer. This task required a longer glance than the short-glance task.

2.1.6.3 Table Task

During the table task, a six-column table was presented with alternating letter and number columns. The letters were associated with radio call signs (e.g. A=alpha, B=beta, etc.). An auditory cue was given with the call sign as the table was displayed. The task was to search each letter column for the call sign letter and to identify the digit to the right of it. Participants entered the three digit code on a touch screen keypad. After entering the first digit, the table disappeared, requiring the driver to memorize the 3-digit sequence before entering their response. The assignment of digits to letters and the order of letter and number presentations in the table were randomly generated for each presentation.

2.2 Experimental Design

There was one independent variable in this experiment: driving condition. This variable had four levels: All participants drove the test course 1) without performing a distracting secondary task, 2) while performing the short glance task, 3) while performing the long-glance task, and 4) while performing the table task. The former condition served as a baseline performance measure and the latter three served as treatment conditions. The resulting design was completely within-subjects.

Several dependent measures were collected. Firstly, participants' reaction time and accuracy on the distraction task and the simulated braking task were collected. Reaction time was measured from the beginning of each task. Accuracy was defined as the percentage of correct trials.

Additionally, participants' performance on the following driving measures was collected: average speed, average number of steering reversals, and average number of throttle reversals. All of the aforementioned measures were sampled at a rate of 250ms and averaged across trials. Speed was measured in mph. Steering reversals were defined as the average number of deflections away from a neutral steering position followed by a reversal of the steering wheel back to the neutral position that were executed within one second.[9] Similarly, throttle reversals were defined as the average number of deflections of the throttle away from a neutral point followed by a reversal of the throttle back to a neutral position that were executed within one second.[8]

2.3 Procedure

Before the experiment began, participants practiced the three different distraction tasks in the stationary vehicle. Afterwards, they were instructed to maintain a 20mph speed limit and drove approximately one quarter of the course in order to gain familiarity with the vehicle. Then, they practiced each of the distraction tasks sequentially while driving.

After practice, participants were informed that their primary task was to drive the vehicle safely and to complete any additional tasks only when they felt that the driving conditions were safe enough to do so. Participants executed four different driving conditions: 1) a baseline condition, in which participants drove without completing a distraction task, 2) a condition in which participants completed the short-glance task, 3) a condition in which participants completed the long-glance task, and 4) a condition in which participants completed the table task. The order of these conditions was counterbalanced across participants. With the exception of the practice period, participants completed only one type of distraction task type within a driving condition. The experiment took approximately 3.5 hours to complete.

3. Results

All dependent measures were inspected for outliers using the z score method.[6] Items receiving a score of ± 3 were replaced with the next highest or lowest score that was not considered an outlier for that particular condition. Only 2.3 percent of the data were replaced. By using this particular method, variance was not unnecessarily reduced.[14]

3.1 Did participants perform as instructed?

Single sample t-tests were conducted to determine whether accuracy on the secondary distracting tasks was significantly different from chance. This was done in order to determine whether participants were performing the task as instructed or whether they were simply guessing (i.e., attaining a 50 percent performance rate). As shown in Table 1, single-sample t-tests revealed that participants performed significantly better than chance on all three secondary tasks. This means that participants were indeed performing the tasks as instructed.

Table 1. Percentage accuracy compared to chance on secondary tasks

Task	Mean	SE	Result
Short-glance	94.10	0.42	$t(66) = 107.83$, $p < .001$
Long-glance	84.59	1.08	$t(66) = 31.89$, $p < .001$
Table	96.26	.40	$t(66) = 116$, $p < .001$

3.2 Were participants significantly distracted?

A one-way ANOVA was conducted in order to determine if participants' response times to the simulated brake light were significantly different during the attentive driving condition compared to each distracted driving condition. The results indicated that participants responded significantly faster to the simulated brake light during the attentive driving condition compared to the distracted driving conditions $F(3, 64) = 62.32$, $p < .001$. As shown in Figure 1, Tukey's comparison tests revealed significant differences between attentive driving and each condition, respectively. Thus, participants were significantly distracted when they performed a concurrent secondary task while driving.

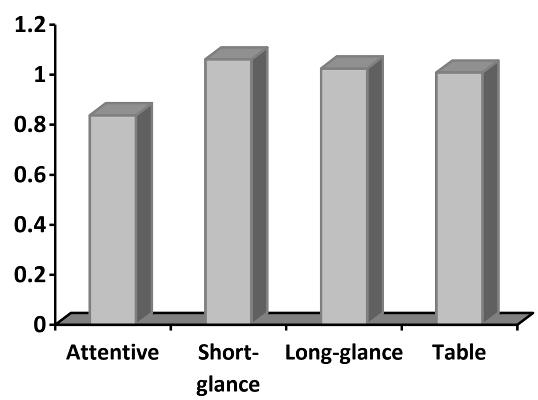

Figure 1. Response times to simulated braking light

3.3 Did the secondary tasks impair driving performance?

Dependent samples t-tests were conducted in order to determine if there were significant differences in performance between distracted and attentive driving conditions for all dependent measures. In order to effectively compare experimental and baseline conditions, the segments from the baseline condition were matched to the exact points along the driving course where the distracted driving tasks occurred for each participant. This was done because distraction tasks occurred along different parts of the route for each participant. Then, all of these points were averaged for each condition. This allowed a direct comparison of participants' driving performance while controlling for the effects of test course difficulty at different points along the route. Thus, each dependent measure has three baseline performance values that correspond to each of the three secondary tasks. All results are significant at $p < .05$.

3.3.1 Average Speed

As shown in Table 2, dependent sample t-tests indicated that participants drove significantly slower during all three of the secondary task conditions compared to the attentive driving condition.

Table 2. Significant differences in average speed between secondary tasks and matched baseline conditions

Secondary Task	Secondary Task		Matched Baseline		Result
	M	SE	M	SE	
Short glance	21.77	.07	22.29	.07	$t(66) = -10.65$, $p < .001$*
Long glance	21.89	.05	22.19	.05	$t(66) = -7.74$, $p < .001$*
Table	21.88	.05	22.08	.05	$t(66) = -5.30$, $p < .001$*

3.3.2 Steering Reversal Frequency

As shown in Table 3, participants had significantly more steering reversals when performing each secondary task compared to a matched baseline condition.

Table 3. Significant differences in steering reversal frequency between secondary tasks and matched baseline conditions

Secondary Task	Secondary Task		Matched Baseline		Result
	M	SE	M	SE	
Short glance	52.19	.57	39.67	.54	$t(66) = 26.92$, $p < .001$*
Long glance	3.87	.05	3.01	.05	$t(66) = 16.85$, $p < .001$*
Table	6.40	.07	4.96	.07	$t(66) = 21.99$, $p < .001$*

3.3.3 Throttle Reversal Frequency

Table 4 shows significant differences in throttle reversal frequency between the short glance and table tasks compared to their matched baseline conditions. The results indicated that participants had significantly more throttle reversals during distracted driving conditions compared to an attentive driving condition. There was no significant difference in throttle reversal frequency between the long-glance task and its matched baseline condition.

Table 4. Significant differences in throttle reversal frequency between secondary tasks and matched baseline conditions

Secondary Task	Secondary Task		Matched Baseline		Result
	M	SE	M	SE	
Short glance	29.72	1.33	23.61	1.08	$t(66) = 4.60$, $p < .001$*
Long glance	1.73	.06	1.77	.06	$t(66) = -.49$, $p > .05$
Table	3.53	.11	2.89	.09	$t(66) = 5.74$, $p < .001$*

4. DISCUSSION

Our results indicated that participants' accuracy on each secondary distraction task was significantly higher than chance. This means that participants were performing the tasks as instructed and that they were not simply guessing. Moreover, participants' accuracy was very high. This may mean that these tasks may have posed a relatively light cognitive load.

Additionally, participants responded significantly more slowly to the simulated brake light during the distracted driving conditions compared to the attentive driving condition. This means that participants' cognitive load was higher during the distracted driving conditions than during the attentive driving condition and that they did not have enough mental resources to execute both tasks successfully.

Moreover, participants showed significant impairment on all driving performance measures when simultaneously executing a secondary task. Participants drove more slowly, executed more steering reversals, and executed more throttle reversal when performing a concurrent secondary distracting task. These results are particularly significant because the secondary tasks posed relatively light cognitive load. Thus, even tasks that are seemingly not distracting may impair driving performance. Additionally, these results suggest that measures that have been employed in simulator studies translated to a real-life driving environment.

Although the aforementioned measures reflected drivers' performance in this context, we must use caution when interpreting these findings. The current study was designed to examine the effects of visual-manual tasks on driving performance in a specific experimental setting. Other factors may influence driving performance in actual military operational driving environments. For example, our participants consisted of civilians rather than military personnel. Similarly, no participants had experience driving a military HMMWV. Additionally, participants drove at low speeds on a dirt road without traffic, pedestrians, or other obstacles.

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