Investigating the Immediate Effects of Periodic Alerts to Assist in Maintenance of Vigilance During Automated Vehicle Operation.

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With the advancement of technology, the presence of automated systems has continued to increase in a variety of environments, including ground transportation. A continuing challenge with increased automation is designing systems that help operators stay in the loop, thus ensuring that they will be able to react when necessary. The means of countering vigilance decrements associated with automation have ranged from such devices as "Dead Man" switches to more complex computer-based interventions that require constant operator attention. This study examined the utility of periodic auditory alerts that required a response by the operator. Fourteen adults drove under automated control in one practice drive and three study drives with a total duration of approximately 75 minutes. At the end of each drive, participants rated their fatigue using a visual analog scale. During two of the three study drives, participants were presented with periodic alerts that required acknowledgement by pressing a button located on the operator's armrest. The immediate effects of these alerts on the operator were recorded. Analysis of the data revealed that operators acknowledged all of the alerts but that there was no statistical difference in reaction time between operator state conditions. Additional analyses revealed that following the alert, operators were more likely to observe the environment outside the cab and were more awake. This study provides useful insights into the effects of periodic alerts used to assist operators of automated control vehicles.

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Introduction

The introduction of automation can be very beneficial to the operation of agricultural vehicles. Automation can help increase the efficiency and effectiveness of various tasks by reducing operator workload and increasing the overall precision of the system. However, the introduction of automation may also lead to some unintended consequences, such as increased boredom and fatigue brought on by extended work hours. Therefore, it is important to understand this complex issue in order to mitigate any potential downsides of automation.

To date, there are several manufacturers and research institutions that have been working on different solutions to the issues of operator alertness. One technique is to create an operator monitoring system that recognizes when an individual is not paying attention to the environment with the goal of generating an intervention designed to help regain attention. One such system is being investigated through the SAfety VEhicle using adaptive Interface Technology (SAVE-IT) program currently being conducted by Delphi and sponsored by the National Highway Traffic Safety Administration (NHTSA) (The Volpe Center, 2004). The goal of this system is to observe driver behavior and performance as well as traffic conditions in an effort to determine when the driver is at increased risk due to inattention so that the driver can have his or her attention directed back to the roadway or be warned of upcoming dangers.

NHTSA's focus on inattention in the automotive domain is justified by the estimated 25-30% of all crashes that occur every year due to lack of driver attention (NHTSA, 2006). One of the main effects of fatigue is the gradual withdrawal of attention from the demands of the road and traffic (Brown, 1994). The inference is that as the driver becomes more fatigued, less effort is placed on the task of selectively attending to the environment, and the driver instead waits for something grab his or her attention (Matthews and Desmond, 2002). Therefore, it would be expected that operators who are more alert would be paying more attention to their surroundings and thus would be performing more visual scans of the environment. A particularly useful measure of this effect is PERcentage of SACcade eye movement over time (PERSAC). Smaller PERSAC indicates increased fatigue. Therefore, operators who are more alert will have increased saccadic movement (Ji, Zhu, and Lan, 2004). Another useful measure of driver fatigue is PERcentage eyeCLOSure over time (PERCLOS). This measure is commonly used as a measure of driver fatigue (NHTSA, 1996).

Auditory alerts are often used to capture the driver's attention, whether it is to a possible collision, a system status alert, or to attempt to combat fatigue (Wickens and Seppelt, 2002). For example, in a study examining the Copilot drowsy driver monitor, two types of auditory alerts were tested: a voice warning and a buzzer (accompanied by a peppermint scent). In that study, it was determined that the audible indicator and a visual gauge were sufficient (Grace, 2001).

It is clear from prior research that there is potential for alerts to help with operator inattention. This paper, which contains an analysis of the results of a larger study, is focused on the effects of auditory periodic alerts on operators' attention. The experimental environment was a highly automated agricultural vehicle model that was installed at the National Advanced Driving Simulator (NADS).

Methods

Study Design

The experiment was a mixed-subject design. The within-subject variable was timing of intervention (quasi-random, at the end of a field, and no intervention), and the between variable was level of alertness (alert and fatigued). Fatigue is often shown to vary in a circadian manner (Tepas and Monk, 1987). As such, level of fatigue (alertness) was assessed according to natural circadian rhythms along with sleep logs administered prior to the experiment and according to self-reported levels of fatigue through a visual analog scale (Monk and Embrey, 1989).

The participant's experimental times were scheduled primarily according to natural circadian rhythms and the sleep logs, with consideration to self-reported levels of fatigue. The alert and degraded alertness (fatigue) trials were originally balanced across participants. However, due to constraints, eight fatigue trials and six alert trials were completed. Table 1 below shows the average times across the sleep log that the participant went to sleep (Sleep Time), woke up (Awake Time), and simulator trial start times (Sim Time) for the participants in the alert condition. Table 2 below shows these times for the participants in the fatigued condition.

Table 1: Sleep, Wake, and Sim Times for participants in the alert condition.

Participant	Sleep Time	Awake Time	Sim Time
3	1:15 AM	8:00 AM	8:45 PM
8	11:00 PM	7:30 AM	10:15 AM
12	10:30 PM	8:15 AM	12:10 PM
13	4:15 AM	9:45 AM	10:45 AM
16	4:15 AM	11:15 AM	10:15 AM
17	1:45 AM	7:30 AM	8:00 AM

Table 2: Sleep, Wake, and Sim Times for participants in the fatigued condition.

Participant	Sleep Time	Awake Time	Sim Time
1	12:15 AM	8:30 AM	12:45 AM
2	10:00 PM	6:45 AM	11:15 PM
4	12:00 AM	8:30 AM	1:30 AM
6	1:00 AM	7:00 AM	3:00 AM
7	11:45 PM	8:00 AM	2:30 AM
9	10:15 PM	6:30 AM	10:15 PM
14	2:45 AM	11:15 AM	8:15 AM
18	11:30 PM	6:45 AM	12:00 AM

Participants

Fourteen participants completed this study. All 14 were males between the ages of 18 and 30. Participants were required to have some experience with agricultural equipment. The experience levels ranged from those who had driven tractors a few times to professional farmers.

Procedures

Participants visited NADS on two occasions. During the initial visit, participants read and signed the informed consent document and obtained three-day sleep logs. At this time, participants were officially enrolled in the experimental study. They documented their sleep patterns for three days. Following this three-day period, the sleep logs were returned to NADS. Experimenters reviewed the sleep logs and scheduled the simulator visit according to a devised experimental test matrix. Experimenters were cognizant of circadian rhythms and scheduled participants according to natural times of sleepiness and wakefulness.

On the day of the study visit, participants drove themselves to NADS. Once at NADS, participants were brought into an experimental prep room. Here they filled out questionnaires related to the study and were provided with experimental training information. Study staff answered any questions participants had regarding the experiment. Participants were then led into the simulator and briefed on the drives and eye-tracking procedures. Participants completed four drives—one 7-minute familiarization drive and three 23-minute study drives.

During each study drive, participants were required only to respond to the alerts and to pull a switch to simulate removing the obstacles in the path, and did not need to control or steer the agricultural vehicle.

Participants were advised that if they wanted to discontinue participation in the experimental study, they could do so at any time. All questionnaires were administered verbally through speakers and microphones installed in the cab. When the final drive was completed, participants were asked to complete the final set of questionnaires and were debriefed. Each simulator visit lasted approximately 2.5 hours, with approximately 1.5 of the hours spent in the simulator.

Scenario

The simulated three main study drives consisted of five rows approximately 762 meters long and 9 meters wide of flat, unplanted field. Foggy conditions with visibility of about 60 meters were used. Obstacles were presented twice per drive. The auditory alerts occurred periodically throughout the drive. There were no alerts in the control condition.

Hypotheses

It was hypothesized that post-alerts periods would be marked by higher levels of attention to the surroundings.

Specifically, it was expected that:

- participants in the alert condition would have shorter reaction times to the alerts than participants in the fatigued condition;
- participants would visually attend more to locations in the field environment immediately following the alert than immediately prior to the alert;

- participants would have less average eye closure immediately following the alert than immediately prior to the alert; and

- participants would have more saccadic eye movements immediately following the alert than immediately prior to the alert.

The focus of this paper was to present the impact of the periodic alerts on the operators' interactions with the environment. We expected the difference in alertness and attention before and after alerts to be greater for fatigued operators than for alert ones.

Dependent Measures

A variety of measures were collected to assess the impact of alerts on operator alertness. These measures included data from the simulator, such as eye tracking and reaction time to the alerts, data from questionnaires, and data from sleep logs collected before the data collection. Several variables were recorded manually upon reviewing the recorded videos of the 10 seconds preceding the alerts to 10 seconds after the response to the alert.

A number of eye-related measures were also collected, including percentage eye closure, saccades, and blinks. These measures were recorded using the FaceLab v. 4.0 eye-tracking application at a rate of 60 Hz. Due to experimental constraints, percentage eye closure was used. Percent eye closure was measured as a percentage of each iris that is covered; this measure is recorded as an average of both eyes. A saccade is defined as a fast motion of the eye to change the gaze point from one fixation point to another. Saccades were treated as binary measurements (true or false) and were analyzed as a count during each 10 second segment. Eye blinks were defined as rapid eye closures followed quickly by a rapid eye opening. Eye blinks were binary measures, with values of either true or false, and were analyzed as a count during each 10-second segment.

Results

Four main analyses are discussed: reaction to the alert, change in behaviour as a result of the alert, change in eye closure, and "other" eye analysis. Each of these analyses provides insight into the potential impact of periodical alerts.

Reaction time to alert – All operators responded to all alerts. There was no significant difference between the reaction times of the participants in the alert and fatigued conditions. The mean reaction time to the alerts by the participants in the alert condition was 1.085 seconds with a standard deviation of 0.572 seconds. The mean reaction time to the alerts by the participants in the fatigued condition was 1.171 seconds with a standard deviation of 0.423 seconds. Although a difference was expected for this variable, it was clear from the video review that the variability in hand placement prior to the alert would mask any differences associated with operator state.

Change in behavior – Several variables were recorded by analyzing video of each alert event from 10 seconds before the alert to 10 seconds after the response to the alert. These analyses utilized the Pearson's Chi-Square Test. In the alert condition operators, there was a significant increase in participants observing surroundings to the left of the cab ($p=.0153$) after the alert compared to before the alert. Eighteen percent of the participants viewed the surroundings to the left of the cab before the alert, while 40 percent viewed their surroundings after the alert. There was also a significant increase in the operators in the alert condition observing both sides of their surroundings (p=.0325) after the alert compared to before the alert. There were no significant changes in the recorded variables in the fatigued condition.

Eye closure – The SAS General Linear Models (GLM) procedure was used to analyze the differences in eye closure between the fatigued and alert conditions, both before and after the alert. There was a significant interaction between operator state relative to the auditory alert for both mean eye closure (p=0.0428) and for 95th-percentile eye closure (p=0.0337). Figure 1 below illustrates that the mean eye closure recorded during the 10 seconds following the response to the alert was less than in the 10 seconds preceding the alert for the alert operator state; however, it remained unchanged in the fatigued state. Figure 2 below shows that for the 95th-percentile eye closure, eye closure recorded during the 10 seconds following the response to the alert was less than in the 10 seconds preceding the alert for the alert operator state, while eye closure percentage increased for the fatigued operator state.

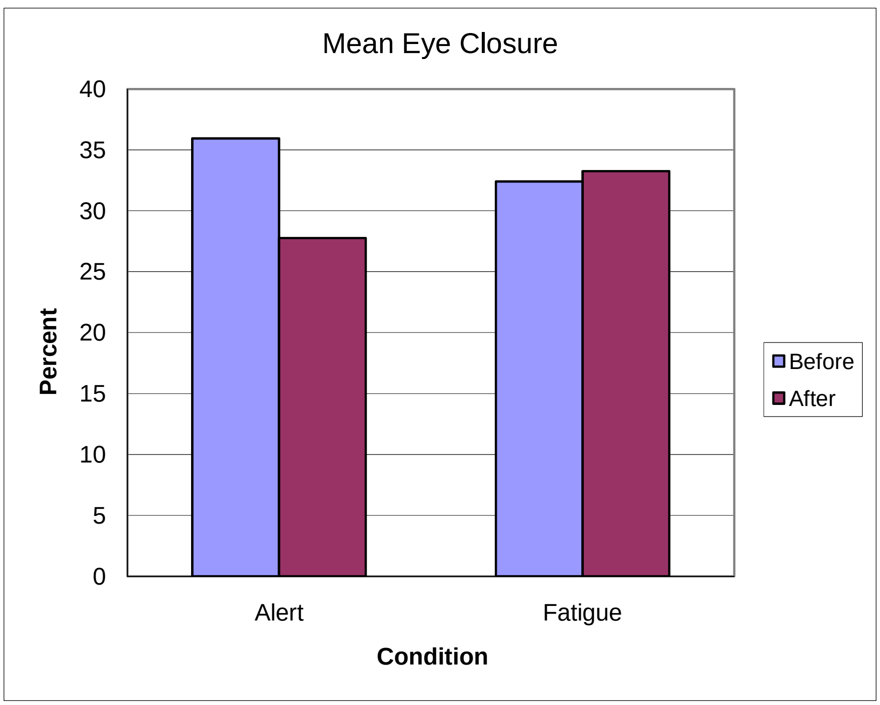

Figure 1: Mean eye closure by operator state.

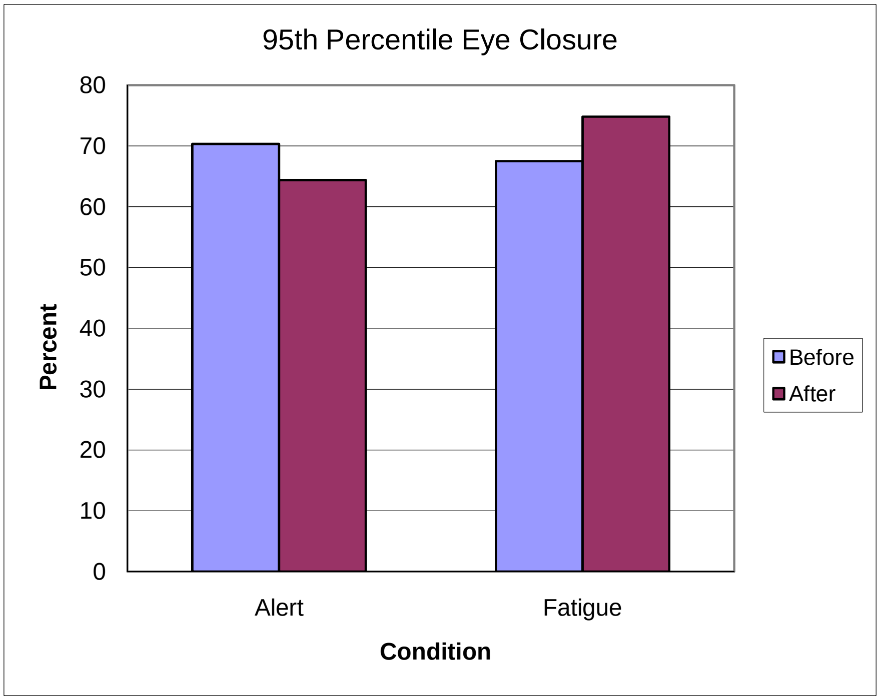

Figure 2: 95th-percentile eye closure by operator state.

Other eye analyses – The number of saccades were recorded during the 10 seconds preceding each alert and following each response. There was a slight increase in the number of saccades after the alert in both the fatigued and alert conditions, but this increase was not significant. The number of eye blinks was also recorded during the 10 seconds preceding each alert and following each response. The average number of eye blinks increased by 0.3482 (12%) after the response to the alert. This difference was found to be significant (p=0.0384). These analyses utilized the SAS GLM.

Discussion

The current study set out to gain a better understanding of the effects of periodic auditory alerts on operator attention. As expected, the results suggest auditory alerts can have a positive impact on operator attention. However, this effect was mainly observed at a local level (10 seconds before and after the alert). It is unclear what the global, long-term effects of such alerts might be from an operator attention standpoint as well as from an operator acceptance perspective.

One important limitation of this study was the nature of defining the operator state as fatigued or alert. Due to experimental constraints, it was necessary to artificially induce fatigue by having the operators tested overnight (i.e., tractor operators do not generally interrupt their sleep overnight to operate a tractor) rather than testing them after numerous hours of tractor operation. The nature of the drive also tended to induce boredom as the operator had no other tasks to perform nor means of providing stimulation (such as listening to the radio) while driving other than to search for obstacles. The monotony of the drive tended to make even alert operators in the middle of the day to be less alert following the drives. As such, it is possible that alert operators are not fully alert, and fatigued operators are in fact even less alert than would be anticipated for fatigued operators.

Assuming these types of intervention can be effective and accepted; challenges still exist in determining the relative frequency of these alerts and whether they should be triggered by specific behaviours of the operator. During the course of data collection, it became obvious that driver state (alertness) changed over time in a complex manner that was not uniform or easily predicable. If alerts are going to be provided when most needed, rather than deterministically based upon time or location, measures will need to be robust enough to capture the complexity of the situation. Based on the data focusing on these brief periods surrounding the alert, it is not clear that the current measures available would be satisfactorily predictive in the agricultural vehicle environment.

Further research is needed to address the limitations of the current study and expand the findings. Research that should be performed in an automated tractor environment includes:

- Testing over a longer period of time in order to better understand the natural progression of the fatigued state in an automated environment.
- Testing of additional warning modes that might be more effective in extremely fatigued states.
- Testing the effectiveness of warnings based on active monitoring in an automated tractor environment.

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