Task Performance and Eye Activity:

Predicting Behavior Relating to Cognitive Workload

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ABSTRACT

Introduction: The focus of this study was to examine oculomotor behavioral changes while subjects performed auditory and driving tasks. ***Methods:*** Thirteen participants completed three 10-minute tasks consisting of driving only, the Paced Auditory Serial Addition Task (PASAT) only, and a dual task of both driving and auditory tasks. For each participant, changes in six measures were assessed as a function of cognitive workload, specifically changes in eye activity, including blink frequency, blink duration, fixation frequency, fixation duration, pupil diameter, and horizontal vergence. In addition, deviations in lateral lane position were assessed as a measure of driving behavior. ***Results:*** Compared with the subjects' behavior in the driving-only task, results showed an increase in blink frequency during the combined driving and auditory task. Also, during the dual task the mean pupil diameter and horizontal vergence increased when subjects performed well in the auditory task in contrast to when the subjects performed poorly. Evidence of visual tunneling or reduced range of scanning and decreases in rearview mirror and odometer glances appeared when subjects performed the driving and auditory dual task. There was no significant change in fixation frequency. However decreased fixation duration appeared to predict upcoming errors in the auditory task. Pupil diameter changes were significantly higher when performing well on the auditory task than when subjects were performing poorly.

Conclusion: Eye behavior trends reported in this study may provide insight to human behavior corresponding with cognitive workload, which may in turn be utilized to produce reliable workload indicators and applications that predict poor performance in real-time.

INTRODUCTION

By examining and monitoring behavior during cognitive tasks, we are looking to detect lapses of attention and reduced performance states. Assessing and predicting poor performance states on a moment-to-moment basis for tasks such as driving, air traffic control, machinery operation and other strenuous tasks would be useful toward improving an individual’s performance level.

Visual attention is critical for everyday activities such as driving. This investigation focuses on the effects of mental tasks on driving performance behavior and assumes that eye movements reflect changes in attention states. Rashbass and Westheimer (13) found that sudden target vergence changes resulted in reaction times of approximately 160 milliseconds for convergent and divergent eye movements showing vision processing time delays.

Advanced eye-tracking technology provides noninvasive measures of the highly dynamic behavior of eye movements. Although eye movements are not reflective of cognitive tasks directly, numerous studies have shown that eye movement behavior changes are correlated to performance on visual tasks such as driving (9,20). A central question throughout eye-movement research is: Can eye behavior parameters reflect visual and attentional constraints during cognitive tasks? In our investigation, we examined if eye movements can reflect and predict decrements in task performance. We chose to combine a visual driving task with an auditory task and measure changes in oculomotor activity as a function of operator workload.

Conditions such as fatigue, stress, motion sickness, and increased workload typically reduce task performance, particularly on tasks requiring ongoing vigilance and decision-making (6). For example, recording eye movements during a tracking task, Van Orden et al. (26) found oculomotor parameters that correlated strongly with performance on the tracking task, including eye blink frequency and duration, re-fixation frequency, size, and pupil diameter which could be combined in a multi-factorial index to detect overload conditions. The eye-movement behavior changes were attributed to changes in level of fatigue. The challenge is to determine if oculomotor metrics can be generalized across tasks and varying levels of task difficulty. A compilation of oculomotor metrics utilized in various workload studies is listed in Table 1. While these studies use different tasks to measure workload, fatigue or other related topics, typical oculomotor metrics such as blink rate and duration were measured. Of the eye parameters available, the following were chosen to be examined as a function of cognitive workload: blink frequency, blink duration, fixation frequency, fixation duration, pupil diameter, and horizontal vergence.

Various studies have examined subject performance during extreme circumstances such as sleep deprivation (16,17,18). In a sleep deprivation study, younger and older subjects were compared while performing a monotonous driving task (15). The study found evidence of visual tunneling occurring with prolongation of the driving task and age. In a flight simulator continued wakefulness study, significant visual neglect of far left and right visual stimuli occurred in pilots beginning at 19 hours of continuous wakefulness (17). In an effort to quantify fatigue effects, another study utilized 53 aviators fitted with a monocular helmet-mounted display to evaluate differences in pre and post-flight ocular differences and found an increase in pupil size, constriction latency, and a decrease in constriction amplitude and saccadic velocity (19). Similar oculomotor results were found in an eight day sleep deprivation driving simulator study that found saccadic velocity as a robust indicator of fatigue (16). In these extreme examples, oculomotor parameters such as large changes in visual scanning may be impacted by fatigue effects. However, a central question is: Do these oculomotor parameters exhibit similar qualities in everyday performance of driving or cockpit performance if a person show signs of short-term fatigue effects or reduced performance?

A task with real-world application that relates to this topic is driver distraction (such as, driving while talking on the phone). The demand for a driver's visual and attentional resources in multiple tasks can be detrimental during overload conditions. Various studies on driver stress suggest that driver performance is vulnerable to cognitive fatigue effects due to overload or underload conditions, where task performance is overwhelmed and accompanied by deterioration in lower priority performance components or loss of performance that may be attributed to insufficient effort (10). Designing criteria or parameters to assess an individual's attentional availability could be a useful tool to prevent mishaps. According to Matthews and Desmond (10), performance impairment may be affected by loss of attentional resources and loss of active regulation of matching effort to task demands. In other studies, results have shown that higher workload reduced the extent of eye movements (9,15). Compared with a simple tracking task, attentional focus narrowing (i.e., visual tunneling) occurred when subjects were asked to perform a tracking task combined with an auditory task. The attended perceptual area was further lessened when the auditory task was made more difficult (28). In a driving and cellular phone study, subjects were found to exhibit "inattention-blindness" where cell phone conversations disrupt performance by diverting attention from the driving task (25). By conversing on cellular phones, subjects were less likely to remember external information in dual task conditions than single task conditions.

The concepts and definitions of workload and resource demand are critical when considering if certain parameters such as eye movements or driving behavior in order to accurately predict performance behavior. The dual task performance utilizes visual processing for the driving task where subjects must maintain their lane position between two cars and simultaneously perform auditory processing of the auditory task. Wickens (29) proposed a four-dimensional representation of the multiple resource model that accounts for the variance in time-sharing performance due to exercising resource demands in modalities, processing codes, stages, and visual channels. The dual task used in this experiment uses visual and auditory modalities, speech comprehension, and verbal rehearsal, coupled with motor responses to visual driving stimuli that are examples of different stage resource operations that may compete and interfere with each other similar with driving coupled with cell phone usage.

Eye movement measures provide a valuable source of information, and parameters such as fixations, blinks, pupil diameter, and vergence angles can be used to measure behavioral performance. In this study we examined changes in the various eye movement parameters across task performance and driving performance as potential measures of cognitive workload. Assuming that attention capacity is limited and task dependent, the oculomotor range is an important measure with increasing mental workload (1). Studies have shown that before a voluntary eye movement is made, attention is covertly shifted to the location of interest (5); thus saccades may be a measure of attention. A parameter related to eye movements is eye blinks. Three types of eye blinks have been identified: reflexive, voluntary, and endogenous. According to Orchard and Stern (11, 22), endogenous blinks are due to perception and information processing. The more attention required by a task, the fewer endogenous blinks occur. Another related parameter we examined was blink duration, typically 40 to 200 milliseconds in length. Our main goal is to understand the trends of these parameters and assess the viability of predicting human behavior in cognitively demanding tasks. We tested the hypothesis that the addition of the Paced Auditory Serial Addition Task (PASAT) to the driving task (DA) would reduce driver control relative to the driving only (D) and auditory only (A) task. We also evaluated the performance of the secondary auditory task as a method to baseline and assess performance conditions.

METHOD

Subjects

Eight male and five female volunteers ages of 21 to 49 years participated in the study (mean 32.5 ± 10.6). Subjects were screened to determine normal or corrected vision and ensure they had a valid driver’s license. Subjects were volunteers recruited through posted notices and advertisements at the Naval Health Research Center (San Diego, California).

The study protocol was approved in advance by the Institutional Review Board (IRB), at the Naval Health Research Center. Each subject was given a full explanation of the experimental procedures and a written informed consent was obtained before participating with the option to withdraw from the study at any time.

Procedure

Practice: The subjects were first briefed on the experiment and on each task they would perform. All subjects were given 15 minutes (5 minutes each) to practice on the driving-only task, auditory-only task, and the dual task of driving and auditory. Subjects performed the auditory task at a starting point of 1.8 seconds that was decreased or increased during the experiment if the subject was performing above or below a 60-70% accuracy rate. Each baseline rate was established to be between 60-70% accuracy to ensure enough data samples of correct and incorrect responses to the auditory task were obtained from each subject.

Calibration: To calibrate the EyeLink II eye-tracking system (SR Research Ltd., Mississauga, Canada), each subject was instructed to move his or her eyes and fixate on the nine target locations that appeared consecutively on the computer screen. These measurements were made twice to ensure that the subjects were making eye movements toward the instructed locations.

Instructions: After calibration, each subject wore the EyeLink II system and they were instructed to perform three 10-minute blocked trials of: driving only (D), auditory Paced Auditory Serial Addition Task (PASAT) only (A), and the dual driving and auditory task (DA). Between the auditory and dual driving and auditory task, the timing of the PASAT for the dual task was adjusted depending on the subject's auditory response range. If a subject performed below 60-70% accuracy during the auditory only task, the PASAT frequency was decreased for the dual task condition. The driving and auditory task was always performed last to ensure sufficient practice on the tasks. The subjects were told to perform both tasks of driving and mental addition to the best of their ability. The auditory task was recorded by the experimenter.

Instruments

Oculomotor assessments: Eye movements were recorded using a high-bandwidth, binocular eye-tracking device. The EyeLink II has high spatial resolution with noise limited at <0.01° and a temporal resolution of 250 samples per second with corneal reflection. The use of the corneal reflections in combination with pupil tracking permits stable tracking of the eyes and reduces errors caused by minor headband slippage or other environmental causes. Primary measures included saccades, fixations, blinks, pupil diameter, and gaze frequency. Subjects wore the head-mounted eye tracker that recorded online eye images with two cameras positioned underneath each eye. Four LED lights mounted on the monitor measured head position. Subjects participated in controlled room light levels of on average 530 lumens.

Driving Simulator: This study utilized the interactive STI fixed-base driving simulator (STISIM, Systems Technology, Inc., Hawthorne, CA). The STI driving simulator has been used for evaluating human driving performance and its validation has been testified in various studies (2, 5). The steering throttle and brake inputs were connected to the computer that controlled the STI simulator software. The visual scenes were custom created by STI and altered by the experimenters to include blue skies with a curvy mountain-driving scenario. Participants were asked to maintain lane position between two fixed-distance vehicles. The two vehicles maintained constant speeds of 50mph. If subjects failed to maintain speed, the result would be a car crash with the front car by speeding too fast or back car by slowing too much. Stimuli were presented on a 17-inch Dell M782 monitor with a refresh rate of 60 Hz and a screen resolution of 1024 x 768 pixels.

Auditory task: The secondary task was an auditory task, a version of the PASAT. A series of numbers was played through a computer speaker. Volunteers were required to add each new number to the previous number and verbally state the sum. In this task, difficulty was a function of the number presentation speed. Typically, a subject started with a number presentation rate of 1.8 seconds and the speed was objectively changed to reflect an approximate 60-70% correct response.

Data Analysis: The relationship of oculomotor responses and auditory task performance assessed through means, paired *t* tests and Pearson correlation coefficient was calculated using Minitab software (Minitab Inc., State College, PA). When comparing parameters such as horizontal vergence, pupil diameter and lane position with auditory task performance, the results were computed as a percentage change for the 13 subjects and plotted with a linear regression using Generalized Linear Model analysis of variance. The plot calculations, linear fit, and correlations were computed with Matlab software.

RESULTS

Oculomotor Responses

The aggregate blink rate during the driving task and dual task of the subjects are presented in Figure 1. The auditory-only task did not include a visual stimulus and was excluded in this data analysis. The paired *t* test for blink rate for the driving and dual task was found to differ and to be statistically significant [t (12) = 3.42 , p = 0.005]. Eleven of the 13 subjects exhibited an increase in blink rate while performing the dual task relative to performing the driving only task. However, the average blink duration between tasks and subjects was not statistically significant.

Paired *t* tests conducted on aggregate fixation frequency and fixation duration during the driving and dual tasks and correct vs. incorrect were not statistically significant. Subjects typically made similar rates of fixations for both tasks.

When examining horizontal vergence, the percent change in average vergence showed an aggregate increasing linear trend when compared with the auditory performance. Vergence and auditory performance for the 13 subjects are graphed in Figure 2. The line in Figure 2 represents a linear fit to the relationship between auditory performance and change in horizontal vergence. Horizontal vergence was calculated by subtracting horizontal gaze coordinates from the right eye to the left eye, averaged per minute. There was no substantial vertical vergence. The Spearman correlation coefficient of the horizontal vergence-auditory relationship is 0.39 [$p < 0.001$, 95% confidence interval (CI), 0.19-0.56].

Driving Simulator Performance

By plotting lane position and auditory performance of the 13 subjects tested in Figure 3, our results show an upward trend in lane position deviation when compared with the auditory task performance. The line represents a linear fit to the increasing lane position deviation as auditory performance improves. The percent correct and lane position were calculated per minute during the 10-minute dual task for each subject and averaged. Lateral lane position was measured in feet relative to the center (a deviation of zero) of the road by the STISIM software. The computed Spearman's correlation coefficient of the lane position auditory relationship is 0.57 [$p < 0.001$, 95% CI, 0.42-0.69]. Note that the trend of poorer driving performance with increasing auditory task difficulty may suggest a potential strategy shift or tradeoff rather than sensitivity to cognitive workload.

When plotting the fixations of subjects, we found evidence of visual tunneling. Fixations by subjects were similar to the example given in Figure 4. A change in the subject gaze areas across the driving task and the dual driving and auditory task was characterized by a change in increased horizon gazing and a decrease in examining peripheral areas such as the rearview mirror and tachometer. The average change in mirror and tachometer fixations changed from 11% to 3.1% from the driving task to the dual task. Visual tunneling appeared to occur in most subjects as a result of increased cognitive workload. With the added auditory task, subjects significantly decreased fixations in two areas of interest: the rearview mirror and the odometer/tachometer [$t(12) = 5.75$, $p < .001$]. Also noted was the constriction of fixations in the interest areas of the subject, particularly on the car they followed in the task or the horizon. On average, subjects increased fixation at the horizon and the car ahead by 5% when given the dual driving and auditory task. While there were changes in visual scanning patterns, fixation durations and saccadic amplitude did not exhibit significant changes across tasks.

Auditory Performance

Paired *t* tests on the auditory task performance versus the dual task performance were statistically significant [$t(12) = 4.77$, $p < .001$] for all 13 subjects. As subjects moved from the auditory task to the dual task, the amount of correct responses to the auditory task reduced by a mean difference of approximately 5%. This difference shows changes in the subjects' auditory task performance when overall task workload increased. Of the 13 subjects, six subjects had the auditory presentation rate adjusted faster by 0.1 seconds. The presentation rate was not altered for the other seven subjects. For example, if a subject performed at a 90% correct rate during the auditory only portion at a 1.8 seconds auditory presentation rate, the subsequent dual task was changed to 1.7 seconds to obtain a higher sample of incorrect responses. The results of the ANCOVA indicated that there were no significant differences among the two adjusted means, suggesting no relationship between the dual task performance and auditory changes, controlling for initial auditory task performance. The following dual task data is collapsed across subjects who had no change in auditory rate presentation and subjects who had a 0.1 second change in the dual task.

Eye Movement Prediction

We were also interested to see if there were predictive eye movement changes in blinks, fixations, and saccades when comparing correct versus incorrect responses before a subject's response occurred. For each of the three eye parameters, we calculated the rates and durations five seconds before each correct or incorrect response. In the 5-second analysis, we found that blink, fixation, and saccade rates were similar when comparing driving and the dual task. However, average fixation durations five seconds before the incorrect auditory responses were shorter than during correct auditory responses for 10 of the 13 subjects. A paired *t* test on the average fixation durations was statistically significant [$t\ (12) = 3.65$, $p = 0.003$]. Blink and saccade duration five seconds before an incorrect versus correct auditory response were not statistically significant.

When conducting this study, subjects participated in controlled room light levels (530 lumens). Since each subject had pupil diameter variability, we compared aggregate findings by examining percent changes in pupil diameter. In Figure 5, the percentage change of pupil diameter is calculated by comparing the pupil diameter changes and the second minute of the 10-minute task. Since the auditory and driving task did not start at the same time, we excluded pupil diameter change comparisons of the first minute because subjects were adjusting to performing both tasks. Figure 5 shows an upward trend or an increase in pupil diameter when subjects performed well on the auditory task. The Spearman's correlation coefficient of the pupil diameter-auditory relationship is 0.36 [$p < 0.001$, 95% CI, 0.16-0.52].

In further analysis of pupil diameter variations, we examined the possibility of predictive behavior when a subject performed correctly or incorrectly in the auditory task. Relative pupil diameter changes during incorrect responses relative to correct responses are shown in Figure 6. According to the EyeLink II software, typical pupil diameter is in the range of 1800-3000 units, with noise levels of 2-10 units RMS. This corresponds to a resolution of 0.015 mm for a 5-mm pupil. Pupil size measurements are also affected up to 10% by pupil position relative to the camera and optical distortion of the cornea of the eye. However, this only concerns unexpected changes such as lighting or camera position changes during the task. Pupil diameter was found to change as a function of correct and incorrect response. During correct versus incorrect auditory responses, paired *t* tests on the pupil diameter increases were significant at the $p < .05$ level for the 13 subjects [$t(12) = 2.28$, $p = 0.04$]. Three subjects were excluded from Figure 6 because they exceeded an overall performance of 79% on the auditory task and less than 60 incorrect response trials sampled. Figure 6 shows that seven of the 10 subjects exhibit at least a 1% decrease in pupil diameter when they respond incorrectly to the auditory task compared with when they respond correctly.

DISCUSSION

Oculomotor behavior changes along with task performance signal the effects of operator workload and task-induced fatigue. Changes in eye activity with increases in cognitive workload are likely influenced by the nature of the tasks.

In our study we assessed blinks and fixations at the aggregate level and found no significance in blink and fixation durations and fixation frequency. According to several studies, blink frequency decreases significantly when subjects are given a visually demanding task (24, 27). In contrast, in our experiment, blink frequency increased when subjects performed the dual task, an unchanging visual driving task and a taxing auditory task. While the blink rate could not be compared in the auditory-only condition, it could be argued that the auditory task disinhibits blink rate independent of workload. Inhibition of blinks and frontal theta band activity was found to be related to mental concentration on visual tasks (32). Thus the requirement to concentrate on an audio task might be equivalent to reducing concentration on the visual task. The importance to real-world applications is that there obviously are sub-types of attention, that appear to be sensory modality related. Whether a global variable of “attention” can be found is as yet unclear. Further, of relevance to real-world applications, it remains to be seen if the PASAT task is similar to interference caused by cell phone use or other distractions for drivers.

Since the PASAT numbers were presented quickly, the auditory task required a high level of attention and altered blink behavior. In a PASAT study, Wills and Leathem (30) found that intelligence and arithmetic ability accounted for 46% of the variance on PASAT scores but found no significant correlation between PASAT performance and age or level of anxiety. While the auditory task performance may be influenced by external factors, the combination of the visual and auditory tasks is taxing and affects the behavior of the participants through increased workload. But despite of the invariance with age and anxiety, the variance that occurs with intelligence and arithmetic abilities suggest that individual calibration of monitoring systems will be necessary. Training may be utilized for both younger and older adults to improve performance on tasks. A study evaluating training tasks, an auditory discrimination task and a visual identification task, found that adults were able to improve in performance and transfer learning (2). It will be important to determine the oculomotor changes that occur with training and experience. Calibration of a system with an untrained operator may not be accurate in the same individual once they have become experienced.

The ability to detect cognitive changes *in advance* of actual performance decrements would be highly useful in stressful, rapid speed environments. Thus the finding that fixation duration decreased significantly 5 seconds prior to errors in the auditory task is provocative. If a robust set of predictive parameters could be found for various specific tasks, improvements in operational conditions, not just training could be found. Thus if individual parameters indicating an operator had high fatigue, high workload and was at risk to make an error, then an automated behavior monitoring system could intervene.

Other changes in eye activity were observed from the single to dual tasks. We analyzed lane position, pupil diameter, and horizontal vergence of all subjects in relation to auditory performance. During poor auditory performance, we found decreasing linear trends in pupil diameter, horizontal vergence and lane position deviation. With pupil diameter and horizontal vergence, minute changes were detected through averaged minute analysis and percentage changes were utilized to accurately portray individual subject behavior during the task. During poor performance, pupil diameters changes were smaller. We found that the pupil diameter during correct responses were 1% higher than during incorrect responses. Vergence angle was a worthwhile parameter to examine since in the real-world, subjects must assess their position between the two cars in real time. The vergence states of the eye are directly related to the object distance of interest in a three dimensional world. However, in this driving task scenario done a flat screen at a fixed distance, the changing horizontal vergence (which should remain fixed) also offers insight into the task performance The decrease in horizontal vergence during poor auditory task performance suggests that in such a high workload condition “attention” to the visual task is reduced and an important oculomotor parameter is allowed to vary. This corresponds to results previously found in our laboratory (28). As many oculomotor recording systems do not measure the movements of both eyes, they cannot measure vergence angle. Thus an important cognitive state monitoring parameter may be missed. Visual tunneling was seen in subjects when they switched from the driving task to the driving and auditory dual task. They significantly reduced their visual monitoring of critical information sources (rear-view mirror and speedometer) when in a high workload state. As with the inappropriate change in vergence angle during high work load, the visual tunneling phenomenon suggests that central attention to the visual task is reduced.

Given the weak correlation of the range in lane position during varying auditory performance, our results illustrate a wide range of individual variability, which could be from other factors such as an individual’s age and/or driving experience or could be due to different strategies in dealing with the tasks. Task priority was not given to our subjects. Future research will be needed to determine the influence of instructions. Further, the relative contribution of the visual and auditory tasks to oculomotor behavior is not clear from our results. An important component of future research will be to vary the difficulty of each task and determine the oculomotor behaviour changes related to those variations.While we did not examine age or experience in this study, others have examined age-related differences in attentional control (2,12,14). The divided driving and counting task by Ponds, Brouwer, and Wolffelar (12) examined age differences in young, middle-aged, and older participants. The study found that the dot-counting task significantly reduced driving performance in the old population (mean = 68.6) but not the young (mean = 27.5) and middle-aged (mean = 46.7) participants. Older adults performing a PASAT and driving task in a related study had reduced speed and steering control relative to a driving only task condition showing a loss in attentional control with increased workload (14). Our study sample ranged from age 21 to 49 and did not show any age-related trends.

CONCLUSION

Monitoring near real-time performance to evaluate operator state could increase reliability in critical workforce settings. The changes in eye activity are related to the type of activities engaged in by the subject as well as other factors including age, time on task, experience, and the external environment. Selection of appropriate parameters will be critical in providing design specifications for monitoring systems to engineers. For example, our observation that vergence angle metrics could be very useful suggests that measurement of both eyes and the relative angle between their two directions of gaze will be important.

Evaluating information processing and the occurrence or disruption of visual information could help assist in detecting fatigue. However, even more provocative is the possibility that behavior such as fixation duration might predict possible error states. Prediction would be useful in both training and operational conditions. Future studies will increase reliability of oculometric indices through development of multi-parameter monitoring systems.

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Table 1. Summary of oculomotor metrics and workload utility from various studies.

Figure 1. Blink Rate Driving (D) vs. Driving and Auditory Task (DA) Condition.

Figure 2. Percentage change in horizontal vergence angle during dual task with linear fit (n = 13).

Figure 3. Lane position performance in feet with linear fit (n = 13).

Figure 4. The top image is a subject’s aggregate fixations during the driving-only performance, The bottom image is during the dual-task performance where subjects typically show a dwell time decrease in the rear-view mirror and instrument panel relative to the driving-only task.

Figure 5. The percentage change in Pupil Diameter during dual-task auditory performance.

Figure 6. Individual participant analysis using a 10-second window during correct and incorrect responses to average Pupil Diameter changes.

Summary of Related Experiments using Oculomotor Metrics

Tasks	Oculomotor Metric	Workload Utility	Reference
Simulate driving & cell phone conversations	Foveal fixation	Conversations resulted in reduced foveal attention.	Strayer, Drew, Johnston
Pilot flight scenario with experienced pilots	Blink rate	Blink rates decreased during high workload.	Wilson
Dual flight and memory task with experienced pilots	Blink rate/intervals, blink duration (BD)	Blink intervals increased, BD decreased with more visual information.	Veltman, Gaillard
Running memory task	Blinks, saccades, pupil diameter (PD), EOG	Blinks increased with time on task (TOT). PD increase is associated with info processing.	Fukuda, Stern, Brown, Russo
Dual tracking and mental arithmetic task	EOG, blinks	Blink interval provided inferences for tracking task workload but not for arithmetic task.	Ryu, Myung
Visuospatial memory task	Moving estimates of blink frequency, BD, fixation frequency, dwell time, saccadic extent, PD over 10-20 sec periods	Blink frequency, fixation frequency, and PD were most predictive variables relating eye activity to target density.	Van Orden, Limbert, Jung
Flight scenarios with manipulated levels of workload	Blink amplitude (BA), BD, Blink rate, long closure rate (500ms+), saccade velocity, saccade rate.	Blink amplitude and long closure rate accounted for over 50% of variance. BA increased	Moris, Miller

Table 1. Summary of oculomotor metrics and workload utility from various studies.

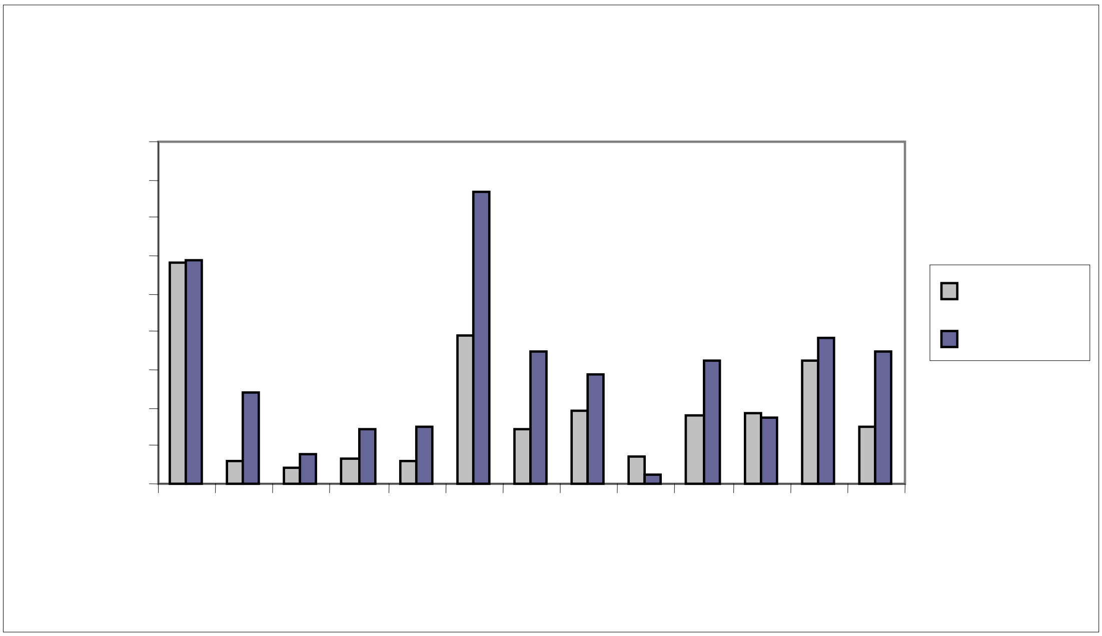

Fig. 1. Blink Rate Driving (D) vs. Driving and Auditory Task (DA) Condition.

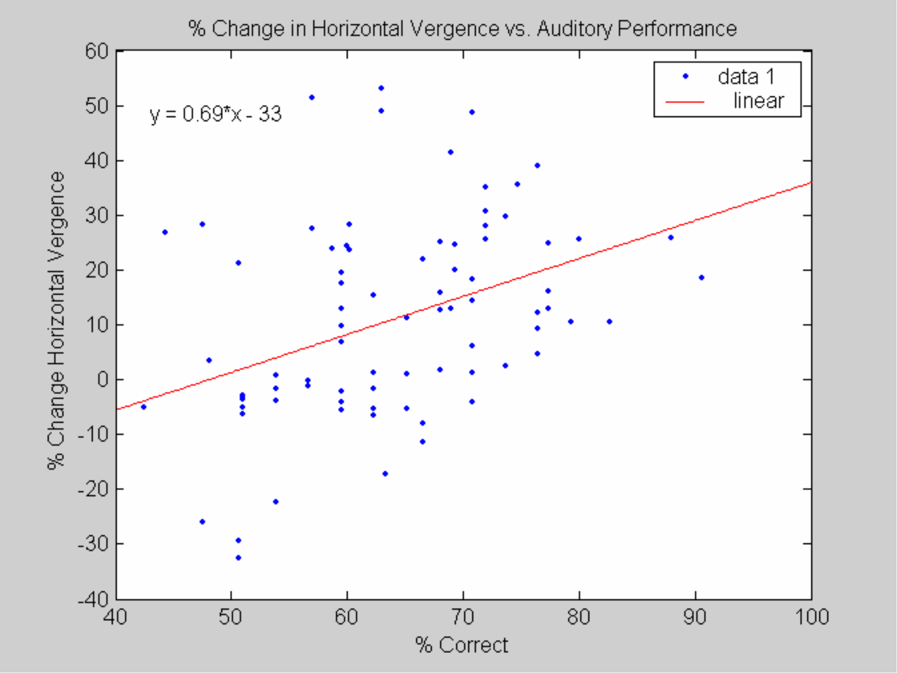

Fig. 2. Percentage change in horizontal vergence angle during dual task with linear fit (n = 13).

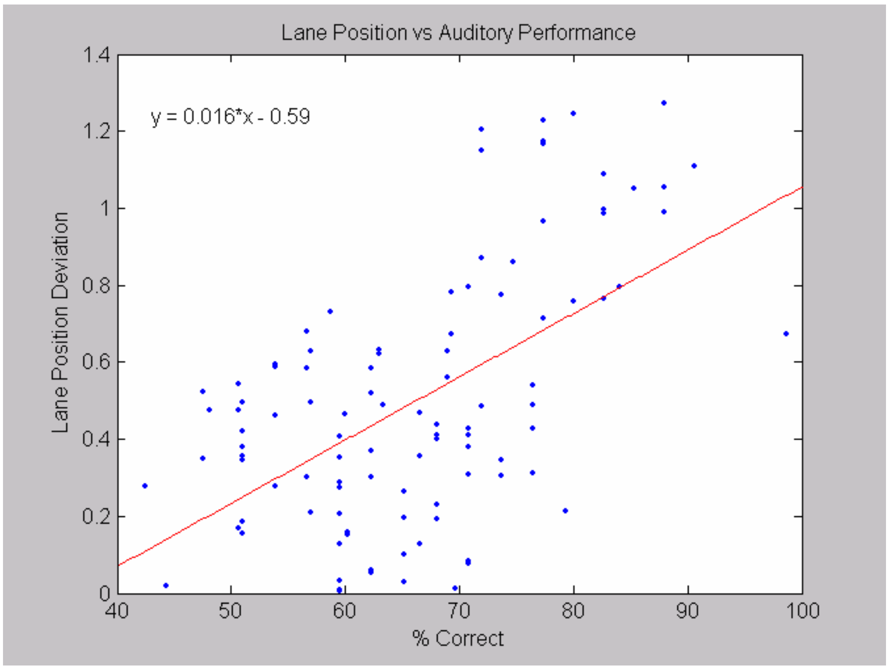

Fig. 3. Lane position performance in feet with linear fit (n = 13).

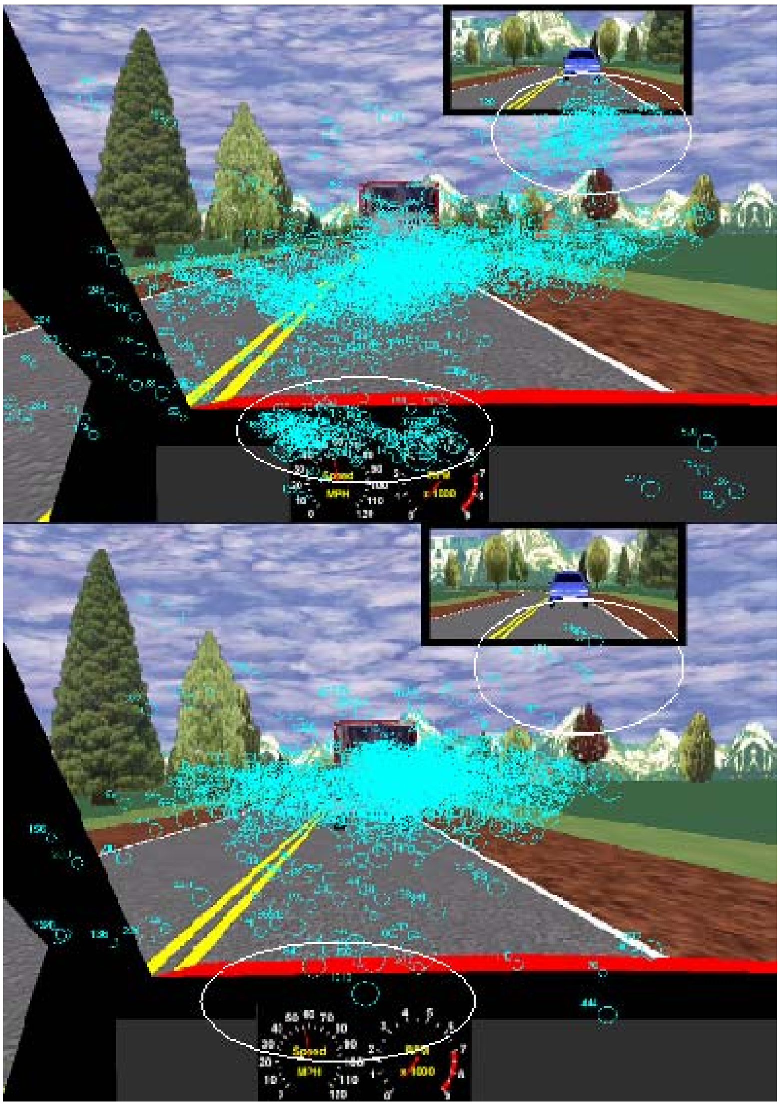

Fig. 4. The top image is a subject's aggregate fixations during the driving-only performance. The bottom image is during the dual-task performance where subjects typically show a dwell time decrease in the rear-view mirror and instrument panel relative to the driving-only task.

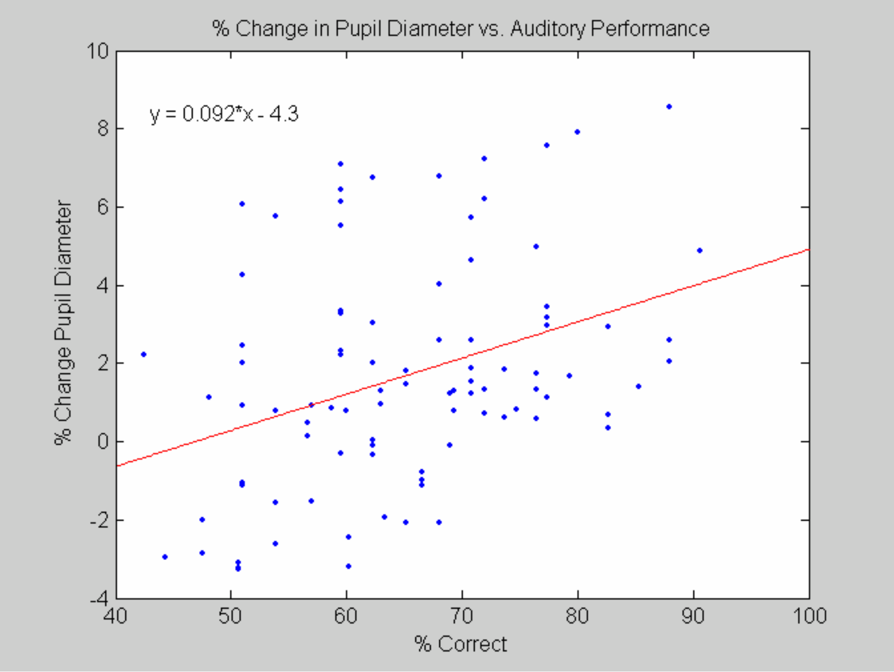

Fig 5. The percentage change in Pupil Diameter during dual-task auditory performance.

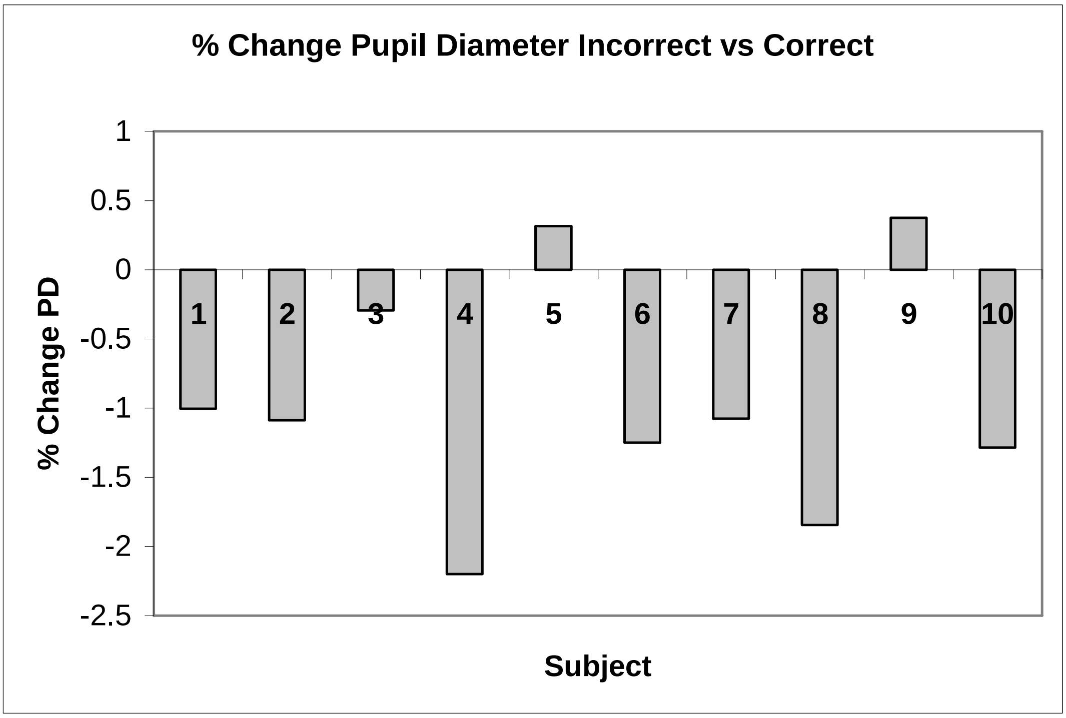

Fig. 6. Individual participant analysis using a 10-second window during correct and incorrect responses to average Pupil Diameter changes.