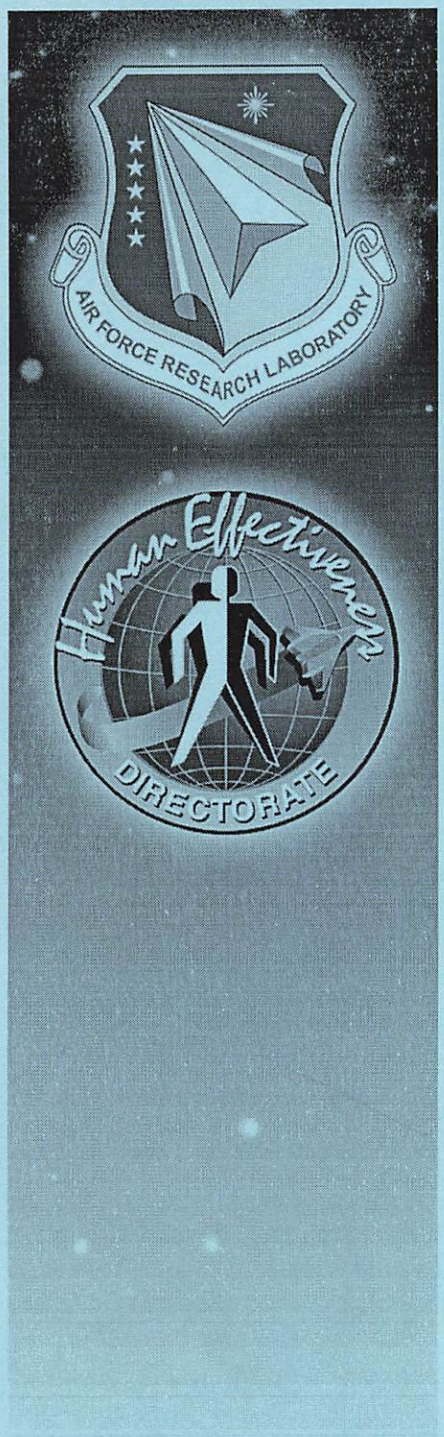
AFRL-HE-BR-TR-2005-0113



Air Force Research Laboratory

REAL-TIME BIO-SENSORS FOR ENHANCED C2ISR OPERATOR PERFORMANCE

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July 2005

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
July 2005	Final	01-07-2004 to 30-04-2005

4. TITLE AND SUBTITLE
Real-Time Bio-Sensors for Enhanced C2ISR Operator Performance

5a. CONTRACT NUMBER
FA8650-04-M-6525

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
65502F

6. AUTHOR(S)
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5d. PROJECT NUMBER
3005

5e. TASK NUMBER
HP

5f. WORK UNIT NUMBER
4R

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Bio-Behavior Analysis Systems
7472 Woodlawn Colonial Systems
St. Louis, MO 63119-4441

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Human Effectiveness Directorate
Biosciences and Protection Division
Fatigue Countermeasures Branch
2485 Gillingham Drive
Brooks City-Base, TX 78235

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/HE

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-HE-BR-TR-2005-0113

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution authorized to U. S. Government agencies (Proprietary Information, Jul 05). Other requests for this document shall be referred to AFRL/HEDM, 8262 Hawks Road, Brooks City-Base, TX 78235.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
We developed a methodology to monitor operators performing computer-based tasks. Most such tasks involve the monitoring of equipment that is highly reliable and requires little intervention on the part of the operator, in other words a "vigilance task." Man's ability to perform such tasks degrades rapidly, especially under conditions of physical or mental "fatigue." The degradation is manifested by periods of lowered alertness lasting for fractions of a second to seconds. Our focus was on the development of non-obtrusive procedures to identify such periods. Three sensing methods were involved: video technology to capture oculomotor activity, Laser Doppler Vibrometry (LDV) to capture cardiovascular signals, and instrumentation of the computer mouse to capture fine motor activity. We developed a task (modeled on the Psychomotor Vigilance Task) in which lapses of alertness could be monitored. We then (1) modified a commercially available eye monitoring system to provide relevant measures, (2) gathered LDV data from the carotid artery of subjects in our task and derived a number of cardiac measures, and (3) instrumented a mouse with pressure sensors to capture manual responses of interest. We also developed the software required to integrate and process all of the relevant data.

15. SUBJECT TERMS
Vigilance, lapses, fatigue, fine motor control, cardiac activity, oculomotor activity, laser Doppler vibrometry, human computer interaction

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Dr. James C. Miller
Unclass	Unclass	Unclass	Unclass	30	19b. TELEPHONE NUMBER *(include area code)* (210) 536-3596

Bio-Behavior
ANALYSIS SYSTEMS

Contractor: Bio-Behavior Analysis Systems, LLC
Contract No.: FA8650-04-M-6525
Project Title: Real-time Bio-Sensors for Enhanced C2ISR Operator Performance
Report Title: Final Report: A Conceptual Model for the Evaluation of Performance Lapses
Date: 13 May 2005

REAL-TIME BIO-SENSORS FOR ENHANCED C2ISR OPERATOR PERFORMANCE

Final Report

A Conceptual Model for the Evaluation of Performance Lapses

1 Introduction

Our focus is on the development of procedures to identify short duration lapses in alertness. It is our conviction that a lapse, occurring together with some infrequently occurring or unexpected event, is a major factor in the occurrence of errors of judgment as well as accidents. It thus behooves us to identify bio-behavioral measures predictive of, or occurring concurrent with, lapses. We are not the only ones to espouse this view. Dinges and Kribbs (1991) in a review of the literature dealing with the effect of experimentally induced sleep loss on performance, come to the conclusion that a major contributor to performance decrements is the occurrence of performance lapses. Their major concern was and is with sleep and pharmacologically induced performance lapses. We have taken the position that such decrements are not unique to sleep loss but that their occurrence during sleep loss is but one example of conditions under which they occur. It is our contention that momentary lapses in alertness occur under a wide variety of conditions. We implicate such lapses in alertness as a major variable accounting for vigilance task performance decrements and assert that there are marked individual differences in the speed with which these lapses evolve. The ability to identify and respond to such lapses as they occur should significantly enhance C2ISR operator performance.

We believe that by monitoring both biological and behavioral measures, which we refer to collectively as bio-behavioral measures, we can discover the cues for the identification of lapses. In order to collect such measures, we have instrumented our data collection and analysis systems to acquire information from the gaze control system, the cardiovascular system, and the motor output system. These systems were selected because they do not require the attachment of sensors.

2 Experimental Task

The Psychomotor Vigilance Task (PVT) was developed by Wilkinson (1982) and improved by Dinges and collaborators (Jewett, et al., 1999) to evaluate performance lapses. It is sensitive to sleep deprivation as well as pharmacological manipulations. Central nervous system depressants decrease and central nervous stimulants increase performance on this task. We believe that demonstrating short-duration attentional lapses in non-sleep-deprived and non-pharmacological conditions requires a more sensitive task, one that incorporates perceptual as well as cognitive demands. We developed a task we will refer to as the Enhanced Psychomotor Vigilance Task (EPVT). We enhanced the test in two dimensions, the first perceptual, and the second cognitive in nature. The perceptual manipulation requires subjects not only to attend to centrally presented information (as found in the PVT), but to information presented at 3 locations, a central location

and locations at 10 degrees to the left and right of the central location. Subjects cannot predict the location of stimulus presentation. A second manipulation requires subjects to abstract information rapidly. The cognitive manipulation requires subjects to retain information (a running memory task) and respond after a sequence of specific events has transpired.

The EPVT presents the operator with three count-up millisecond timers all initially displaying a time value of 0000. One of the three timers is started, and the subject is required to depress the left mouse button to stop the timer. For the cognitive task, the operator is required to retain information about the nature of the digit in the millisecond position of the response time shown on the timer that has just been stopped. The subject is required to depress the right mouse button following a sequence of three response times that have odd integers at the millisecond position.

Thus, the subject has to abstract information, retain it in memory, and finally respond after a sequence of 3 odd response time values have been presented. The millisecond position of the response timer is under experimenter, rather than subject, control. Therefore, we control, without the subject's awareness, the frequency with which a sequence of three odd integers occurs.

Stimulus onset asynchrony is variable, averaging 2.5 seconds and ranging from 1.5 to 3.5 seconds. The subject's manual response to detecting the scrolling timer stops the timer and the resulting response time value remains on the screen for 400 ms.[1] The timer then resets to a default value of 0000 so that all three count-up timers are back in their initial state of displaying the value 0000. After the variable stimulus onset asynchrony period ends, one of the three count-up timers starts again, and the process repeats itself.

3 Data Collection Procedures

Subjects were Washington University student volunteers and were paid $30.00 for participating in this experiment. They came to an office at the Washington University School of Medicine and were required to fill out a number of forms including an informed consent. Following this they were brought to the laboratory and the instrumentation and procedure were explained to them. The camera-based data acquisition system was calibrated. This took on average 30 seconds. A piece of reflecting tape was placed over the site from which cardiac activity was to be recorded with the Laser-Doppler Vibrometer (LDV)[2]. Subjects then read the instructions for the EPVT on the computer screen and were provided with a 5-minute practice period.

The experimenter observed stimuli and responses during the practice period to ensure that the subject was following instructions. Some subjects had difficulty in understanding the instructions for the memory task. The practice period gave us the opportunity to further instruct them in the performance of this task. We also monitored reaction time (RT) to the simple RT task, and prior to starting the experiment proper, asked subjects to attempt to maintain their response latencies at or better than a specified level. This level was dependent on their response latencies during the

[1] If a subject does not respond to the presentation of a count-up timer stimulus, the count-up timer stops automatically after an interval of 4.0 seconds.
[2] The recording site was at or near the carotid artery.

practice task. The suggested latency was identified as their modal latency plus approximately 50 ms.

Once the practice session is completed, subjects performed the EPVT for 60 minutes. We thus acquire in excess of 1000 simple RT responses per subject.

We planned to collect data for a minimum of 10 subjects for this effort.

4 Measures Utilized

The following data was collected as the subject performed the experimental task.

1. Gaze Control Measures

   Using camera-based video technology, the Eyegaze System[3] allows for abstracting the following information at a rate of 60 Hz.

   - Gaze location in the horizontal and vertical plane
   - Center of eyeball location in both planes
   - Pupil diameter in the vertical plane

2. Laser-Doppler Vibrometry Measures

   Aiming a Laser-Doppler Vibrometer at the carotid artery on the neck allows us to perform a fine-grained analysis of cardiac activity including the identification of the opening and closing of the aortic valve. We also collected EKG data to allow for the determination of additional parameters of interest – such as the pre-ejection period (PEP) as well as the inter-beat intervals (IBI).

3. Performance Measures

   In addition to using the mouse output to identify reaction times, we instrumented the mouse with pressure sensors located over the two response buttons as well as on the left side of the mouse over the location where the subject's thumb was most likely to be placed. We argue that pressure sensors should provide us with additional information, such as partial pressure on the mouse button that might reflect anticipatory responses.

   Since Plant et al. (2003) have established that variable delays on the order of 10s of milliseconds can be introduced by the hardware and software associated with a particular mouse, we also were interested in the difference in R.T. as recorded with the mouse versus those recorded with the pressure sensors.

   A second reason for utilizing the pressure sensors was that in pilot studies subjects occasionally reported that they needed to press the left mouse button a second time in order to stop the timer. Thus using the pressure sensors gave us an opportunity to evaluate the reliability with which mouse responses were recorded.

[3] The Eyegaze Analysis System from L.C. Technologies, Inc., Fairfax, Virginia, USA, http://www.eyegaze.com

5 Criterion Measures for the Identification of Lapses in Alertness

For the present analysis, we used the simple RT data for identification of lapses in alertness. We have arbitrarily taken the position that the slowest 50 simple RT responses for a subject (of the more than 1000 such responses for each subject) constitute lapses in alertness.

The first issue to be dealt with was the question of whether the task produced decrements in performance as a function of time-on-task (ToT). If the likelihood of slow responding increases as a function of ToT, the distribution of such responses over time should favor later over early portions of task performance. The distribution of the 50 longest latency responses for each subject is shown in Table 1 below.

		Elapsed Time in Seconds					
		0-600	601-1200	1201-1800	1801-2400	2401-3000	3001-3600
Subject	F10*	0	0	3	10	21	16
	F11	0	4	18	26	2	0
	F12*	4	5	3	14	8	16
	F13*	0	2	4	11	14	19
	F14	4	17	7	8	10	4
	F17*	0	1	3	12	10	24
	M10*	3	1	5	12	17	12
	M11*	0	3	11	7	13	16
	M12*	1	1	5	5	18	20
	M13	11	23	12	3	0	1

Table 1: Distribution of 50 longest latency responses

The distribution of response latencies for 7 of the 10 subjects (those marked with an asterisk *) accords with our expectation that the majority of long latency responses would occur late in task performance. Of the three subjects not demonstrating this pattern, two (F14 and M13) show a pattern of longer latency responses early in task performance suggesting that the practice period was not long enough to get them to a stable level of performance before starting the task proper.

Subject F11 shows a pattern radically different from the others, with the majority of long latency responses occurring in the middle of task performance.

We conclude that for the majority of subjects tested, the EPVT is sensitive to ToT effects. Unfortunately, not all long latency responses identified by mouse response qualify as long latency responses based on an evaluation of both mouse and pressure sensor data. Occasionally the pressure sensor picks up a response followed rapidly by a second response with the latter occurring concurrent with a mouse response. This phenomenon was described by some of our subjects when they indicated that the first time they responded the timer did not stop and they had to enact a second response. A second exclusion of an identified Long Latency Response (LLR) occurs on the trial following a specific type of lapse. Subjects occasionally respond to a stimulus and "forget" to release the mouse button, releasing it when the next stimulus occurs, the response to that stimulus is thus delayed. A third criterion for exclusion of an LLR occurs when subjects make "anticipatory" responses that overlap stimulus presentation. Responding to the stimulus is delayed. One can consider the anticipatory response as a special type of lapse. The last criterion for exclusion is the occurrence of an LLR on the trial following correct identification of a sequence of three odd integers. Some subjects delay in responding to that stimulus, we believe, in part because they know that this stimulus will not require retention of information. These observations suggest that there are some constraints on the use of the mouse to monitor reaction time. More about this later.

6 Bio-Behavioral Measures Reflecting Attentional Lapses

Our major interest is in determining whether long latency responses could be identified on the basis of oculometric, cardiovascular, and behavioral measures. Two procedures were implemented for this analysis. The first involved selecting from the 50 longest latency responses, 20 trials for comparison with 20 trials with average response latencies. We selected trials 31 – 50, where trial 1 was the longest latency response. Thus we did not select the slowest responses.

To identify 20 trials with "normal" response latency for comparison with the 20 long latency response trials, we initially identified the 100 trials around the mean and selected trials from this data set that were close in time to the long latency response trials. Since this placed unacceptable constraints on how close in time we could select normal response latency trials to be compared to our long response latency trials, we changed our procedure for the selection of normal latency response trials to select trials that occurred close in time to the long latency response trial and, where possible, were responses to a stimulus at the same location as the long latency response.

The second, and preferred procedure involved the evaluation of all 50 LLR trials as well as 50 trials semi-randomly selected from the data set and evaluating them using the same criteria used for the evaluation of LLR trials.

Using our selected "normal" latency response trials and comparing them to the long latency response trials, we evaluated the following measures.

7 Measures Evaluated

7.1 Pupil diameter

Pupil diameter is responsive to both affective as well as cognitive manipulations. We argue that one component to which lapses could be attributed is a lowering of alertness or interest in the task. This lowering of interest should be accompanied by smaller pupils as compared to periods where subjects are alert and interested in task performance. We sampled pupil diameter at stimulus presentation and at response initiation. This was done both for long as well as for "normal" latency responses.

We presume that responding may serve an alerting function when RT is long. Therefore, we evaluated pupil diameter at response initiation as well as 102 ms later. We expected an increase in pupil diameter from response initiation time to 102 ms later for long latency response trials. If a long latency response indicates a lapse in attention to the task, we expect that lapse to be reflected in smaller pupil diameters. Once the response is made, the alerting effect of the response should be reflected in larger pupil diameters.[4]

In the case of normal latency responses, we expected that there might be a period of relaxation following responding. Thus for these trials we expected to see a decrease or no change in pupil diameter over the 102 ms period between responding and the second pupil diameter sample.

Pupil diameter should also change as a function of time on task, and thus may provide a tonic "alertness" measure. If subjects become less alert over time, one should see a decrease in pupil diameter over time. On the other hand, in order to counteract boredom induced by the long duration of the task, subjects may have to expend more "energy" to maintain a high level of performance.

7.2 Camera data loss

It is obvious that if the eyes are closed when visual information requiring action is presented, there will be a delay in responding until the eyes reopen. Though the technology used in the present experiment does not allow for discriminating between data loss associated with lid closure and data loss that is the consequence of head movements large enough for the camera to lose the eye, we suspect that most periods of data loss can be attributed to the former rather than the latter reason. Thus, if pupillometric information were lost prior to and during stimulus presentation, one would expect a delay in responding.

Camera data loss is also likely to show a change as a function of ToT. To varying degrees, subjects demonstrate a variety of signs of physical discomfort over the 60 minutes of task performance. These include head movements, body movements, yawning, stretching, slumping

[4] The choice of 102 ms was arbitrary. While evaluating the data, it became apparent that a somewhat longer interval, such as 204 ms might be more appropriate. Pupil data was sampled at 17 ms intervals, therefore time intervals had to be chosen in 17 ms increments. This explains the choice of 102 ms (6 samples) and the suggestion of 204 ms (12 samples).

in the chair, moving about in the chair, moving their legs, and altering the way they hold the mouse. The way they press the mouse buttons also changes, rather than placing the appropriate fingers on the left and right mouse button, they shift to a strategy of flexing the fingers and tapping the mouse button when required to respond. These shifts in strategy persist for some time, and subjects then return to their accustomed procedure for responding. They also blink and occasionally close their eyes for short or extended periods of time. To tap these dimensions, data loss information was abstracted by measuring camera data loss on the pupil diameter channel.

To measure data loss, we need to have a clear definition of what constitutes data loss. In our data collection system, when the eye camera system cannot find the pupil (and thus cannot determine the gaze location, eyeball center location, or pupil diameter), the output from the camera system for all measures drops to its lowest possible value. The period during which these lowest values occur is a "dropout" period, and the channel's values during this period do not reflect the gaze location, eyeball center position, or pupil diameter.

However, we have learned through experience using our camera-based equipment that there are a small number of samples just prior to a dropout and a small number of samples following a dropout that are also not accurate reflections of the camera-based measures. Thus, we have chosen to identify a data loss period as starting at 34 ms (2 data samples) prior to a dropout and running through 34 ms after a dropout.

The camera-based channels occasionally have dropouts that are very short, perhaps only one or two samples (17 ms or 34 ms) long. When we convert such a dropout into a period of data loss by adding 34 ms to the beginning and ending, we get a data loss period of 85 ms or 102 ms. However, we do not consider such dropouts to be biological in nature, but instead we attribute them to noise in the recording system. That is, we do not consider these to be periods of true data loss. To account for that fact, we exclude from our analysis any data loss periods that are less than 102 ms.

A number of analyses of the resulting data were conducted. First, to assure ourselves that there was an increase in the duration of data loss as a function of time, we evaluated total period of data loss per 10-minute segment across the 60 minutes of task performance. Second, following the demonstration of a significant effect of ToT on total data loss duration, we asked whether the increase was a function of an increase in the number of periods of data loss, an increase in the duration of the individual data loss periods, or a combination of the two.

Further discussion of our analysis follows.

1. Duration of data loss for successive 10-minute periods

   To test the hypothesis that there would be an increase in the duration of data loss for successive 10-minute periods, we identified all periods of data loss and summed data loss for each 10-minute period. The data are depicted in Table 2.

	Time Period (minutes)					
	0-10	**11-20**	**21-30**	**31-40**	**41-50**	**51-60**
Total/10 min						
Mean (sec.)	67.6	76.7	92.6	100.6	118.6	142.7
Standard Dev.	38.9	37.0	50.1	45.8	55.1	61.5
Average rank	1.57	2.29	3.14	3.57	4.57	5.71
Frequency/10 min						
Mean	210.4	227.1	243.6	236.9	247.1	262.2
Standard Dev.	87.0	87.7	99.1	97.2	98.1	106.1
Average rank	1.93	2.93	3.71	2.86	4.0	5.14
Correlation between Frequency and Duration						
	0.649	0.708	0.771	0.69	0.509	0.470

Table 2: Data loss analysis

2. Frequency of occurrence of data loss per 10-minute period

   Since there was a significant increase in the duration of data loss for successive 10-minute periods, we wished to determine whether the increase was attributable to an increase in the duration of successive periods of data loss, to an increase in the frequency of occurrence of data loss per 10-minute period, or a combination of the two. (The current technology does not allow for discriminating between these two reasons for data loss.[5]) The results of this analysis are also depicted in Table 2.

   It is readily apparent that there is both an increase in duration as well as frequency of data loss as a function of ToT. Rank order ANOVA's calculated on both data sets are significant at better than the 0.001 level. Of the 14 subjects only one did not demonstrate an increase in data loss as a function of ToT, subject M13 demonstrated the majority of data loss during the initial 30 minutes of task performance. For all other subjects the period from min 51-60 had the largest (N=12) and one the second highest rank. There was approximately a doubling of the amount of data loss from the initial to the final 10-minute period. The increment in frequency of occurrence of data loss, though also significant was not as dramatic. The differences in distribution of the rank ordering of events depicts this nicely.

[5] We are in the process of developing an eye tracking system that will allow for such discrimination.

We correlated frequency of data loss with duration of data loss to determine whether these two measures demonstrated differential effects. A high correlation would indicate that either one would be equally suitable for demonstrating ToT effects. The correlations for early time periods are consistently higher than the last two periods. Thus we have the suggestion that the two measures are somewhat independent of each other.

7.3 Evaluation of "long latency" responses

As identified above, we monitored mouse button response latency and identified the 50 longest response latencies to the detection task. There were relatively few trials where there was no response. Such trials are not included in this evaluation. For each of these 50 longest latency response trials we placed the trial into one of the following categories:

Category 1. No camera data during stimulus onset

We presume that when there is no camera data that the subject either has shifted gaze outside of the field of view of the camera or that the eyes are closed. Based on our observations both of subjects and of the data, we came to the conclusion that the majority of such data loss was associated with eyelid closures. Thus, there should be more instances of such data loss with long latency responses as compared to normal responses.

Category 2. Blink during stimulus presentation

If a short duration period of data loss (less than 200 ms) occurred in close contiguity to stimulus initiation, we identified it as a blink related period of data loss. Since during a blink vision is obscured and since there is "blink inhibition" (reduced capability for perceiving and processing information) for a period following a blink, one can assume that this may be a contributing factor to longer latency responses.

Category 3. Multiple saccades between stimulus onset and response

Multiple saccades occur under a number of conditions. For example, if gaze is at the left location and stimulus presentation is at the right location, subjects frequently make two saccades, the first returning gaze to the central location, the second one to the target location. Subjects also occasionally shift gaze in the wrong direction to stimulus presentation. When this occurs, shifting gaze to the appropriate location requires a number of saccades. Multiple saccades also occur when the initial saccade is in the correct direction but does not shift gaze far enough in the target direction and thus requires a second saccade.

Category 4. Slow saccades and "eye drift"

Slower than normal saccades have been described in sleep-deprived subjects as well as in tasks where subjects were required to perform for extended periods. Our definition of slow saccades includes low velocity saccades as well as glissades, i.e., gaze shifts where the initiation or termination of the gaze shift is

slower than normal. Saccades where there was a brief (less than 102 ms) fixation followed by another saccade were also included in this category. (The second of these saccades can be considered an "express saccade".) Eye drifts are gaze shifts that are slower than saccades and, in our experience, are most frequently seen (in electro-oculographic tracings) under eyes closed conditions. The latter eye movements have been referred to in the literature as SEM's, Slow Eye Movements. They are infrequently seen under eyes open conditions.

Category 5. Relatively large head movement component to gaze shift

Amplitude of the head movement component was selected as another potential contributor to the making of the discrimination for two reasons:

1. There is suggestive evidence in the literature that amplitude of the head movement component is responsive to task difficulty.
2. Large amplitude head movements also occur as a sign of discomfort on the part of the operator. We argued that if such signs of discomfort occur concurrent with stimulus presentation it might well delay responding.

Category 6. No reason

There were occasions in which we could not identify any of the above conditions associated with the response under consideration.

For the first analysis, which was also used to generate the list of criteria identified above, we performed the following operations for data from three pilot subjects.

1. Oculometric data for the 2 s period preceding and following a Long Latency Response (LLR) trial and temporally comparable Normal Latency Response (NLR) trials were abstracted. Information dealing with both mouse and pressure sensor outputs were deleted from the data. For each subject, 20 paired events were displayed and judges were asked to identify the LLR events. Before attempting this task they were provided with the "criterion measures" listed in section 7.3 above. Two judges performed this task. Their accuracy in correctly identifying the LLR's was 88% for judge 1 and 80% for judge 2. Since generating such data sets was time consuming and it could be argued that a biased experimenter could select sets that were obviously different, we decided not to continue with this approach to data analysis.
2. How were these criterion measures generated? The P.I. who generated the samples of LLR and NLR's allowed a month to pass before performing the paired judgment task on the data set himself. His accuracy was 81.6%. Thus the items selected to allow for discrimination between LLR and NLR's may well be useful for discriminating between lapses and normal performance.

Finally, there were occasions where the data was "noisy" enough that no determination of the above categories could be made. Such data segments were excluded from analysis, and we identified the number of trials on which the analysis is based.

For comparison purposes we evaluated 50 semi-randomly selected trials. These were selected using the following criteria:

For the time period from task initiation until 2100 seconds into the task performance, we selected trials at approximately 100 s, 200 s, 300 s, 400 s, etc. into the task. For subsequent trials, we selected trials every 50 seconds. The more frequent sampling for later trials was based on the increase in long latency responses as a function of time on task. No attempt was made to exclude long latency response events in this analysis.

Excluded from this analysis were measures such as saccade latency, a measure which clearly discriminated between long and normal latency responses, but one that should not be used since it requires the identification of the event of interest. Our concern is with the identification of lapses in situations where we do not have the luxury of knowing the timing of stimuli of interest.

The results are shown in Table 3 and Table 4.

		Category						
		1	**2**	**3**	**4**	**5**	**6**	**Total**
Subject	F10	24	9	14	3	0	0	50
	F11	32	4	2	10	0	0	48
	F12	1	26	3	0	7	13	50
	F14	28	6	0	7	0	4	45
	M10	11	2	7	1	11	11	43
	M11	23	2	8	10	0	5	48
	M12	15	0	9	9	0	7	40

Table 3: Long latency response categories

		Category						
		1	2	3	4	5	6	Total
Subject	F10	5	5	10	2	0	28	50
	F11	4	2	3	1	3	37	50
	F12	2	6	3	1	1	37	50
	F14	9	4	8	4	1	24	50
	M10	3	0	0	0	5	41	49
	M11	2	1	12	2	0	33	50
	M12	2	0	2	4	2	37	47

Table 4: Semi-randomly selected response categories

It is readily apparent in a comparison of the long latency and semi-randomly selected responses that the above measures are effective in discriminating between these two types of responses. There are, however, marked individual difference with respect to the pattern of variables entering into the identification of long latency responses. The formal analysis of these results will be conducted when data for all 20 subjects has been analyzed.

8 Using Pupil Diameter to Discriminate Between Long and Normal Latency Responses

We also paired LLR trials and NLR trials that were close in time and compared a number of pupil diameter related measures between the LLR and NLR trials. The following are the measures compared.

Measure 1. Pupil diameter at stimulus onset

We calculated the percentage of trials for which the pupil diameter was larger at stimulus onset for the NLR trial as compared to its corresponding LLR trial. The larger pupil diameter should reflect a higher level of attention to the task. Thus, for subject F 10 for example, 83% of the paired comparisons demonstrated larger pupil diameter for the NLR as compared to the paired LLR trial.

The results of these calculations are shown in the "Measure 1" column of Table 5 below. Presuming that a 50% likelihood indicates no difference between NLR and LLR trials we find three subjects (F12, F15, and M10) who demonstrate such a pattern. The remaining subjects all showed smaller pupils at time of stimulus presentation for LLR as compared to NLR trials.

Measure 2. Pupil diameter change from response onset to 102 ms post response onset

We calculated the percentage of trials for which the pupil diameter increase was larger for the LLR trial as compared to its corresponding NLR trial. The making of a response should have an alerting effect for trials in which alertness is at a low point at time of stimulus presentation. For all subjects we see that the percentage

of trials on which the pupil diameter increases is larger for LLR than NLR trials. The three subjects for whom measure 1 did not discriminate demonstrate the lowest percentage of such events.

No analysis of pupil diameter change between stimulus and response onset was conducted since the time interval between stimulus and response onset differed so markedly between LLR trials and NLR trials.

The results of these calculations are shown in the "Measure 2" column of Table 5 below.

Measure 3. Second measure of pupil diameter change from response onset to 102 ms post response onset

We calculated the percentage of trials in which there was an increase in pupil diameter from response onset to response onset plus 102 ms for NLR trials (represented in the "Measure 3NLR column of Table 5 below) and for LLR trials (represented in the "Measure 3LLR" column of Table 5 below). The incidence of pupil diameter increase for the NLR condition is, with the exception of three subjects (F11, F15, M13) small. In fact the majority of subjects demonstrate a decrease in pupil diameter. This will be investigated further.

			Measure			
		N	1	2	3NLR	3LLR
Subject	F10	12	83.3	91.7	25.0	91.7
	F11	20	95.0	90.0	45.0	90.0
	F12	16	43.8	62.5	18.8	37.5
	F14	17	100.0	100.0	15.9	100.0
	F15	16	50.0	62.5	50.0	68.8
	F17	20	80.0	90.0	10.0	85.0
	M10	18	50.0	77.7	5.5	22.2
	M11	20	80.0	80.0	20.0	50.0
	M12	19	68.4	84.2	15.8	57.9
	M13	17	94.1	76.5	70.6	82.4

Table 5: Percentages of trials for Measures described above

9 Heart Period and Pre-ejection Period Analysis of Long and Normal Duration Fixation Pauses

We are developing a system for a fine-grained analysis of cardiovascular changes during an inter-beat interval. That system is not as yet operational.

A manual analysis of what transpires during the IBI preceding stimulus onset was completed for three subjects (F11, F12, M11). Information abstracted included timing of the R wave and opening of the aortic valve, presuming that the time between R wave peak and opening of the aortic valve is a reasonable approximation for identifying the pre-ejection period (PEP). Twelve or thirteen paired events (long latency response trials and normal latency response trials within a 30 second window) were evaluated for each subject. There were no differences in the IBI between the two conditions for subjects F11 and M11. For 10 of the 12 paired comparisons for subject F12, heart period for the long latency response trials were longer than for the comparable normal latency response trials.

This was in line with our expectation that long latency responses are associated with lowered levels of alertness (as reflected in the case of heart period, longer IBI). No difference in average pre-ejection period duration was found. The duration of the IBI, the PEP, as well as the ratio of PEP/IBI differed across the three subjects. The one with the longer IBI had consistently longer duration PEP. This was to be expected. We also evaluated the PEP divided by IBI to identify the portion of the IBI taken up by the PEP. There were no differences in these ratios between the two conditions. However the PEP/IBI ratio for subject M11 was also consistently larger than for subject F11. The only suggestive result (for subject F11) was that if one evaluated PEP's that were less than 110 ms in duration, such events were more likely to occur in the normal latency conditions (8 of 13 events for normal latency responses, only 3 of 13 events for long latency responses. Further analyses are required to determine whether this effect is reliable. As is readily apparent we are at the early stages of evaluating this data and are awaiting development of algorithms to automatically or semi-automatically abstract the relevant data. These results are depicted in Table 6.

	Heart Period	PEP	PEP/IBI %
F11: LLR Trials	756.5	108.1	14.4
F11: NLR Trials	755.8	107.2	14.3
F12: LLR Trials	783.5	107.9	13.94
F12: NLR Trials	735.5	111.8	15.39
M11: LLR Trials	916.4	170.6	18.6
M11: NLR Trials	915.2	168.6	18.5

Table 6: Early results of Heart Period on PEP analysis

We propose to continue this evaluation and hopefully add data on the ejection period and post ejection period as well.

10 Evaluation of Pressure Sensor Output and Comparison with Mouse Button Response

Based on results from pilot studies, we placed the pressure sensing instrumentation at locations where we consistently were able to obtain pressure responses. These pilot experiments were usually of short duration. To our surprise, we found that when subjects were required to perform the task for an extended period of time (60 minutes), there were periods where, although we obtained a mouse button press response, we did not see a response from the pressure sensor. By observing subjects, it was determined that this was most likely to occur when subjects did not place the first or second phalange over pressure sensor pad but arched their finger so that only the finger tip touched the mouse pressure pad. The very tip of the mouse pressure pad was not instrumented with the pressure sensor with resultant data loss. We also had assumed that the output from the pressure sensor was linear. This also was not the case. Thus data analysis of output from the pressure sensors was conducted manually, a time consuming procedure.

To date, two analyses have been performed on a subset of the data.

The first dealt with the time difference between pressure sensor and mouse button activation under conditions where the pressure sensor was activated "concurrent" with the mouse button. We evaluated between 20 and 30 such events for each of 5 subjects. In all cases the pressure sensor was activated before or concurrent with the mouse switch. The average discrepancy was 60 ms with a range of 55–64 ms across the five subjects. Thus, using the mouse button as the device for measuring R.T. has some shortcomings. These have been elaborated in a number of

publications: (Plant et al., 2003; Visser, et al. 2004) The five subjects for whom the above data were abstracted also provided trials where partial pressure was exerted on the mouse pressure pad prior to stimulus onset with further pressure on the mouse pressure pad to activate the switch. One might expect that response latency would be faster under conditions where partial pressure is exerted prior to actual mouse response. For 4 of the 5 subjects this was the case with R.T. differences of 72, 41, 63, and 28 ms in favor of the condition where partial pressure had been applied to the mouse pressure pad. The one subject for whom this was not the case showed the same average response latency for both conditions. The time difference between sensor and mouse switch activation was calculated for these 5 subjects. The differences all were in favor of more rapid responding with the pressure sensor. The differences were 0.064, 0.055, 0.058, 0.059 and 0.064 seconds.

When the pressure sensors were recording appropriately, they provided additional information about aspects of performance. For example, anticipatory responses involving pressure and release of the sensor were recorded much more frequently with the pressure sensors than the mouse. Subjects' report of the mouse requiring two presses to stop the count-up timer could be verified. There were occasions when the pressure sensor recorded two consecutive responses and the mouse only the second response.

We also saw what we would consider to be "overflow" responses. These were responses with the thumb or ring finger when a simple reaction time response was enacted. Such responses tended to occur more frequently late in task performance as compared to early in task performance.

Partial pressure responses seemed to occur in groups, i.e., one would see a sequence of these responses followed by a sequence of non-partial-pressure responses. It is possible that subjects are more alert to task performance under the former conditions. This measure would thus provide information about alertness to task demands in addition to the pupillometric measure described earlier.

11 Laser-Doppler Vibrometry

Research in the Washington University Medical School laboratory of Dr. John Rohrbaugh has demonstrated the utility of this technology in capturing muscle activity, cardiovascular activity, respiration, as well as voice activity without the need for attaching electrodes. There are a number of problems with the technology that require further efforts. The first involves the ability to maintain focus of the laser beam on a specific location on the human body. This technology is evolving with the help of investigators from the Washington University School of Engineering. We are evaluating the use of both standard as well as 3 dimensional cameras for solving this problem. The application of the resultant technology to the recording of eye position information, the accurate measurement of pupil diameter, and determining whether data loss is due to eyelid closure or the eye moving out of range of the camera will be incorporated into subsequent phases of this project.

With respect to the current phase, we have collected both EKG (with electrodes) as well as the LDV output with the laser aimed at the carotid artery. We are developing software to abstract

information from the LDV that reflects opening and closing of the aortic valve. Those two bits of information, in conjunction with the EKG signal should allow us to evaluate:

- Pre-ejection period
- Ejection period
- Recovery period.

We have, to date, evaluated one component of interest, namely the effect of expectancy on heart period. There is a large literature dating back to the 1960's dealing with a phenomenon described as the fixed foreperiod effect. In simple reaction time tasks where presentation of a stimulus requiring a response is preceded by a warning signal, one sees decreases in heart rate (increase in heart period) during the anticipation period. We argued that this phenomenon should apply in the current context in the condition where subjects are required to make a response following the identification of a series of three odd integers. We would not expect any increase between the first and second odd integer but following the second odd integer one should see an increase in heart period in anticipation of the next odd integer. Such increases in heart period should be observed in both the sequence where a response is required – odd-odd-odd-response, as well as in the sequence odd-odd-even-no response. Evaluating heart period changes under both sequences should allow one to discriminate between the situation in which a response is made and in which a response has to be inhibited. One can further ask whether the cardiac response is associated with the conscious identification of the three odd integers or whether it occurs in situations where no response is made, as well as in situations where there is a false alarm, i.e., a response in the absence of the third odd integer.

12 Heart Period Analysis: Effect of Anticipation

12.1 Description of analyses performed

This analysis dealt with the evaluation of cardiac activity during periods of anticipation. Prior research from our as well as other laboratories has demonstrated that heart period duration increases when subjects are anticipating a relatively infrequently occurring event (Sirevaag, et al. 1999). We sought to confirm this in the preliminary data collected with the EPVT.

Data was evaluated for five subjects. For four of the subjects, the analysis was conducted on data collected with the Laser-Doppler Vibrometer (LDV), and we used the opening of the aortic valve to trigger identification of the inter-beat interval. For the fifth subject standard EKG data was available and the peak of the R wave was used to identify IBI's. Data analysis utilized a computer routine for identifying the peak of the R wave and was manually edited for artifacts. The major purpose of this analysis was to determine whether we could reliably collect cardiovascular data with the LDV under the conditions of this experiment. The answer to the latter question is YES.

The first analysis of heart period change associated with anticipation involved measuring the duration of the five heart periods preceding and following occurrence of a third odd integer (O-O-O-R). Since anticipation was not limited to the occurrence of three odd integers, but

anticipation that the integer following a series of two odd integers would be odd, a further analysis was conducted on the five beats preceding and following the memory task response where no response was required, i.e. high level of expectation and disconfirmation of the expectation (O-O-E- no response).

It was expected that anticipation of the third odd integer would lead to lengthening of the heart period. In our earlier study the inter-stimulus interval was constant, subjects could thus not only anticipate the occurrence of an event requiring a response but also could anticipate time of occurrence. In the present study the inter-stimulus interval was varied so that anticipation of when a stimulus occurred was not available.

We evaluated the inter-beat interval (IBI) for the five periods preceding onset of the third integer, the period involving presentation of the third integer and the five periods following the third integer. (Since the inter-stimulus interval varied around an average of 2.5 s, this analysis frequently included periods where stimuli were presented.) Three analyses were conducted, one for the situation where a response was required and enacted (with response), one for events where a response was required but not made (missed signal – no response) and for the situation where two odd integers were followed by an even integer (3rd even). The analysis was conducted both for "raw" data as well as for "normalized" data. Data was normalized using, for each subject, the average of the first IBI as the "comparison" value and expressing successive average values for each individual as a percentage of the first interval. An analysis of variance was done on heart period duration following normalization. The results demonstrated a significant difference across the inter-beat intervals with a $p < 0.01$.

Figure 1 depicts the results of the heart period analysis both for average (i.e. "raw" heart periods) as well as normalized values under the condition in which a response to the memory task was required.

As depicted in both Figure 1 and Figure 2, the heart period for the interval involving presentation of the third integer and for the interval following it demonstrate a lengthening of heart period for both the conditions where a response was required and made, and the condition where anticipation of the third odd integer was disconfirmed and no response was made. The analysis of variance showed a significant difference between the heart periods with a p-value of < 0.01.

In the "with response" condition we evaluated, for each of the 20 trials analyzed for each subject, the period in which the longest inter-beat interval occurred. For two subjects, the heart period preceding the response was most often the longest. In the other three subjects this heart period contained the longest period the second most times.

The next analysis evaluated the condition where two odd integers were followed by an even integer. Approximately 30 occurrences of this sequence were analyzed for each subject.

An analysis across all subjects demonstrated cardiac deceleration in the interval containing the third (even) integer, and the period directly following it. The pattern was similar to that seen in the analysis above. An analysis of variance done on the data from all subjects after normalization showed a significant difference with $p < 0.01$.

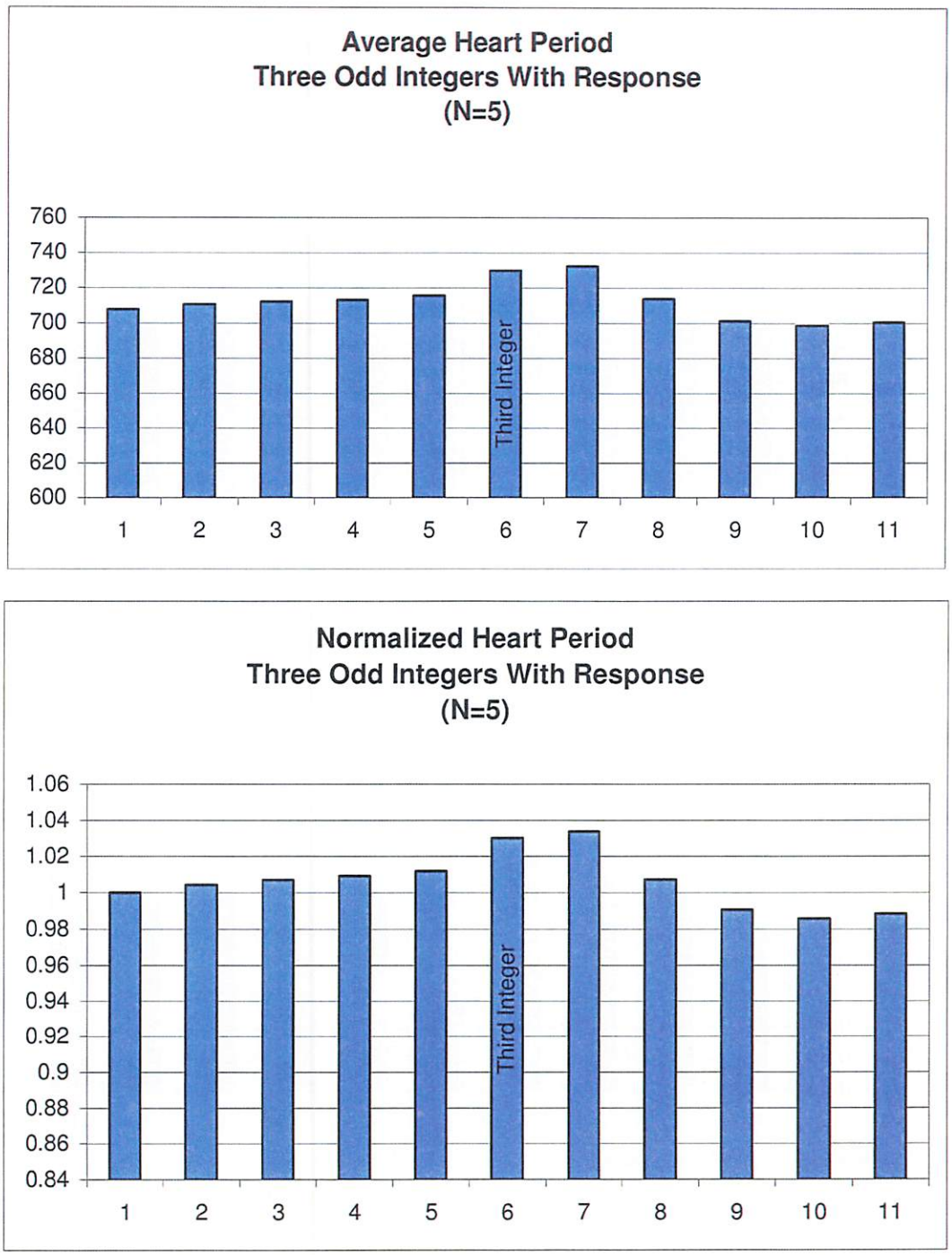
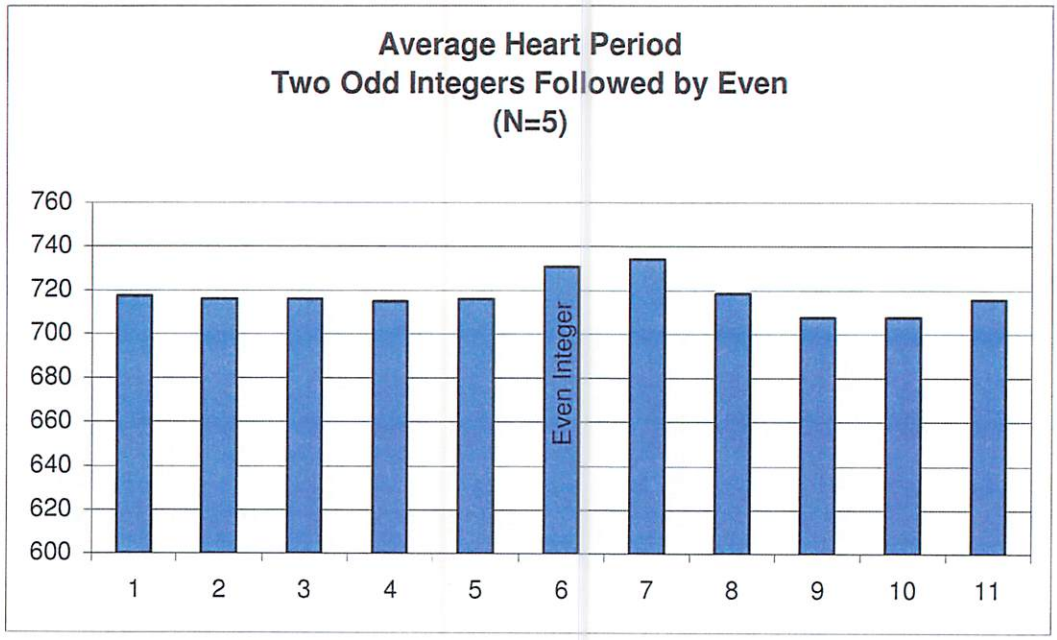


Figure 1: Raw and normalized heart period for 3 odd integers with memory task response required



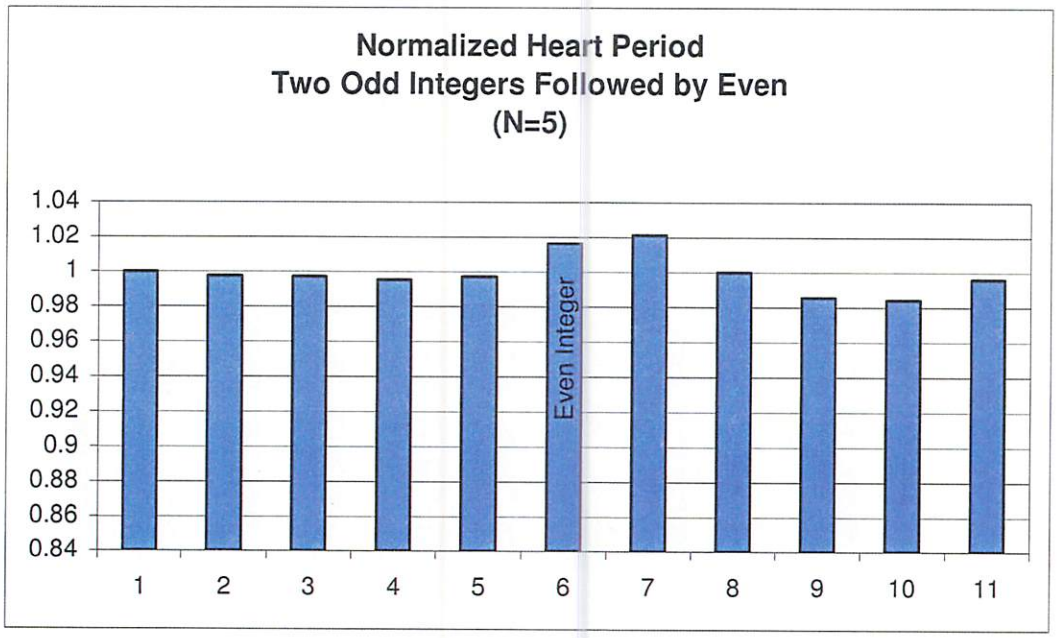
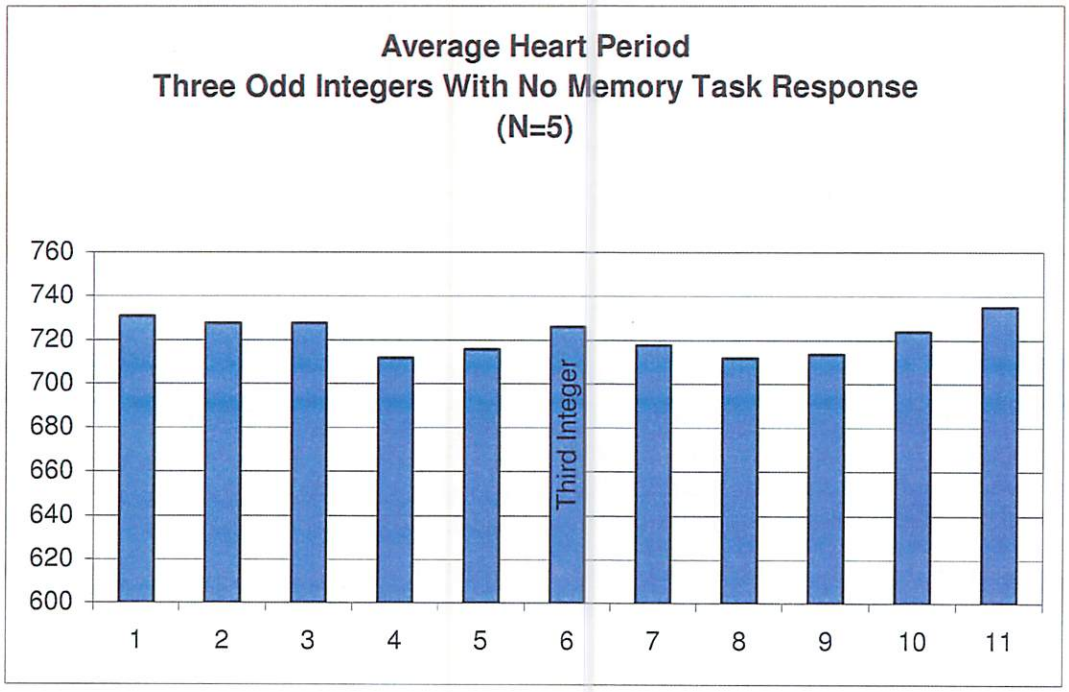


Figure 2: Raw and normalized heart period for 2 odd integers with memory task response not required

The last analysis was conducted to determine if heart period slowing occurs when a subject should be showing anticipation but does not. These instances occur when a sequence of three odd integers is not followed by a response. This event occurred relatively infrequently and the average number of such events was 5.4 times per subject. This analysis was done with the five heart periods before the third odd integer and the seven periods after the integer. No significant effects were obtained. Figure 3 suggests a decrease in heart period both preceding and following presentation of the third integer, but these effects were not reliable.

After all three conditions were analyzed, a further analysis was done comparing the three conditions (O-O-O-R; O-O-O-no response; and O-O-E-no response). An analysis of variance was done across all three groups to determine if there was a significant difference in the pattern. The results showed a difference with a $p< 0.01$ in the normalized data. Subsequently, t-Tests were conducted. They demonstrated no differences between the correct response condition and the condition with the third integer even ($p>.2$) for any of the comparisons. The t-Tests demonstrated that the condition with three odd integers and no response was significantly different from the other two conditions ($p<0.05$).

Figure 4 shows both the raw average heart period and the normalized heart period data for all three conditions.



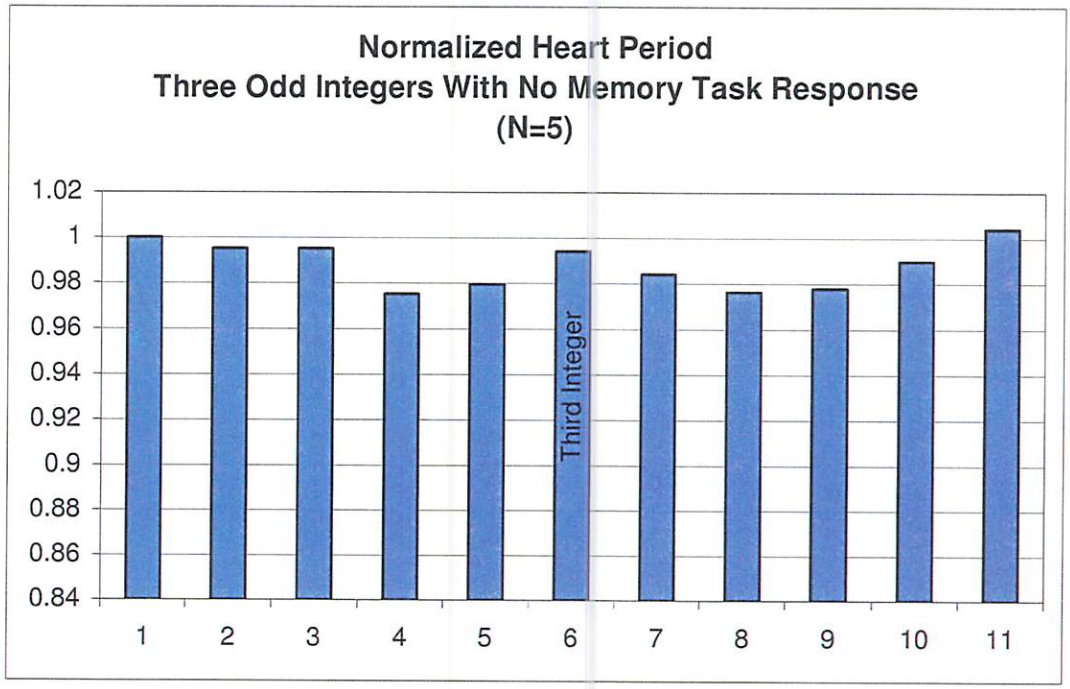
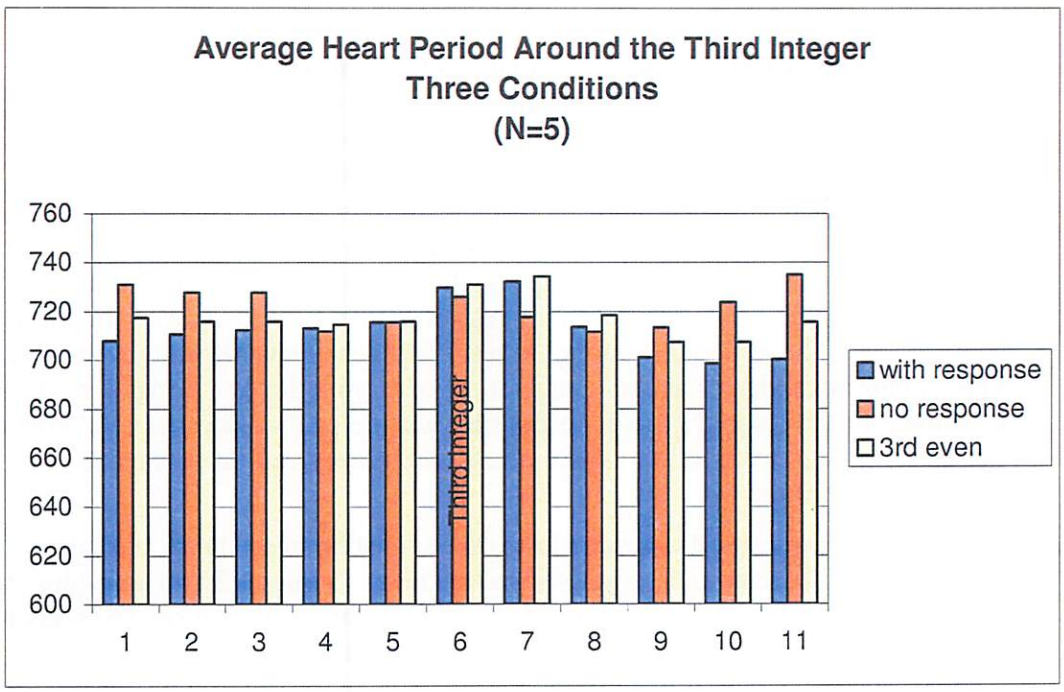


Figure 3: Raw and normalized heart period for 3 odd integers with no memory task response



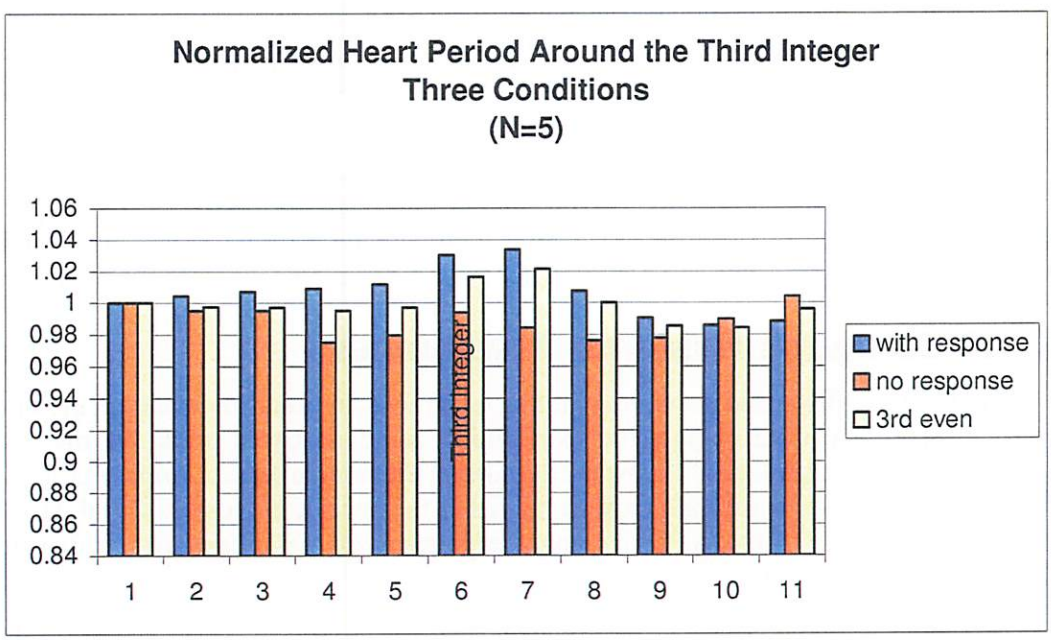


Figure 4: Raw and normalized heart period for all three conditions described

12.2 Discussion

Previous research (Lacey, 1974; Jennings, 1992; van der Molen, 2000; Somsen, 2004) using principally fixed foreperiod reaction time tasks demonstrated that in response to visual stimuli and anticipation the heart rate of a subject will slow. The studies show that the anticipation response is greatest when stimulus onset is predictable. It is attenuated in conditions where timing of stimulus presentation is not predictable, as was the case in our study. Our data support the contention that the effect is still present when stimulus timing is not predictable. We show that when subjects are correctly anticipating (the correct response condition, and the no third odd integer condition) heart rate slows in response to the third integer. In the condition where subjects should be responding but fail to respond, such cardiac slowing is not present. Our results thus demonstrate that it is the anticipation of a stimulus requiring a response and not the enactment of the response that is responsible for the cardiac deceleration. When anticipation is not present, i.e., the condition where a response is required but not made, the cardiac slowing does not materialize.

This slowing is presumed to be due to vagal stimulation of the heart, this supposition has in turn been supported by empirical physiological evidence (Somsen, 2004). Previous studies by Lacey (1974, 1977, 1978) and a review of this and other studies by Somsen (2004) demonstrate that a visual stimulus can affect the inter-beat interval (IBI) if it is presented early enough in the interval, or the interval directly following it if it is presented in the later part of the IBI. In the present study, no attempt was made to have stimulus presentation coincide with a particular phase of the cardiac cycle. The wider distribution of heart period increase found in associated with anticipation may reflect the fact that the imperative stimulus was presented at random phases in the cardiac cycle.

Since our LDV technology in combination with EKG will allow us to fractionate the cardiac cycle into three components (pre-ejection period; ejection period; recovery period) we will be able to determine whether all components of the cardiac cycle are equally affected by "anticipation" or, as we suspect, the effect will discriminate between the three components.

13 Computer Systems Development

As has been discussed previously in this document, in order to develop a system for monitoring the attentional state of operators performing computer-based tasks, we must identify the bio-behavioral measures that can be used to detect attentional lapses. Additionally, we must develop the computer software and hardware to gather the necessary bio-behavioral data, locate events of significance in that data, and recognize patterns of significant events that are indicative of momentary attentional lapses.

For such a system to be at all practical, it must be able to perform these functions and give feedback about an operator's attentional state in real-time. For our current purposes "real-time" means feedback within a few seconds (or less) of when an attentional lapse occurs. During this phase of the project, the focus of the computer systems development effort has been on assessing

the feasibility of putting together the hardware and developing the software to perform attention monitoring in real-time.

In our project proposal, we identified the following subsystems that would be necessary for the creation of a real-time attention monitoring system: a Console Operator's Subsystem, an Eye Monitoring Subsystem, a Vibrometry Subsystem, a Pressure Monitoring Subsystem, a Data Gathering Subsystem, and lastly an Attentiveness Monitoring Subsystem. The following sections briefly review the function of each subsystem and describe the progress made in each area.

Console Operator's Subsystem

This subsystem is the computer that the operator is "using" (i.e. the computer that is presenting task-relevant information to the operator and with which the operator is interacting via mouse, keyboard, etc.) To make our attention monitoring system as widely applicable as possible, we do not wish to require the operator to use a specialized computer. Instead, we would like to be able to instrument whatever computer is normally used by the operator for the task being monitored.

As has been described above, in this phase we created a prototype version of a mouse that could be used to gather pressure data in addition to providing us with the standard set of mouse clicks. While there were some problems with getting consistent data from the mouse pressure sensors, we believe that we have a good handle on what caused these problems. Most importantly, our prototype pressure sensitive mouse has proven the feasibility of gathering pressure data during a task using a modified version of a standard mouse.

Eye Monitoring Subsystem

This subsystem receives input from the eye monitoring cameras and converts captured images into eye position, gaze location, and pupil diameter information.

We have successfully modified a commercially available eye monitoring system (the Eyegaze System mentioned previously) to provide us the relevant measures in a form that can be integrated with our other data (response information, pressure information, cardiac information, etc.)

The primary remaining problem to be solved for this subsystem is keeping the eye-monitoring camera focused on the eyes as the operator moves naturally and freely about while performing the task. As is mentioned above, we have initiated a relationship with investigators from the Washington University School of Engineering to solve this problem. Those investigators have currently demonstrable ability to track head position within an image and locate a subject's eyes in a single plane using standard camera equipment.

Once again, this has proven the feasibility of gathering oculometric data in a "natural" setting for the operator and using that data in an attention monitoring system.

Vibrometry Subsystem

This subsystem controls the LDV device and provides a steady stream of vibration information from the location on the subject's body at which the laser is focused.

During this phase we have successfully gathered LDV data from the carotid artery of subjects in our task, and that data has been integrated with our other available measures. We have successfully used this data to derive a number of cardiac measures.

The primary issue to be resolved with the use of the LDV is the same as the primary issue for the eye-monitoring camera: namely keeping the device correctly aimed as the operator moves freely. The same techniques discussed above for aiming the eye-monitoring camera will also be used to aim the LDV device. Therefore, we have found that it is quite feasible to gather and use this data in an attention monitoring system.

Pressure Monitoring Subsystem

This subsystem was intended to gather data from a set of pressure monitors and abstract relevant information. In this phase, we sent pressure data from our prototype mouse pressure devices directly to our data collection subsystem. This worked well, and it is expected that a separate subsystem for pressure monitoring will not be necessary.

Data Gathering Subsystem

This subsystem gathers signals from all the previously mentioned subsystems and combines the data into one set of time-synchronized channels of data. Such a system needs to be able to store data in long-term storage (e.g. on a computer hard drive) and simultaneously make the data available to the Attentiveness Monitoring Subsystem.

In this phase we investigated various off-the-shelf data acquisition systems and found a high quality one that will allow us to store the gathered channels of data, display some or all of the channels as they are being gathered, and simultaneously make that data available to the Attentiveness Monitoring Subsystem[6]. The availability of such a data acquisition system is significant in that it will lower the overall development cost for an attention monitoring system by eliminating the need to write data digitization, data storage, and data display software "in house".

This confirms the feasibility of creating such a subsystem for our attention monitoring system.

Attentiveness Monitoring Subsystem

This subsystem receives information for the Data Gathering Subsystem and monitors data across channels to locate significant events and detect patterns in the bio-behavioral signals that indicate periods of low attentiveness.

This is the subsystem that requires the most software development. As is described in our original proposal, we intend to develop the software for this subsystem as a framework that can

[6] DI-720 Series hardware using WinDaq/Pro software from Dataq Instruments, Akron, OH on a standard PC.

be adapted to various bio-behavioral signals that are available and to various algorithms designed to use those bio-behavioral measures to detect lapses in attention.

During this phase, our work on this software has progressed along three interrelated areas. First, software was developed in support of the analyses mentioned earlier in this paper; second, work was done directly on the design and development of the attentiveness monitoring framework; third a prototype application was created from the framework. We will outline the progress made in each of these areas.

A number of different pieces of software were developed in support of the current analyses. One example involves the automatic detection of response events in channels of data, differentiation between simple reaction time responses and memory task responses, association of a response with the stimulus event which evoked the response, and calculation of various response parameters like latency and duration. This work was done for the present analyses, but was specifically designed and implemented to fit into the attentiveness monitoring framework so that similar detection, association, and calculation can be included in a real-time attention monitoring application. Similar work was done for other event types such as saccadic eye movements.

Design and development work was also done on the framework proper. Software that implements a standardized algorithm for receiving channels of data in a reconfigurable way and applying pluggable and interchangeable event detection algorithms like those discussed in the previous paragraph was implemented in this phase. Work on the design of pluggable and interchangeable pattern recognition algorithms for recognizing patterns of events that indicate possible lapses in attention was begun in this phase also.[7]

The framework was used during this phase to create a prototype application which simulated the receiving of real-time data from the Data Gathering Subsystem and applied an event detection algorithm to that data for detection of saccadic eye movements and computation of various parameters of the saccadic eye movements (e.g. duration, velocity, peak velocity, etc.) The prototype application served as a proof of concept that we can receive and process such data in real-time without losing data points and provided the appropriate venue for developing software for such a system to monitor itself to ensure that real-time data is not being lost as processing of previously received data is occurring. Most importantly, this proved the feasibility of creating an Attentiveness Monitoring Subsystem that can provide results in real-time and is based on an Attentiveness Monitoring Framework.

[7] One example of such an algorithm based on the current work would be one which recognizes relatively rapid pupil dilation associated with responding as a possible sign that the making of a response has had an alerting effect upon the operator. Thus indicating that the operator was perhaps not quite as alert as required prior to making the response.

14 Project Summary

We are developing a methodology to monitor operators performing computer-based tasks. Most such tasks involve the monitoring of equipment that is highly reliable and requires little intervention on the part of the operator, in other words a "vigilance task". Man's ability to perform such tasks degrades rapidly, especially under conditions of physical or mental "fatigue". The degradation is manifested by periods of lowered alertness lasting for fractions of a second to seconds. Our focus is on the development of non-obtrusive procedures to identify such periods. Three sensing methods are involved, namely video technology to capture oculomotor activity, Laser Doppler Vibrometry to, in the present instance, capture cardiovascular signals, and instrumentation of the mouse to more sensitively capture fine motor activity on the part of the operator. We believe that these measures can provide the necessary procedures for the on-line monitoring of attentional lapses. We propose to develop the software necessary for such on-line analysis with the intention of rapid transition from the laboratory to real-world environments in which maintenance of alertness is of paramount importance.

The phase I effort involved the development of a task (modeled on the Psychomotor Vigilance Task) in which lapses of alertness can be monitored. We have instrumented a mouse with pressure sensors to capture manual responses of interest. We also developing the software required to process relevant data. Lapses in alertness in the laboratory task are reflected in:

a. Missed signals
b. False alarms
c. Delayed responses
d. Responses in the absence of stimuli requiring a response.

The metric of bio-behavioral measures associated with such lapses includes the following oculometric measures:

a. Periods of eyelid closures, especially slow closures
b. Delayed or slowed gaze shifts to target location
c. Gaze shifts independent of target presentation
d. Wrong direction gaze shifts, and multiple saccades
e. Head movements associated with gaze shift to target location
f. Temporal patterning of blinks, eye movements and head movements
g. Pupil diameter changes, both tonic and phasic.

For Laser-Doppler Vibrometry based cardiovascular measures:

a. Changes in heart rate variability
b. Alterations within the cardiac cycle, i.e., time associated with pre-ejection period, ejection period, and recovery
c. Respiratory activity
d. Speech activity.

For behavioral measures:

a. Response initiation
b. Response completion
c. Partial responses.

These measures will be used both independently and jointly. By joint measurement we mean, for example, the timing of behavioral and oculomotor responses – are there changes in the temporal pattern of joint occurrence of these two events?; the timing of eye blinks and gaze shift – the occurrence of blinks independent of gaze shifts signals a less efficient strategy than when the two occur concurrently; the occurrence of "overflow" movements in the behavioral measure.

Should phase II or other funds become available, we propose to conduct a series of laboratory investigations under "ideal" conditions, i.e. conditions where subjects are well rested and highly motivated, and in collaboration with the Laboratory at Brooks A.F.B. evaluate subjects who have been sleep deprived and are performing an AWACS simulation task. The specifics of which of the three ASACS directors (sweep, strike, intelligence) will be studied will evolve from discussions upon award of additional funding.

15 References

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