THE DEVELOPMENT AND VALIDATION OF ALGORITHMS FOR THE DETECTION OF DRIVER DROWSINESS

by

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(ABSTRACT)

This study was undertaken to determine which variables and combination of variables could be used for the prediction of on-the-road drowsiness. Numerous driver-vehicle performance measures and secondary task performance measures were collected so that the predictability of several definitional measures of drowsiness could be tested. Twelve volunteer subjects were employed in the algorithm development phase of this study. All subjects were from the driver population in the Blacksburg, Virginia area. The participants were sleep deprived and drove a moving base simulator late at night in order to increase the likelihood that they would experience drowsiness while driving. After completion of data collection, numerous algorithms were developed using multiple regression and discriminant analysis methods. Another twelve volunteer subjects were subsequently employed in the algorithm validation phase of this study. Similar physiological and driving performance measures were collected during both phases of the study. All subjects were from the same driver population. All subjects were run under similar conditions as those in the algorithm development phase. Algorithms that appeared promising which were developed in the first phase of study were validated by applying them to the new data in an attempt to predict drowsiness on a new subject pool. It was

found that drowsiness could be detected on a new subject pool and that the rate of correct predictions was quite high. There was no general decrease in predictive power of the drowsiness detection algorithms when applied to new data. Results showed that an accuracy rate of over 90 percent could be accomplished when output from the detection algorithms were classified into categories of "Awake," "Questionable," and "Drowsy."

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INTRODUCTION

Extent of Drowsiness on the Road

One of the leading causes of single- and multiple-car accidents is driver impairment due to drowsiness (Office of Crash Avoidance Research, 1991). Unfortunately, drowsiness while driving may be perceived as less of a problem than it actually is because of the difficulty of attributing drowsiness as a cause of an accident. However, as more research is being conducted concerning drowsy drivers, it is becoming indisputable that a major problem does exist. Also, there may be many more incidents in which the initial cause of the loss of control of a vehicle is drowsiness yet is reported to be caused by something other than drowsiness.

A study conducted in 1973 at Duke University by Tilley, Erwin, and Gianturco provides evidence that drowsiness while driving is an all too common occurrence. In this study two experimenters, stationed in the Durham, North Carolina Department of Motor Vehicles, administered questionnaires pertaining to driving habits and behaviors to 1500 individuals who were successful in renewing their driver's license. Of those 1500 people, 64% responded that they had, at one time or another, become drowsy while driving. Also, over 7% responded that they had gone to sleep for short periods while driving. Of those who answered that they had had trouble with drowsiness while driving, 31.2% responded that they had become drowsy before they were aware of their condition. Of those who did experience drowsiness while driving, approximately 10% reported that they had been in one or more accidents due to drowsiness or falling asleep at the wheel. Another 10% responded that they had been in a near accident due to drowsiness.

A survey completed in 1980 by the Kanagawa Prefectural Police, based on questionnaires collected near the Tokyo-Nagoya Expressway, shows that approximately

75% of the drivers admitted to being sleepy while driving (Seko, 1984). Unfortunately, Seko does not give an indication in his article concerning the extent of the drowsiness experienced by the polled drivers. Seko also cites a survey of the causes of accidents on the Tokyo-Nagoya Expressway since 1969. He found that most of the rear-end collisions at night were attributable to drowsiness. A survey cited by Seko (1984) which was carried out by the Shizuoko Prefectural Police states that in 1973 nine percent of all traffic accidents were caused by drowsiness, but 45% of all traffic deaths were due to drowsiness. This indicates that drowsiness is related to serious automobile accidents. Planque, Chaput, Petit, Tarriere, and Chabanon (1991) report that fatigue is the cause of 26% of the fatal accidents occurring on the highways in France.

In 1991 a summary of crash statistics was compiled by the Human Factors and Heavy Vehicle Research Division of the Office of Crash Avoidance Research (OCAR). OCAR is a group within the National Highway Traffic Safety Administration (NHTSA). A summary of the OCAR findings is as follows:

- Annually, there are 72,000 police-reported crashes in which driver fatigue/drowsiness is cited (1.1 percent of all crashes).
- 14,000 accidents involving drowsy drivers result in serious injuries (2.9 percent of all serious injuries).
- There are 1,550 fatalities due to driver drowsiness (3.4 percent of all fatalities).
- Due to under reporting, actual involvement of driver fatigue/drowsiness is probably much greater.

Statistics on crash characteristics directly and indirectly related to drowsiness/impairment are as follows:

- Crashes peak between midnight and dawn, with a second smaller peak between 3 p.m. and 5 p.m. Over 40 percent of crashes occur between 1 a.m. and 7 a.m. The rate is lowest between 9 a.m. and noon. Time distribution is similar for fatal crashes.

- Approximately 70 percent of crashes occur in non-urban areas.
- The principal first harmful events are as follows:
    1. Rollover: 7 percent
    2. Collision with another motor vehicle in transport: 17 percent
    3. Collision with parked vehicle: 6 percent
    4. Collision with fixed objects (signposts, guardrails, culverts, trees, etc.): 64 percent
- Most crashes occur on non-divided roadways.
- Most crashes occur on roadways with 55-65 mph speed limits.

REVIEW OF DROWSINESS LITERATURE

Previous Studies

A study conducted in 1984 by Skipper, Wierwille, and Hardee found results that indicated that it was possible to detect the onset of driver drowsiness by observing drivers' reactions to steering wheel torque and front wheel disturbances produced by the automobile simulator. However, while subjects were involved in a normal driving scenario the experimenters found that it was also possible to predict the onset of drowsiness. Several variables were examined, but eyelid closure was the most consequential.

Dingus, Hardee, and Wierwille (1985) performed a study that examined the effects of drowsiness on driver performance. Dingus, et al. employed both sleep deprived subjects and a control group consisting of the same subjects in a rested condition. The sleep-deprived runs took place from 2:00 a.m. to 3:30 a.m. The initial analyses of the collected data were correlation analyses between the eyelid closure measures and lane position measures. The lane position measures were indicators of driver impairment while the eyelid closure measures were indicators of drowsiness. Eyelid closure was recommended by Erwin (1976) since it has been found that eyelid closure is a very stable physiological indicator of drowsiness. It was found that a relatively high correlation between eyelid and lane position measures was present, as seen in Table 1.

Dingus et al. (1985) ran a second set of correlation analyses between the indicators of driver impairment, which included eyelid closure and lane position measures, and other measures. Dingus et al. state that any measure that demonstrated reasonably consistent correlations across the impairment indicators of approximately 0.25 or greater was considered promising. The potentially reliable impairment detectors based on correlation analyses run by Dingus et al. concerning drowsiness can be seen in Table 2. Table 3 shows drowsiness impairment indicators and

Table 1: Eye measure vs. lane measure correlations. (From Dingus, Hardee and Wierwille, 1985)

	EYEMEAN	EYEMEAS	PERCLOS
LANEX	.47	.54	.62
LANEDEVV	.50	.55	.60
LANEDEVSQ	.55	.59	.60
LANEDEV4	.36	.40	.40

- EYEMEAN: Mean eyelid closure (zero = wide open)
- EYEMEAS: The mean-square of the eyelid closure signal.
- PERCLOS: Percentage of time that the eyes are 80% to 100% closed.
- LANEX: Count of the number of samples taken while the simulated vehicle was out of the lane.
- LANEDEVV: Lane position variance.
- LANEDEVSQ: Weighted lane deviation. Heavier weighting away from the center of the lane by a squared function.
- LANEDEV4: Heavily weighted lane deviation. Heavier weighting away from the center of the lane by a fourth power function.

Table 2: Impairment Detectors Based on Correlation Analysis (From Dingus, Hardee and Wierwille, 1985)

YAWVAR
STEXEED
STVELVAR
LGREV
SEATMOV
HRTRTM
HRTRTV

- YAWVAR: Yaw deviation variance.
- STEXEED: Count of steering velocity occurrences over 150 degrees per second.
- STVELVAR: Steering velocity variance.
- LGREV: The number of times the steering wheel position increment exceeds 5 degrees (after steering wheel velocity passed through zero).
- SEATMOV: Seat movement counter.
- HRTRTM: Heart rate mean.
- HRTRTV: Heart rate variance.

Table 3: Drowsiness Impairment Discriminant Analysis. Six-Minute Interval Data -- Best Results.

		Predicted: Impaired	Predicted: Not Impaired	Total
Actual	Impaired	20	8 (28.57%)	28
	Not Impaired	4 (2.63%)	148	152
		24	156	180

APER = 6.7%

Model Variables:

YAWVAR	.7692
SEATMOV	.6218
LANDEVSQ	.4152
YAWMEAN	.2460
STEXEED	-.0292

associated confusion matrix for six-minute interval data from the Dingus et al. study. The six-minute interval data were found to provide slightly better discrimination of drowsiness-induced impairment.

It was found through stepwise discriminant analyses that YAWMEAN, YAWVAR, STEXEED, SEATMOV, and LANDEVSQ contained significant independent detection information. By employing eyelid closure as a definition of drowsiness it was possible for Dingus et al. to create several models of driver impairment based upon driving performance. This was an important development since the performance measures could be unobtrusively implemented using an in-car drowsiness detection system. Performance measures will be discussed in more detail in the *Driving Performance Measures* section of this proposal.

In the study conducted by Dingus, Hardee, and Wierwille (1985) EYEMEAS, as seen in Figure 1, seems to be affected by degree of sleep deprivation as well as time on task. Each segment seen in Figure 1 consists of a 30-minute interval. However, when compared to EYEMEAS data found in the Hardee, Dingus, and Wierwille (1985) study as seen in Figure 2, it becomes apparent that time on task may be as important as degree of sleep deprivation. In Figure 3 a comparison of the EYEMEAS data from both studies with starting times aligned is presented.

Stages of Sleep

To understand the terminology concerning drowsiness and sleep a discussion of the stages of wakefulness will be presented. An understanding of the various stages of sleep is important when carrying out studies that examine the physiology, psychology, or behavior of sleep deprived subjects. It should be noted however, that while driving an automobile, a person will most likely be at one of two stages of wakefulness -- either stage W or stage 1 sleep. Below is a summary explanation of the various stages of sleep. The descriptions of the stages is taken, in part, from Carskadon (1980).

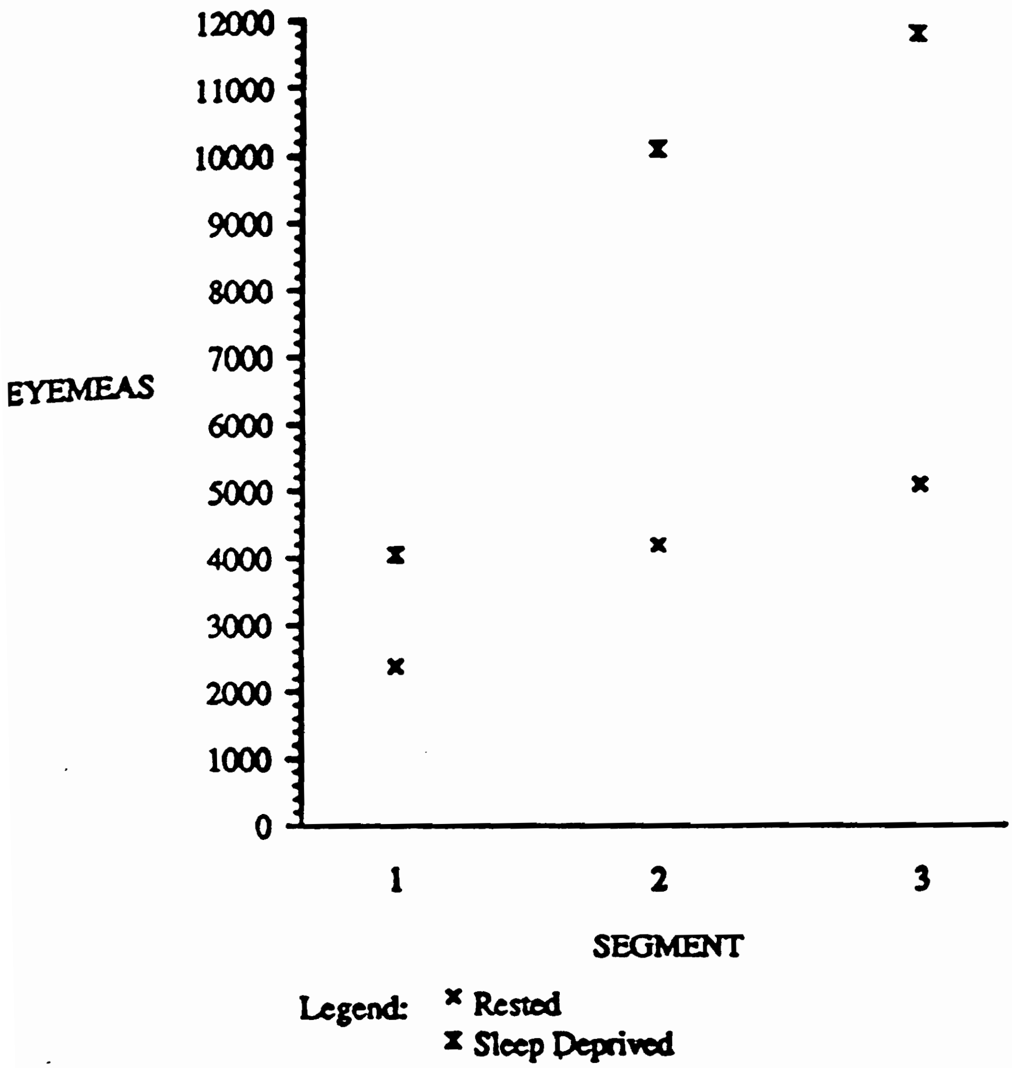


Figure 1: EYEMEAS Means vs. Driving Segment Plotted by Sleep Level.

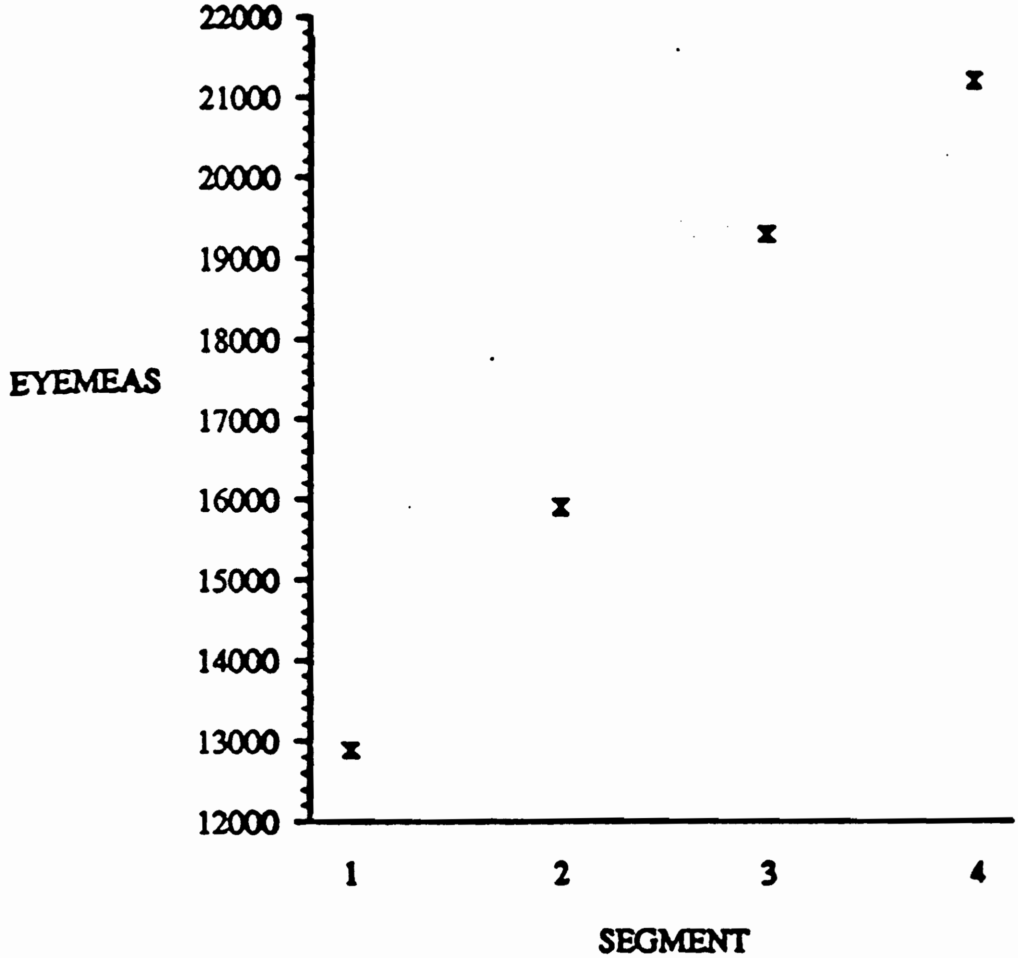


Figure 2: EYEMEAS Means vs. Driving Segment.

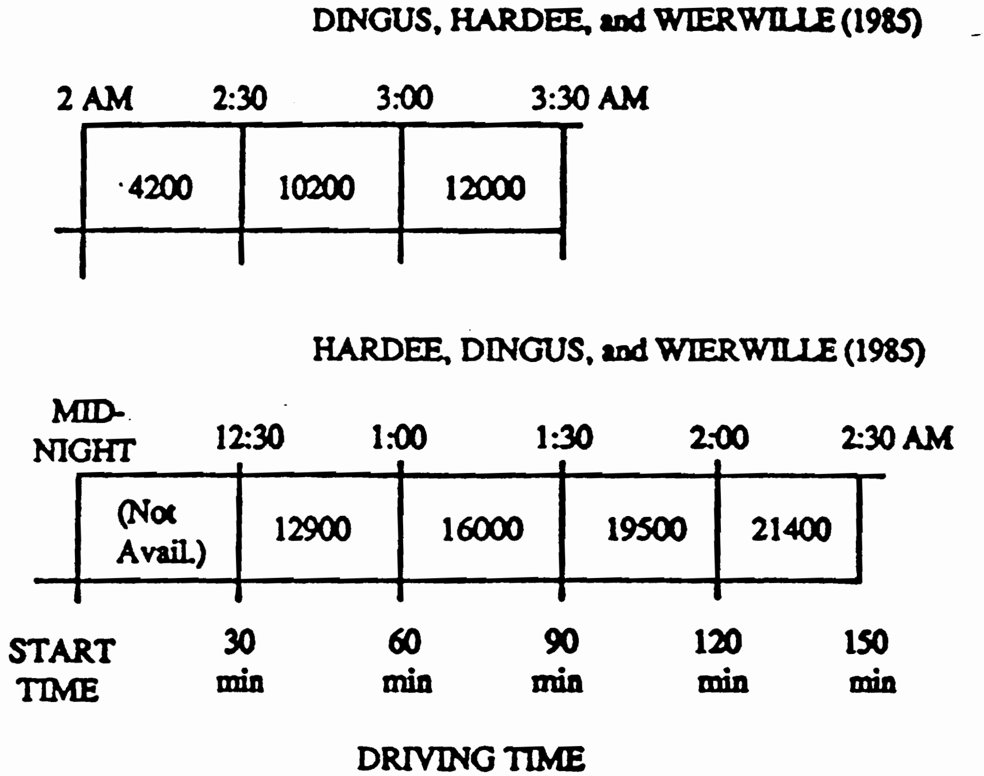


Figure 3: Comparison of EYEMEAS Values for Two Experiments with Start-Times Aligned.

- Stage W sleep. Stage W does not actually describe a sleep state but rather a state of wakefulness. This stage is usually accompanied by a relatively high tonic EMG. Rapid eye movements and eye blinks are present in this stage.

- Stage 1 sleep. This is the stage that intervenes between wakefulness and other sleep stages. In most subjects, the duration of stage 1 sleep usually is not longer than several minutes. Stage 1 sleep may occur after large movements of the body which are caused by the relaxation of the muscles in the body of a person entering this stage of wakefulness. Stage 1 sleep following wakefulness is often accompanied by slow eye movements. Each slow eye movement may be several seconds in duration. Rapid eye movements are absent at this stage. Tonic EMG levels are commonly below EMG signals of individuals in a relaxed but wakeful state.

- Stage 2 sleep. No eye movements are usually seen in stage 2 sleep. Stage 2 sleep can last as long as one hour and become interspersed with periods of REM sleep.

- Stage 3 sleep. Stage 3 sleep is a transitional stage between stage 2 and stage 4 sleep early in the night. Sometimes stage 3 sleep will not be followed by stage 4 if it occurs in the NREM portion of the sleep cycle.

- Stage 4 sleep. Stage 4 sleep usually occurs during the first third of the night. This stage is characterized by a predominance of high amplitude slow brain waves.

- REM sleep. This stage usually occurs within the first 100 minutes after sleep onset. REM sleep is characterized by low voltage, mixed frequency EEG, bursts of rapid eye movement (REM) and low amplitude EMG.

Promising Physiological Measures Found in the Literature

The purpose of this section is to discuss measures that may lead to a more refined, operational definition of drowsiness and the onset of stage 1 sleep or drowsiness. A review of the sleep and drowsiness literature has been conducted and the most likely measures to be successfully employed in the refinement of the operational definition of drowsiness, that may eventually aid in the detection of the onset of drowsiness in various applications, are discussed below.

Eyelid closure. Eyelid closure has been found to be a very reliable predictor of the onset of sleep (Erwin, 1976) and degraded task performance (Dingus, Hardee, and Wierwille, 1985; Hardee, Dingus, and Wierwille, 1985; Skipper, Wierwille, and Hardee, 1984). Erwin examined various measures to determine whether they were predictive of sleep onset, including plethysmography, respiration rate, electroencephalography (EEG), skin electrical characteristics, electromyography (EMG), heart rate variability, and eyelid closure. It was found that eyelid closure was the most reliable predictor of the onset of sleep among the measures examined. Eyelid closure is indicative of sleep onset and undoubtedly the cause of poor performance in visual tasks, especially tracking tasks such as driving. It seems quite obvious that if a driver's eyelids are closed, the ability to operate a vehicle would be greatly hampered.

Skipper, Wierwille, and Hardee (1984) examined the ability of sleep deprived drivers to perform a one and one half hour driving task. Various disturbances were purposely input into the steering system of the driving simulator to mimic on-the-road conditions. It was found that performance measures such as lane deviation, yaw deviation, and steering velocity were highly correlated with eyelid closures.

The apparatus used to capture eyelid closures in the Dingus et al, Hardee et al., and Skipper et al. studies was a low-light level camera. A linear potentiometer was used by an experimenter to track the eyelid movement of the subjects manually.

Eye movement. There are two general reasons that one may desire to record eye movements during sleep or before sleep. First, a principal sign of REM sleep is the phasic burst of rapid eye movements. Second, the onset of sleep in most subjects is heralded by or accompanied by slow, rolling eye movements (Carskadon, 1980).

Slow, rolling eye movements may accompany the onset of sleep or are precursors of sleep onset. This phenomenon also occurs with the transition to stage 1 sleep during the night. The characteristics of human eye movements change greatly with alertness level. Slow eye movements (SEMs) prove to be one of the most characteristic signs of the phase of transition between wakefulness and sleep (Planque, Chaput, Petit, and Tarriere, 1991). Dement (1975) states that the SEM event is a crucial occurrence in the sleep onset process.

Slow, lateral eye movements are quite different than eye movements typically seen in a person who is fully awake. A completely awake individual can be observed as having quick eye movements. As subjects become drowsy their eyes move in a pendular motion from left to right (Hiroshige, and Niyata, 1990) and the number of quick, voluntary movements of the eyes begins to lessen. Endo, Inomata, and Sugiyama (1978) found that attentiveness begins to disappear in conjunction with drowsiness due to the lessened number of lateral voluntary eye movements that would normally be used in a driving situation to check the rear view mirrors, side windows, etc. In other words, as alertness decreases, attentiveness also decreases. Numerous SEMs are detected during stage 1 sleep, but they also appear during the long period separating waking from sleep (Hiroshige, and Niyata, 1990). Torsvall et al. (1988) noted that the proportion of SEMs increased sharply with the advent of drowsiness on train drivers making long trips. Convergence of the eyes is also possible when a person becomes drowsy.

Electrooculography (EOG) involves the measuring of eye movements via electrodes in contact with the skin surrounding the eyes. The process of measuring eye movements with EOG is quite simple due to the electrical nature of the human body. In the eyeball, there is a small electropotential difference from the front to the back. The front (cornea) of the eye is positive with respect to the back (retina) of the eye.

Before a certain point in a person's awake but drowsy state, SEMs do not exist. However, after a particular moment in the onset of sleep, slow, rolling, lateral, ocular movements create sinusoidal activity in the EOG (Dement, 1975). On the EOG signal, the SEMs are translated by slow deflections lasting more than a second. It is likely that amplitudes of at least 100 microvolts will be seen (Torsvall and Akerstedt, 1988). The EOG waves that are normally observed are moderate in amplitude initially, but increase with the degree of drowsiness (Santamaria and Chiappa, 1987).

Planque et al. (1991) found that after several minutes of driving only blinking and glances at simulator instrumentation were recorded. Approximately 30 minutes into the study deterioration of deliberate eye movement was seen. Planque et al. state that by analyzing the EOG, it is possible to follow clearly the deterioration of alertness.

Muscle activity. Sleep onset may be accompanied by the reduction of muscle activity, or muscle tonicity, especially in the facial muscles. However, Erwin (1976) states that measures of muscle activity offer essentially no predictive information pertaining to sleep onset and that significant sleep can occur for several minutes prior to any significant change in muscle tone. Unfortunately, it is not clear as to which muscle groups he examined.

A study conducted by Yabuta, Iizuka, Yanagishima, Kataoka, and Seno (1985) demonstrates that facial expression is effected by drowsiness. Yabuta et al. state that special attention was focused on subjects' facial expression, among other physiological measures, because facial expression is known to vary according to the alertness level of the subject. Observing the muscle activity which causes the changes in facial expression with drowsiness is one method of quantifying this measure.

Electromyography (EMG) is a common method used for recording muscle activity. Often times, EMGs are used to evaluate various sleep and muscle disorders. EMG measures of facial muscles may be an efficient method of quantifying facial expression, or more specifically, facial muscle tone.

Hauri (1982) demonstrates that EMG recorded on the chin steadily, though not dramatically, decrease as a person nears stage 1 sleep. Even when a subject is totally relaxed, small muscle potentials will be seen (Carskadon, 1980). This is due to the fact that every muscle is composed of many contractile fibers that are innervated by nerves. When a muscle fiber is activated through nerve innervation, a change in the electrical potential is seen. When the muscle is relaxed, fewer nerves discharge, thus a smaller EMG potential is recorded.

Brain wave activity. Sleep produces distinctive alterations in the amplitude and frequency of the signals from the brain. Erwin (1976) states that there is no reliable alteration in background brain activity prior to eyelid closure. Upon eyelid closure Erwin found that a very rapid shift in brain wave patterns takes place. This shift is identifiable as stage 1 sleep. However, Planque et al. (1991) states that sharp changes in the frequency content of brain wave activity are observed during the crossing from alertness to a stage of hypoalertness, then to drowsiness, and finally to sleep. A slowdown of the cerebral activity, in general, an increase in the percentage of alpha waves and, in turn, a decrease in the percentage of beta waves, is observed at the same time that a decline in performance is seen. Seko (1984) reports that alpha waves appear during decreased alertness such as absentmindedness or "cloudy consciousness." Seko cites the work of Kuroki, Kitakawa, and Oe (1974) wherein alpha waves were hardly detected at the beginning of a driving session but as the driving session continued and the level of driver/subject alertness decreased, high-amplitude alpha waves occurred frequently. Planque et al. (1991) suggest that analysis of the beta, alpha, and theta frequencies are the most appropriate for examining/detecting the onset of sleep.

Planque et al. state that automatic processing of the EEG signal has proved very difficult to implement. Presently, various phases of sleep (stage 1, stage 2, REM, etc.) are identifiable via automated methods, however an examination of drowsiness and sleep onset is distinguished by much less distinctive physiological events. Therefore, Planque et al. suggest the manual method for analysis of EEG as well as EOG which was discussed previously.

Skin potential level. The SPL measures the potential difference between the outermost layer of skin (stratum corneum) and the layer immediately below it (stratum lucidum). In a study by Erwin, Hartwell, Volow, and Alberti (1976) it was found that a correlation exists between changes in skin potential level (SPL) and stages of arousal. In all cases, EEG-defined sleep occurred only after a shift in skin potential level (Erwin et al., 1976). It was also found that significant shifts in skin potential level preceded not only stage 1 sleep but also the transition that occurs prior to stage 1 sleep. In the several minutes following the SPL shift, subjects oftentimes became drowsy as evidenced by decreased performance, frequent eyelid closures of more than one second, and occasionally, EEG manifestations of sleep (Erwin, 1976). Although decreased skin potential negativity was shown to be a prerequisite of sleep onset, decreased potential values preceding sleep onset varied in lengths of time. This fact may indicate that SPL is by no means the only deterministic factor of arousal level (Erwin et al., 1976).

Erwin et al. (1976) discounted the hypothesis that electrodermal shifts are simply a function of time from initial arousal. This was done by observing that spontaneous and evoked EEG arousal was accompanied by a return to waking skin potential levels.

Some obstacles do exist, however, when it comes to applying SPL as a measure of drowsiness. First, recordings of some subjects may give indications of shift changes in SPL without showing drowsy behavior or sleep onset and with no performance decrements seen. As stated earlier, in all cases, EEG-defined sleep occurred only after a shift in skin potential level. From this, it can be hypothesized that SPL shifts must occur for a person to drift into sleep although a shift in SPL is not always followed by sleep onset. Second, there is a considerable variation in baseline values of SPL. This variation can be seen between and within subjects. SPL is susceptible to alterations in subjects' mood, activity level, and temperature.

Heart rate variability. Heart beat interval variability has been found to correlate with drivers' fatigue level (Wierwille and Muto, 1981). As cited in the literature by Wierwille et al., (1981) Sugarman and Cozad (1972) and Riemersma, Sanders, Widervanck, and Gaillard (1977) found even greater amounts of variability in heart rate with fatigue. On the other hand, Volow and Erwin (1973) found no correlation between heart rate variability and sleep onset. However, Volow states that in real (or simulated) driving situations there may be sufficient motoric demands on the driver such that the interaction of driving activity may produce significant variations.

Pupil aperture size variability. The pupil serves as a window into central nervous system activity. Spontaneous pupillary movement in darkness in the normal awake individual has been described as reflecting "tiredness," "fatigue," and "sleepiness" (Lowenstein and Loewenfeld, 1963; Lowenstein and Loewenfeld, 1964). The state of the autonomic nervous system has been thought to reflect fatigue and wakefulness for quite some time. For instance, over 200 years ago, pupillary constriction was believed to be associated with sleep (Fontana, 1765). Marked changes in pupillary stability and extent of oscillations have been consistently shown to occur in normal "tired" subjects (Lowenstein and Loewenfeld, 1951; Lowenstein and Loewenfeld, 1963; Lowenstein and Loewenfeld, 1964). Pupillary behavior in individuals suggests that the actions of the pupil do reflect autonomic events and that it is consequently an indirect but accurate indicator of sleepiness or arousal level.

Secondary Task Measures

A study was conducted by Hardee, Dingus, and Wierwille (1985) which employed secondary tasks in a simulator study using sleep deprived subjects. This experiment was run starting at 12:00 am instead of 2:00 am as in the Dingus, Hardee, and Wierwille (1985) study. Hardee et al. found that auditory or visual secondary tasks, along with heart rate variability, predicted quite well whether a subject was impaired or unimpaired due to drowsiness. However, it was found that secondary tasks did not keep the subjects from becoming drowsy.

Subjective Ratings

Observer ratings. Most of the studies that have been carried out rely on the subjective evaluation of drowsiness by the subjects themselves. One study that does investigate observer rating of drowsiness was carried out by Carroll, Blisewise, and Dement (1989). The results of this study show a high interrater reliability for observations of the sleep-wake cycle of 39 nursing home residents.

A study carried out recently by Wierwille and Ellsworth (1992) determined the accuracy and consistency of raters when judging different levels of drowsiness of sleep deprived subjects. In this study three main factors were examined including:

1. Intrarater reliability: To determine if the same rater assigns scores consistently.
2. Test-retest reliability: To determine if a rater will score similarly on the same measure at two different points in time.
3. Interrater reliability: To determine raters' ability to assign similar scores using the same instrument under the same conditions.

In the Wierwille and Ellsworth (1992) subjective rating study six raters were employed. Each rater/subject observed numerous videotaped segments of sleep deprived individuals who were at various levels of drowsiness. Each subject observed the same video tapes. The subjects were instructed to rate the video taped individuals by placing a vertical mark across a horizontally oriented continuous-graphical scale. The graphical scale was then graded by an experimenter and a numerical value ranging from zero to one-hundred was assigned to each mark.

Ellsworth et al. (1993) found that informed raters appear to rate consistently. A correlation analysis of intrarater reliability and test-retest reliability resulted in Pearson r values of 0.88 and 0.81 respectively. It was also found that interrater reliability was quite high with a Pearson r value of 0.81. This result demonstrates that raters tended to agree with each other when rating sleep deprived subjects.

Subject self-rating. Ellsworth, Wreggit and Wierwille (1993) used a continuous, rotational control for use in collecting data concerning subjects' own perception of their drowsiness level. Subjects were asked before the experiment began to rate themselves accordingly whenever they thought that their drowsiness level had changed. This measure was found to be highly correlated with eye closure measures.

A Preliminary Study

Various physiological measures were examined by Ellsworth, Wreggit, and Wierwille (1993) in an attempt to refine measures of drowsiness. The objective of the research by Ellsworth et al. was to investigate means to establish an operational definition of drowsiness and then to establish various definitions that could be used in other research in a consistent manner. It must be noted, however, that eye closure measures have been used with great success in the past (Dingus, Hardee, and Wierwille, 1985; Hardee, Dingus, and Wierwille, 1985; Skipper, Wierwille, and Hardee, 1984). Nevertheless, refinement of these measurements was thought necessary to further research in the area of drowsiness detection.

It was found that various physiological measures correlated quite highly with performance of mathematical and search tasks. The math problems were presented visually and included addition, subtraction, multiplication, and division of two numbers.

The search task consisted of a target letter that had to be detected among various distractor letters. The results of the letter tasks were found to be more consequential than the mathematical tasks. Ellsworth et al. (1993) state that this finding may be due to the fact that since the math tasks were more difficult in nature, some subjects may have made mistakes while still wide awake, thus minimizing the predictive value of the task. A global detection variable was created by employing the four variables examined by Ellsworth et al. which include response time to correct letter, response time to correct math, sum of letter errors, and sum of math errors.

Ellsworth et al. (1993) determined through the use of correlation analyses that various physiological variables appeared promising and that further analyses should be undertaken. Six-minute interval data were used for regression analyses since the correlation analyses showed that the six-minute interval data resulted in the highest correlations. These results are similar to those of earlier studies conducted by Dingus, Hardee, and Wierwille (1985) and Hardee, Dingus, and Wierwille (1985) in which it was found that six-minute intervals were better suited to detect driver impairment due to drowsiness than data taken from shorter intervals.

The six-minute interval data for each subject was pooled for multiple regression analyses. The purpose of these analyses was to determine which measures could be employed in future studies to reliably detect impairment due to drowsiness. Before final analyses using multiple regression techniques were carried out, all data were baselined and divided by the standard deviation of that data set. Baselining is simply a procedure in which the first several minutes (in this case, the first two six-minute segments) are averaged and then subtracted from the rest of the data. This procedure was employed so that the regression coefficients would emphasize changes in variables being examined.

After using a backwards stepwise-regression approach for the data analyses, an attempt was made to reduce the number of variables further while still retaining approximately the same R value. The final results of the study by Ellsworth, Wreggit, and Wierwille (1993) can be seen in Tables 4, 5, 6, 7 and 8.

The measures that were found to be most viable were incorporated into a definition of drowsiness due to their predictive or accompanying nature of sleep onset/drowsiness. These measures will assist in the refinement of sleep onset detection algorithms which can be used in the future for sleep detection measures with higher accuracy than is presently possible.

Driving Performance Measures as Indicators of Driver Drowsiness

Driving performance measures that can be used to predict the onset of drowsiness are important since it has been shown that sleep loss produces decrements in driving skills (Hulbert, 1972). Driving performance measures include lane-related measures, steering-related measures, and heading- and lateral acceleration-related measures. These measures

are obviously important since drivers must maintain proper lane position to avoid vehicles in nearby lanes and objects located on the side of the roadway. The purpose of this section is to discuss various measures used in the past to evaluate driver drowsiness while a subject is actually behind the wheel of an automobile (either simulated or on the road). Measures of performance have potential for driver impairment prediction and are, in some cases, relatively easy to install in an on-the-road vehicle. An overview of performance measures as indicators of driver drowsiness has been addressed by Wierwille, Wreggit, and Mitchell (1992) and will be presented, in summary, below.

Lane-related measures. Several studies have found lateral control measures to be closely related to prolonged driving. Dureman and Boden (1972) found that lane tracking ability degrades as time on task increases over a four-hour period. Several other researchers (Mast, Jones, and Heimstra, 1966; Sussman, Sugarman, and Knight, 1971) found similar results in that lane position errors increased over a four-hour period.

Table 4: Response Time to Correct Letter - Baseline Data - Reduced Set of Measures - Relative Weighting (Ellsworth, Wreggit, and Wierwille, 1993).

Regression Statistics	
Multiple R	0.805049
R Square	0.648104
Adjusted R Square	0.638529
Standard Error	0.601225
Observations	152

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	4	97.86377	24.46594	67.68439	2.23E-32
Residual	147	53.13623	0.361471		
Total	151	151			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.66629	0.058643	45.46658	5.2E-90	2.550398	2.782182
PERCLOSE	1.04249	0.077295	13.48714	1.04E-27	0.889737	1.195243
MNALPHA	-0.95694	0.081989	-11.6715	7.72E-23	-1.11897	-0.79491
MNTHETA	0.366761	0.082854	4.42658	1.83E-05	0.203022	0.530501
MNSQHRT	0.252605	0.055577	4.545109	1.12E-05	0.142772	0.362439

Table 5: Sum of Letter Errors - Baseline Data - Reduced Set of Measures - Relative Weighting (Ellsworth, Wreggit, and Wierwille, 1993).

Regression Statistics	
Multiple R	0.759315
R Square	0.57656
Adjusted R Square	0.567977
Standard Error	0.657285
Observations	152

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	3	87.06054	29.02018	67.17271	1.8E-27
Residual	148	63.93946	0.432023		
Total	151	151			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.005765	0.063093	0.091371	0.927319	-0.11891	0.130445
PERCLOSE	0.438903	0.075234	5.833865	3.18E-08	0.290232	0.587574
MNTHETA	0.509367	0.086005	5.922525	2.06E-08	0.339411	0.679324
MNBETA	-0.52393	0.065423	-8.00835	2.89E-13	-0.65321	-0.39465

Table 6: Global Drowsiness Detection Variable - Baseline Data - Reduced Set of Measures - Relative Weighting (Ellsworth, Wreggit, and Wierwille, 1993).

Regression Statistics	
Multiple R	0.805406
R Square	0.648679
Adjusted R Square	0.639119
Standard Error	0.600734
Observations	152

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	4	97.95047	24.48762	67.85507	1.98E-32
Residual	147	53.04953	0.360881		
Total	151	151			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.146987	0.058595	36.64113	4.93E-77	2.03119	2.262784
PERCLOSE	1.045374	0.077232	13.5355	7.75E-28	0.892745	1.198002
MNALPHA	-0.8835	0.081922	-10.7846	1.83E-20	-1.0454	-0.7216
MNTHETA	0.306236	0.082787	3.6991	0.000302	0.142631	0.469842
MNSQHRT	0.167559	0.055532	3.017341	0.002994	0.057815	0.277303

Table 7: Global Drowsiness Detection Variable - Baseline Data - Reduced Set of Measures - Relative Weighting (Ellsworth, Wreggit, and Wierwille, 1993).

Regression Statistics	
Multiple R	0.814009
R Square	0.66261
Adjusted R Square	0.653429
Standard Error	0.588703
Observations	152

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	4	100.0541	25.01352	72.17435	1.03E-33
Residual	147	50.94591	0.346571		
Total	151	151			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.127565	0.056516	37.64558	1.24E-78	2.015877	2.239254
PERCLOSE	0.862511	0.074882	11.51832	1.99E-22	0.714527	1.010494
MNALPHA	-0.58323	0.098423	-5.9257	2.03E-08	-0.77773	-0.38872
MNTHETA	0.321845	0.08132	3.957742	0.000116	0.161137	0.482552
MNBETA	-0.29266	0.074217	-3.94336	0.000123	-0.43933	-0.14599

Table 8: Global Drowsiness Detection Variable - Baseline Data - Reduced Set of Measures - Relative Weighting (Ellsworth, Wreggit, and Wierwille, 1993).

Regression Statistics	
Multiple R	0.821551
R Square	0.674946
Adjusted R Square	0.663814
Standard Error	0.579816
Observations	152

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	5	101.9168	20.38336	60.63114	6.36E-34
Residual	146	49.0832	0.336186		
Total	151	151			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.151302	0.056569	38.02996	3.09E-79	2.039503	2.263101
PERCLOSE	0.939449	0.08067	11.64561	9.06E-23	0.780018	1.098881
MNALPHA	-0.66039	0.10233	-6.45351	1.4E-09	-0.86263	-0.45815
MNTHETA	0.345228	0.080706	4.277585	3.34E-05	0.185725	0.504732
MNSQHRT	0.128913	0.054767	2.353869	0.019867	0.020676	0.237151
MNBETA	-0.25655	0.07469	-3.43482	0.000766	-0.40416	-0.10893

Several lane-related measures have been found to be accurate and reliable measures for the detection of drowsiness, all of which are feasible for on-the-road use. The names of the measures described below are simply the variable names used in previous studies.

- LANEDEVM: Lane deviations which were heavily weighted for lane exceedences were found to be highly correlated with eye closure and were influenced by sleep deprivation and time on task (Skipper, Wierwille, and Hardee, 1984).

- LANESTD: The standard deviation of the lane position was found to be highly correlated with eye closure and was influenced by sleep deprivation and time on task (Skipper, Wierwille, and Hardee, 1984).

- LANEDEV: the global maximum lane deviation was found to be highly correlated with eye closure and was influenced by sleep deprivation and time on task (Skipper, Wierwille, and Hardee, 1984).

- LANEDEVSQ: The mean square of the lane deviation has been found to contain a significant amount of independent information. The measure is considered to be an accurate and reliable measure for the detection of drowsiness (Dingus, Hardee, and Wierwille, 1985).

- LATPOSM: The mean square of the high pass lateral position (heavily weighted for rapid changes in lateral position) shows potential as a drowsiness indicator (Dingus, Hardee, and Wierwille, 1985).

Steering-related measures. The frequency and type of steering reversal is related to lane tracking. This relation is seen since drivers who are impaired due to drowsiness are typically inattentive to the driving task. As a result, the number of "micro-wheel adjustments" may decrease. Ryder, Malin, and Kinsley (1981) found that steering reversals decreased in frequency with time on task and Hulbert (1963), cited in Dingus, Hardee, and Wierwille (1985) found that sleep deprived drivers have a lower frequency of steering reversals than rested drivers. Sugarman and Cozad (1972) found that steering magnitude increased with time. Other researchers such as Dureman and Boden (1972), cited in Haworth, Vulcan, Triggs, and Fildes (1989) and Mast, Jones, and Heimstra (1966), cited in Haworth et al. (1989) have found that there is a deterioration of steering performance with drowsiness. Erwin (1976) has also found a reduction of "micro-wheel adjustments" during drowsiness. However, Erwin states that the wheel adjustment measure may not be predictive since EEG signals that indicate the onset of drowsiness precede the change in steering wheel adjustment behavior. Several steering-related measures have been found to be accurate and reliable measures for the detection of drowsiness, all of which are feasible for on-the-road use. The names of the measures described below are simply the variable names used in previous studies.

- STVELM: The steering velocity weighted heavily for fast maneuvers has been found to be highly correlated with eye closure and was influenced by sleep deprivation and time on task (Skipper, Wierwille, and Hardee, 1984).

- STEXEED: The number of times steering velocity exceeded a criterion (150 degrees/second over a three minute interval) was found to contain a significant amount of independent information. This measure is considered to show some potential as a drowsiness indicator (Dingus, Hardee, and Wierwille, 1985).

- STVELV: Steering velocity variance (calculated over a three-minute interval) was found to show potential as a drowsiness indicator (Dingus, Hardee, and Wierwille, 1985).

- LGREV: The number of times the steering wheel position increment exceeded 5 degrees (after steering wheel velocity passed through zero) was found to show potential as a drowsiness indicator (Dingus, Hardee, and Wierwille, 1985).

Heading/head rate/lateral acceleration related measures. Heading errors can quickly become a major problem when driving at high speeds. For example, if heading changes by 1 degree from straight ahead at 60 miles per hour, the lateral velocity will be approximately 1.5 feet per second. It is easy to see that heading is closely related to lane maintenance and steering-related measures. It is no surprise then that changes in heading and heading rate may also be possible measures that could be employed to detect drowsiness. Several heading- and heading rate-related measures have been found to be accurate and reliable measures for the detection of drowsiness, all of which are feasible for one-the-road use. The names of the measures described below are simply the variable names used in previous studies.

- YAWDEV: The global maximum yaw deviation was found to be highly correlated with eye closure and was influenced by sleep deprivation and time on task (Skipper, Wierwille, and Hardee, 1984).

- YAWVAR: The yaw deviation variance (calculated over a three-minute period) was found to contain a significant amount of independent information. This measure is considered to be an accurate and reliable measure for the detection of drowsiness (Dingus, Hardee, and Wierwille, 1985).

- YAWMEAN: The mean yaw deviation (calculated over a three-minute period) was found to contain a significant amount of independent information. This measure is considered to be an accurate and reliable measure for the detection of drowsiness (Dingus, Hardee, and Wierwille, 1985).

Braking and acceleration measures. The ability of a driver to apply brakes and accelerator adequately so as to maintain consistent driving speed is of obvious importance. Erratic driving or slowed braking responses may be a factor that could contribute to an accident.

Hulbert (1963) found that sleep deprivation contributes to the slowing of accelerator behavior. Safford and Rockwell (1967) found that accelerator pedal reversals were highly correlated with time during a twenty-four hour driving study. However, a literature review conducted by Hardee, Dingus, and Wierwille (1985) reported little evidence that accelerator behavior was related to time on task or drowsiness. Several other studies confirm the findings by Hardee et al (Brown, 1965; Brown, 1966; Brown, Simmons, and Tickner, 1967; Huntley and Centybear, 1974). It was also found by Huntley and Centybear that brake usage did not significantly change with sleep deprivation. Several other studies also confirm these findings (Brown, 1965; Brown, 1966; Brown, et al., 1967).

Related to braking and acceleration behavior is speed-related behavior. Speed variability, including longitudinal acculturation and velocity maintenance, have not shown consistent results with regard to performance degradation in sleep deprived subjects. Mast, Jones, and Heimstra (1966) found significant differences between subjects' abilities to maintain constant velocity during the first and last hours of both four- and six-hour simulated driving sessions. Riemersma, Sanders, Wildervanck, and Gaillard (1977) found that speed variability significantly increased during night driving. However, three studies (Brown, 1965; Brown, 1966; Brown, et al., 1967) did not find a significant change in velocity maintenance ability in both eight- and twelve-hour driving tasks. Safford and Rockwell (1967) found no increases in speed variability during a 24 hour driving test.

The ability to follow a lead car at a consistent and safe distance is quite important while driving at high rates of speed. It was found by Muto and Wierwille (1982) that subjects' reaction times to an emergency situation involving the sudden deceleration of a lead car in a simulated car-following task were significantly greater after driving for 30, 60, and 150 minutes when compared to baseline runs. Muto and Wierwille state, however, that repeated response trials may not provide valid indications of fatigue-induced decrements in performance.

Independent Versus Dependent Measures

In regression the definitions of independent/dependent variables are different than the definitions of independent/dependent variables in traditional experimental design. In traditional experimental design the variable being manipulated by an experimenter is the independent variable and the dependent variable is the measure affected by the independent variable. However, in regression and similar statistical techniques, the term independent variable refers to predictor variables and the term dependent variable refers to the variable that is being predicted. To avoid confusion in this dissertation, additional descriptors accompany the terms *independent* and *dependent* to provide clarification of terminology.

RESEARCH OBJECTIVES

The primary goals of the reported research were to 1) determine the best procedure for drowsiness-detection algorithm development, 2) develop drowsiness-detection algorithms that could be used in an on-the-road application, and 3) validate the most promising developed algorithms by applying data from a new group of subjects.

To determine the best procedure for algorithm development, combinations of independent measures (driver-related and performance-related) were used in the development of numerous algorithms. Algorithms were developed using multiple regression and discriminant analysis procedures. The accuracy of various algorithms developed with each procedure were compared.

The procedure best suited for algorithm development was used for development of all subsequent algorithms. Statistical analysis and optimization techniques were used to determine which independent measures contributed most to the prediction of driver drowsiness.

Validation procedures were carried out on the most promising developed algorithms by employing a new subject pool and applying various algorithms to a new set of driver-vehicle/secondary-task performance data.

PHASE TWO

DEVELOPMENT OF DROWSINESS DETECTION ALGORITHMS

Research Objectives of the Algorithm Development Phase

The principal objective of this phase was the development of practical methods for the detection of driver impairment due to drowsiness, fatigue, time-on-task, and sleep deprivation. Various measures were used to create algorithms for the detection of drowsiness while driving. The drowsiness detection algorithms were created through methods employing multiple regression and discriminant analysis. A variety of algorithms were derived. The reasons for obtaining multiple algorithms were 1) that different definitions of drowsiness can be used, and 2) operational measures available for measurement may vary from time to time in an actual vehicle.

METHOD

<u>Subjects</u>

Twelve volunteer subjects (six male and six female) were used in this study. All subjects lived in the Blacksburg, Virginia area. As part of a screening procedure all potential subjects were asked various questions over the phone concerning their driving habits, sleeping habits, and other relevant questions. The questionnaire that was used to gather this information over the phone is presented in Appendix A. Subjects who had atypical sleeping patterns, sleeping disorders, or were not prone to drowsiness were not used in the study. Potential subjects who smoked more than three cigarettes per day were not employed as subjects. This decision was made because subjects would not be allowed to smoke from approximately 7 P. M. to 3 A. M. It was felt that if heavy smokers either smoked during those hours or not did not smoke during those hours the subjects' arousal level may have been affected.

Subjects' ages ranged from 18 to 40 years. All subjects were given a Landholt C vision exam and had to demonstrate that they had corrected vision of at least 20/30. All subjects were required to have a valid driver's license.

Subjects were paid $5.00 per hour from 6:00 P.M. to midnight and $8.00 per hour from midnight to 3:00 A.M. However, if the study ran to a time later than 3:00 A.M. subjects were compensated accordingly. All subjects were informed before the study began that they could terminate participation in the study at any time for any reason and be paid for time actually spent. However, all subjects completed the experiment.

During the data collection one subject drove the automobile simulator in an unrealistic and inconsistent manner. In particular, this subject consistently drove on the shoulder for extended periods of time, but appeared alert. Another subject seemed highly stimulated and exhibited high heart rate and no signs of drowsiness. These subjects were run through the entire experiment and paid for their time. However, the data collected from these two subjects were not used. Two other volunteer subjects were used as replacements.

Apparatus

A pictorial representation of the peripheral equipment used for algorithm development is seen in Figure 4.

Simulator. The simulator used in the study is an automobile simulator that handles like a midsize vehicle. The simulator had been validated by Leonard and Wierwille (1975) with regard to driver-vehicle performance measures by comparing it with an actual automobile. It had also been validated in regard to visual glance times for in-vehicle tasks (Kurokawa and Wierwille, 1990).

The simulator is computer controlled and has a hydraulically powered moving-base with four degrees of freedom. The physical motions include pitch, yaw, lateral movement, and longitudinal movement. The moving base is also capable of mimicking roadway vibration. Time delays inherent in the motion platform over and above normal vehicle delays are estimated to be 25 milliseconds (Dingus, Hardee, and Wierwille, 1985) and were compensated for in the vehicle dynamics.

The roadway imaging system of the simulator provided an image of a two-lane roadway with a center strip and side markings. Additionally, horizontal lines were displayed to give the driver a feeling of looking at a roadway that was embedded in the horizontal plane. This was important to further the impression that the simulated roadway continued into the distance. A monochrome CRT was used to present the roadway image to the driver. The CRT was viewed through a Fresnel lens. When the drivers' eyes were focused on the simulated roadway a majority of their peripheral vision was used to view the screen. Also present in the subject's view was a simulated automobile hood that appeared at the correct distance and was of the correct size.

An audio system was included in the design of the automobile simulator to provide additional realism. Simulated sounds included tire noise, engine/drive train noise, tire

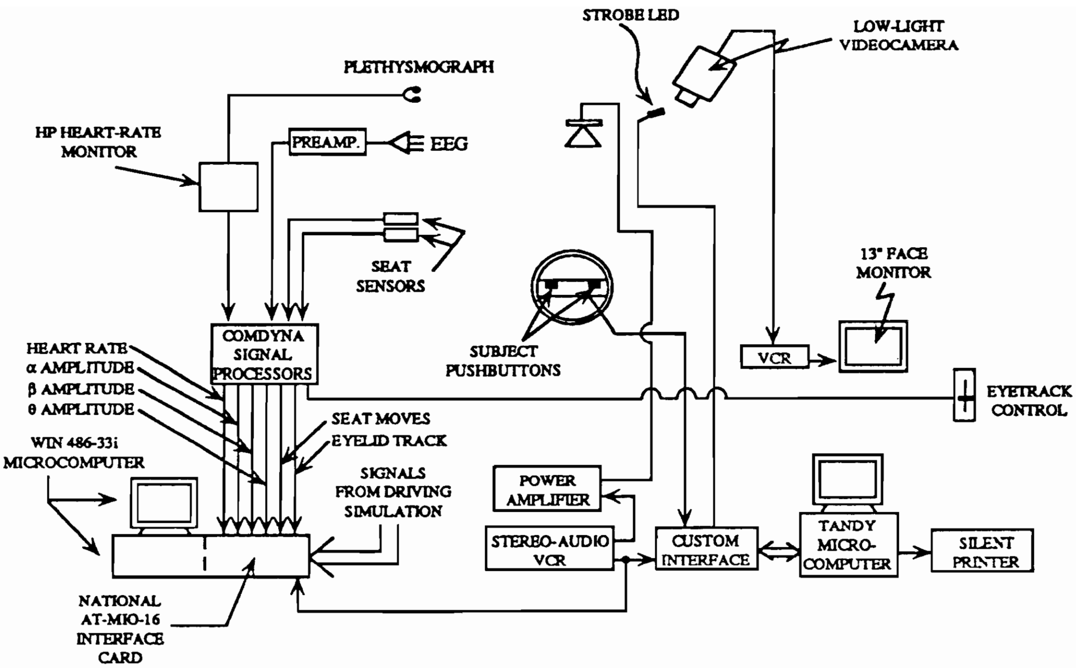


Figure 4: Peripheral Equipment Used for Algorithm Development

screech on severe braking, and tire squeal on severe cornering (Dingus, Hardee, and Wierwille, 1985).

Video recording equipment. A low light level camera (RCA TC1004-UO1) was used to continuously monitor a subject's entire face, including eye movements. Since the camera could operate at very low light levels, it was unobtrusive. The video signal was passed through a VCR and was then viewed by an experimenter on a Sanyo VM 4512A monitor.

After all subjects completed the study the research team viewed the recorded images of the subjects so that further analyses could be performed.

Linear potentiometer. An experimenter manually tracked the subject's eyes by means of a linear potentiometer. As the subject's eyes closed, the potentiometer was pushed down so as to track the movement of the eyelids. If the subject's eyes were 100% closed the potentiometer was moved to the bottom of its range. If the subject's eyes were 0% closed the potentiometer was moved to the top.

Steering wheel controls for subsidiary task. The simulator steering wheel had been altered so that it included two push buttons on the cross member (thick spokes). One button was located on the left and the other on the right. The right button was labeled "YES" and the left button was labeled "NO." The subjects responded to subsidiary task stimuli presented to them by pressing either the "YES" or "NO" button. The responses were interfaced to a microcomputer for storage and analyses. This microcomputer was dedicated to subsidiary-task response scoring and timing.

Win 486-33i microcomputer and analog-digital interface card. A majority of the data gathering for this experiment was performed by another microcomputer (Win 486-33i) and interface card. The interface card used was a National Instruments AT-MIO-16 card. This allowed for the collection of analog data which was converted to digital format for compatibility with a microcomputer.

Yet another computer/processor was used to collect data for several physiological measures including heart rate, eye closure, and EEG. The EEG measures included alpha, beta, and theta waves. The signals that were received by the processor included signals generated from two electrodes placed over the occipital lobe (EEG measures), an ear plethysmograph (heart rate), a linear potentiometer (eye closure), and various signals from the automobile simulator. Output from the processor was then routed to the WIN 486-33i microcomputer, which was programmed in QuickBASIC to collect and store the appropriate data as well as to perform on-line calculations.

The on-line calculations that were performed by the WIN microcomputer on the collected data took place over each one-minute segment. These calculations resulted in the proportion of the time that a subject's eyes were closed 80% or more (PERCLOS), the mean-square of the eyelid closure signal (EYEMEAS), mean alpha amplitude (MNALPHA), mean beta amplitude (MNBETA), mean theta amplitude (MNTHETA), mean heart rate (MNHRT), and squared mean heart rate (MNSQHRT), among others.

The Win 486-33i microcomputer was used for a majority of the statistical analyses. The software that was used included Microsoft Excel 4.0 and Statistica 4.2 for Windows.

Electrodes and plethysmograph. Biopotential skin electrodes were placed over the occipital lobe and the lead wires were secured behind the driver/subject so that they could not be seen by the subject. An athletic headband was placed around the subject's head so that the electrodes were held securely to the subject's head. As mentioned above, the EEG signals passed through a GRASS high performance preamplifier and then to the processor. Once the signals passed through the processor they were sampled by the AT-MIO-16 analog to digital card. After this stage the signal was ready for measures computation.

The plethysmograph sensor was placed on the antihelix of the subject's ear for collection of heart rate data. The plethysmograph's lead wire was secured behind the subject so that it was unobtrusive. To keep the sensor and lead wire in place the same athletic headband that was used for the electrodes was used to hold them to the subject's head. The signal obtained from the plethysmograph passed through a Hewlett-Packard 7807C heart rate monitor. The signal then passed through the signal processor and on to the AT-MIO-16 card before reaching the microcomputer.

Experimental Design

The experimental design involved a regression-discriminant analysis approach to data analysis. Of the twelve subjects employed in the study, four were asked to simply drive the simulator, four subjects carried out an subsidiary task every fifteen seconds while driving, and four subjects interacted with the dashboard controls approximately every eight to ten minutes while driving. In each group there were two randomly assigned females and two randomly assigned males.

Several categories of measures were gathered during the study. Within each category were various measures. Below is a list of the collected measures grouped within the appropriate category.

Seat movement-related measures:

- NMRMOVS: The number of times the seatback sensor signals exceeded the threshold value (corresponding to movement in the seat).
- THRESMVS: The proportion of total time that the seat sensor signals exceeded the threshold value.

Steering-related measures:

- NMRHOLD: The number of times the hold circuit output on the steering wheel exceeded a threshold value (corresponding to holding the steering wheel still for 0.4 second or longer).

- THRSHLD: The proportion of total time that the hold circuit on the steering wheel exceeded a threshold value.
- STVELV: The variance of steering velocity.
- LGREV: The number of times that steering excursions exceeded 15 degrees after steering velocity passed through zero.
- MDREV: The number of times that steering excursions exceeded 5 degrees (but less than 15 degrees) after steering velocity passed through zero.
- SMREV: The number of times that steering excursions exceeded 1 degree (but less than 5 degrees) after steering velocity passed through zero.
- STEXED: The proportion of time that steering velocity exceeded 150 degrees/sec.

Lane-related measures:

- LANDEV: The standard deviation of lateral position relative to the lane.
- LANVAR: The variance of the lateral position relative to the lane (square of LANDEV).
- LNMNSQ: The mean square of lane position (The "zero" position was defined as that position occurring when the vehicle was centered in the lane.)
- LNRTDEV: The standard deviation of the time derivative of lane position.
- LNRTVAR: The variance of the time derivative of lane position (square of LNRTDEV).
- LANEX: The proportion of time that any part of the vehicle exceeded a lane boundary.
- LNERRSQ: The mean square of the difference between the outside edge of the vehicle and the lane edge when the vehicle exceeded the lane. When the vehicle did not exceed the lane, the contribution to the measure was zero.

Accelerometer-related measures:

- ACCDEV: The standard deviation of the smoothed output of the lateral accelerometer. (Smoothing was accomplished with a low-pass filter having a corner frequency at 7.25 Hz.)
- ACCVAR: The variance of the smoothed output of the accelerometer. (square of ACCDEV)
- INTACDEV: The standard deviation of the lateral velocity of the vehicle. (This signal was obtained by passing the smoothed accelerometer signal through an additional low pass filter (leaking integrator) with a corner frequency of 0.004 Hz.)
- INTACVAR: The variance of the lateral velocity of the vehicle (square of INTACDEV).
- ACEXEED: The proportion of time that the magnitude of lateral acceleration exceeded a magnitude threshold of 0.3 g (9.66 ft/second^2).

Heading-related measures:

- HPHDGDEV: The standard deviation of the high-pass heading signal.
- HPHDGVAR: The variance of the high-pass heading signal (square of HPHDGDEV).
- DSYAWDEV: The standard deviation of the display yaw signal.
- DSYAWVAR: The variance of the display yaw signal (square of DSYAWDEV).

Subsidiary (A/O) task-related measures: (Obtained from four of the driver subjects.)

- AOTIME: Mean response time to a correct response. Incorrect responses and no-responses were specified as 12 seconds.
- NMWRONG: Mean number of incorrect responses.

- NMNR: Mean number of stimuli for which there was no response.

Brain wave activity:

- MNALPHA: Mean alpha amplitude. (The detected amplitude of the output of a bandpass filter of the EEG having a passband from 8 to 12 Hz.)
- MNBETA: Mean beta amplitude. (The detected amplitude of the output of a bandpass filter of the EEG having a passband from 12 to 24 Hz.)
- MNTHETA: Mean theta amplitude. (The detected amplitude of the output of a bandpass filter of the EEG having a passband from 4 to 8 Hz.)

Heart rate measures:

- MNHRT: Mean heart rate. (The mean of the instantaneous output of the heart rate monitor.)
- MNSQHRT: Mean-square heart rate. (The mean square of the instantaneous output of the heart rate monitor.)

The data that were collected during this study were used to compute several definitional measures of drowsiness. The drowsiness measures were:

- EYEMEAS: The mean square of the percentage of the subject's eye closure.
- PERCLOS: The proportion of the time that a subject's eyes were closed 80% or more.
- AVEOBS: The average drowsiness rating of three observers for each one-minute interval. (This measure was obtained <u>after</u> the experimental runs by viewing the videotapes of the subjects' faces.)

- NEWDEF: Definition developed by Ellsworth, Wreggit, and Wierwille (1993):

  Y = 18.45722(PERCLOS) - 0.01569(MNALPHA) + 0.020173(MNTHETA) - 0.00549(MNBETA) + 0.000698(MNSQHRT).
- MASTER: The sum of the standardized values of AVEOBS, EYEMEAS, NEWDEF, AND PERCLOS.

Procedure

Subject procedure. All subjects were involved in two sessions. The first was a screening process that took place over the telephone. During the screening session all potential subjects were asked questions in regard to driving habits, smoking habits, work schedules, and health (see Appendix A).

Subjects that passed the screening and were chosen for the study were told to carry out their normal activities during the day on which the study was scheduled. It was mandatory that all subjects awake at approximately 7:00 A.M. Individuals who slept during the day were not allowed to participate. At 6:00 P.M. a member of the experimenter team met the subject at the subject's residence. The experimenter took the subject to dinner at a fast-food restaurant. Subjects were not allowed to intake sugar, caffeine, alcohol or any other stimulant or depressant after 6:00 P.M. Subjects were allowed to smoke during or immediately following dinner. By coincidence, no smokers participated in the study. After eating dinner, subjects were driven to the Vehicle Analysis and Simulation Lab.

The subject was given a Landholt C vision exam upon arrival at the laboratory. Each subject was required to demonstrate corrected vision of at least 20/30. Once a subject passed the vision test he or she was given an instruction sheet (see Appendix B) that gave further details concerning the experiment. After reading the instructions the subject was asked if there were any questions concerning the study. Once questions were answered by the experimenter the subject was asked to sign an informed consent form (see Appendix C). While subjects waited for the study to begin they were allowed to watch television, read, study, etc. An experimenter stayed with the subject at all times except restroom breaks.

The experiment was run from approximately midnight to 3:00 A.M. At midnight, two rested experimenters arrived to relieve the first member of the team. At that time the subject was again asked if there were any questions concerning the study. After any questions were answered, an experimenter placed the subject in the simulator and the laboratory lights were dimmed. The subject practiced driving the simulator for approximately five minutes. Once the five-minute practice session was complete the laboratory lights were turned on and the subject was allowed to get out of the simulator for a short time before beginning the experiment. This procedure was used to acclimatize the subject to the simulator.

The subjects in the group that interacted with the dashboard controls were shown the various controls and displays that they would have to use. Several practice commands were given to the subjects to familiarize them with the controls. The subjects that were in the A/O subsidiary-task group were given several practice commands as well. Any questions that the subjects had at this time were answered by the experimenter.

The experimenters began applying physiological monitoring equipment to the subject at approximately 12:15 A.M. Various equipment was turned on and the laboratory lights were dimmed. Thereafter the subject was told to begin driving the simulator and accelerate to 60 miles per hour. At the beginning of the driving session several more practice tasks were given to the subjects who were to manipulate the dash board controls or perform the A/O subsidiary task. Several minutes after the subject began to drive and the experimenters felt that the driver was maintaining 60 m.p.h. in a consistent manner, data collection was initiated. The driving session in which data were collected lasted 2 1/2 hours.

After completion of the study the physiological monitoring equipment was removed from the subject by an experimenter. The subject was assisted out of the simulator, paid for time spent, and debriefed. The subject was then driven home by one of the experimenters.

Experimental task. The subject drove the simulated automobile as if it were an actual car. The subject attempted to stay within the side markings of the simulated roadway and in the appropriate lane. However, since this was a simulated roadway and vehicle, the driver was not harmed if the "vehicle" left the roadway or went into the wrong lane.

Four of the twelve subjects were asked to perform an A/O task. This consisted of a subsidiary task that involved an auditory presentation of various words. If the presented word contained an "A" or "O" the subject was to press the button labeled "YES" located on the steering wheel. If the presented word did not include an "A" or "O" the subject was to press the button labeled "NO" located on the steering wheel. A new word was presented verbally every 15 seconds by means of an audio track on a pre-recorded videotape. The letters "A" and "O" were chosen as target letters because words could be found that include the letters "A" and "O" that are easily distinguishable from one another. Simple words were chosen so that subjects' spelling ability would not confound the data.

Four of the twelve subjects were asked to manipulate various controls on the dash board. These tasks involved following auditory commands to adjust radio controls, push buttons, and operate vertical slide controls. One auditory command was given approximately every eight to ten minutes. This dash board manipulation task was used simply to distract the driver from the driving task as would happen in an actual on-the-road setting. This was important because the data would then include small amounts of "noise" that would actually be seen in an automobile. The commands were fairly infrequent so that the task of manipulating the controls by the subject would not create too much of an arousal effect. Also, the frequency of control manipulation would be similar to a person's activity while driving on the road.

Data Analysis Overview

All measures were first computed over one-minute intervals. Data manipulation procedures were then undertaken to prepare data for statistical analyses. Initially, the first two minutes from all measures were deleted. This was done so that the data to be analyzed did not include the time when subjects were suspected of "settling in" to the driving task. Even though all subjects were given a practice driving session it was thought that in the first two minutes of driving some subjects demonstrated inconsistencies concerning their driving behavior, reactions, and physiological measures.

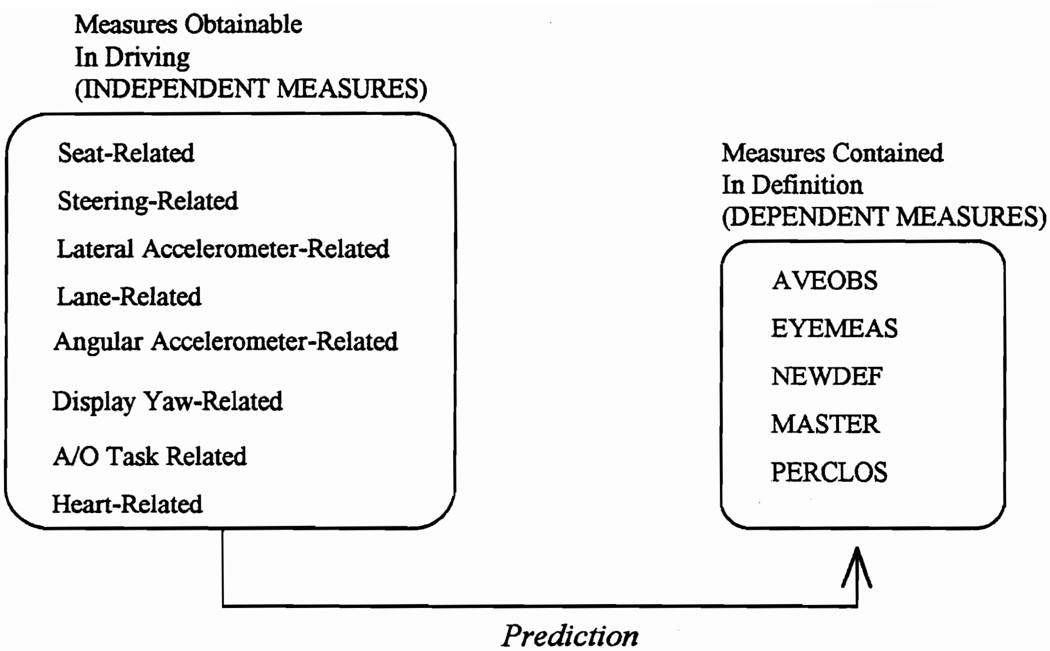
All independent (predictor) measures were baselined using the average of the first ten minutes (after the actual first two minutes had been deleted) of data. The average of the first ten minutes of data were then subtracted from every subsequent interval within that measure. Each interval consisted of a one-minute average of data. After completion of the baselining procedure the data were averaged across six-minute intervals. The first two intervals were five-minute averages to compensate for the earlier deletion of the first two minutes of data. Six-minute averages had been shown previously to have higher correlation values than either one-minute, two-minute, or four-minute averages (Ellsworth, Wreggit, and Wierwille, 1993). See Figure 5 for a pictorial overview of the data manipulation procedure.

After data manipulation, multiple regression and discriminant analyses were performed on the collected data to determine the best predictors of drowsiness (as previously defined). A pictorial representation of the multiple regression/discriminant analysis objective is given in Figure 6.

2 minutes: The first 2 minutes are deleted from all data	
5 minutes: 5 minute average calculated	The first 10 minutes of data used for baselining*
5 minutes: 5 minute average calculated	
6 minutes: 6 minute average calculated	
6 minutes: 6 minute average calculated	
6 minutes: 6 minute average calculated	
6 minutes: 6 minute average calculated	
6-minute averages continued until the entire set of one-minute segments (150 minutes) was manipulated. 148 total minutes were used due to the deletion of the first two minutes of data. Therefore, two 5-minute intervals and twenty-three 6-minute intervals were created.	

* Baselining is a procedure in which the initial ten minutes of data are averaged and then subtracted from all subsequent one-minute segments. Baselining was carried out so that data relative to the subject's initial data values could be obtained.

Figure 5: Pre-Analysis Data Manipulation Procedures.



*NEWDEF score is from Ellsworth et al. (1993)

Figure 6: Multiple Regression/Discriminant Analysis Objective

The difference between multiple regression and discriminant analysis can be seen in the methods used to choose the coefficients. In multiple regression the coefficients are selected to minimize the sum of the squared differences between a person's predicted and actual criterion score. In discriminant analysis the coefficients are selected to maximize correct classification. Also, the criterion variable for discriminant analysis is discrete rather than continuous as with multiple regression. The main purpose of the multiple regression and discriminant analyses was to find optimized combinations of variables that would best predict "drowsiness" during driving sessions.

Multiple regression analyses were initially used for several reasons. First, it was possible to track any portion of the data using multiple regression. Another important consideration was the fact that the threshold value could be changed to any level after application in the future. In other words, it would be possible to change the "sensitivity" of an onboard detection system if algorithms developed through the use of multiple regression were employed. Also, by using multiple regression, it was possible to gain valuable insight into which measures contributed consistently to the prediction of drowsiness. For example, it was found that seat movement measures (NMRMOVS and THRESMVS) did not significantly contribute to the prediction of drowsiness and therefore they were dropped from further analyses. Finally, multiple regression was also used to determine which measures would be used in the discriminant analyses.

Multiple regression was performed on all twelve subjects and separately on the four subjects involved with the A/O subsidiary task. A block diagram of the algorithm development procedure is shown in Figure 7. When performing the multiple regression analyses the beta weights of the various measures were first examined. This allowed for the removal of measures that were linearly related. Measures that contained large, offsetting coefficients were eliminated one at a time. (The equal and opposite coefficients demonstrated that the measures contained approximately the same predictive information.

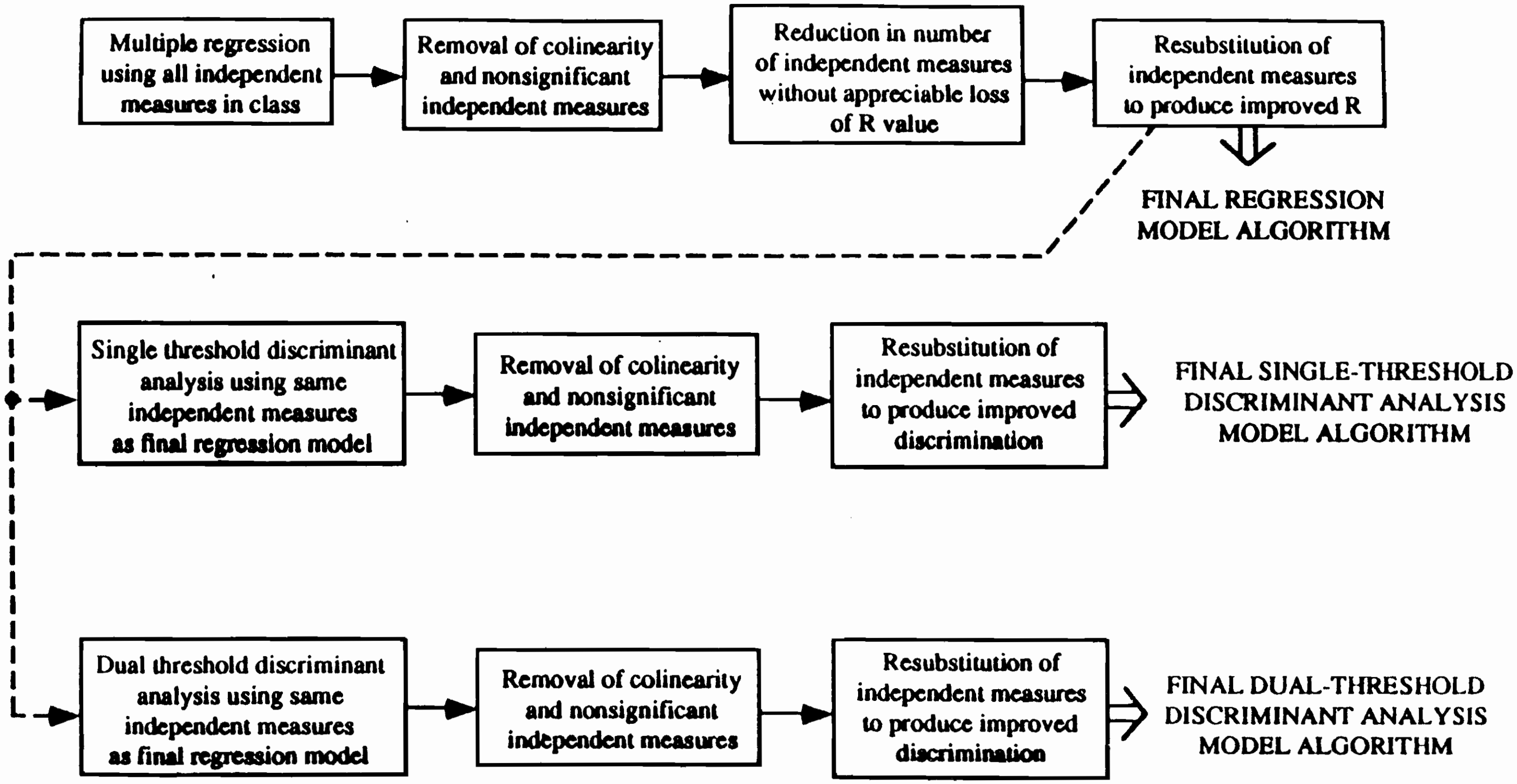


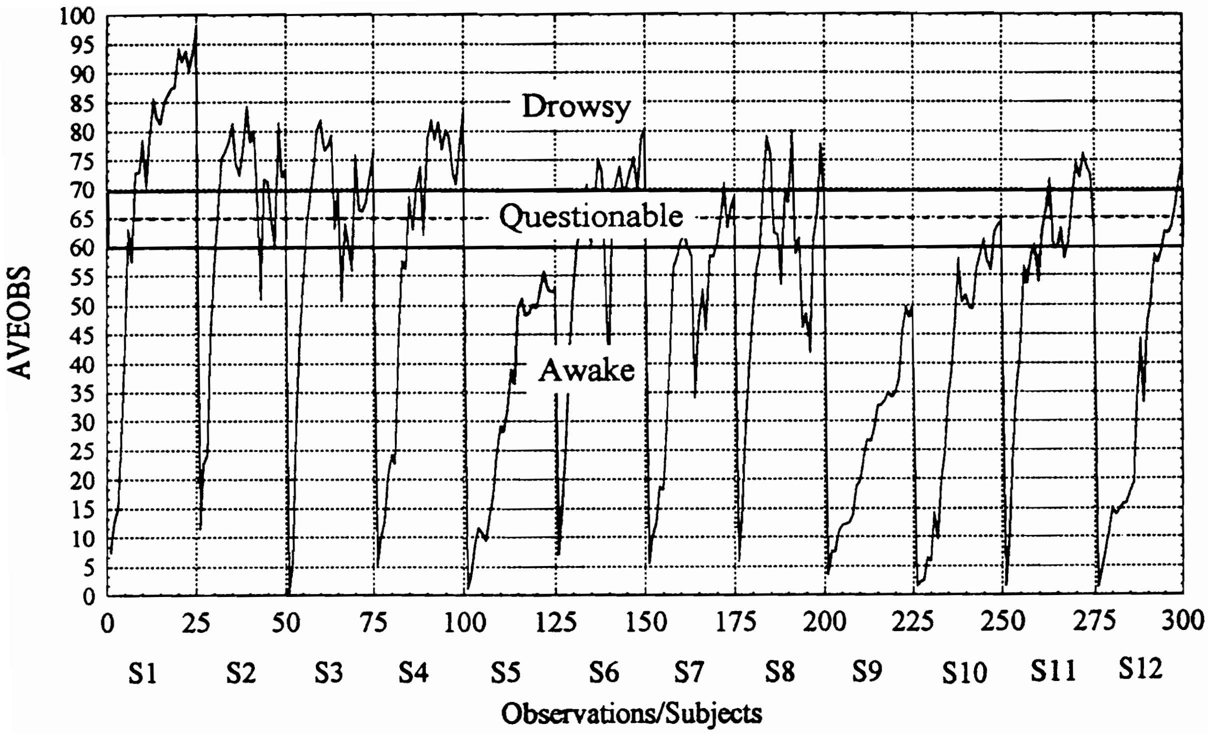
Figure 7: **Block Diagram of the Main Steps in the Algorithm Development Procedure.**

Therefore one had to be removed from the analysis.) Once any large, offsetting coefficients had been taken care of, the elimination of measures with $p > 0.05$ significance levels began, starting with the measure having the smallest F-ratio. Once the set of measures was reduced to four or five measures (sometimes more or less), substitution of various measures back into the set began. From this backward stepwise approach to multiple regression the best set of results were found.

Once the best multiple regression results were found for each dependent (definitional) variable MNHRT and MNSQHRT were added to the final set of independent (predictor) measures. The purpose of this procedure was to examine whether heart rate would increase the accuracy of drowsiness prediction. After adding the two heart rate variables it was found that some of the significant measures found previously would become nonsignificant due to the inclusion of the heart rate variables.

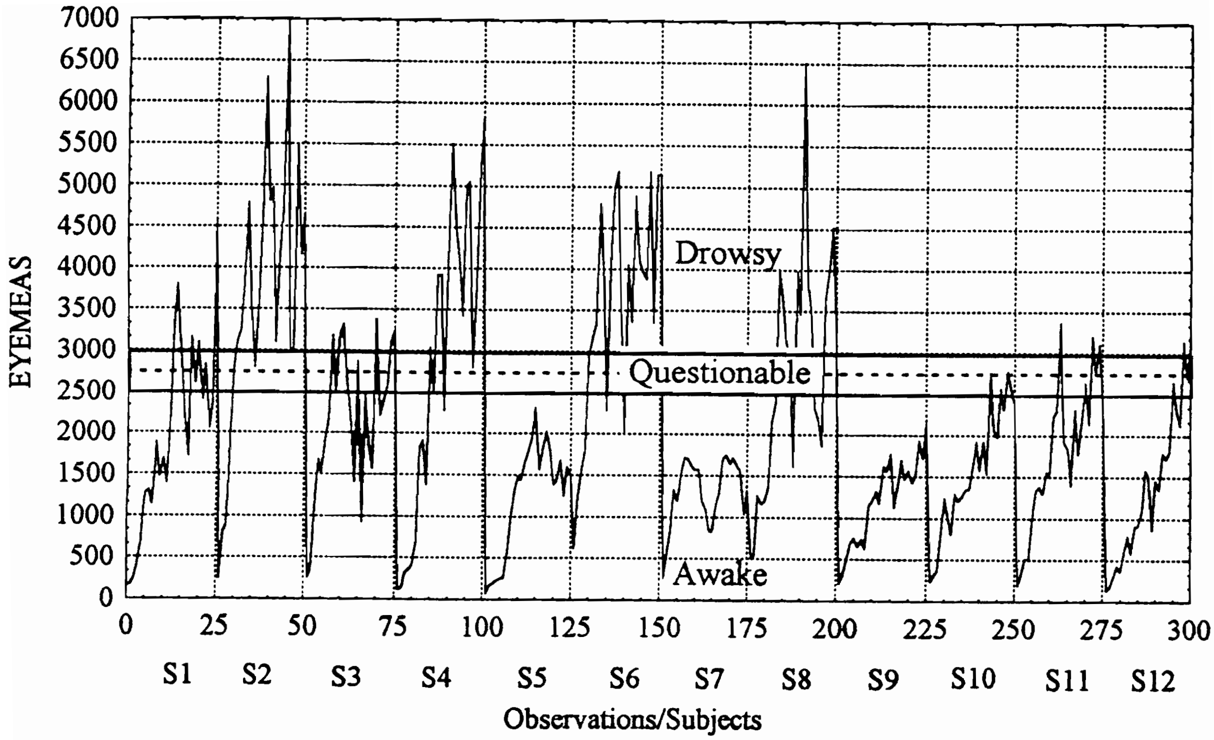
The measures that were used in the discriminant analyses were based on the measures found to have the most predictive power in the multiple regression analyses. By using the measures found to be significant predictors of drowsiness in multiple regression it was felt that the discriminant analyses would begin with a strong foundation of measures. Since multiple regression attempts to fit predicted and observed data as closely as possible, it was hypothesized that these variables would contain high integrity in a similar setting (other subjects carrying out similar activities). In using the measures found to be significant in multiple regression an attempt was made to bolster the future accuracy of the algorithms developed with discriminant analyses.

The discriminant analyses that were carried out examined the predictability of two distinct categories of wakefulness (awake and drowsy) and three distinct categories of wakefulness (awake, questionable, and drowsy). As seen in Figures 8, 9, 10, 11, and 12 the five dependent (definitional) variables have been graphed for each subject with threshold lines drawn in. In these graphs, the first 25 points on the abscissa correspond to



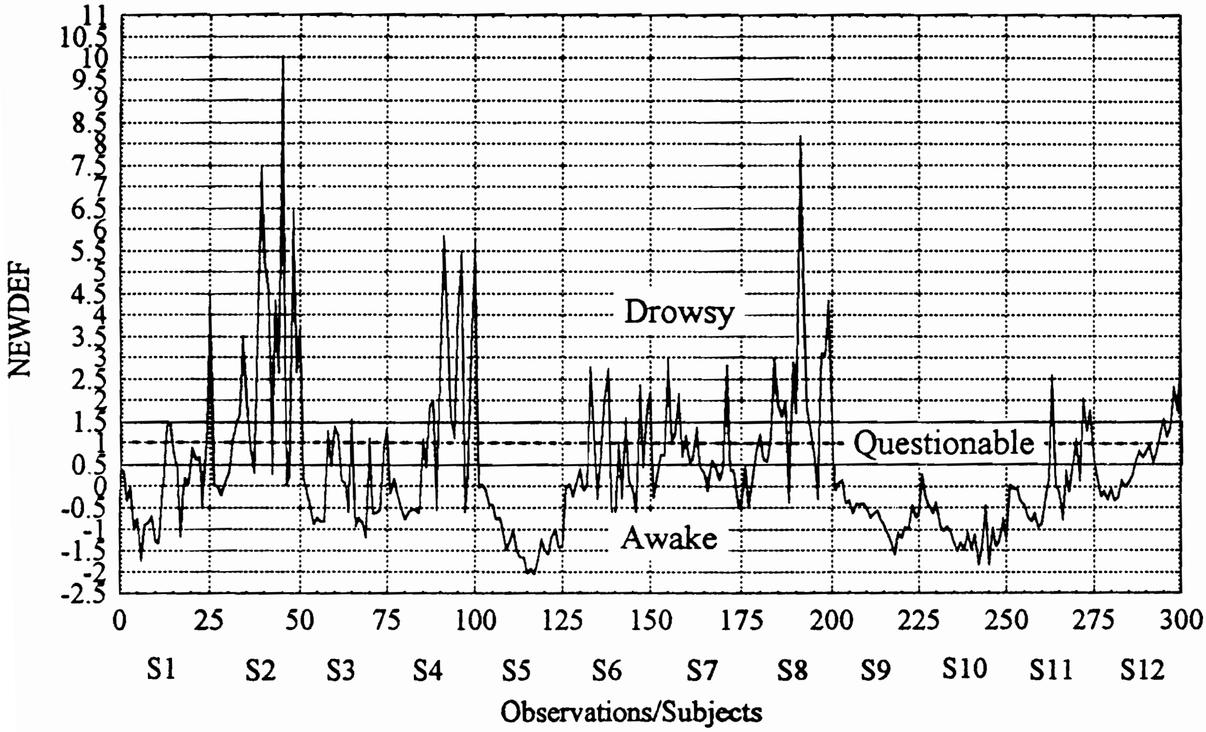
NOTE: The first 25 points on the abscissa correspond to subject 1, the next 25 points correspond to subject 2, and so on.

Figure 8: AVEOBS Data With Upper and Lower Criterion Lines for Three Categories and Single Criterion Line for Two Categories.



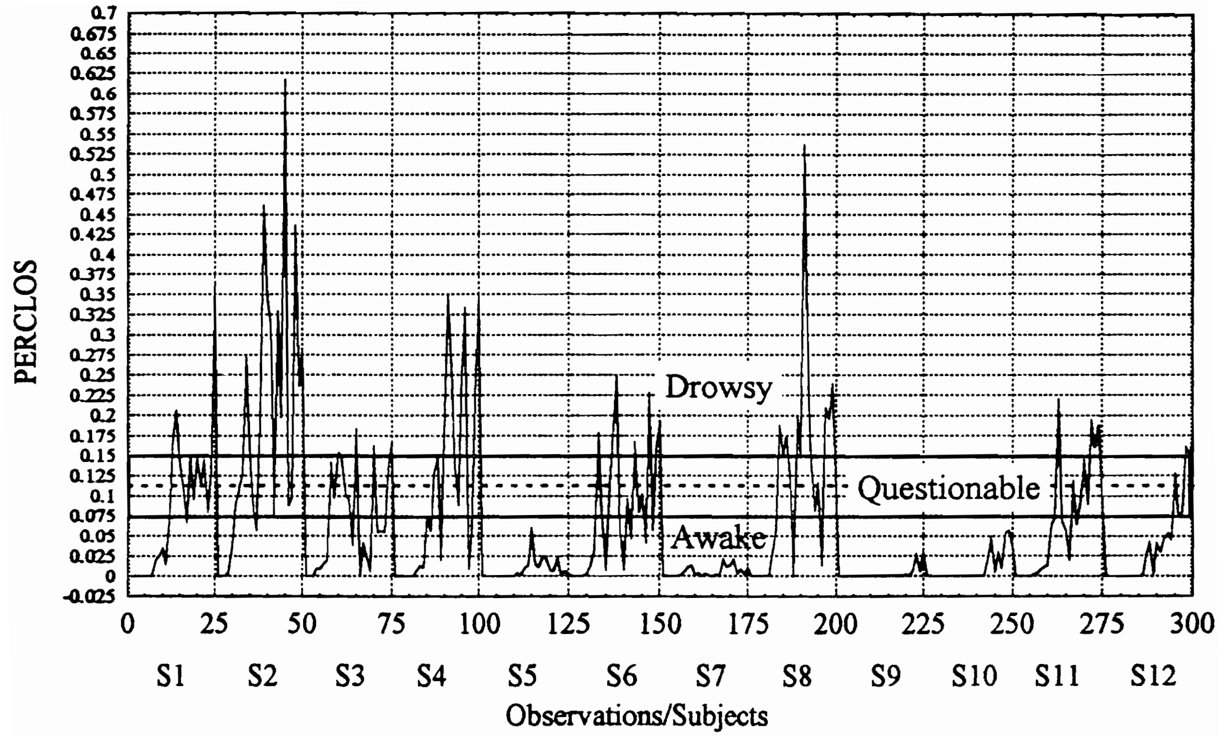
NOTE: The first 25 points on the abscissa correspond to subject 1, the next 25 points correspond to subject 2, and so on.

Figure 9: EYEMEAS Data With Upper and Lower Criterion Lines for Three Categories and Single Criterion Line for Two Categories.



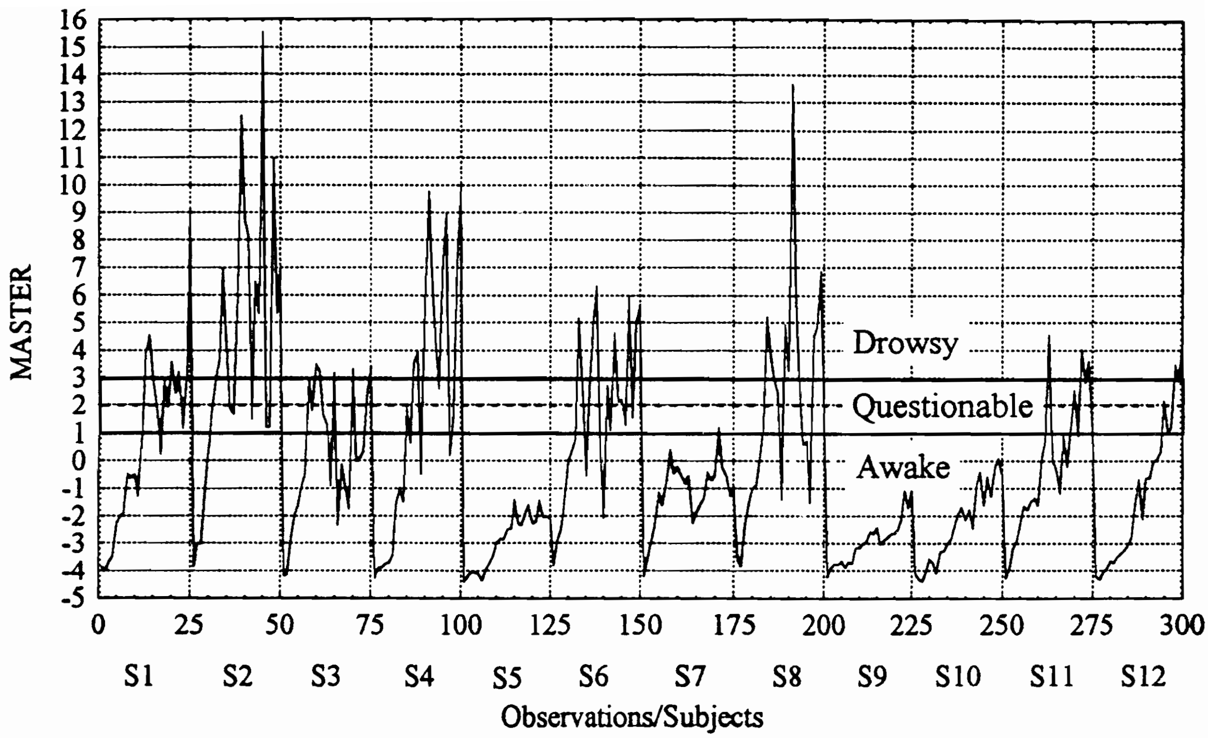
NOTE: The first 25 points on the abscissa correspond to subject 1, the next 25 points correspond to subject 2, and so on.

Figure 10: NEWDEF Data With Upper and Lower Criterion Lines for Three Categories and Single Criterion Line for Two Categories.



NOTE: The first 25 points on the abscissa correspond to subject 1, the next 25 points correspond to subject 2, and so on.

Figure 11: PERCLOS Data With Upper and Lower Criterion Lines for Three Categories and Single Criterion Line for Two Categories.



NOTE: The first 25 points on the abscissa correspond to subject 1, the next 25 points correspond to subject 2, and so on.

Figure 12: MASTER Data With Upper and Lower Criterion Lines for Three Categories and Single Criterion Line for Two Categories.

subject 1, the next 25 point correspond to subject 2, and so on. The upper and lower threshold levels that were chosen for the three category discriminant analyses were based upon visual examination of the five dependent (definitional) variables in conjunction with the known driving performance of each subject. For example, the experimenters rated subjects 5, 7, 9 and 10 as "alert" or "moderately alert" and these subjects performed adequately while driving. Therefore, the criterion line between "awake" and "questionable" was drawn so as to avoid the inclusion of a great majority of these subjects' data. The spikes in the definitional variable data that extend into the "drowsy" category of the graphs correspond with poor driving performance. Therefore, the criterion line between "questionable" and "drowsy" was drawn to include the spikes in the data that corresponded with poor driving performance. The placement of the criterion line for the two category discriminant analyses was calculated by taking the average of the upper and lower thresholds of the three category analyses. In other words, the threshold is at the center of the "questionable" band.

Various drowsiness-detection algorithms were developed for possible implementation in an on-board detection system. Each set of algorithms used a slightly different set of measures so that loss of any measure does not mean failure of the detection system. The concept of using several algorithms for the detection of drowsiness employs a "step-up" and "step-down" approach. For example, if all signals are valid, the best available algorithm for drowsiness detection would be used. However, if one of the sensors necessary for the best algorithm is not providing a valid signal, the next best algorithm that does not require the invalid signal would be used. This procedure uses the "step-down" approach. A "step-up" procedure involves the use of newly validated signals. Table 9 shows the different sets of measures that were used in the multiple regression analyses and the discriminant analyses that make it possible to use the "step-up" and "step-down" process. (In the table, "accelerometer" refers to lateral accelerometer.)

Table 9: Sets of Measures Used in Multiple Regression and Discriminant Analyses for Each Dependent (Definitional) Variable.

Independent Measures	Dependent Measures				
	AVEOBS	EYEMEAS	NEWDEF	PERCLOS	MASTER
Steering and Accelerometer					
Steering, Accelerometer, & HPHDGDEV/VAR					
Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ					
Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)					
Steering, Accelerometer, all lane measures, & DSYAWDEV/VAR					
A/O Task Measures Only					
A/O Task, Steering, & Accelerometer					
A/O Task, Steering, Accelerometer, & HPHDGDEV/VAR					
A/O Task, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ					
A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ					
Heart, Steering, & Accelerometer					
Heart, Steering, Accelerometer, & HPHDGDEV/VAR					
Heart, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ					
Heart, Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)					
Heart, Steering, Accelerometer, all lane measures, & DSYAWDEV/VAR					
A/O Task and Heart					
A/O Task, Heart, Steering, & Accelerometer					
A/O Task, Heart, Steering, Accelerometer, & HPHDGDEV/VAR					
A/O Task, Heart, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ					
A/O, Heart, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ					

RESULTS of the DEVELOPMENT PHASE

Two groups of data were analyzed. As explained earlier, the two groups included the A/O subsidiary-task group that consisted of four subjects, and a group including all subjects. It was found through the use of multiple regression and discriminant analyses that the use of only four subjects resulted in higher R values and lower Wilk's Lambda scores than when using data from twelve subjects. These results occur because an increase in the number of subjects causes greater difficulty in fitting predicted and observed data. It must be noted here that this was expected and must be kept in mind when reviewing the results of this study.

Multiple Regression

Table 10 is a summary of results that were attained from the multiple regression analyses. More complete results of the multiple regression analyses can be seen in Appendices D through V.

An examination of the average R scores across all sets of independent (predictor) variables for each of the five dependent (definitional) variables gives a good idea of the relative predictive strengths of the dependent variables. The results of the average R-score analysis seen below were obtained by averaging the R values contained within each column of Table 10.

1. MASTER: Average R = 0.8775 across 11 sets.
2. PERCLOS: Average R = 0.8563 across 12 sets
3. AVEOBS: Average R = 0.8303 across 16 sets
4. EYEMEAS: Average R = 0.8154 across 9 sets
5. NEWDEF: Average R = 0.7523 across 16 sets

The number of sets used to calculate each average was determined by the number of independent variable sets used to independently predict each dependent variable.

The multiple regression procedure was carried out in several steps. Mean heart

Table 10: Summary Table of Multiple Regression Analyses Results Showing R Values.

	Independent Measures	Dependent Measures				
		AVEOBS	EYEMEAS	NEWDEF	PERCLOS	MASTER
D	Steering and Accelerometer	0.747	0.764	0.677	0.789	0.801
E	Steering, Accelerometer, & HPHDGDEV/VAR	0.793	0.809	0.700	0.847	0.852
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	0.826	0.837	0.731	0.872	0.886
G	Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	* 0.824	▲	0.757	0.872	▲
H	Steering, Accelerometer, all lane measures, & DSYAWDEV/VAR	0.826	0.836	* 0.751	▲	▲
I	A/O Task Measures Only	0.761	0.768	0.660	0.810	0.822
J	A/O Task, Steering, & Accelerometer	Accel. 0.824	0.824	Accel. 0.740	0.836	0.876
K	A/O Task, Steering, Accelerometer, & HPHDGDEV/VAR	0.917	Steering 0.855	▲	Accel. 0.868	0.903
L	A/O Task, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ	Δ	0.874	0.768	0.875	0.903
M	A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ	0.922	Δ	Δ	0.902	0.936
N	Heart, Steering, & Accelerometer	0.785	0.772	0.711	□	□
O	Heart, Steering, Accelerometer, & HPHDGDEV/VAR	0.813	□	0.761	0.851	0.854
P	Heart, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	0.838	□	0.774	0.874	□
Q	Heart, Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	* 0.816	□	0.802	□	□
R	Heart, Steering, Accelerometer, all lane measures, & DSYAWDEV/VAR	Lane Rate 0.837	□	steer/LnRT 0.797	▲	□
S	A/O Task and Heart	□	□	0.774	□	□
T	A/O Task, Heart, Steering, & Accelerometer	Accel. 0.837	□	Accel. 0.810	□	□
U	A/O Task, Heart, Steering, Accelerometer, & HPHDGDEV/VAR	0.918	□	▲	Accel. 0.880	0.909
V	A/O Task, Heart, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	□	□	0.823	□	0.910
	A/O, Heart, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	□	Δ	Δ	□	□

KEY:

▲ In regression analyses introduction of variable did not improve R value. See entry directly above for model with same R and fewer terms.

□ Heart Measures did not improve regression as compared with non-heart equivalent. See corresponding non-heart entry for model with same R value and fewer terms.

Δ A/O task measures did not improve regression as compared with non-A/O task measure equivalent. See corresponding non-A/O task measure entry for model with same R value and fewer terms.

* A cell designated with an asterisk could have been given the ▲ symbol. However, the asterisk denotes a substantially changed algorithm in term of measures used.

NOTES: Any measure specified in a cell was deleted because of non significance.
Letter in left-hand column corresponds to appendix in which analysis is presented.

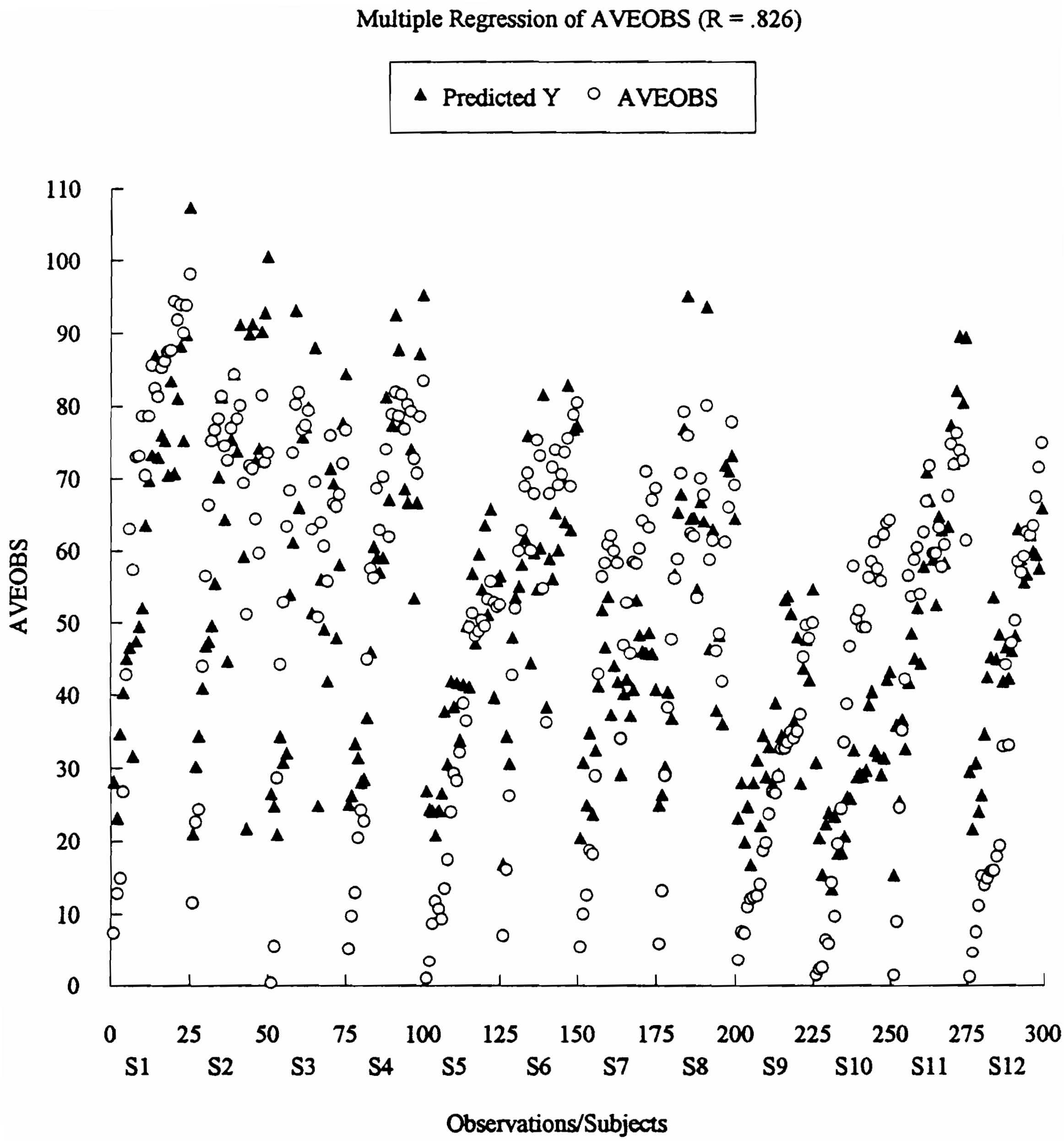
rate and mean square heart rate measures were added to the best multiple regression sets to determine whether the heart rate variables contributed to the prediction of drowsiness. A general increase in R scores was seen with the addition of heart rate measures.

The addition of A/O task measures increased R values in comparison with results from data that did not incorporate the A/O task. However it must be remembered that the A/O task measures were collected using four subjects, thus somewhat inflating the R value relative to the results seen when analyzing data from twelve subjects.

After completing some initial multiple regression analyses it was found that seat movement measures did not contribute to the prediction of drowsiness. The seat movement measures, NMRMOVS and THRESMVS, were then eliminated from further analyses.

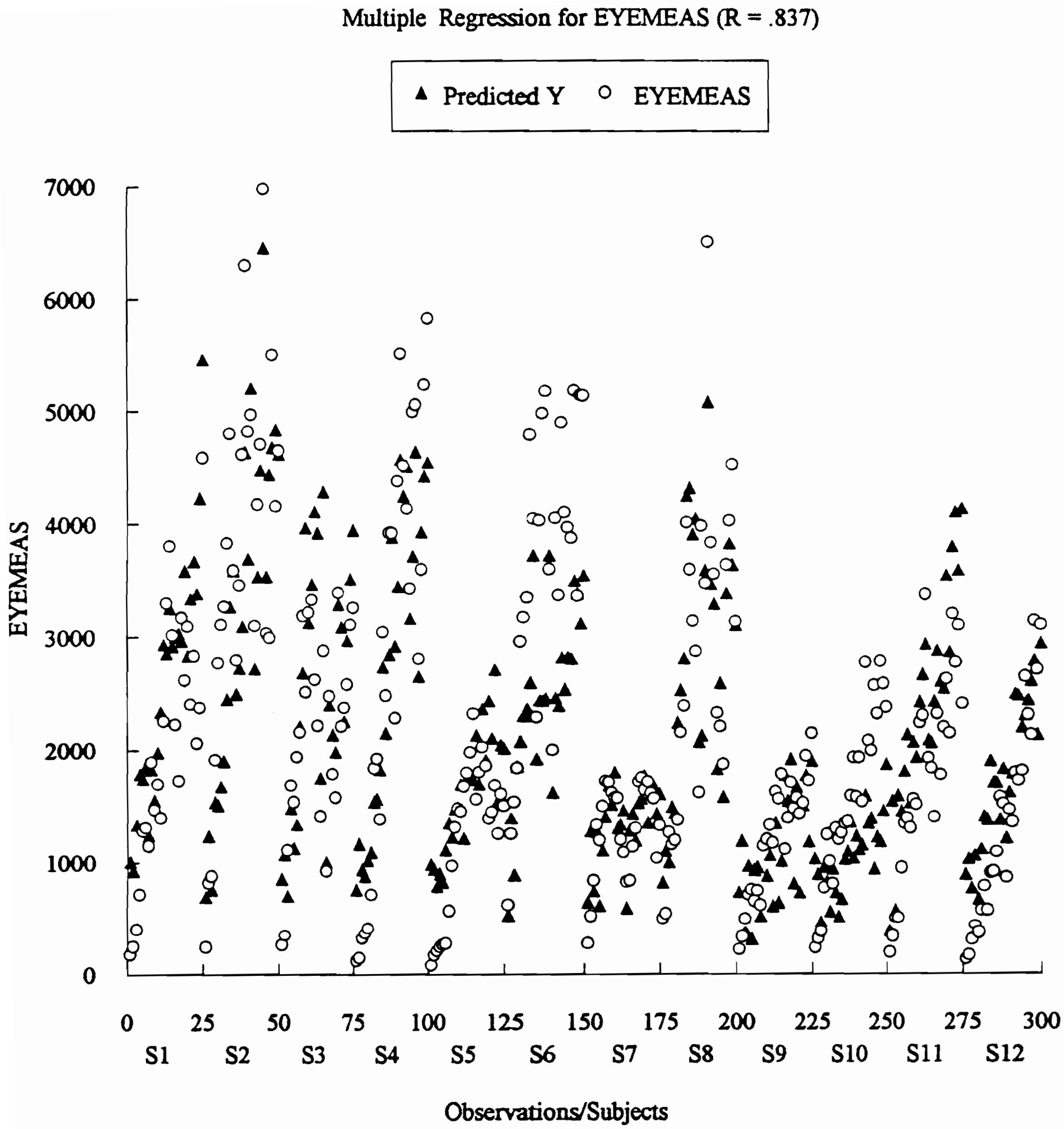
Multiple regression analyses demonstrated that it was possible to track any portion of data. As can be seen in Figures 13, 14, 15, 16, and 17 predicted data tracks the observed data quite accurately. The graphed examples of multiple regression analyses have R values that range from 0.731 to 0.886 as seen in line three of Table 10. The regressors used for these analyses include steering measures, accelerometer measures, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ. (The results correspond to row three of Table 10 and to Appendix F.)

Figure 18 shows a classification matrix that was generated from a *thresholded* multiple regression analysis of the predictor measure PERCLOS. The data that have been classified are the same as those graphed in Figure 16. The thresholds that were used for the purpose of classification in this case were the same as the thresholds used for the discriminant analysis procedure (see Figure 11). Figure 18 shows classifications and misclassifications of three categories of wakefulness. These categories include "Awake," "Questionable," and "Drowsy." The categories of wakefulness are presented along the left side of the table (observed) and across the top of the table (predicted). As an example of



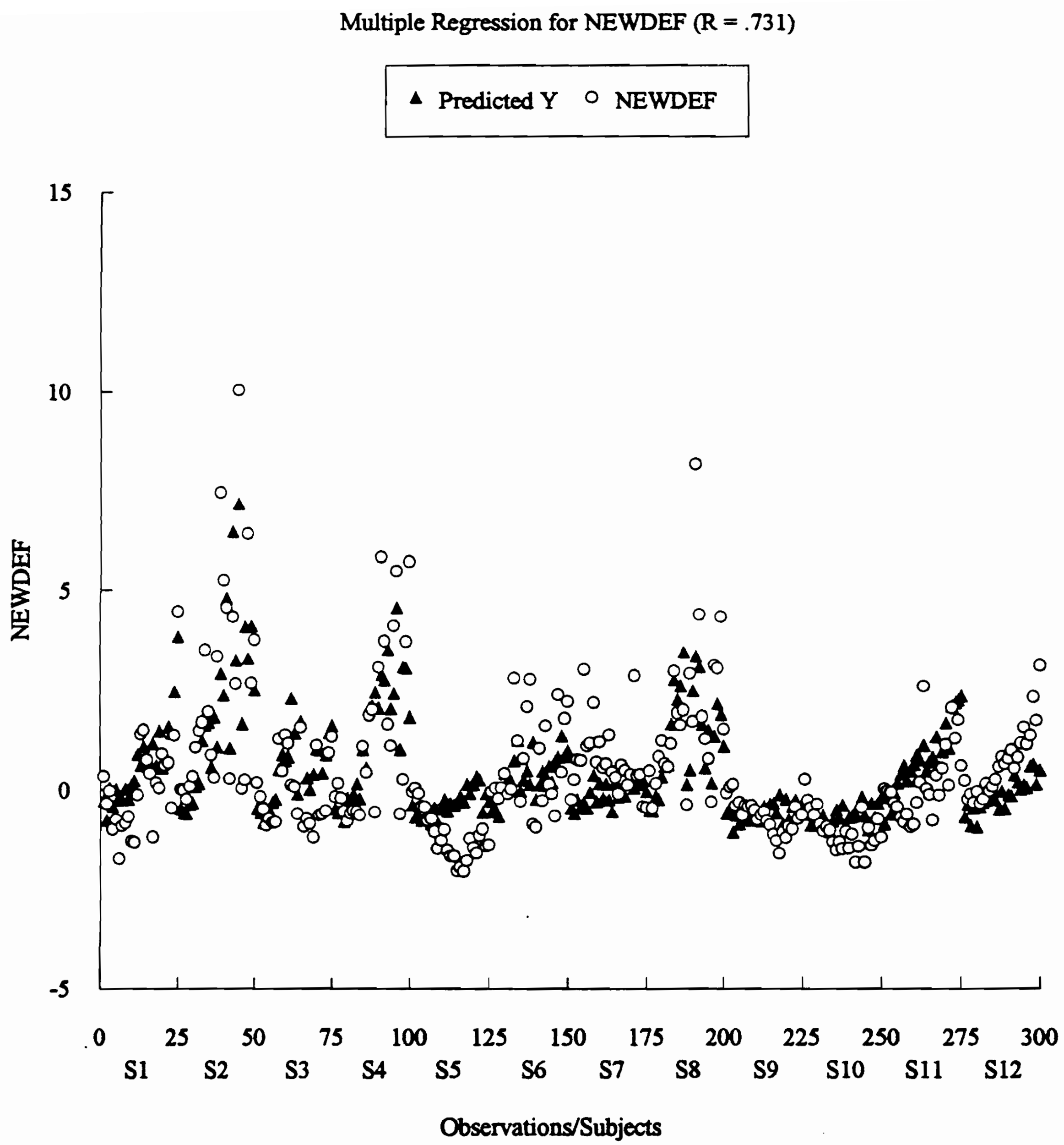
NOTE: The first 25 points on the abscissa correspond to subject 1, the next 25 points correspond to subject 2, and so on.

Figure 13: Scatter Plot of AVEOBS Data -- Predicted vs. Observed.



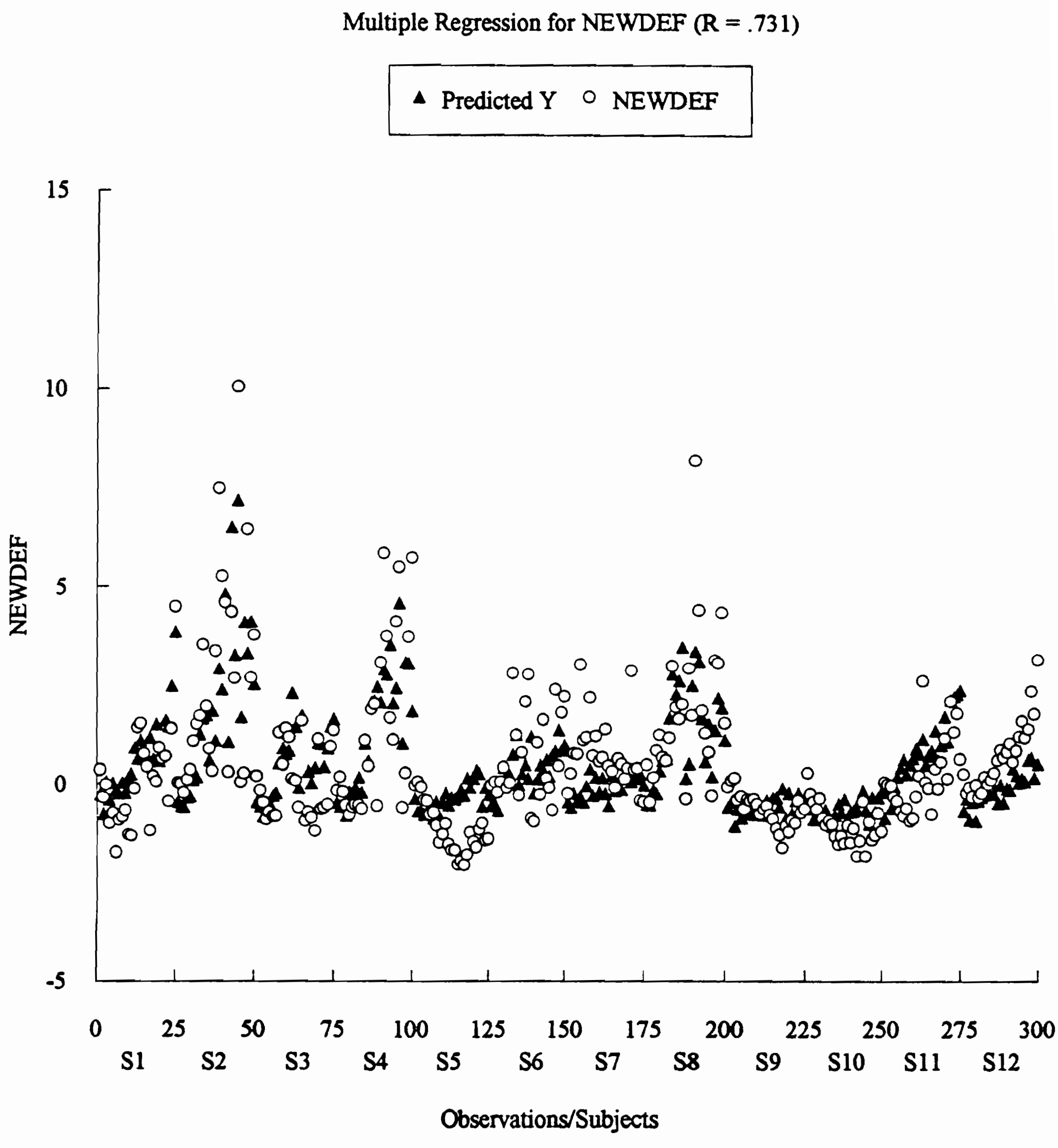
NOTE: The first 25 points on the abscissa correspond to subject 1, the next 25 points correspond to subject 2, and so on.

Figure 14: Scatter Plot of EYEMEAS Data -- Predicted vs. Observed.



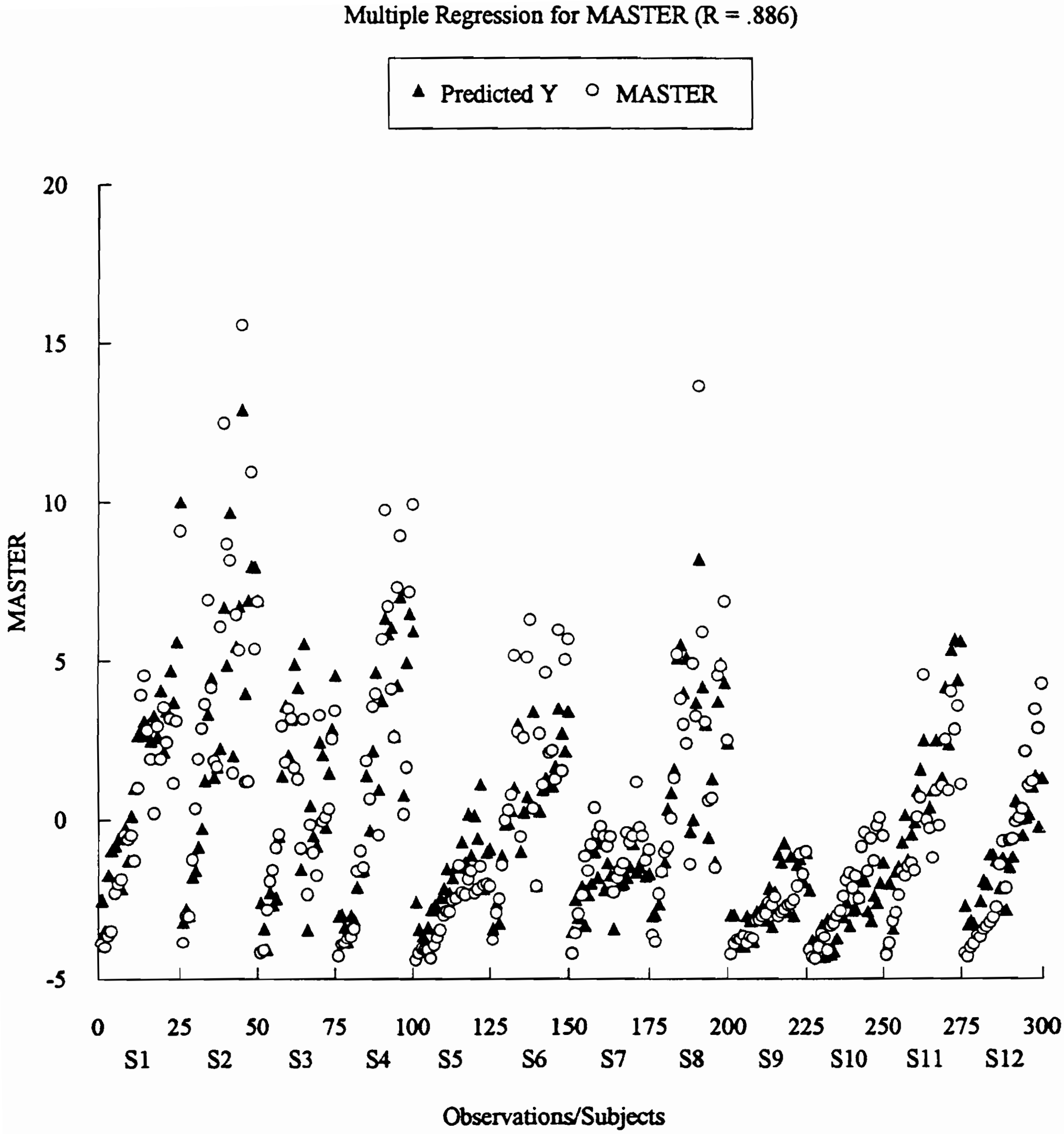
NOTE: **The first 25 points on the abscissa correspond to subject 1, the next 25 points correspond to subject 2, and so on.**

Figure 15: Scatter Plot of NEWDEF Data -- Predicted vs. Observed.



NOTE: The first 25 points on the abscissa correspond to subject 1, the next 25 points correspond to subject 2, and so on.

Figure 16: Scatter Plot of PERCLOS Data -- Predicted vs. Observed.



NOTE: The first 25 points on the abscissa correspond to subject 1, the next 25 points correspond to subject 2, and so on.

Figure 17: Scatter Plot of MASTER Data -- Predicted vs. Observed.

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
	Awake	89.76	**184**	18	3
Observed	Questionable	47.27	7	**21**	16
	Drowsy	62.75	3	16	**32**
	Total	79.00	194	55	51

PERCLOS (R = 0.872).

Apparent Accuracy Rate (large misclassifications): 0.98

Apparent Accuracy Rate (all misclassifications): 0.79

Figure 18: Classification Matrix Generated From Multiple Regression Analysis of PERCLOS Data. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

how to interpret this table find the "18" in the cell located under the predicted category of "Questionable" in the classification matrix. This cell contains 18 misclassifications due to the fact that those 18 data points were classified as "Questionable" by the multiple regression equation but were actually in the "Awake" category. A "large error" is defined as any misclassification in which the predicted classification is two categories away from the observed (actual) classification. For example, data within a cell predicted as "drowsy" that was actually "awake" has been misclassified by two cells. The cells containing "184," "21," and "32" are correct classifications, or hits. Similar thresholded multiple regression results for dependent (definitional) measures EYEMEAS, NEWDEF, and MASTER are located in Figures 33, 35, and 39. These matrices have been placed there for easy comparison with other data in the next phase of the study.

As stated earlier, when performing the multiple regression analyses the beta weights of various measures were first examined. By examining the beta weights the experimenters were able to reduce linear dependency between variables. However, *B*, the nonstandardized numbers from the multiple regression analyses (see Appendices D-V), are the numbers that could be used for further application. The *B* values are the numbers that can be used to create a drowsy driver detection algorithm.

Discriminant Analyses

The results of the discriminant analyses that were run corresponded, in general, with the results attained from the multiple regression analyses. In other words, a high R value resulting from multiple regression usually resulted in an accurate classification matrix. However, it was found that in some instances several of the variables that significantly contributed to drowsiness prediction with multiple regression were not significant with discriminant analysis. The dropping out of previously significant prediction measures was most profound when the set of variables being examined included lane measures or high pass heading measures.

Tables 11, 12, and 13 are summary tables of results obtained from the discriminant analyses. These tables show APARs (apparent accuracy rates) for two-category classifications and three category classifications (all classification errors and large classification errors). Large errors are defined as misclassifications in which a prediction of "awake" is made when the subject is actually "drowsy" or vice versa. More complete results of the discriminant analyses can be seen in Appendices D-V.

Table 14 contains two columns of numbers. One column consists of three-category thresholded regression results and the other consists of three-category discriminant analysis results. This table allows comparison of the results of the thresholded regression models with corresponding three-category discriminant analysis results. When comparing these results it can be seen that the gain in prediction accuracy from discriminant analyses when compared with that of multiple regression is negligible. Two-category thresholded multiple regression analyses were not carried out for comparison with the two-category discriminant analyses because the results would have corresponded closely with the three-category results.

Table 11: Summary Table of Two Category Discriminant Analyses Results Showing APAR.

	Independent Measures	Dependent Measures				
		AVEOBS	EYEMEAS	NEWDEF	PERCLOS	MASTER
D	Steering and Accelerometer	84.0	83.7	81.3	85.0	82.7
E	Steering, Accelerometer, & HPHDGDEV/VAR	84.7	84.3	81.7	89.7	85.7
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	88.7	85.3	84.3	90.33	89.67
G	Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	* 88.0		* 83.0	▲	
H	Steering, Accelerometer, all lane measures, & DSYAWDEV/VAR	89.0	85.0	* 83.7		
I	A/O Task Measures Only	87.0	84.0	83.0	85.0	86.0
J	A/O Task, Steering, & Accelerometer	Accel. 92.0	86.0	Accel. 88.0	88.0	92.0
K	A/O Task, Steering, Accelerometer, & HPHDGDEV/VAR	Accel. 94.0	▲		Accel. 91.0	Δ
L	A/O Task, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ		Δ	87.0	89.0	Δ
M	A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ	Δ			96.0	92.0
N	Heart, Steering, & Accelerometer	85.7	83.7	82.67		
O	Heart, Steering, Accelerometer, & HPHDGDEV/VAR	87.0		83.0	❒	❒
P	Heart, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	89.3		85.7	❒	
Q	Heart, Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	* 87.7		▲		
R	Heart, Steering, Accelerometer, all lane measures, & DSYAWDEV/VAR	❒		steer/LnRT 84.0		
S	A/O Task and Heart			83.0		
T	A/O Task, Heart, Steering, & Accelerometer	Accel. 92.0		Accel. 85.0		
U	A/O Task, Heart, Steering, Accelerometer, & HPHDGDEV/VAR	❒			❒	❒
V	A/O Task, Heart, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ			❒		❒
	A/O, Heart, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ					

KEY:

▲ In these discriminant analyses introduction of variable did not improve prediction value. See entry directly above for model with same prediction value and fewer terms.

❒ Heart measures did not improve prediction value as compared with non-heart equivalent. See corresponding non-heart entry for model with same prediction value and fewer terms.

Δ A/O task measures did not improve prediction value as compared with non-A/O task measure equivalent. See corresponding non-A/O task measure entry for model with same prediction value and fewer terms.

* A cell designated with an asterisk could have been given the ▲ symbol. However, the asterisk denotes a substantially changed algorithm in term of measures used.

NOTES: Blank cells indicate that analysis was not computed because corresponding regression did not show improvement in R value.
Any measure specified in a cell was deleted because of nonsignificance.
Letter in left-hand column corresponds to appendix in which analysis is presented.

Table 12: Summary Table of Three Category Discriminant Analyses Results Showing APAR For All Classification Errors.

	Independent Measures	Dependent Measures: AVEOBS	EYEMEAS	NEWDEF	PERCLOS	MASTER
D	Steering and Accelerometer	72.7	80.7	74.0	78.3	77.7
E	Steering, Accelerometer, & HPHDGDEV/VAR	73.0	81.0	73.3	81.3	80.3
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	77.0	82.7	71.7	85.0	82.3
G	Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	✳ 74.7		75.3	▲	
H	Steering, Accelerometer, all lane measures, & DSYAWDEV/VAR	78.3	83.0	73.0		
I	A/O Task Measures Only	81.0	82.0	72.0	79.0	80.0
J	A/O Task, Steering, & Accelerometer	87.0	85.0	Accel. 89.0	Accel. 77.0	85.0
K	A/O Task, Steering, Accelerometer, & HPHDGDEV/VAR	Accel. 90.0	▲		Δ	Accel. 87.0
L	A/O Task, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ		86.0	79.0	82.0	Δ
M	A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ	Δ			89.0	90.0
N	Heart, Steering, & Accelerometer	72.7	79.0	75.0		
O	Heart, Steering, Accelerometer, & HPHDGDEV/VAR	73.0		76.3	❑	❑
P	Heart, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	78.3		76.7	83.7	
Q	Heart, Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	✳ 77.7		▲		
R	Heart, Steering, Accelerometer, all lane measures, & DSYAWDEV/VAR	✳ 77.7		LnRT 77.3		
S	A/O Task and Heart			77.0		
T	A/O Task, Heart, Steering, & Accelerometer	Accel. 85.0		Accel. 89.0		
U	A/O Task, Heart, Steering, Accelerometer, & HPHDGDEV/VAR	❑			❑	❑
V	A/O Task, Heart, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ			82.0		❑ Δ
	A/O, Heart, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ					

KEY:

▲ In these discriminant analyses introduction of variable did not improve prediction value. See entry directly above for model with same prediction value and fewer terms.

❑ Heart measures did not improve prediction value as compared with non-heart equivalent. See corresponding non-heart entry for model with same prediction value and fewer terms.

Δ A/O task measures did not improve prediction value as compared with non-A/O task measure equivalent. See corresponding non-A/O task measure entry for model with same prediction value and fewer terms.

✳ A cell designated with an asterisk could have been given the ▲ symbol. However, the asterisk denotes a substantially changed algorithm in term of measures used.

NOTES: Blank cells indicate that analysis was not computed because corresponding regression did not show improvement in R value.
Any measure specified in a cell was deleted because of nonsignificance.
Letter in left-hand column corresponds to appendix in which analysis is presented.

Table 13: Summary Table of Three Category Discriminant Analyses Results Showing APAR for Large Classification Errors.

	Independent Measures	Dependent Measures				
		AVEOBS	EYEMEAS	NEWDEF	PERCLOS	MASTER
D	Steering and Accelerometer	93.3	87	91.7	94.0	95.0
E	Steering, Accelerometer, & HPHDGDEV/VAR	94.33	88.3	91.3	96.3	96.7
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	96.7	90.0	92.0	97.3	97.0
G	Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	✳ 95.7		93.0	▲	
H	Steering, Accelerometer, all lane measures, & DSYAWDEV/VAR	✳ 95.7	90.3	✳ 92.7		
I	A/O Task Measures Only	89.0	87.0	91.0	95.0	94.0
J	A/O Task, Steering, & Accelerometer	93.0	90.0	Accel. 93.0	Accel. 96.0	99.0
K	A/O Task, Steering, Accelerometer, & HPHDGDEV/VAR	Accel. 98.0	▲		Δ	Accel. 99.0
L	A/O Task, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ		93.0	100.0	94.0	Δ
M	A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ	Δ			99.0	99.0
N	Heart, Steering, & Accelerometer	94.3	86.3	93.00		
O	Heart, Steering, Accelerometer, & HPHDGDEV/VAR	95.3		93.7	❑	❑
P	Heart, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	96.0		94.7	96.7	
Q	Heart, Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	96.33		▲		
R	Heart, Steering, Accelerometer, all lane measures, & DSYAWDEV/VAR	✳ 96.0		LnRT 95.0		
S	A/O Task and Heart			92.0		
T	A/O Task, Heart, Steering, & Accelerometer	Accel. 94.0		Accel. 96.0		
U	A/O Task, Heart, Steering, Accelerometer, & HPHDGDEV/VAR	❑			❑	❑
V	A/O Task, Heart, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ			96.0		❑ Δ
	A/O, Heart, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ					

KEY:

▲ In these discriminant analyses introduction of variable did not improve prediction value. See entry directly above for model with same prediction value and fewer terms.

❑ Heart measures did not improve prediction value as compared with non-heart equivalent. See corresponding non-heart entry for model with same prediction value and fewer terms.

Δ A/O task measures did not improve prediction value as compared with non-A/O task measure equivalent. See corresponding non-A/O task measure entry for model with same prediction value and fewer terms.

✳ A cell designated with an asterisk could have been given the ▲ symbol. However, the asterisk denotes a substantially changed algorithm in term of measures used.

NOTES: Blank cells indicate that analysis was not computed because corresponding regression did not show improvement in R value.
Any measure specified in a cell was deleted because of nonsignificance.
Letter in left-hand column corresponds to appendix in which analysis is presented.

Table 14: Comparison of Apparent Accuracy Rates for Thresholded Regression Models and Corresponding Discriminant Analysis Models. (Comparisons are for the Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ Independent Measure Cases; Appendix F).

Definitional (Dependent) Measures	Type of Accuracy	Regression Results	Three-Category Discriminant Analyses
AVEOBS	APAR (Large Errors)	0.957	0.967
	APAR (All Errors)	0.753	0.770
EYEMEAS	APAR (Large Errors)	0.937	0.900
	APAR (Large Errors)	0.780	0.827
NEWDEF	APAR (All Errors)	0.957	0.920
	APAR (All Errors)	0.710	0.717
PERCLOS	APAR (Large Errors)	0.980	0.973
	APAR (All Errors)	0.790	0.850
MASTER	APAR (Large Errors)	0.980	0.970
	APAR (All Errors)	0.830	0.823
AVERAGES OF	APAR (Large Errors)	0.962	0.946
ABOVE	APAR (All Errors)	0.772	0.797

DISCUSSION and CONCLUSIONS of the DEVELOPMENT PHASE

In general, all five definitional (dependent) measures were reasonably predictable as seen in Tables 10, 11, 12, and 13. Discriminant analyses showed, in particular, that the number of large errors is relatively small. In fact, in a few cases the number of large errors is as low as one or two per 100 cases. In addition, the difference between discriminant analysis results and multiple regression results was quite small in many cases and nonexistent in others.

Models Including Heart Measures Versus Models Not Including Heart Measures

The potential gains are quite modest if it is assumed that a plethysmograph could be secured to an automobile driver. When comparing heart and non-heart models in Tables 10-13 (lines 1 through 5 versus 11 through 15) the number of open cells (cells containing no R value or APAR number), cells containing squares, and cells containing solid triangles in lines 11 through 15 demonstrates that in many cases there is no improvement when heart rate measures are introduced. The R value of NEWDEF improves by approximately 0.05 when heart measures are added. However, in most cases the addition of the heart rate variables contributes little or nothing to the prediction accuracy of drowsiness. On the whole, it is not worth encumbering the driver with a plethysmograph to obtain heart rate measures for the slight improvement in the prediction of drowsiness.

Models Including A/O-Task Measures Versus Models Not Including A/O-Task Measures

Models in which A/O-task measures have been introduced produce relatively high predictive values compared with non-A/O task measure results as seen in Tables 10-13. The number of large errors is in the range of 1% or less. Results of this nature suggest that the A/O task does contribute to prediction accuracy. However, it must be recognized that the A/O-task models are based on data from four subjects and therefore the models may have higher R values and APAR values because it is easier to fit a model to four subjects than to twelve subjects.

Overview

It is concluded on the basis of Table 14 that regression models, after thresholding, are capable of producing comparable accuracy to three-category (two-threshold) discriminant analysis models. In fact, large errors are slightly fewer in multiple regression than in discriminant analysis. However, the total number of errors is slightly greater for multiple regression than for discriminant analysis.

While the models developed in this study are relatively accurate, the fact remains that they will produce some false alarms. The best estimate of the false alarm rate for drivers who have been sleep deprived is that given by the large error APARs that appear in Table 14. The results suggest that error rates of 2% to 3% are likely to occur. (Error rates for alert drivers are likely to be lower because they would be less likely to produce model outputs near threshold).

The fact that a finite false alarm rate remains suggests that a two-stage detection algorithm procedure should be used. In the first stage, the A/O task would not be performed and an algorithm appearing in rows one through five of Table 10 would be used. Once threshold is exceeded, indicating potential drowsiness, the driver would be asked to perform the A/O task. If the A/O-task algorithm then produced a value above threshold the driver would be assumed to be drowsy. A two-step algorithm of this type might produce sufficiently low false alarm rates so as to be acceptable for applications.

The first stage of detection involves driver-vehicle performance measures only. It is suggested that the first and third rows of Table 10 represent the most viable algorithms. The third row assumes the availability of a lane track and provides better accuracy than row one. However, if a lane track is not available the first row could be used. Algorithms in the first row of Table 10 include steering and lateral accelerometer measures. These two measures are assumed to be nearly 100% reliable and should be used exclusively if a valid lane track is not available.

With regard to the predictability of the definitional measures of drowsiness, results demonstrate that PERCLOS and MASTER are most predictable, followed by EYEMEAS, AVEOBS, and NEWDEF. These results are best seen in Table 14 but also show up in Tables 10, 11, 12, and 13. In general, the results suggest that the algorithms developed by regression and using a threshold with a two stage process should provide a viable, accurate, and low false alarm system of detection for drowsy drivers.

On the basis of Table 14 it would be concluded that a two-category regression model would have comparable accuracy to a two-category discriminant analysis model. Because of the comparable accuracy obtainable for regression models it is recommended that only regression models with thresholds be implemented in future validation and full scale studies. The advantage of using thresholded regression models is that the threshold(s) can be adjusted for sensitivity in operational settings. Discriminant analysis models, on the other hand, must be re-computed for each new setting of threshold. This would involve an on-line optimization process.

PHASE THREE

VALIDATION OF DROWSINESS DETECTION ALGORITHMS

Research Objectives of the Algorithm Validation Phase

This portion of the drowsy driver detection study involves the validation of algorithms resulting from multiple regression analyses obtained during the algorithm development phase. Selected drowsiness detection algorithms were used in the validation procedure. Validation of the algorithms was achieved by placing a new group of subjects under conditions similar to those experienced by the subjects used in the development phase. The detection algorithms were then applied to the new data. The purpose of testing several of the algorithms was 1) to test the algorithms' drowsiness prediction strength over differing subject pools, and 2) to test algorithms employing differing variables so that a step-up, step-down procedure might be developed in the future for on-the-road applications.

METHOD

Subjects

In the validation portion of the study, data were collected from twelve subjects, as was the case for data collection for the algorithm development phase of the study. The subject population was located in the Blacksburg, Virginia area and the same screening procedures were used as the previous phase of the study. However, eight males and four females were used during the validation study instead of six males and six females. The use of twice as many males as females was determined to be a more accurate representation of the high risk driver population. It has recently been determined that males substantially outnumber females in drowsiness related automobile accidents (Knipling and Wierwille, 1994). The subjects ranged in age from 18 to 47. The subjects were paid according to the hourly rate of the previous phase of the study and were involved with the experiment for approximately the same amount of time.

During data collection one subject stayed completely awake and had a heart rate of 90 beats per minute for the entire run. This subject's data were not used. While running another subject the EEG electrodes loosened late in the run. Examination of the data led the experimenters to suspect that the EEG data had been corrupted and therefore, the subject's data were not used. The two problem subjects were replaced with two additional subjects, resulting in a total of twelve complete data sets.

Apparatus

The apparatus employed was identical to that of the previous phase of the study with one exception.

Simulator. The simulator was equipped with a cruise control system that allowed the experimenters to place the simulator in a cruise-control state which locked the velocity of the simulated automobile at 60 miles per hour. The cruise control could also be switched off by the experimenters, at which time it was necessary for the driver to maintain the speed of the automobile using the accelerator pedal.

Experimental Design

The experimental design involved a regression approach to data analysis. All drivers were subjected to the following conditions during driving: with cruise/with task, with cruise/without task, without cruise/with task, and without cruise/without task. The "task" in this case refers to the A/O subsidiary task described previously in the algorithm development report (Wreggit, Kirn, and Wierwille, 1993). Each subject performed the A/O task for one-half of the entire run. Therefore, it was necessary for each subject to perform the A/O task for 72 minutes. While the A/O task performance measures were being collected, all other measures were being collected simultaneously. Subjects received counter balanced combinations of the conditions. Each condition lasted 36 minutes. The subjects did not interact with the instrument panel as was done by some subjects in the algorithm development phase.

The performance and physiological measures that were gathered during the study were the same as the performance and physiological measures included in the previously developed drowsiness detection algorithms.

Procedure

All subjects underwent the same pre-driving procedures as the previously run subjects and stayed at the Vehicle Analysis and Simulation Lab for approximately the same amount of time.

Experimental task. All subjects drove the simulated automobile as if it were an actual car. All subjects performed the same A/O subsidiary task that was employed during the algorithm development phase. In addition, a cruise control condition was incorporated into the driving task. When the cruise control was engaged the simulated automobile maintained 60 miles per hour. When the cruise control was not engaged the subject was asked to maintain approximately 60 miles per hour. Subjects drove for a total of 156 minutes.

Data Analysis Overview

All collected measures were averaged on-line and one-minute intervals were recorded. Data manipulation procedures were then undertaken to prepare data for statistical analyses. Initially, the first two minutes from all measures were deleted. This was done so that the data to be analyzed did not include the time when subjects were "settling in" to the driving task. This procedure was consistent with the algorithm development phase.

The collected one-minute averages of all independent (predictor) measures were baselined using the average of the first ten minutes of data (after the actual first two minutes had been deleted). The average of the first ten minutes of data was then subtracted from every subsequent one-minute interval within that measure. After completion of the baselining procedure the ten minutes of data used for the baselining average were discarded. Following the baselining procedure the data were averaged across six-minute intervals. See Figure 19 for a pictorial overview of the data manipulation procedure.

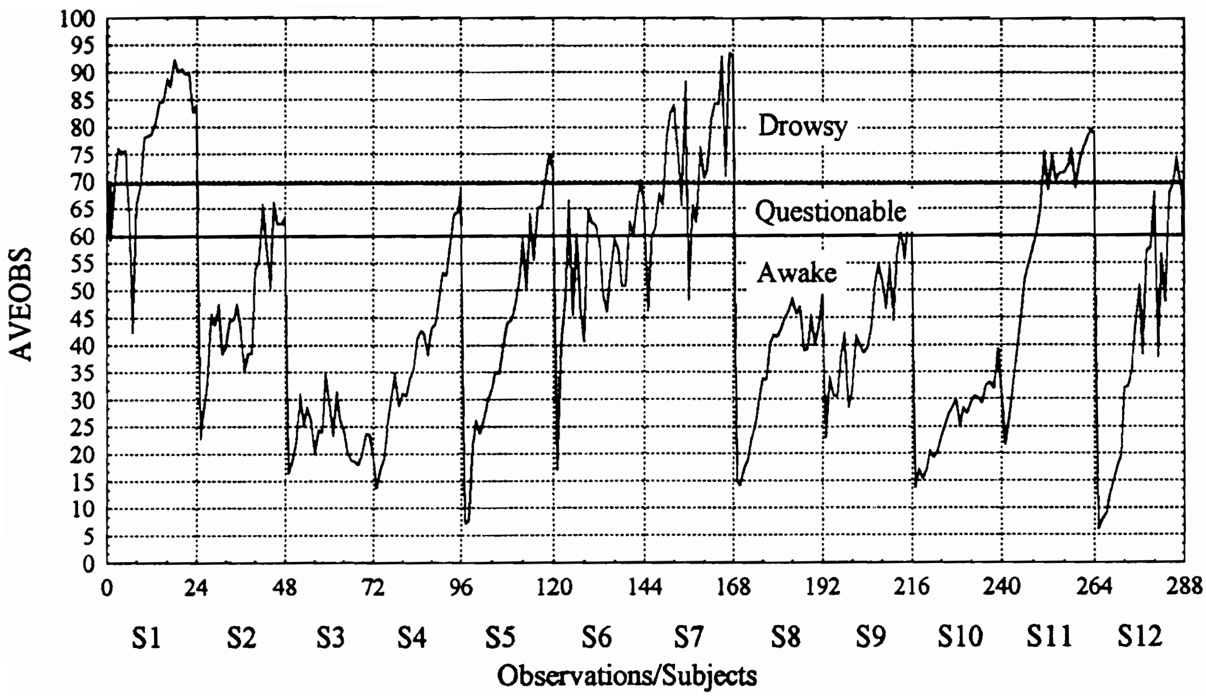
As seen in Figures 20, 21, 22, 23, and 24 the five dependent (definitional) variables were graphed for each subject with threshold lines drawn. The threshold lines were developed during the algorithm development study and were placed over the new data set. In these graphs, the first 24 points on the abscissa correspond to subject 1, the next 24 points correspond to subject 2, and so on.

After data manipulation, previously developed drowsiness detection algorithms were applied to the new data set. Once algorithm outputs (predicted values) were calculated, a regression analysis was run between those values and the applicable definitional measure (observed) values. After completion of this procedure a comparison between the R values attained from the original data and new data was carried out. The algorithms that were tested can be seen highlighted in Table 15. (Those with gray background were not tested.)

2 minutes: The first 2 minutes are deleted from all data	
First 10 minutes after deletion of 2 previous minutes 10 minute average calculated	10 minutes used for baselining* 10 minutes discarded after baseline
6 minutes: average of 6 one-minute measure values	
6 minutes: average of 6 one-minute measure values	
6 minutes: average of 6 one-minute measure values	
6 minutes: average of 6 one-minute measure values	
6 minutes: average of 6 one-minute measure values	
6-minute averages continued until the entire set of one-minute segments (144 minutes) was manipulated. 156 total minutes were used due to the deletion of the first 12 minutes of data. Therefore, twenty-four 6-minute intervals were created.	

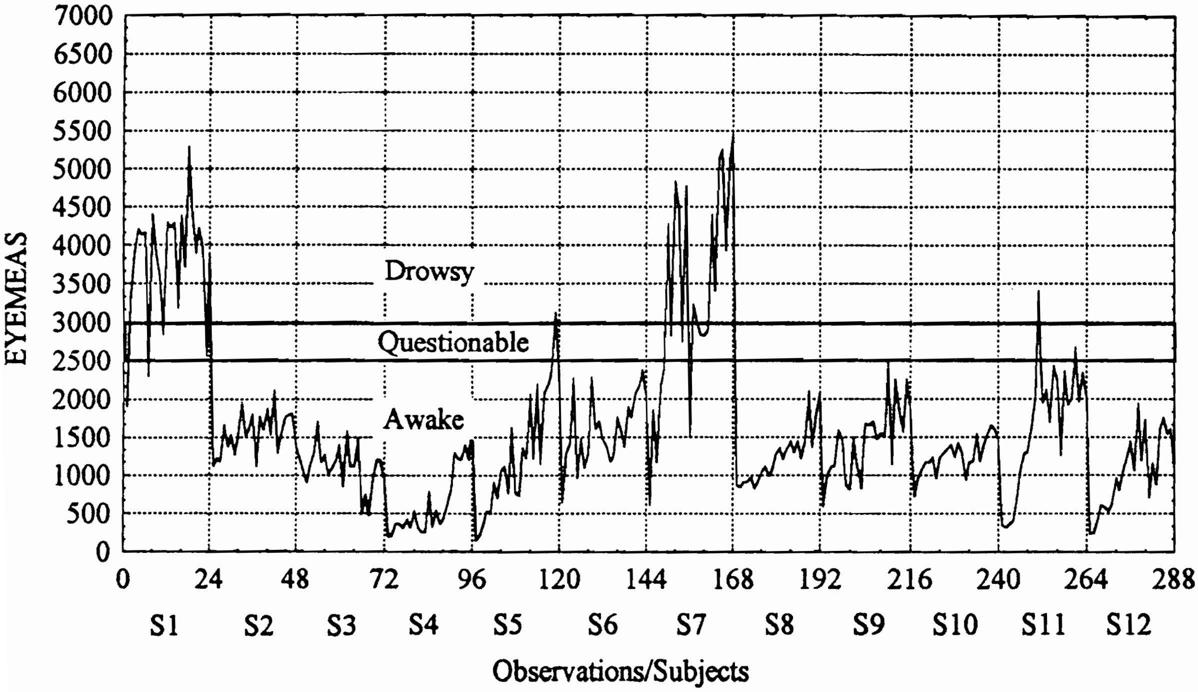
* Baselining is a procedure in which the initial ten minutes of data are averaged and then subtracted from all subsequent one-minute segments. Baselining was carried out so that data relative to the subject's initial data values could be obtained.

Figure 19: Pre-Analysis Data Manipulation Procedures.



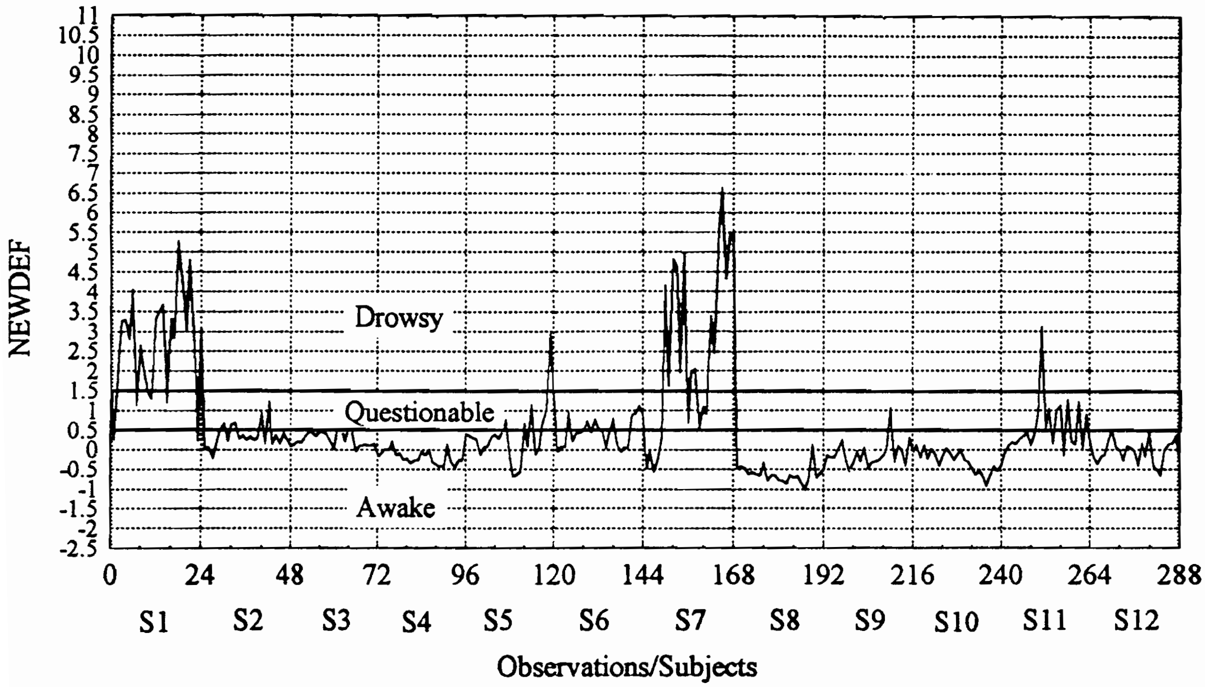
NOTE: The first 24 points on the abscissa correspond to subject 1, the next 24 points correspond to subject 2, and so on.

Figure 20: AVEOBS Data With Upper and Lower Criterion Lines (New Data).



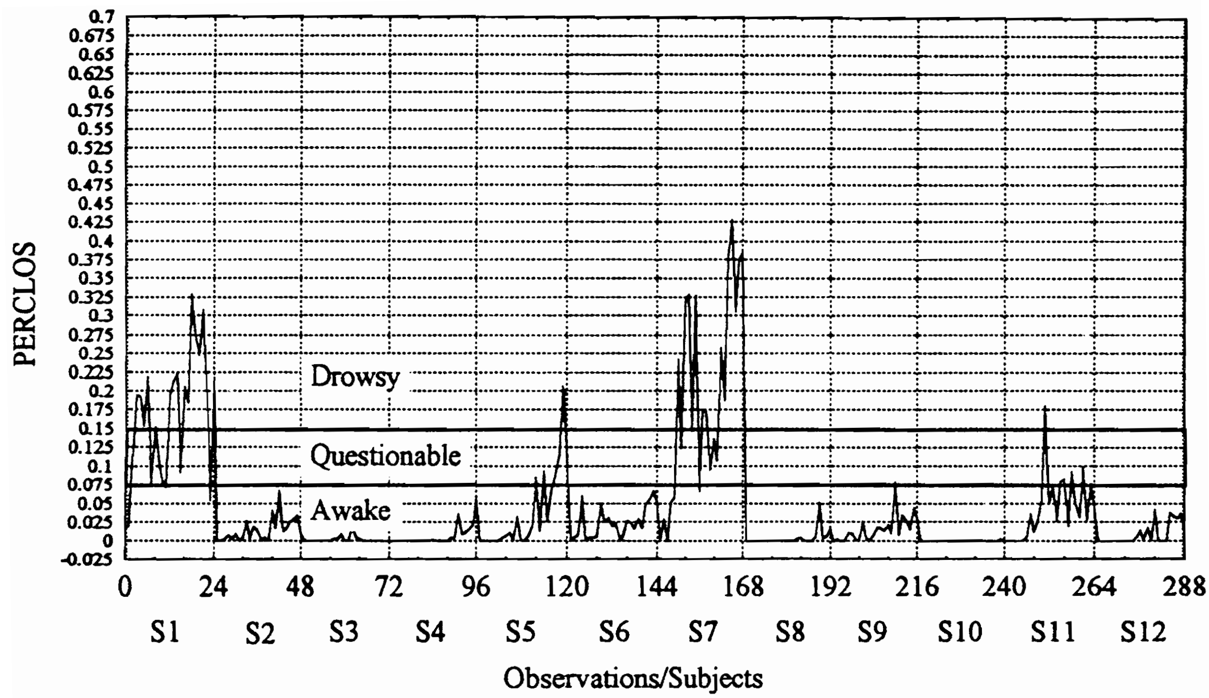
NOTE: The first 24 points on the abscissa correspond to subject 1, the next 24 points correspond to subject 2, and so on.

Figure 21: EYEMEAS Data With Upper and Lower Criterion Lines (New Data).



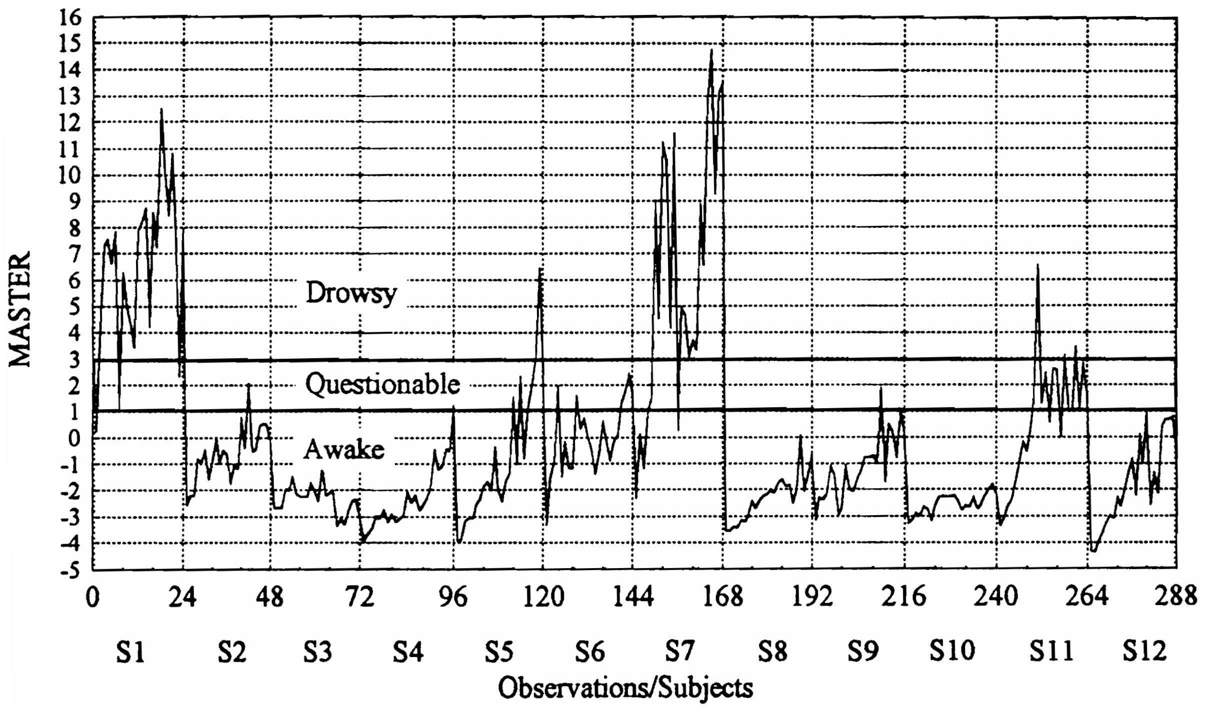
NOTE: The first 24 points on the abscissa correspond to subject 1, the next 24 points correspond to subject 2, and so on.

Figure 22: NEWDEF Data With Upper and Lower Criterion Lines (New Data).



NOTE: The first 24 points on the abscissa correspond to subject 1, the next 24 points correspond to subject 2, and so on.

Figure 23: PERCLOS Data With Upper and Lower Criterion Lines (New Data).



NOTE: The first 24 points on the abscissa correspond to subject 1, the next 24 points correspond to subject 2, and so on.

Figure 24: MASTER Data With Upper and Lower Criterion Lines (New Data).

Table 15: Summary Table of Multiple Regression Results (Calculated in the Development Phase) Showing Algorithms Used for Validation.

	Independent Measures	Dependent Measures: AVEOBS	EYEMEAS	NEWDEF	PERCLOS	MASTER
D	Steering and Accelerometer	**0.747**	**0.764**	**0.677**	**0.789**	**0.801**
E	Steering, Accelerometer, & HPHDGDEV/VAR	0.793	0.809	0.700	0.847	0.852
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	**0.826**	**0.837**	**0.731**	**0.872**	**0.886**
G	Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	0.824	▲	0.757	0.872	▲
H	Steering, Accelerometer, all lane measures, & DSYAWDEV/VAR	✳ 0.826	0.836	✳ 0.751	▲	▲
I	A/O Task Measures Only	**0.761**	**0.768**	**0.660**	**0.810**	**0.822**
J	A/O Task, Steering, & Accelerometer	Accel 0.824	0.824	Accel. 0.740	**0.836**	0.876
K	A/O Task, Steering, Accelerometer, & HPHDGDEV/VAR	0.917	Steering 0.855	▲	Accel. 0.868	0.903
L	A/O Task, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ	Δ	0.874	0.768	**0.875**	0.903
M	A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ	0.922	Δ	Δ	0.902	**0.936**
N	Heart, Steering, & Accelerometer	0.785	0.772	0.711	❐	❐
O	Heart, Steering, Accelerometer, & HPHDGDEV/VAR	0.813	❐	0.761	0.851	0.854
P	Heart, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	0.838	❐	0.774	0.874	❐
Q	Heart, Steering, Accelerometer, & all lane measures (includes LNRTDEV/VAR)	✳ 0.816	❐	0.802	❐	❐
R	Heart, Steering, Accelerometer, all lane measures, & DSYAWDEV/VAR	Lane Rate 0.837	❐	steer/LnRT 0.797	▲	❐
S	A/O Task and Heart	❐	❐	0.774	❐	❐
T	A/O Task, Heart, Steering, & Accelerometer	Accel. 0.837	❐	Accel. 0.810	❐	❐
U	A/O Task, Heart, Steering, Accelerometer, & HPHDGDEV/VAR	0.918	❐	▲	Accel. 0.880	0.909
V	A/O Task, Heart, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	❐	❐	0.823	❐	0.910
	A/O, Heart, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	❐	Δ	Δ	❐	❐

KEY:

▲ In regression analyses introduction of variable did not improve R value. See entry directly above for model with same R and fewer terms.

❐ Heart Measures did not improve regression as compared with non-heart equivalent. See corresponding non-heart entry for model with same R value and fewer terms.

Δ A/O task measures did not improve regression as compared with non-A/O task measure equivalent. See corresponding non-A/O task measure entry for model with same R value and fewer terms.

✳ A cell designated with an asterisk could have been given the ▲ symbol. However, the asterisk denotes a substantially changed algorithm in term of measures used.

NOTES: Letter in left-hand column corresponds to appendix in which analysis is presented. Highlighted values indicate algorithms that were validated by applying new data.

The comparison between the R values attained from the original data and the new data was accomplished using t-test and analysis of variance procedures. Multiple R values were used as data for these comparisons.

The algorithms that were chosen for validation were selected for several reasons. It was desirable for the R values to be relatively high and for the measures within the algorithms to be attainable in an on-the-road vehicle. Also, it was necessary to choose algorithms that could be employed in a step-up, step-down procedure. For example, if all incoming signals to be used in an algorithm are valid, the best available algorithm for drowsiness detection would be used. However, if one of the sensors necessary for the best algorithm is not providing a valid signal, the next best algorithm that does not require the invalid signal would be used.

RESULTS of the VALIDATION PHASE - DRIVER-VEHICLE PERFORMANCE MEASURES ONLY

This section describes the validation process for algorithms using driver-vehicle performance measures only. During the experimental runs there were intervals during which the A/O task was performed and there were intervals during which the A/O task was not performed. Similarly, there were intervals during which the cruise control was engaged and during which it was not engaged. Throughout these various intervals, driver-vehicle performance measures were computed. This section reports on the validation results using the driver-vehicle performance measures only. That is, it does not include measures taken from the A/O task itself. The term "all-data" indicates that performance data are included from all 156 minutes of each driver's data run, regardless of whether or not the A/O task was being performed and regardless of whether or not the simulated vehicle was in cruise. When specific sections of the data runs are referred to they are so designated. For example, the section of the run in which the A/O task was being performed and cruise was not engaged is referred to as "With Task, W/O Cruise."

Application of Algorithms to New Data

Table 16 is a summary of 1) results that were attained from multiple regression analyses of the original data and 2) the correlation between new observed data and the algorithm output when the algorithm was applied to new data. The R values attained from the original data set are included in this table so that easy comparison between R values can be made. There was no general decrease in predictive power of the algorithms when applied to the new data $\underline{t}(9) = 0.24$, $p > 0.05$. The average R values of the original and new data can be seen graphically in Figure 25.

The new data were divided into four categories, including combinations of cruise control and A/O subsidiary task data so that the effects of cruise control and A/O task

Table 16: R Values From Multiple Regression Analyses of Original Data and R Values Achieved After Application of Algorithms to New Data.

	Independent Measures	AVEOBS	EYEMEAS	NEWDEF	PERCLOS	MASTER
			Dependent Measures			
D	Steering and Accelerometer	**(original) 0.747** **Algorithm D1a** **(new) 0.727**	(original) 0.764 Algorithm D2a (new) 0.777	(original) 0.677 Algorithm D3a (new) 0.746	**(original) 0.789** **Algorithm D4a** **(new) 0.800**	**(original) 0.801** **Algorithm D5a** **(new) 0.837**
F	Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ	(original) 0.826 Algorithm F1a (new) 0.570	**(original) 0.837** **Algorithm F2a** **(new) 0.838**	**(original) 0.731** **Algorithm F3a** **(new) 0.819**	**(original) 0.872** **Algorithm F4a** **(new) 0.862**	**(original) 0.886** **Algorithm F5a** **(new) 0.885**

NOTES: Letters in left column indicate appendices containing detailed analyses on original data set.

Algorithm numbers located in each cell correspond to the multiple regression table within a given appendix.

Classification matrices were created for the highlighted (bolded) R values. (See Figures 27, 29, 31, 33, 35, 37, and 39 .)

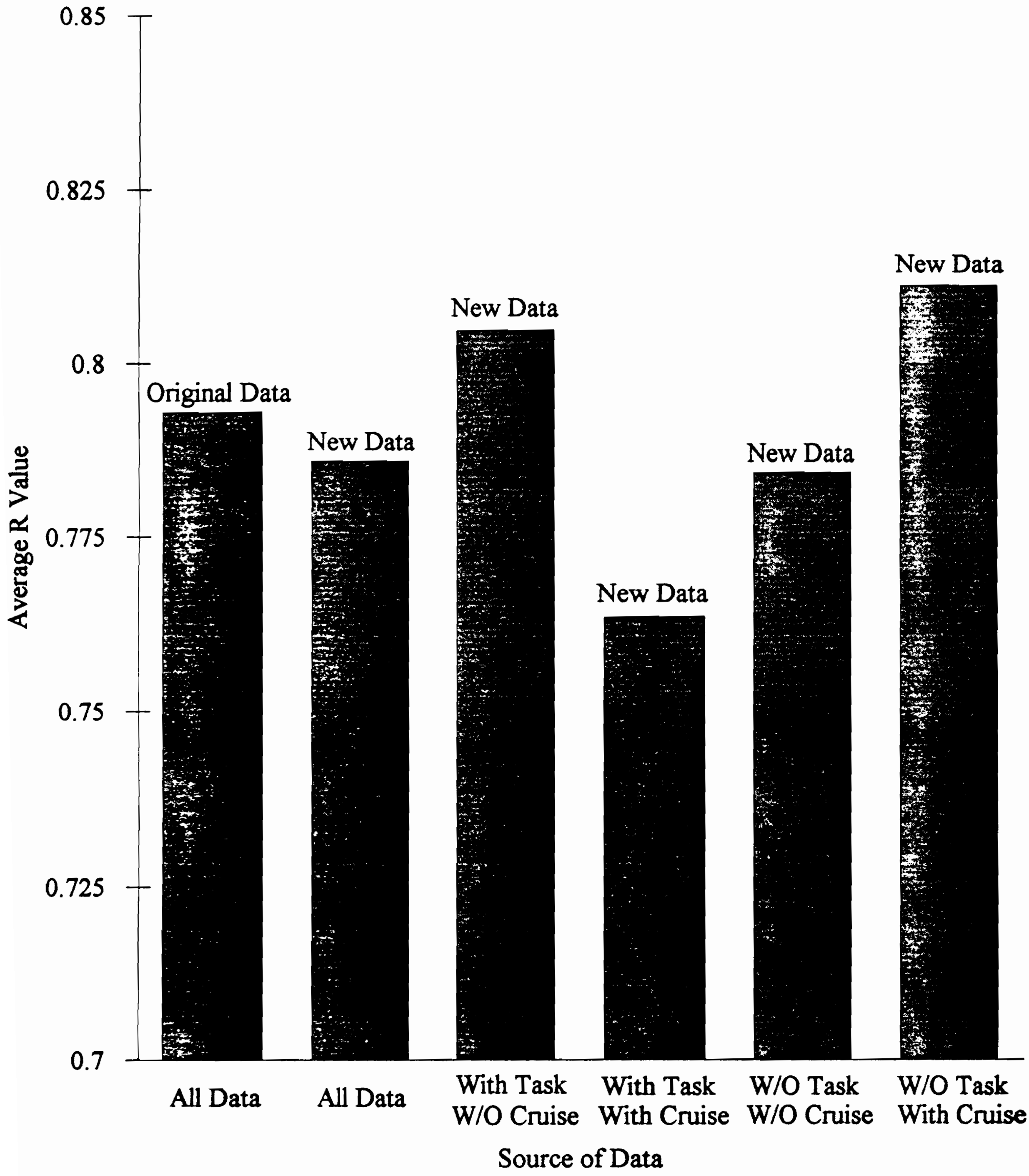


Figure 25: Average R Values for Ten Algorithms (See Table 16) Applied to Original Data, New Data, and Four Conditions From the New Data

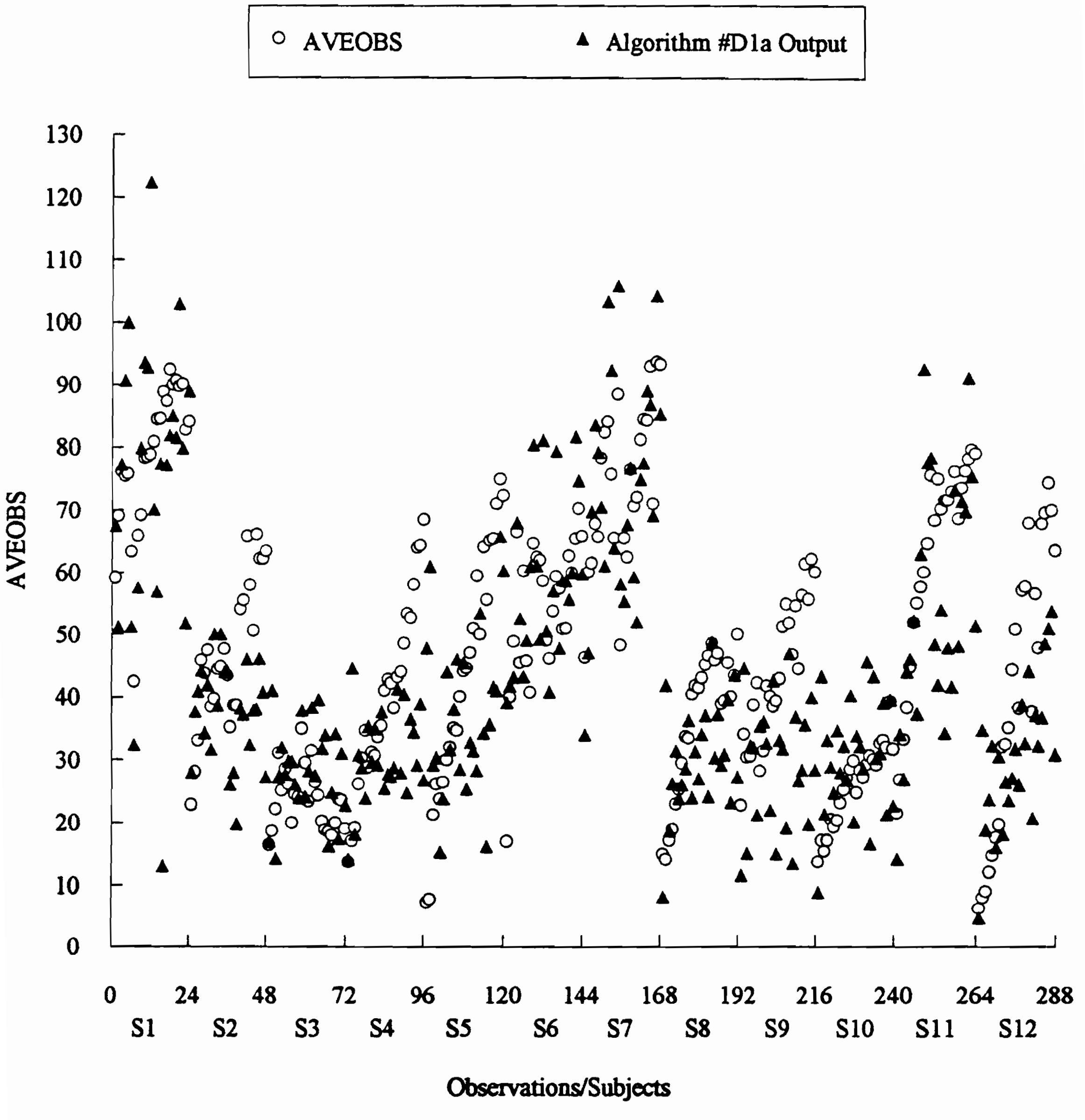
could be examined (Figure 25). A 2 x 2 within subjects analysis of variance was run to test for the effects of cruise control and secondary task performance on R values. No significant main effects were seen (Cruise Control: $\underline{F}(1, 9) = 0.177$, $p > 0.05$, A/O Task: $\underline{F}(1, 9) = 0.129$, $p > 0.05$). However, a significant cruise control-A/O-task interaction was indicated by the results of the analysis of variance $\underline{F}(1, 9) = 10.67$, $p < 0.01$. To determine how the groups differed, a Tukey HSD test was used. The results of the post hoc test showed that only the Without Task/With Cruise condition and the With Task/With Cruise condition were significantly different from one another at a 0.05 level of confidence. The differences between the other pair of conditions were not significant at a 0.05 level of confidence.

Regression analyses on the new observed data (definitional measure values) and the new predicted data (from application of algorithms) demonstrated that it was possible to track any portion of the new data with the previously developed detection algorithms. As can be seen in Figures 26, 28, 30, 32, 34, 36, and 38, predicted data tracks the observed data quite accurately. The graphed examples have R values that range from 0.727 to 0.885 (See bold entries in Table 16).

Figures 27, 29, 31, 33, 35, 37, and 39 show classification matrices that were generated from a thresholded multiple regression analysis of the five definitional measures of drowsiness. The upper matrices in Figures 26, 28, 30, 32, 34, 36, and 38 are classified original data (algorithm output) and the lower matrices are classified new data (algorithm output). The data that were classified are the same as those graphed in Figures 26, 28, 30, 32, 34, 36, and 38. The thresholds that were used for the purpose of classification were the same as those produced during the algorithm development phase. The thresholds are illustrated in Figures 20, 21, 22, 23, and 24.

Regression lines were drawn using the bolded <u>original</u> R values seen in Table 16 and the corresponding APAR values of the <u>new</u> data in Figures 26, 28, 30, 32, 34, 36, and 38.

New AVEOBS and Algorithm #D1a Applied to New Data (R = 0.727)



NOTE: The first 24 points on the abscissa correspond to subject 1, the next 24 points correspond to subject 2, and so on.

Figure 26: Scatter Plot of AVEOBS Data -- Predicted vs. Observed.

		Predicted				
	Group	% Correct	Awake	Questionable	Drowsy
Original	Awake	93.41	**156**	6	5
Observed	Questionable	18.87	36	**10**	7
	Drowsy	50.00	19	21	**40**
	Total	68.67	211	37	52

AVEOBS (R Value = 0.747)

Apparent Accuracy Rate (large misclassifications): 0.920
Apparent Accuracy Rate (all misclassifications): 0.687

Classification Matrix Generated From Multiple Regression Analysis of **Original AVEOBS** Data Resulting in **Algorithm D1a**. (Independent variables employed included Steering and Accelerometer.)

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	96.43	**189**	5	2
Observed	Questionable	12.20	29	**5**	7
	Drowsy	62.75	14	5	**32**
	Total	78.47	232	15	41

AVEOBS (R Value = 0.727)

Apparent Accuracy Rate (large misclassifications): 0.944
Apparent Accuracy Rate (all misclassifications): 0.785

Algorithm D1a Applied to New Data and Compared with New Observed **AVEOBS** Data

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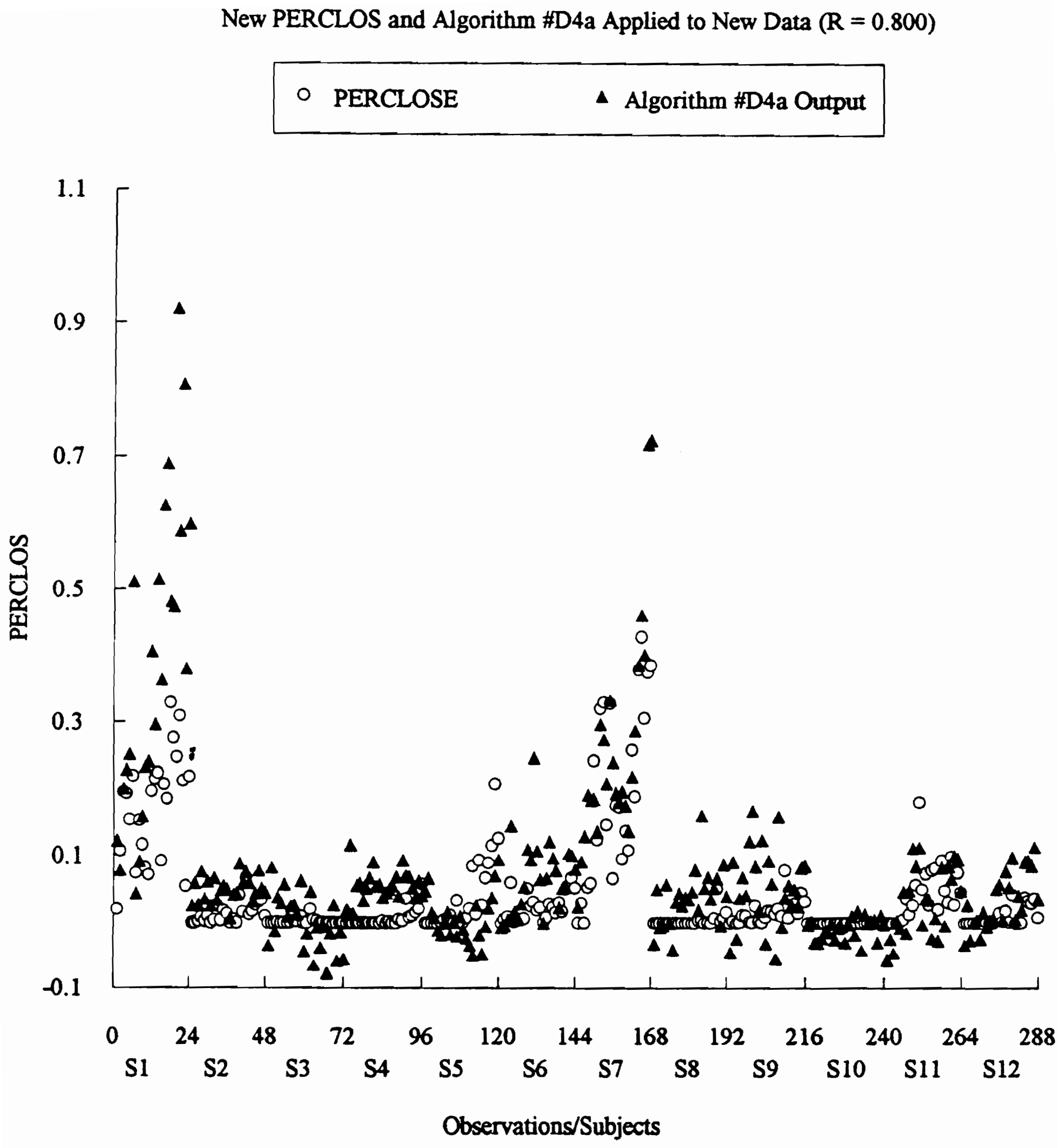
Figure 27: Classification Matrices Showing Accuracy of Algorithm D1a When Applied to Original Data (Upper) and New Data (Lower)



NOTE: The first 24 points on the abscissa correspond to subject 1, the next 24 points correspond to subject 2, and so on.

Figure 28: Scatter Plot of PERCLOS Data -- Predicted vs. Observed.

		Predicted				
	Group	% Correct	Awake	Questionable	Drowsy
Original	Awake	88.29	**181**	22	2
Observed	Questionable	43.18	11	**19**	14
	Drowsy	52.94	2	22	**27**
	Total	75.67	194	63	43

PERCLOS (R Value = 0.789)

Apparent Accuracy Rate (large misclassifications): 0.987
Apparent Accuracy Rate (all misclassifications): 0.757

Classification Matrix Generated From Multiple Regression Analysis of **Original PERCLOS** Data Resulting in **Algorithm D4a**. (Independent variables employed included Steering and Accelerometer.)

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	79.32	**188**	40	9
Observed	Questionable	30.00	8	**6**	6
	Drowsy	90.32	1	2	**28**
	Total	77.08	197	48	43

PERCLOS (R Value = 0.800)

Apparent Accuracy Rate (large misclassifications): 0.965
Apparent Accuracy Rate (all misclassifications): 0.771

Algorithm D4a Applied to New Data and Compared with New Observed **PERCLOS** Data

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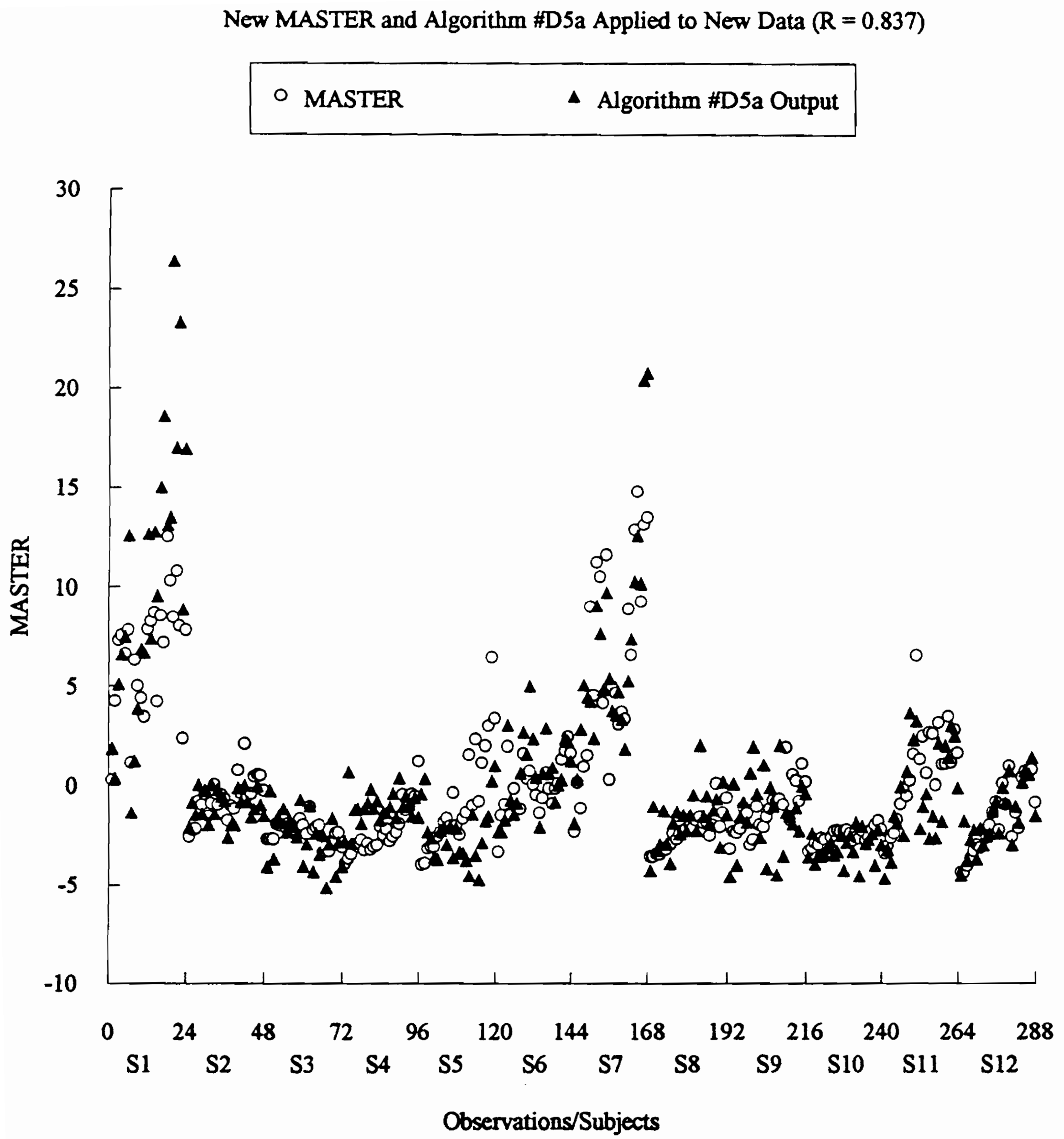
Figure 29: Classification Matrices Showing Accuracy of Algorithm D4a When Applied to Original Data (Upper) and New Data (Lower)



NOTE: The first 24 points on the abscissa correspond to subject 1, the next 24 points correspond to subject 2, and so on.

Figure 30: Scatter Plot of MASTER Data -- Predicted vs. Observed.

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
Original	Awake	93.53	**188**	10	3
Observed	Questionable	33.33	14	**14**	14
	Drowsy	52.63	3	24	**30**
	Total	77.33	205	48	47

MASTER (R Value = 0.801)

Apparent Accuracy Rate (large misclassifications): 0.980
Apparent Accuracy Rate (all misclassifications): 0.773

Classification Matrix Generated From Multiple Regression Analysis of **Original MASTER** Data Resulting in **Algorithm D5a**. (Independent variables employed included Steering and Accelerometer.)

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	93.52	**202**	10	4
Observed	Questionable	25.93	16	**7**	4
	Drowsy	80.00	4	5	**36**
	Total	85.07	222	22	44

MASTER (R Value = 0.837)

Apparent Accuracy Rate (large misclassifications): 0.972
Apparent Accuracy Rate (all misclassifications): 0.851

Algorithm D5a Applied to New Data and Compared with New Observed MASTER Data

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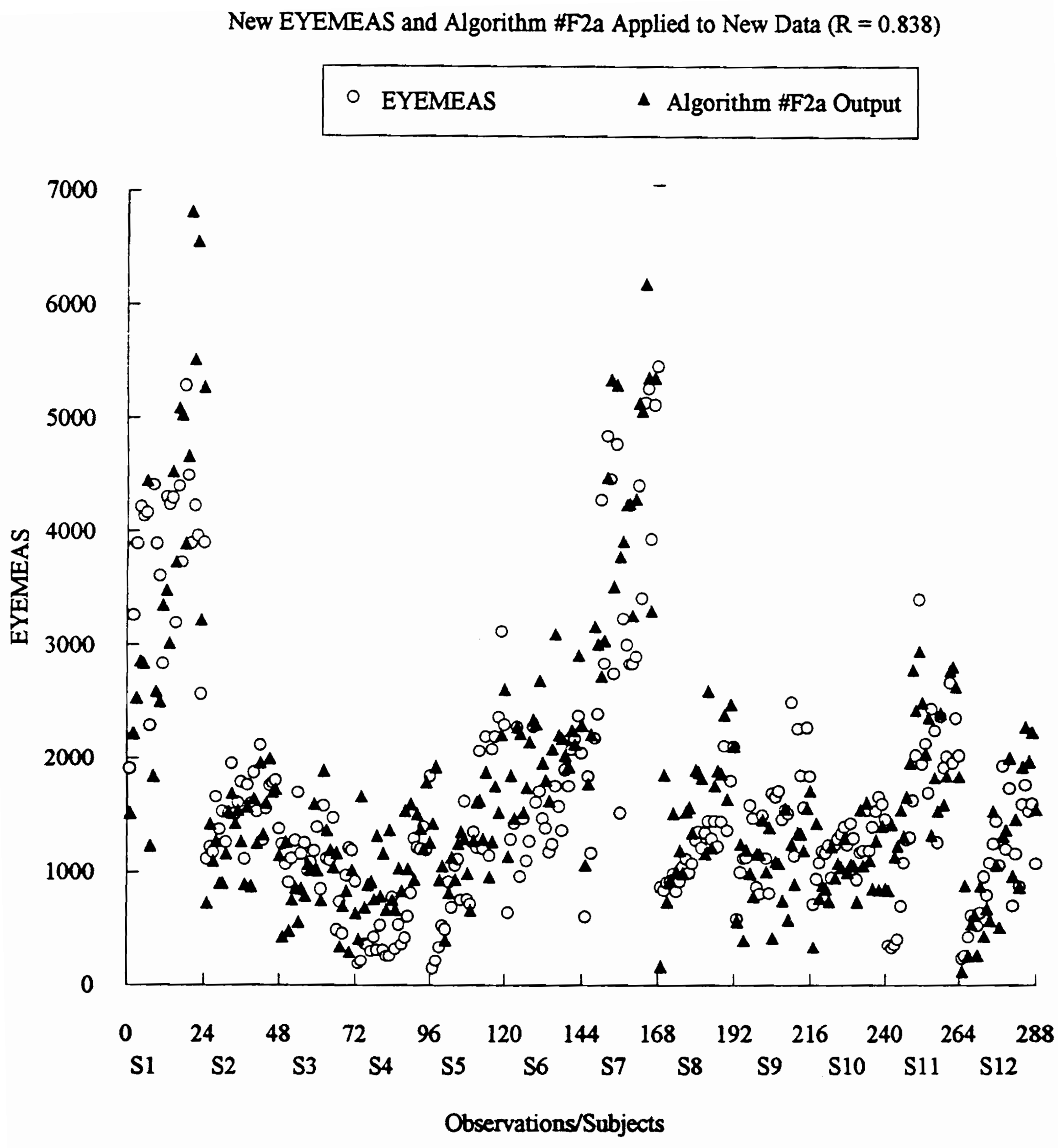
Figure 31: Classification Matrices Showing Accuracy of Algorithm D5a When Applied to Original Data (Upper) and New Data (Lower)



NOTE: The first 24 points on the abscissa correspond to subject 1, the next 24 points correspond to subject 2, and so on.

Figure 32: Scatter Plot of EYEMEAS Data -- Predicted vs. Observed.

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
Original	Awake	90.10	**182**	12	8
Observed	Questionable	10.00	9	**2**	9
	Drowsy	64.10	11	17	**50**
	Total	78.00	202	31	67

EYEMEAS (R Value = 0.837)

Apparent Accuracy Rate (large misclassifications): 0.963
Apparent Accuracy Rate (all misclassifications): 0.780

Classification Matrix Generated From Multiple Regression Analysis of **Original EYEMEAS** Data Resulting in **Algorithm F2a**. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	95.51	**234**	7	4
Observed	Questionable	12.50	0	**1**	7
	Drowsy	71.43	3	7	**25**
	Total	90.28	237	15	36

EYEMEAS (R Value = 0.838)

Apparent Accuracy Rate (large misclassifications): 0.976
Apparent Accuracy Rate (all misclassifications): 0.903

Algorithm F2a Applied to New Data and Compared with New Observed **EYEMEAS** Data

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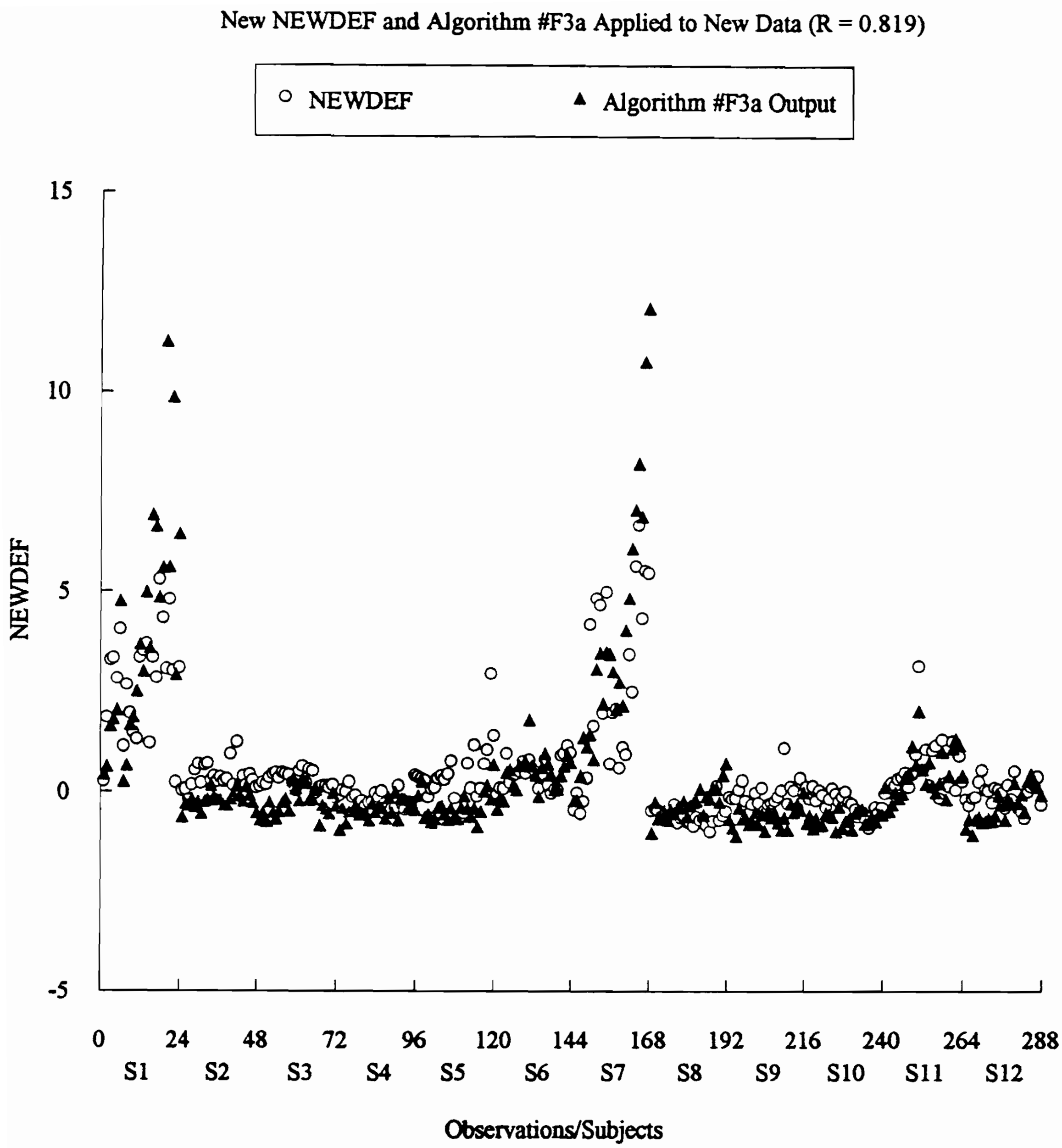
Figure 33: Classification Matrices Showing Accuracy of Algorithm F2a When Applied to Original Data (Upper) and New Data (Lower)



NOTE: The first 24 points on the abscissa correspond to subject 1, the next 24 points correspond to subject 2, and so on.

Figure 34: Scatter Plot of NEWDEF Data -- Predicted vs. Observed.

		Predicted				
	Group	% Correct	Awake	Questionable	Drowsy
Original	Awake	83.42	**161**	26	6
Observed	Questionable	35.29	25	**18**	8
	Drowsy	62.50	8	13	**35**
	Total	71.33	194	57	49

NEWDEF (R Value = 0.731)

Apparent Accuracy Rate (large misclassifications): 0.953

Apparent Accuracy Rate (all misclassifications): 0.713

Classification Matrix Generated From Multiple Regression Analysis of **Original NEWDEF** Data Resulting in **Algorithm F3a**. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	93.36	**197**	13	1
Observed	Questionable	26.19	23	**11**	8
	Drowsy	85.71	1	4	**30**
	Total	82.64	221	28	39

NEWDEF (R Value = 0.819)

Apparent Accuracy Rate (large misclassifications): 0.993

Apparent Accuracy Rate (all misclassifications): 0.826

Algorithm F3a Applied to New Data and Compared with New Observed **NEWDEF** Data

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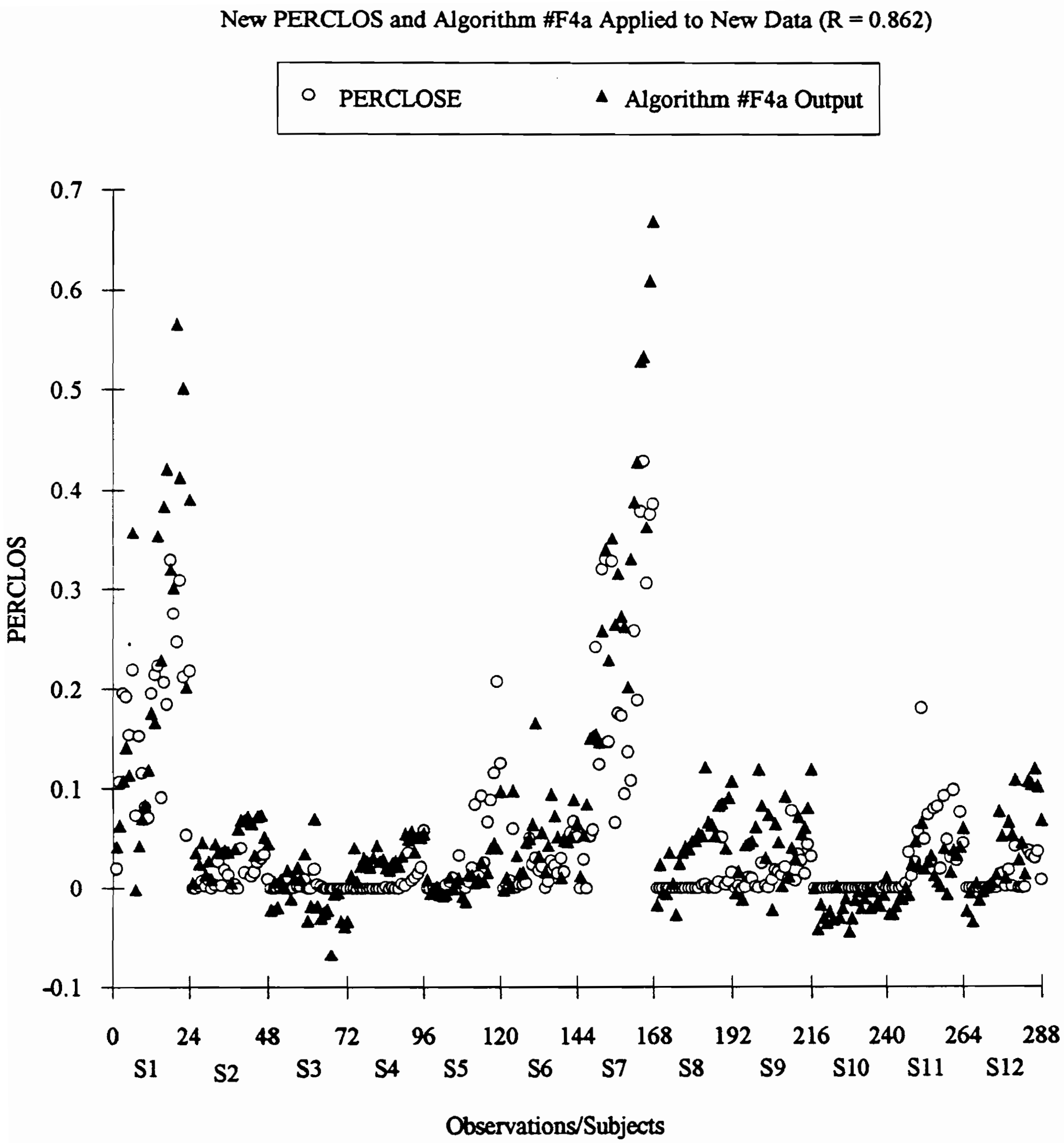
Figure 35: Classification Matrices Showing Accuracy of Algorithm F3a When Applied to Original Data (Upper) and New Data (Lower)



NOTE: The first 24 points on the abscissa correspond to subject 1, the next 24 points correspond to subject 2, and so on.

Figure 36: Scatter Plot of PERCLOS Data -- Predicted vs. Observed.

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
Original	Awake	89.76	**184**	18	3
Observed	Questionable	47.73	7	**21**	16
	Drowsy	62.75	3	16	**32**
	Total	79.00	194	55	51

PERCLOS (R Value = 0.872)

Apparent Accuracy Rate (large misclassifications): 0.980
Apparent Accuracy Rate (all misclassifications): 0.790

Classification Matrix Generated From Multiple Regression Analysis of **Original PERCLOS** Data Resulting in **Algorithm F4a**. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	89.03	**211**	22	4
Observed	Questionable	15.00	12	**3**	5
	Drowsy	80.65	3	3	**25**
	Total	82.99	226	28	34

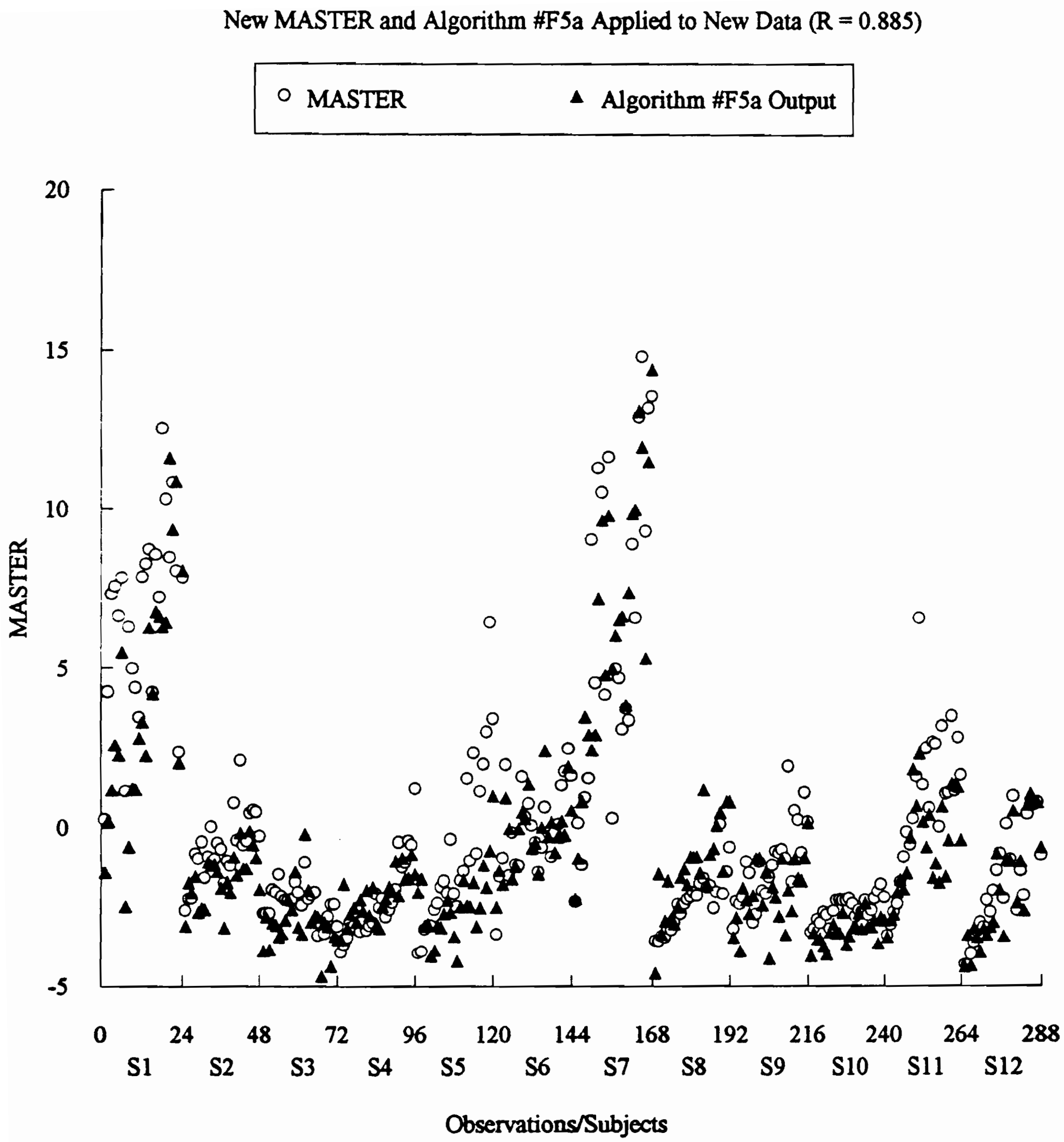
PERCLOS (R Value = 0.862)

Apparent Accuracy Rate (large misclassifications): 0.976
Apparent Accuracy Rate (all misclassifications): 0.830

Algorithm F4a Applied to New Data and Compared with New Observed **PERCLOS** Data

---

Figure 37: Classification Matrices Showing Accuracy of Algorithm F4a When Applied to Original Data (Upper) and New Data (Lower)



NOTE: The first 24 points on the abscissa correspond to subject 1, the next 24 points correspond to subject 2, and so on.

Figure 38: Scatter Plot of MASTER Data -- Predicted vs. Observed.

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
Original	Awake	94.53	**190**	9	2
Observed	Questionable	45.24	9	**19**	14
	Drowsy	71.93	3	13	**41**
	Total	83.33	202	41	57

MASTER (R Value = 0.886)

Apparent Accuracy Rate (large misclassifications): 0.983
Apparent Accuracy Rate (all misclassifications): 0.833

Classification Matrix Generated From Multiple Regression Analysis of **Original MASTER** Data Resulting in **Algorithm F5a**. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	96.76	**209**	5	2
Observed	Questionable	18.52	22	**5**	0
	Drowsy	62.22	6	11	**28**
	Total	84.03	237	21	30

MASTER (R Value = 0.885)

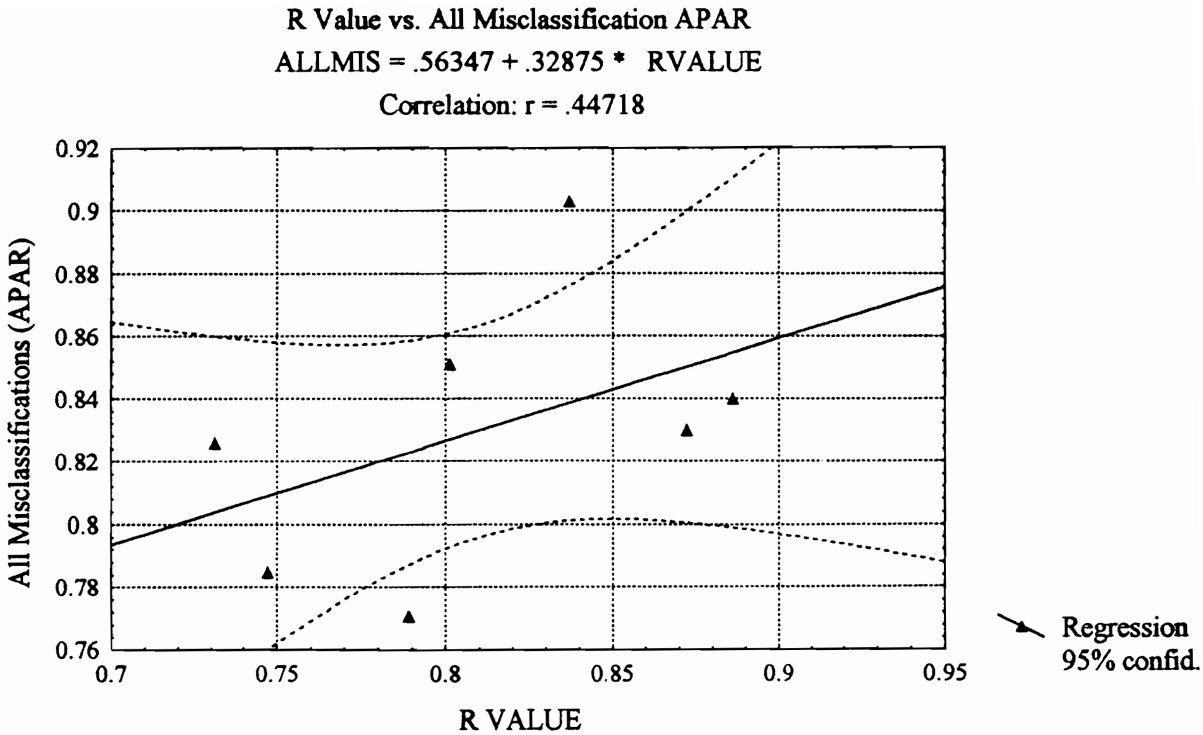
Apparent Accuracy Rate (large misclassifications): 0.972
Apparent Accuracy Rate (all misclassifications): 0.840

Algorithm F5a Applied to New Data and Compared with New Observed **MASTER** Data

---

Figure 39: Classification Matrices Showing Accuracy of Algorithm F5a When Applied to Original Data (Upper) and New Data (Lower)

The regression lines can be seen in Figure 40. The two plots give a general idea of what APAR value can be achieved given certain drowsiness prediction R values for twelve subjects. In other words, if an algorithm based on data from twelve subjects is developed, it can be expected to produce APAR values in a validation study as provided by the regression lines in Figure 40. The reader is cautioned that the correlation coefficients associated with the data are not significant ($p > 0.05$), and therefore the prediction capabilities provided by Figure 40 are indicative and not conclusive.



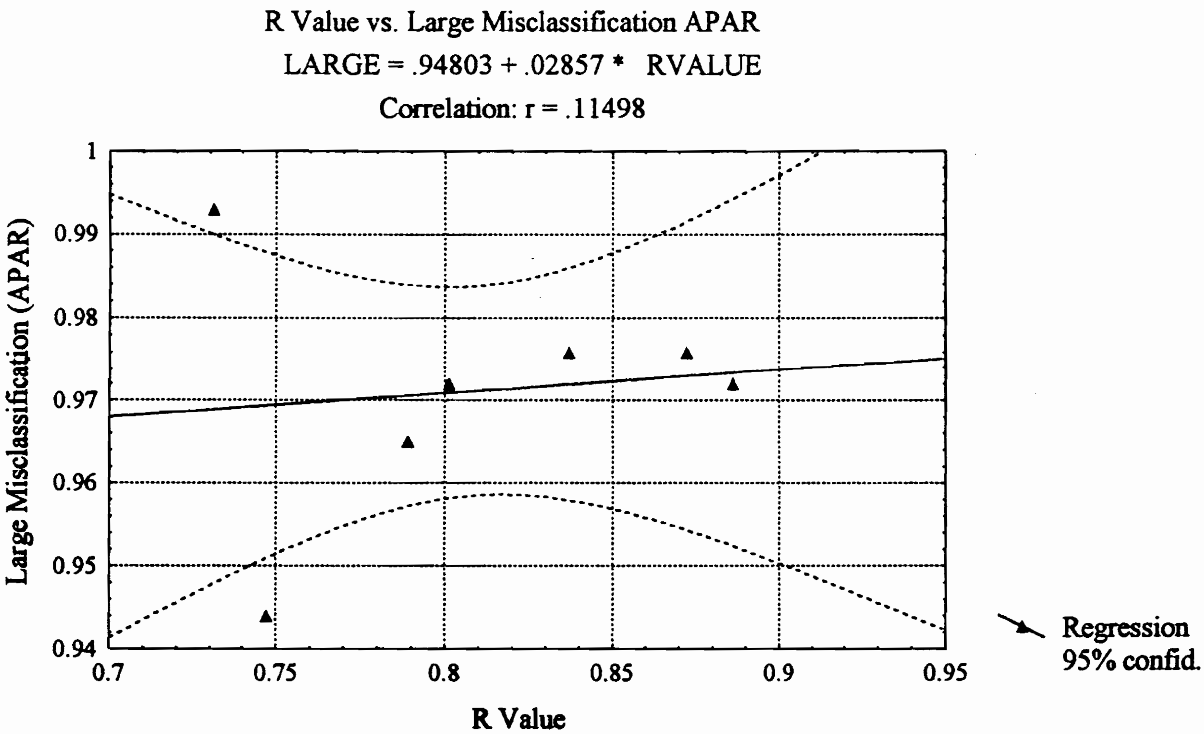


Figure 40: R Values vs. New Data APAR Values -- APAR Include All Misclassifications (Upper Graph) and Large Misclassifications Only (Lower Graph).

RESULTS of the VALIDATION PHASE - INCLUSION OF A/O TASK PERFORMANCE DATA

Models Containing A/O Task Performance Measures

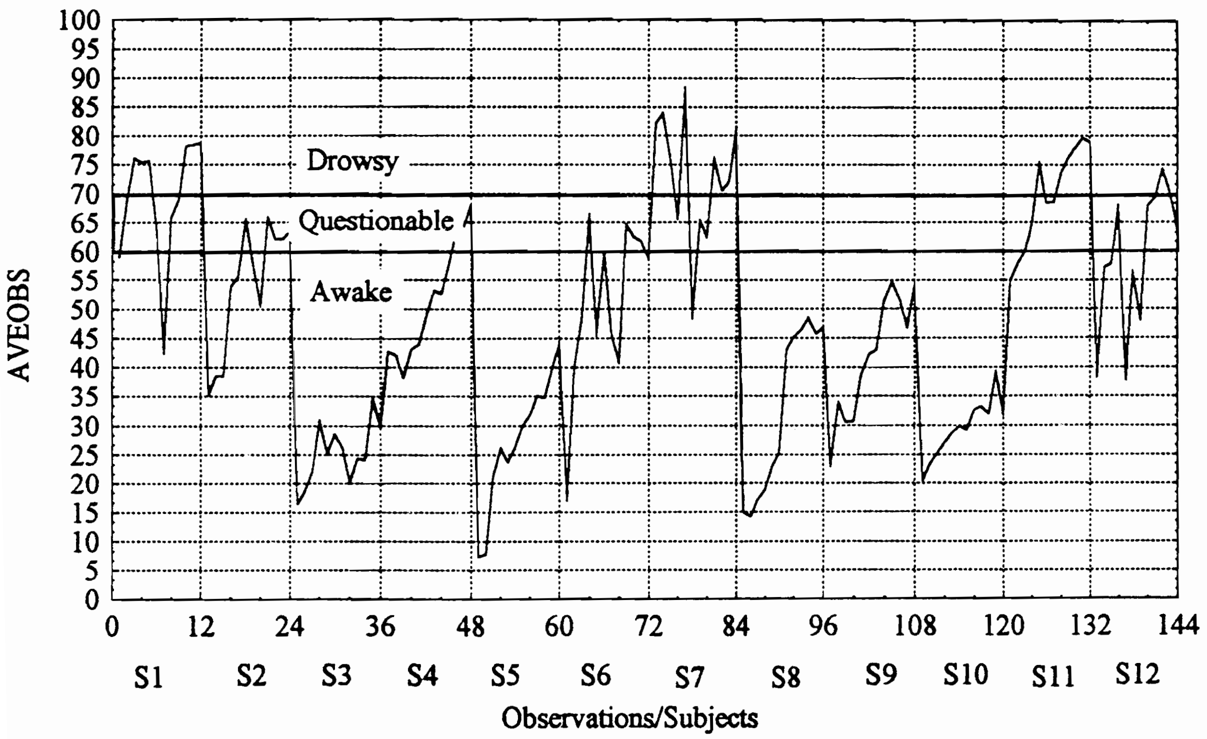
This section contains the results of validation tests that include A/O task performance measures. In some cases these measures were used by themselves in developed algorithms and in other cases they were used in combination with driver-vehicle performance measures. Since the A/O task was performed during only half of each subject's data run, the data base used in this section is half the size of that used in the previous section.

Application of Algorithms (Employing A/O Task Measures) to New Data

As seen in Figures 41, 42, 43, 44, and 45 the five dependent (definitional) variables were re-graphed to include only the segments of time in which the subjects performed the A/O task. The threshold lines in the figures were developed during the algorithm development phase of the study and are the same as those seen in Figures 20, 21, 22, 23, and 24. In the graphs, the first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on.

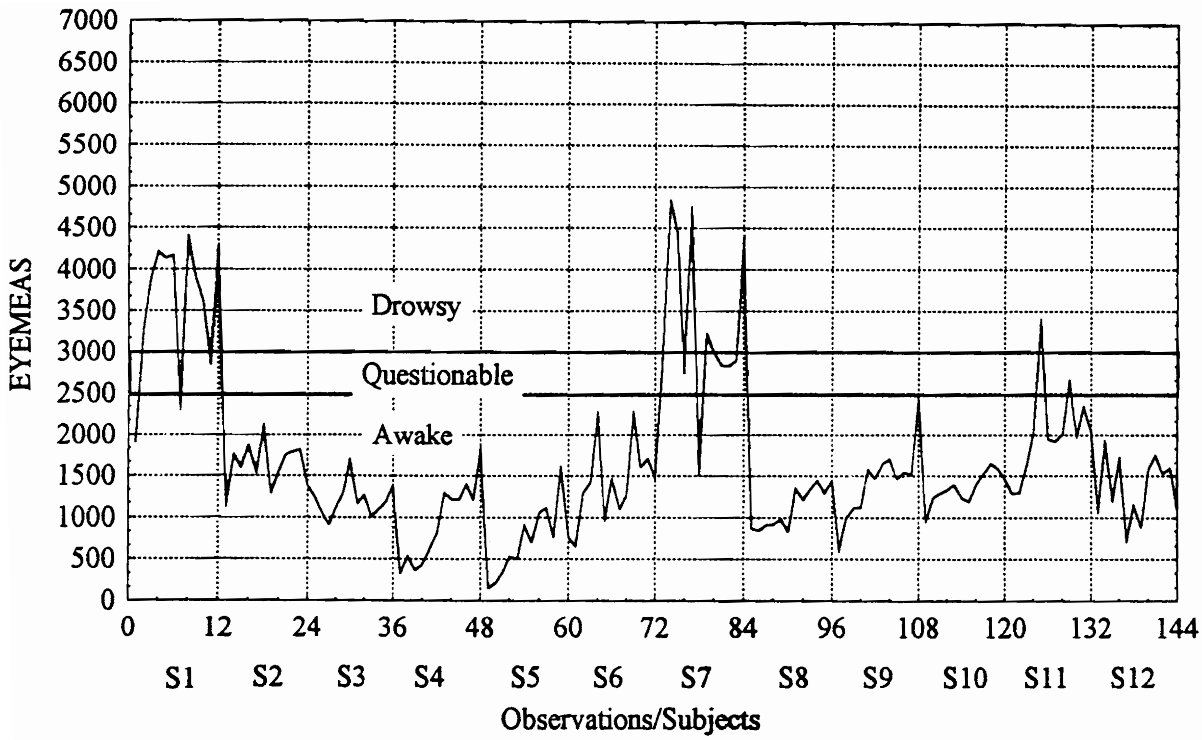
Table 17 is similar to Table 16 in that is contains a description of the algorithms that were tested on the new data. The table contains the original R values (those associated with application of the algorithms to the original data set) and new R values (those associated with application of the algorithms to the new data set.) The table shows which types of algorithms were tested and the appendix in which the algorithms were presented.

Table 17 shows that there was a general decrease in predictive power of the algorithms when applied to the new A/O data (average R value = 0.606) as compared with the original data (average R value = 0.809) $\underline{t}(7) = 6.21$, $p < 0.01$. This result is graphed in Figure 46. Figure 46 also shows the effects of cruise control on the new R values. When



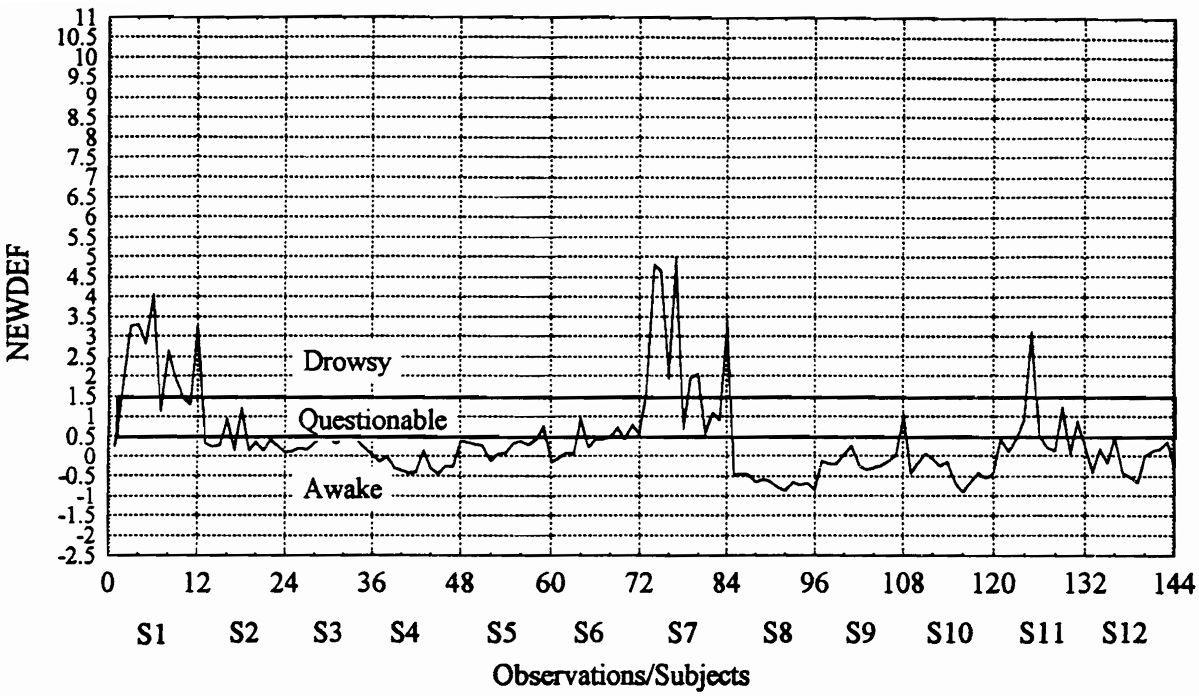
NOTE: The first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on.

Figure 41: AVEOBS Data With Upper and Lower Criterion Lines (New Data During A/O Task).



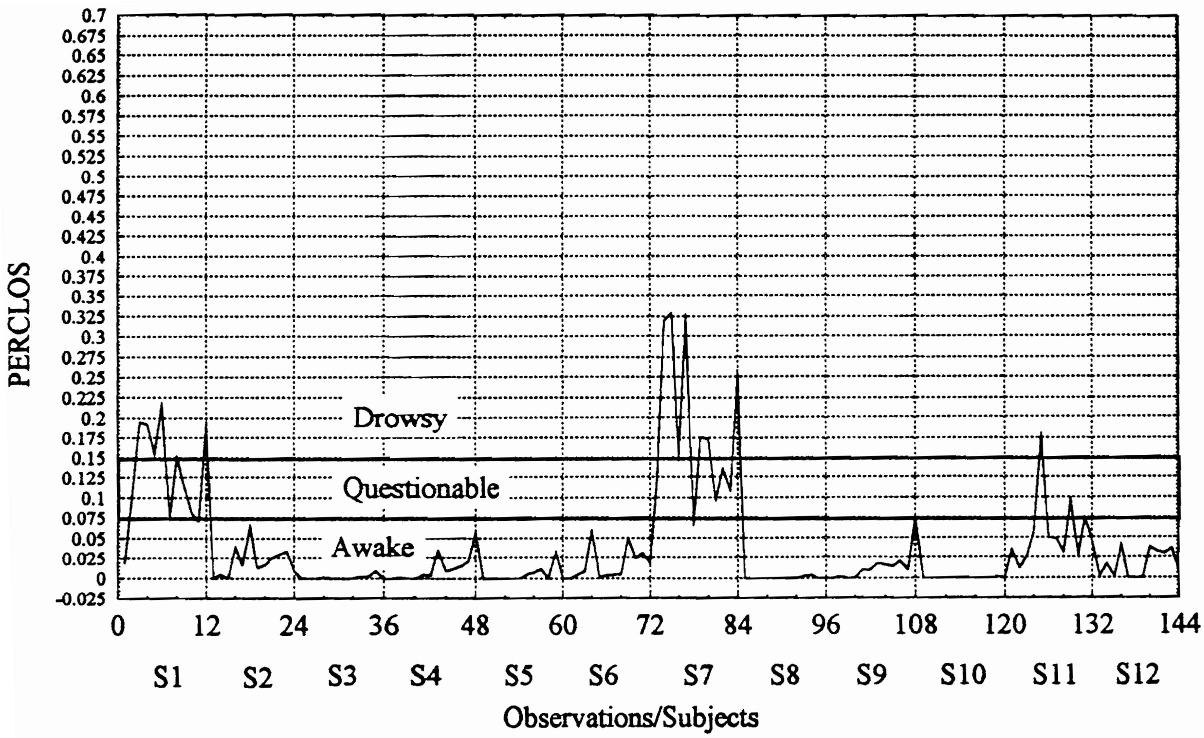
NOTE: The first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on.

Figure 42: EYEMEAS Data With Upper and Lower Criterion Lines (New Data During A/O Task).



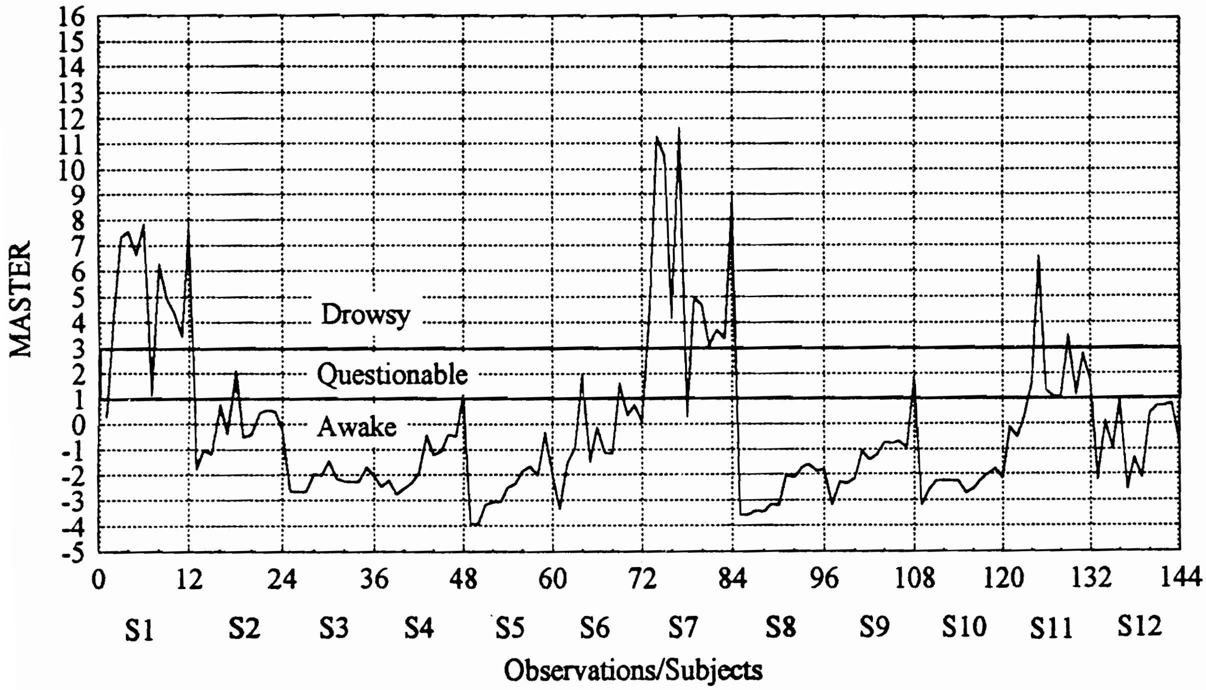
NOTE: The first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on.

Figure 43: NEWDEF Data With Upper and Lower Criterion Lines (New Data During A/O Task).



NOTE: The first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on.

Figure 44: PERCLOS Data With Upper and Lower Criterion Lines (New Data During A/O Task).



NOTE: The first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on.

Figure 45: MASTER Data With Upper and Lower Criterion Lines (New Data During A/O Task).

Table 17: R Values From Multiple Regression Analyses of Original A/O Data and R Values Achieved After Algorithms Were Applied to New A/O Data.

	Independent Measures	Dependent Measures: AVEOBS	EYEMEAS	NEWDEF	PERCLOS	MASTER
I	A/O Task Measures Only	(original) 0.761 **Algorithm I1a** **(new) 0.595**	(original) 0.768 **Algorithm I2a** **(new) 0.570**	(original) 0.660 **Algorithm I3a** **(new) 0.422**	(original) 0.810 **Algorithm I4a** **(new) 0.447**	(original) 0.822 **Algorithm I5a** **(new) 0.570**
J	A/O Task, Steering, & Accelerometer	-------	-------	-------	**(original) 0.836** **Algorithm J4a** **(new) 0.599**	-------
L	A/O Task, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ	-------	-------	-------	(original) 0.875 **Algorithm L3a** **(new) 0.796**	-------
M	A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ	-------	-------	-------	-------	**(original) 0.936** **Algorithm M3a** **(new) 0.845**

NOTES: Letters in left column indicate appendices containing detailed analyses on original data set.

Algorithm numbers located in each cell correspond to the multiple regression table within a given appendix.

Classification matrices were created for the highlighted (bolded) R values. (See Figure 48, 50, 52, 54, 56, 58, 60, 62.)

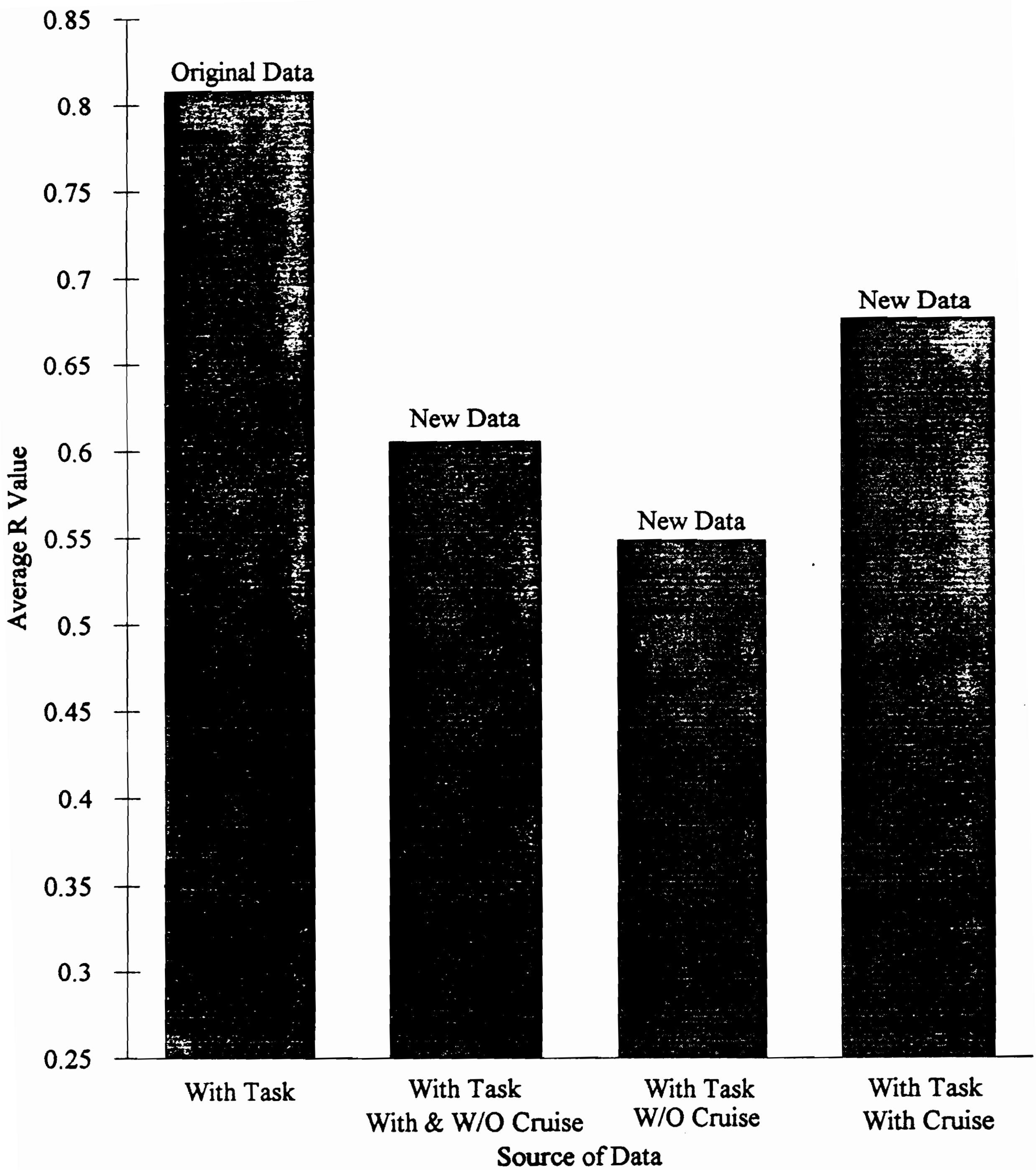


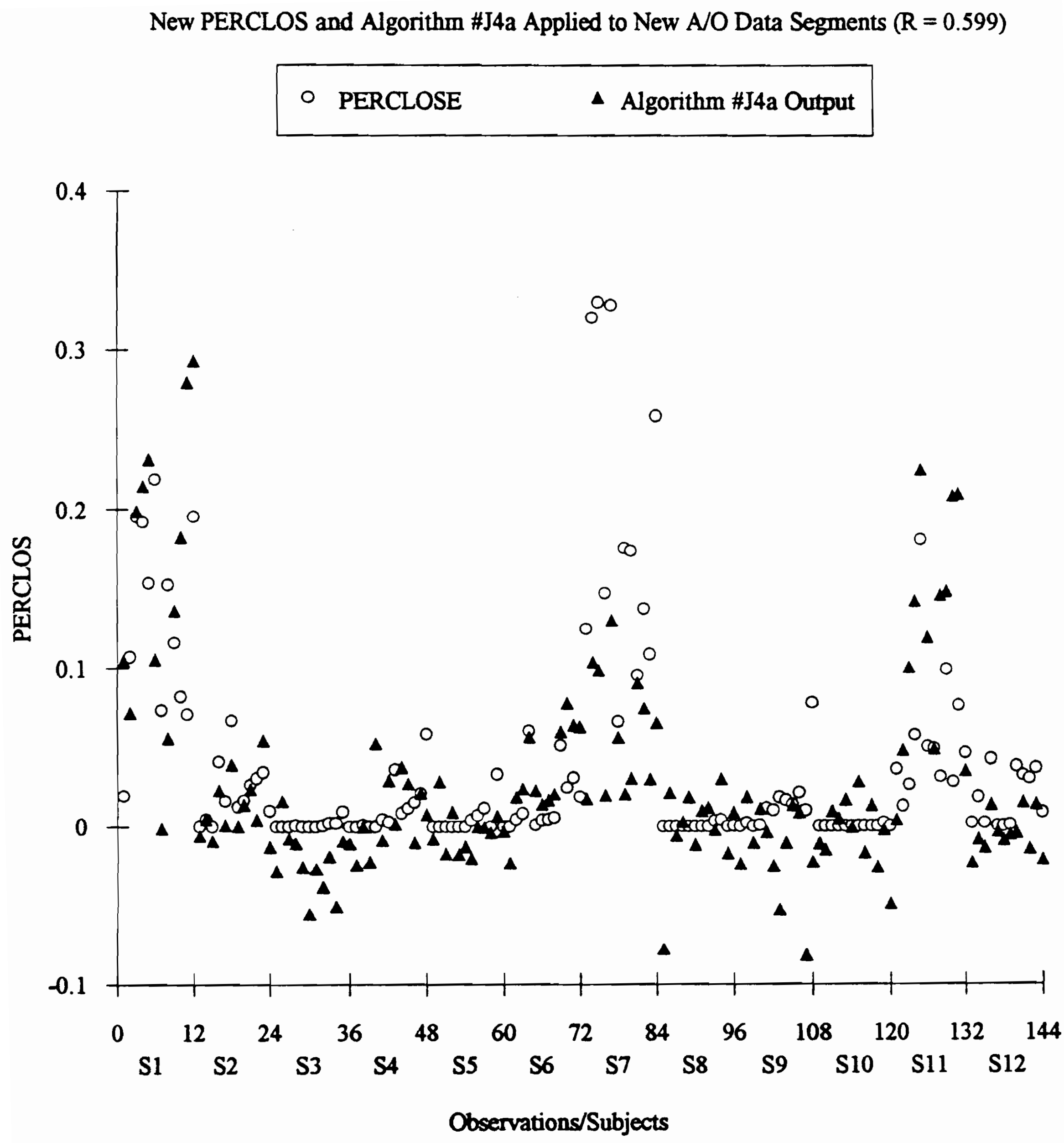
Figure 46: Average R Values for Eight Algorithms (See Table 17) Applied to Original A/O Data, New A/O Data, New A/O Data With Cruise Control Engaged, and New A/O Data Without Cruise Control Engaged.

cruise control was engaged, the new R values increased significantly from an average of 0.549 (when not engaged) to an average of 0.677 (when engaged); $t(7) = 2.50$, $p < 0.05$.

To obtain a better understanding of drowsiness prediction using the new data, graphical comparisons were made between the definitional measures and the algorithm outputs applied to new data. Figures 47, 49, 51, 53, 55, 57, 59, and 61 show the results. As can be seen, the algorithms seem to do a reasonable job of tracking the variations in observed (definitional) measures, even though there are some obvious discrepancies.

Classification matrices were also developed for the algorithms that were treated. These matrices used the thresholds shown in Figures 41 though 45. The results of the classifications are presents in Figures 48, 50, 52, 54, 56, 58, 60, and 62. (Figures 48 and 50 include matrices displaying classified original data which can be used for comparative purposes.) The matrices correspond to the bolded algorithms in Table 17. In general, the number of misclassifications appears to be smaller than the R values would seem to indicate.

Finally, regression lines were drawn using the original R values shown in Table 17 and the corresponding APAR values of the new data in Figures 48, 50, 52, 54, 56, 58, 60, and 62. The regression lines are shown in Figure 63. The two plots give a general idea of what APAR value can be achieved given certain drowsiness prediction R values. The reader is cautioned that the correlation coefficients associated with the data are not significant ($p > 0.05$), and therefore the prediction capabilities provided by Figure 63 are indicative and not conclusive.



NOTE: The first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on.

Figure 47: Scatter Plot of PERCLOS Data -- Predicted vs. Observed

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
Original	Awake	94.29	**66**	3	1
Observed	Questionable	43.75	2	7	7
	Drowsy	42.86	2	6	**6**
	Total	79.00	70	16	14

PERCLOS (R Value = 0.836)
Apparent Accuracy Rate (large misclassifications): 0.970
Apparent Accuracy Rate (all misclassifications): 0.790

Classification Matrix Generated From Multiple Regression Analysis of **Original PERCLOS** Data Resulting in **Algorithm J4a**. (Independent variables employed included A/O Task, Steering, and Accelerometer.)

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	93.33	**112**	6	2
Observed	Questionable	27.27	6	**3**	2
	Drowsy	38.46	4	4	**5**
	Total	83.33	122	13	9

PERCLOS (R Value = 0.599)
Apparent Accuracy Rate (large misclassifications): 0.958
Apparent Accuracy Rate (all misclassifications): 0.833

Algorithm J4a Applied to New Data and Compared with New Observed **PERCLOS** Data

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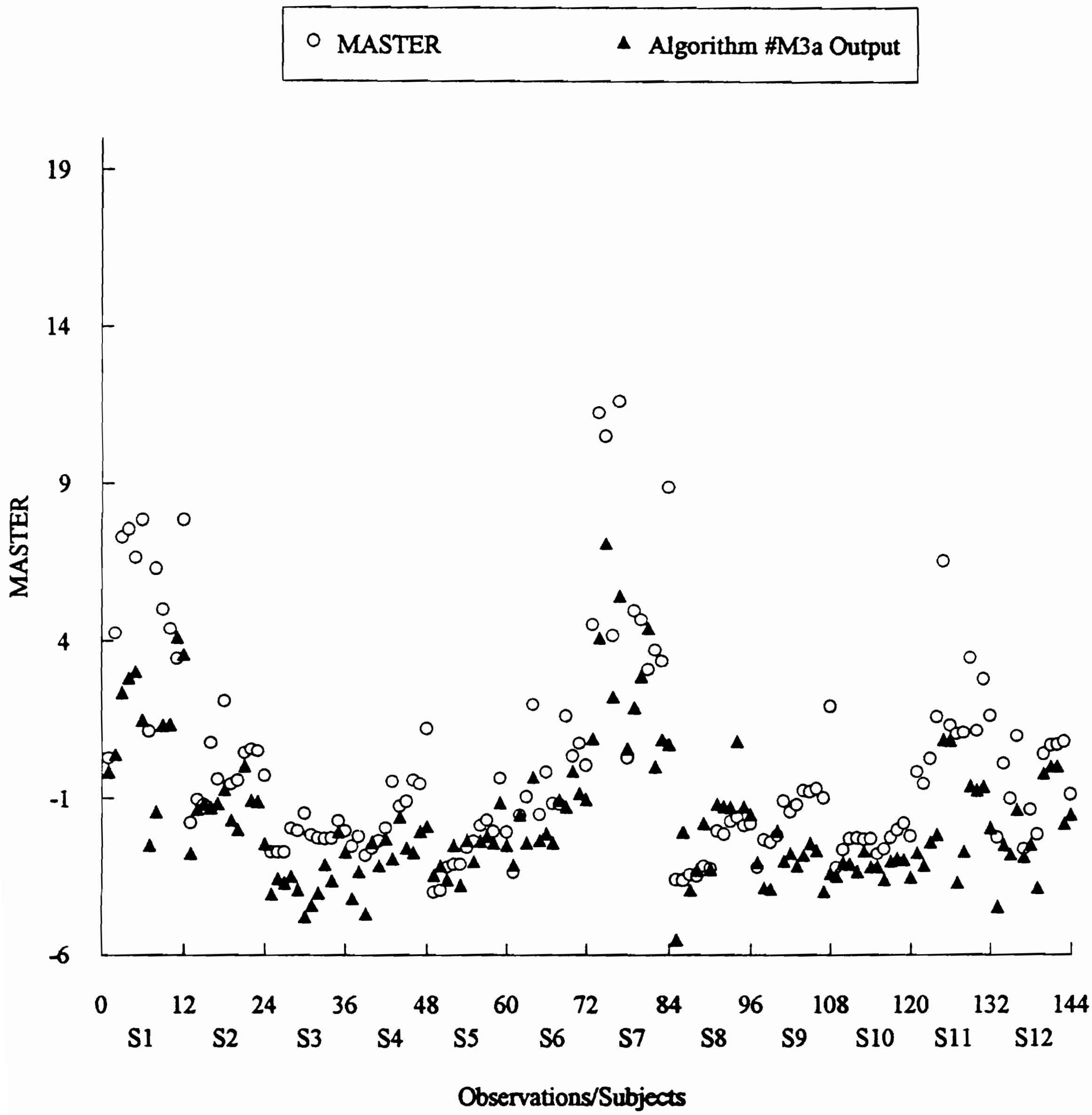
Figure 48: Classification Matrices Showing Accuracy of Algorithm J4a When Applied to Original Data (Upper) and New Data (Lower)

New Master and Algorithm #M3a Applied to New A/O Task Segments (R = 0.845)



NOTE: The first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on.

Figure 49: Scatter Plot of MASTER Data -- Predicted vs. Observed

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
Original	Awake	95.59	**65**	3	0
Observed	Questionable	50.00	3	7	4
	Drowsy	72.22	0	5	**13**
	Total	85.00	68	15	17

MASTER (R Value = 0.936)
Apparent Accuracy Rate (large misclassifications): 1.000
Apparent Accuracy Rate (all misclassifications): 0.850

Classification Matrix Generated From Multiple Regression Analysis of **Original MASTER** Data Resulting in **Algorithm M3a**. (Independent variables employed included A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	100.00	**108**	0	0
Observed	Questionable	0.00	13	**0**	0
	Drowsy	30.43	8	8	**7**
	Total	79.86	129	8	7

MASTER (R Value = 0.845)
Apparent Accuracy Rate (large misclassifications): 0.944
Apparent Accuracy Rate (all misclassifications): 0.799

Algorithm M3a Applied to New Data and Compared with New Observed **MASTER** Data

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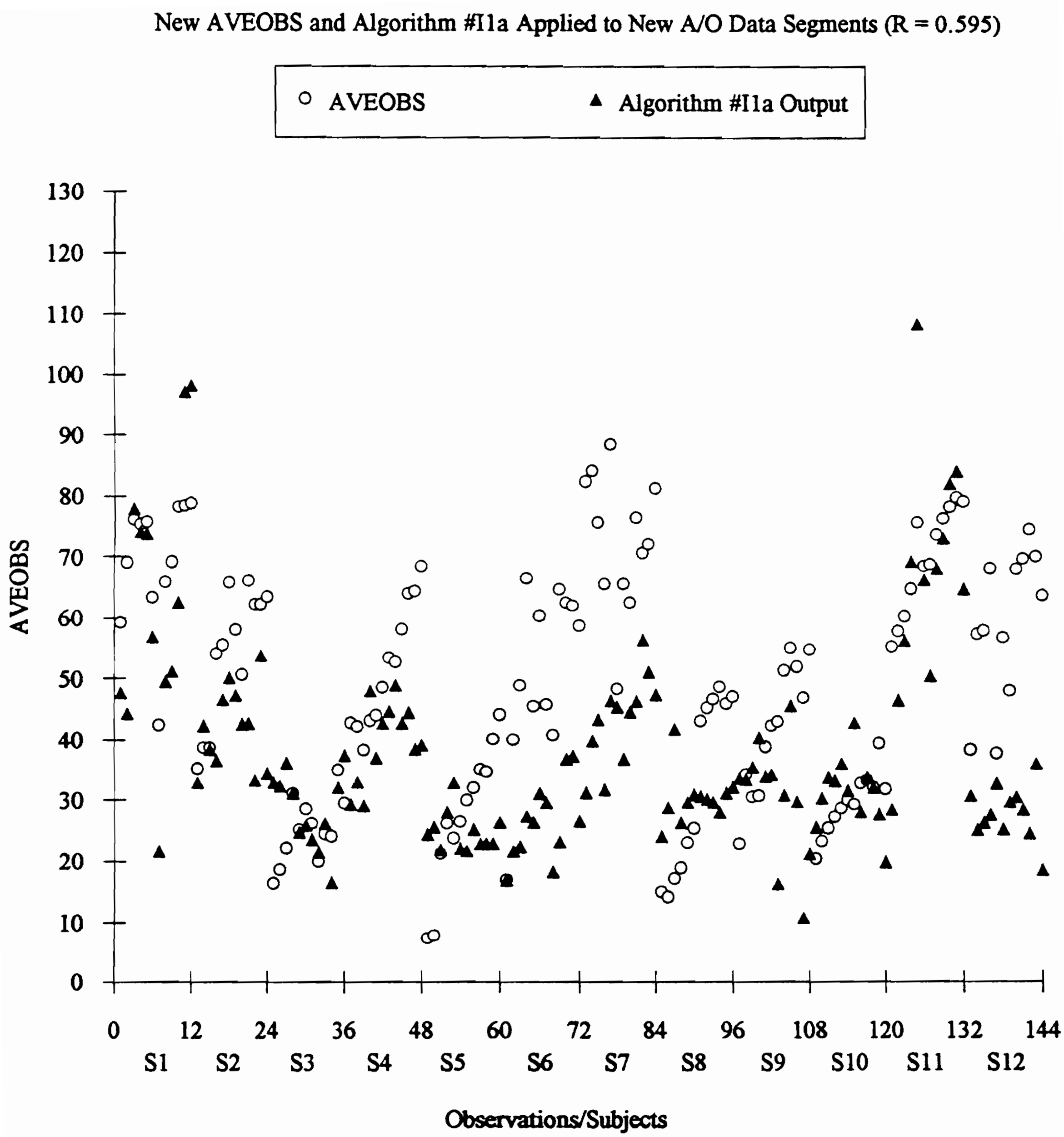
Figure 50: Classification Matrices Showing Accuracy of Algorithm M3a When Applied to Original Data (Upper) and New Data (Lower)



NOTE: The first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on.

Figure 51: Scatter Plot of AVEOBS Data – Predicted vs. Observed

Corresponding Original R Value: 0.761

			Predicted		
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	100.00	**94**	0	0
Observed	Questionable	7.14	26	**2**	0
	Drowsy	40.91	10	3	**9**
	Total	72.92	130	5	9

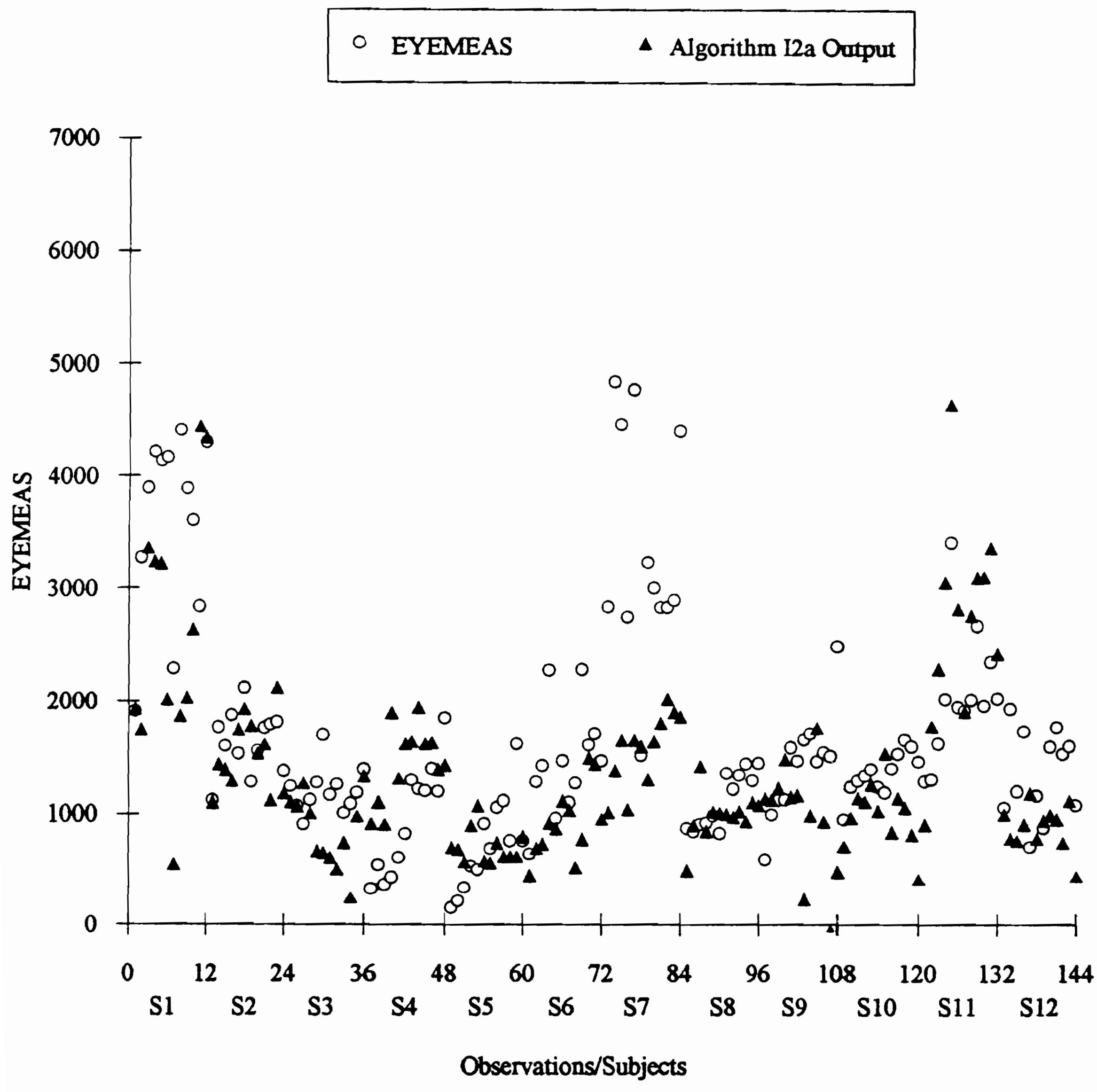
AVEOBS (R Value = 0.**595**)

Apparent Accuracy Rate (large misclassifications): 0.931
Apparent Accuracy Rate (all misclassifications): 0.729

Algorithm I1a Applied to **New** Data and Compared with New Observed **AVEOBS** Data

Figure 52: Classification Matrix Showing Accuracy of Algorithm I1a When Applied to New Data.

New EYEMEAS and Algorithm #I2a Applied to New A/O Data Segments (R = 0.570)



NOTE: The first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on.

Figure 53: Scatter Plot of EYEMEAS Data -- Predicted vs. Observed

Corresponding Original R Value: 0.768

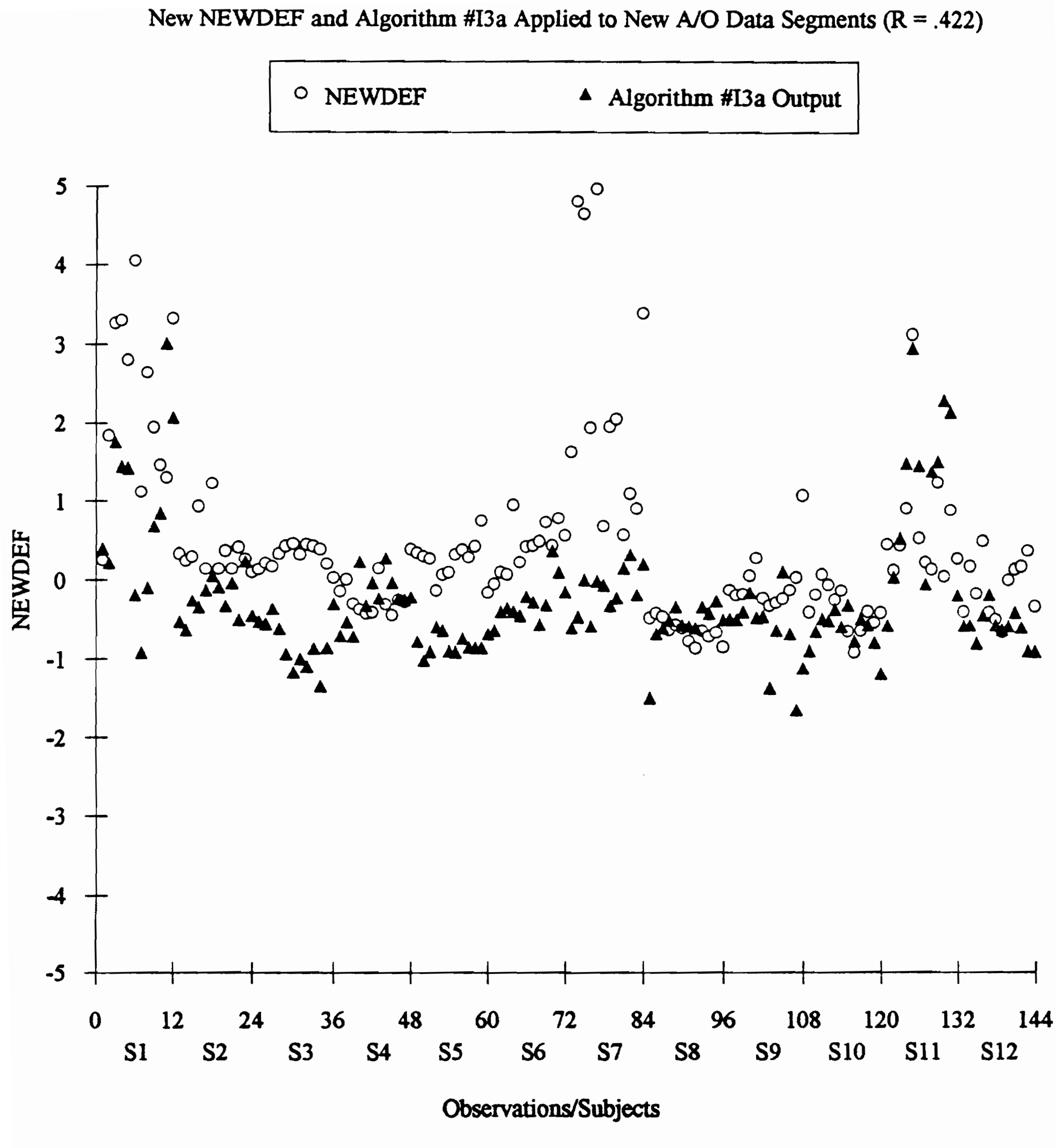
		Predicted			
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	95.87	**116**	2	3
Observed	Questionable	0.00	5	**0**	2
	Drowsy	31.25	10	1	**5**
	Total	84.03	131	3	10

EYEMEAS (R Value = 0.**570**)

Apparent Accuracy Rate (large misclassifications): 0.910
Apparent Accuracy Rate (all misclassifications): 0.840

Algorithm I2a Applied to **New** Data and Compared with New Observed **EYEMEAS** Data

Figure 54: Classification Matrix Showing Accuracy of Algorithm I2a When Applied to New Data.



NOTE: The first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on.

Figure 55: Scatter Plot of NEWDEF Data -- Predicted vs. Observed

Corresponding Original R Value: 0.660

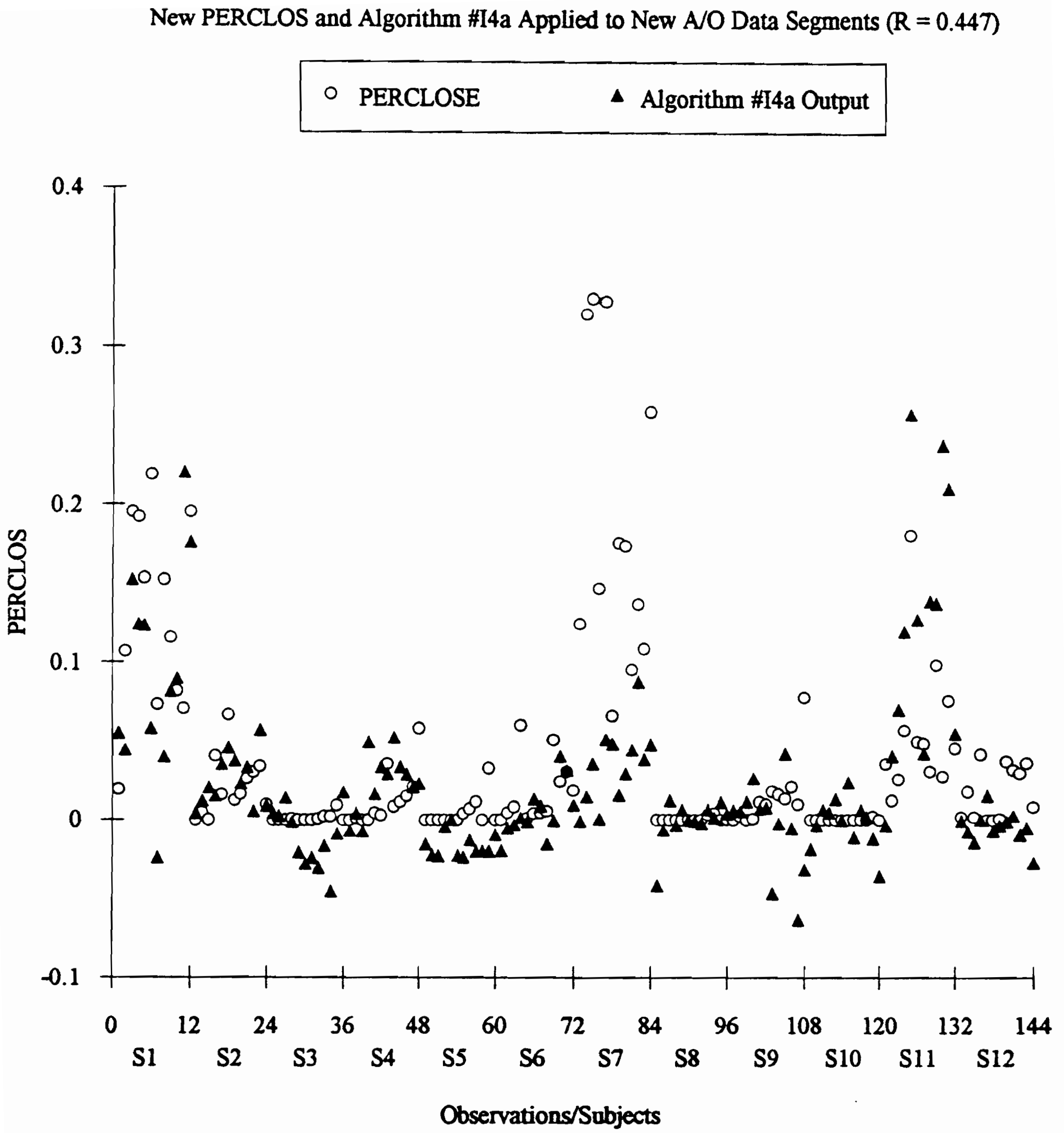
			Predicted		
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	98.15	**106**	1	1
Observed	Questionable	15.79	13	**3**	3
	Drowsy	17.65	11	3	**3**
	Total	77.78	130	7	7

NEWDEF (R Value = 0.**422**)

Apparent Accuracy Rate (large misclassifications): 0.917
Apparent Accuracy Rate (all misclassifications): 0.778

Algorithm I3a Applied to **New** Data and Compared with New Observed **NEWDEF** Data

Figure 56: Classification Matrix Showing Accuracy of Algorithm I3a When Applied to New Data.



NOTE: The first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on.

Figure 57: Scatter Plot of PERCLOS Data -- Predicted vs. Observed

Corresponding Original R Value: 0.810

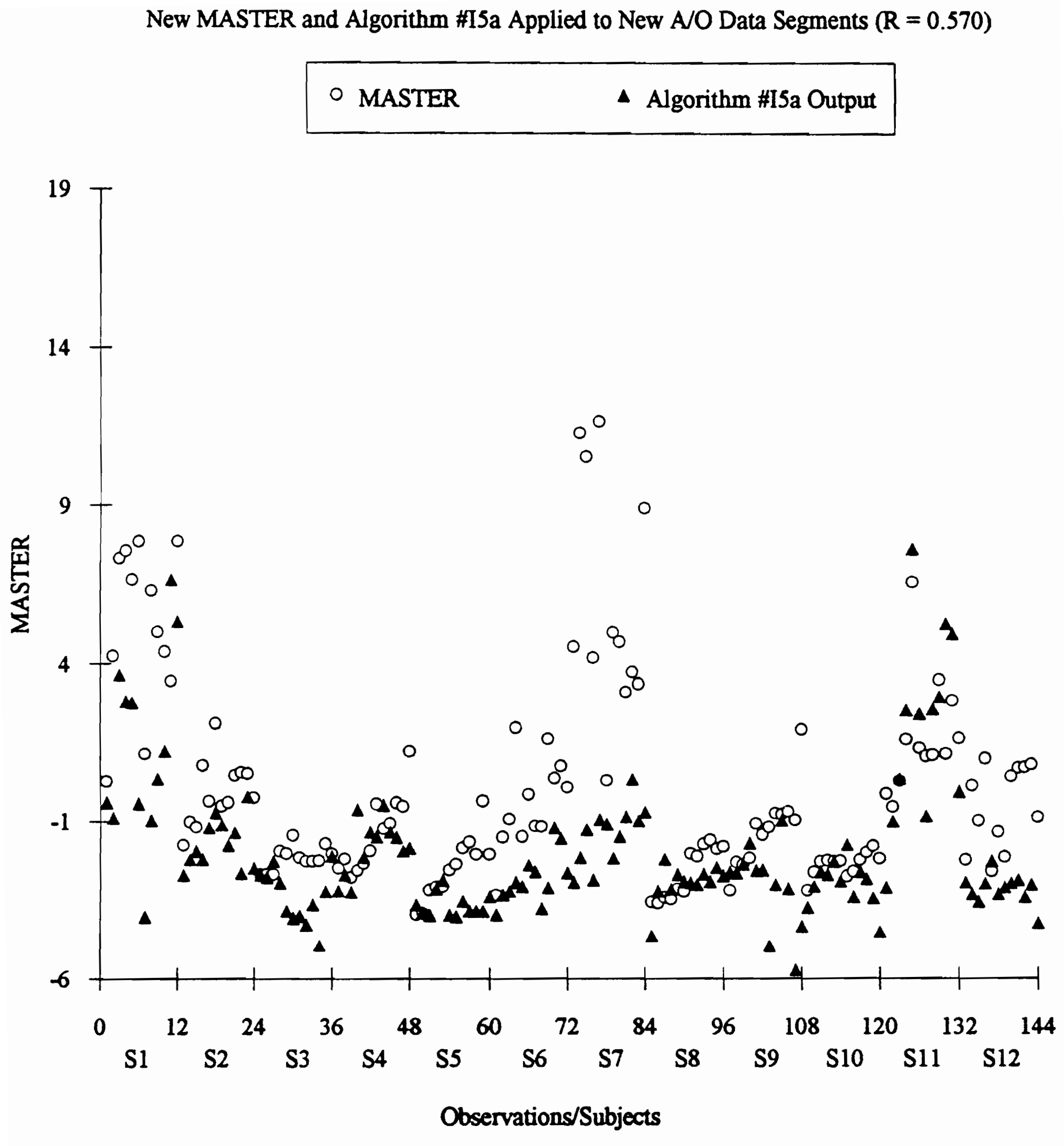
			Predicted		
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	95.83	**115**	3	2
Observed	Questionable	36.36	6	**4**	1
	Drowsy	23.08	8	2	**3**
	Total	84.72	129	9	6

PERCLOS (R Value = 0.447)

Apparent Accuracy Rate (large misclassifications): 0.931
Apparent Accuracy Rate (all misclassifications): 0.847

Algorithm I4a Applied to **New** Data and Compared with New Observed **PERCLOS** Data

Figure 58: Classification Matrix Showing Accuracy of Algorithm I4a When Applied to New Data.



NOTE: The first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on.

Figure 59: Scatter Plot of MASTER Data -- Predicted vs. Observed

Corresponding Original R Value: 0.822

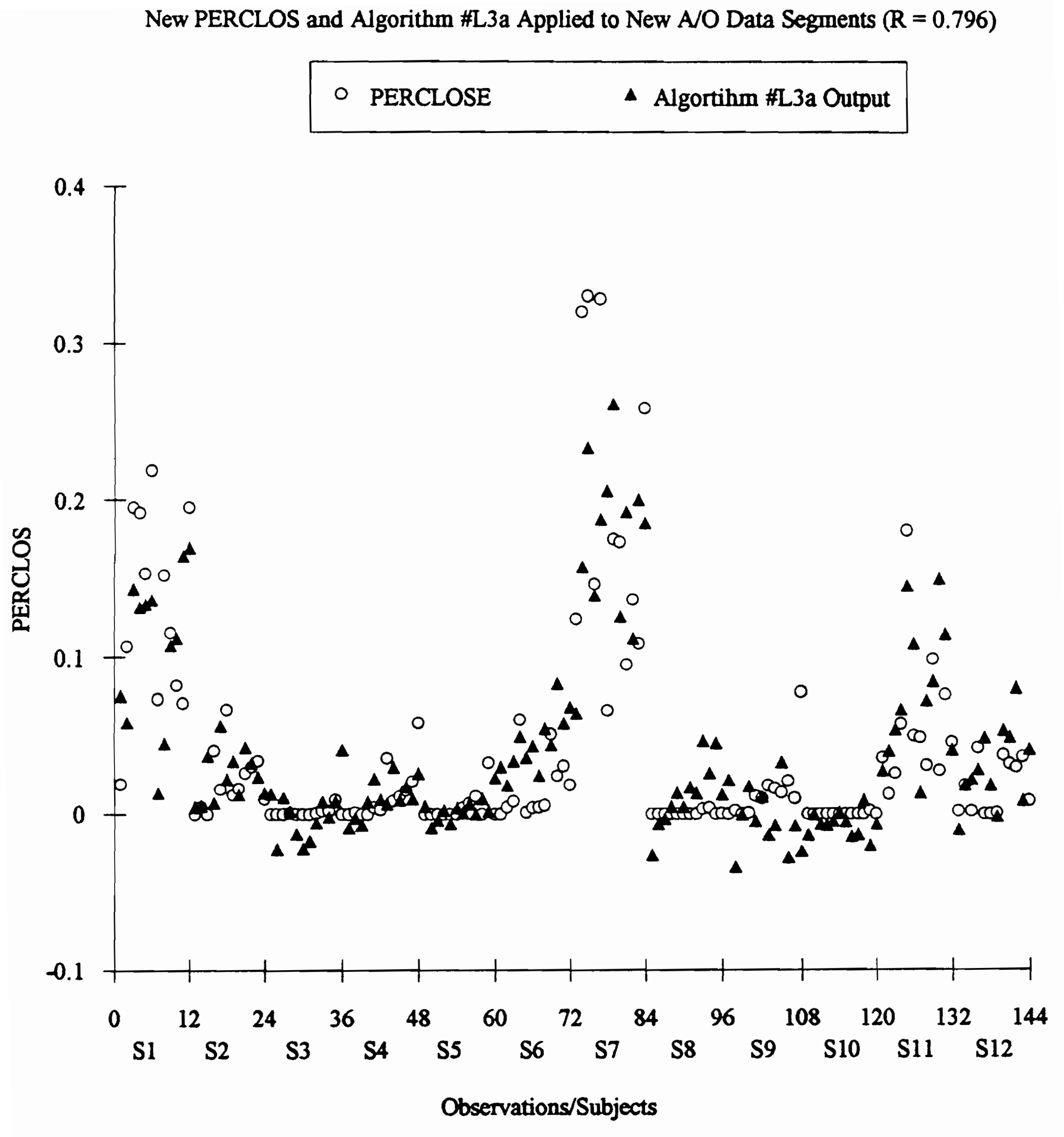
		Predicted			
	Group	% Correct	Awake	Question	Drowsy
New	Awake	100.00	**108**	0	0
Observed	Question	23.08	8	**3**	2
	Drowsy	17.39	15	4	**4**
	Total	79.86	131	7	6

MASTER (R Value = 0.570)

Apparent Accuracy Rate (large misclassifications): 0.896
Apparent Accuracy Rate (all misclassifications): 0.799

Algorithm I5a Applied to **New** Data and Compared with New Observed **MASTER** Data

Figure 60: Classification Matrix Showing Accuracy of Algorithm I5a When Applied to New Data.



NOTE: The first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on.

Figure 61: Scatter Plot of PERCLOS Data -- Predicted vs. Observed

Corresponding Original R Value: 0.875

	Predicted				
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	94.17	**113**	5	2
Observed	Questionable	54.55	3	**6**	2
	Drowsy	46.15	1	6	**6**
	Total	86.81	117	17	10

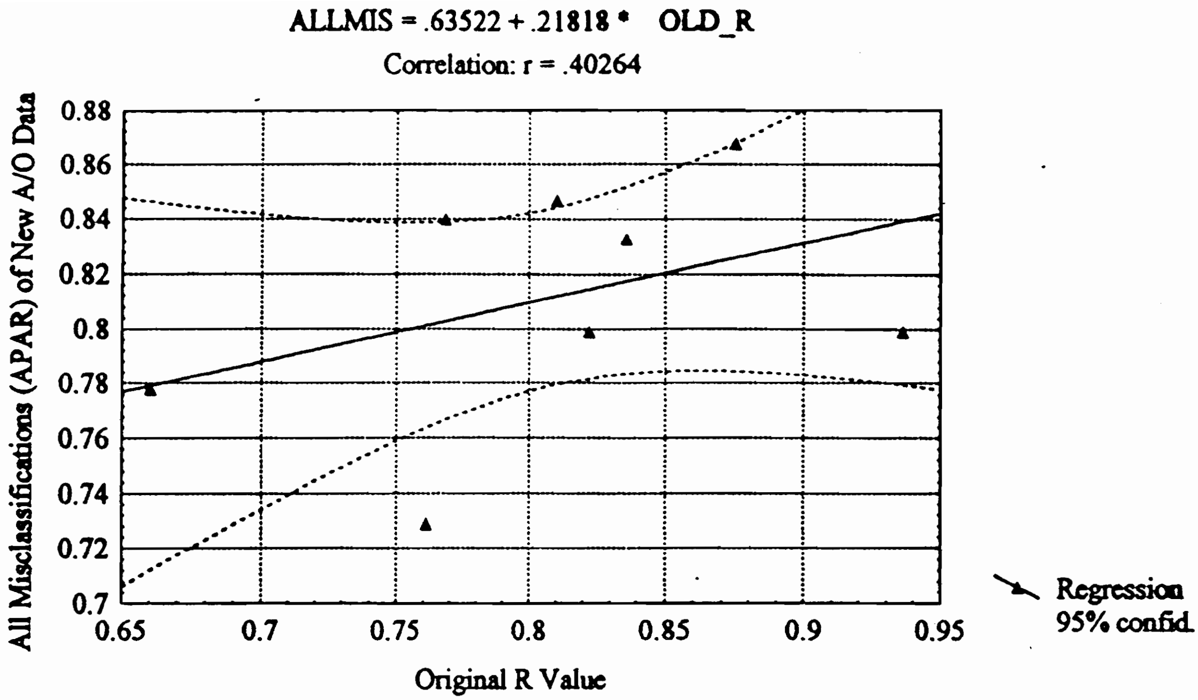
PERCLOS (R Value = 0.**796**)

Apparent Accuracy Rate (large misclassifications): 0.979

Apparent Accuracy Rate (all misclassifications): 0.868

Algorithm L3a Applied to **New** Data and Compared with New Observed **PERCLOS**

Figure 62: Classification Matrix Showing Accuracy of Algorithm L3a When Applied to New Data.



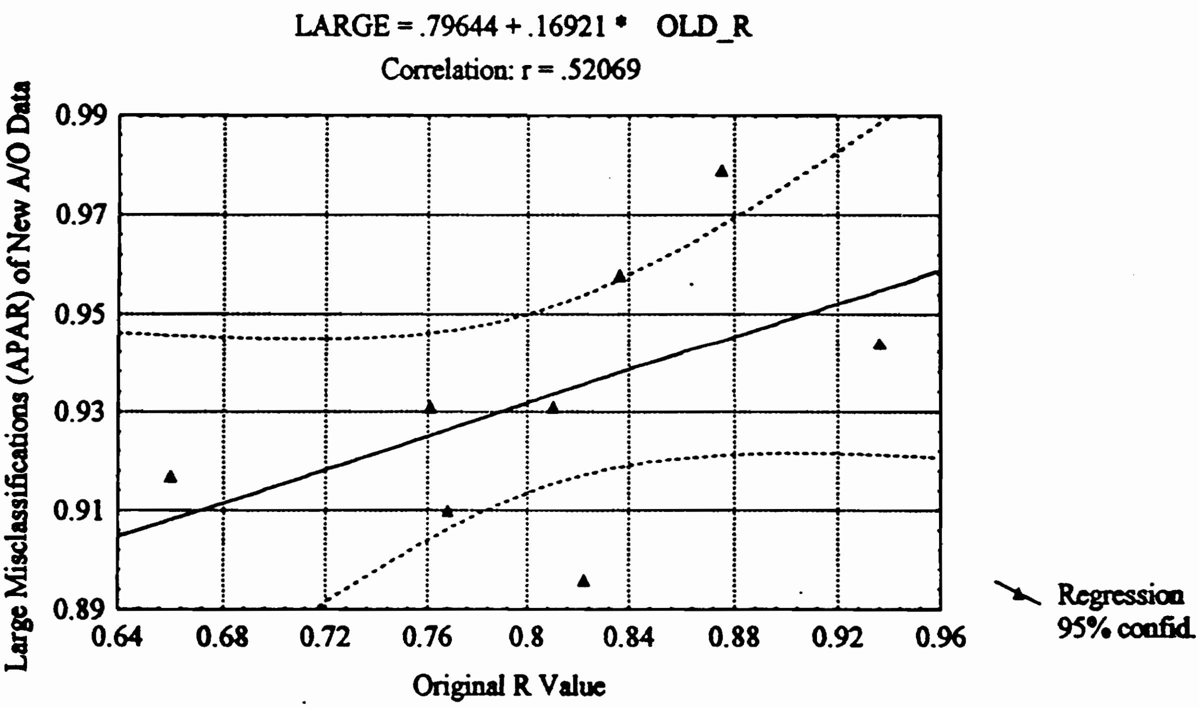


Figure 63: R Values vs. New APAR Values -- APAR Includes All Misclassifications (Upper Graph) and Large Misclassifications (Lower Graph).

DISCUSSION and CONCLUSIONS of the VALIDATION PHASE

Validation of Algorithms Using Driver-Vehicle Performance Measures

When choosing the algorithms to validate, it was important that the component measures were very reliable and attainable in an on-the-road situation. The algorithms located in Appendices D and F were chosen for the purpose of validation since they contained both reliable and probably attainable measures (Table 16).

Another important aspect of the models within Appendices D and F is that their use allows for a step-up, step-down detection procedure. Models in Appendix D employ steering and lateral accelerometer measures and models in Appendix F employ steering, lateral accelerometer, and lane-related measures. Therefore, loss of a lane-related measure does not cause failure of the detection system. Rather, the system simply "steps-down" to a model in Appendix D. This would be the case if one of the sensors necessary for the best algorithm did not provide a valid signal (i.e. lane sensors). A "step-up" procedure involves the use of newly validated signals (i.e. lane sensors pick up valid signal from the road).

The average R values achieved after application of drowsiness detection algorithms to new data were found to have no significant loss in drowsiness prediction compared with the original data upon which the algorithms were developed. As seen in Figures 26, 28, 30, 32, 34, 36, and 38 the output of the drowsiness detection algorithms track the observed data extremely well. This finding is encouraging. Drowsiness classifications (Figures 27, 29, 31, 33, 35, 37, and 39) were accomplished with only small percentages of error. The algorithms that were validated using the driver-vehicle performance measures were found to be robust. This conclusion is drawn from the fact that no significant loss in drowsiness prediction was observed when the detection algorithms were applied to new data. This is an extremely important finding.

The Effect of Cruise Control and A/O Task on Detection Rate of Driver-Performance Measure Algorithms. The detection algorithms from Appendices D and F were applied to the segments in time in which driver/subjects were under a cruise control condition combined with the A/O secondary task. It was found that when cruise control was engaged and the task was not being performed, the average drowsiness prediction R value was higher than when cruise control was engaged and the secondary task was being performed (Figure 25). The higher average R value for the Without Task/With Cruise condition is attributed to the fact that this condition is the most boring. The drivers did not have to monitor speed or interact with the push buttons mounted on the steering wheel while answering "yes" or "no" with the secondary task. It is hypothesized that the boredom experienced by the subjects tended to increase drowsiness. Subjects thus experienced a range of alertness that was greater than under the other conditions. In other words, subjects may have gone from alert to very drowsy within this condition. Therefore, the observed data were spread out, allowing the predicted data to track (fit the data) with higher relative success.

Validation of Algorithms Containing A/O Task Performance Measures

The detection algorithms which contained A/O task measures that were examined are shown in Table 17. The average R value for drowsiness detection, using data other than that which was used for the development of the algorithms, decreased significantly. This is likely a result of using only four subjects in the development of the prediction algorithms (based on A/O task performance data). With the original data set, upon which the algorithms were based, better results occurred because the use of only four subjects allowed for an easier fit of predicted and observed data. However, the use of only four subjects in the development stage may have limited the *predictive* capabilities of the algorithms, thus a lower average R value was observed in the validation phase.

Another factor that may have contributed to the reduction of drowsiness prediction

R values with new data involved an unrepresentatively small amount of drowsiness observed during the portions of runs in the new data in which the A/O task was being performed. As can be seen in the classification matrices in Figure 48, 50, 52, 54, 56, 58, 60, and 62 the observed "awake" classifications were the great majority of the data. Since there was a relatively small domain of drowsiness (mostly "awake" and few "questionable" or "drowsy" observations) an unrepresentatively low R value may have occurred. Unfortunately, with the data that were collected during the validation phase, the algorithm was not exercised to an extent that would result in R values similar to the original R values. In other words, the new data were more tightly grouped.

Classification matrices were constructed using observed algorithm output and observed definitional measures of drowsiness for the new A/O task algorithms (Figures 48, 50, 52, 54, 56, 58, 60, and 62). The classification matrices resulted in surprisingly high correct classification rates given the relatively low R values of the prediction algorithms based on A/O task measures. The good results of the classification matrices suggest that an unrepresentative sample of drowsiness data is largely the cause for deflated R values instead of a limited predictive capability of the algorithms.

It was found that the average drowsiness-detection rate was greater for algorithms applied to new A/O data when cruise control was engaged as compared with new A/O data when cruise control was not engaged. One explanation for this finding is that drivers/subjects did not have to monitor their speed when cruise control was engaged. Therefore more resources could be allocated to the driving task and the A/O task. Since this may have been the case, alert drivers who were frequently monitoring the speed of the vehicle would have glanced at the speedometer often. With the greater amount of time available for subjects to glance at the speedometer the greater the chance for the driving task and A/O task to degrade. In other words, when cruise control was engaged, the degradation in driving performance may be purely due to the inattention or drowsiness of the driver.

Another interesting finding concerning the validation of the A/O task algorithms was discovered when examining the scatter plots of A/O task algorithms and driver-related/performance-related algorithm. In regard to the algorithms that were based on driver-related/performance-related data (and no A/O task measures), the predicted and observed data tracked closely for the Subject 7 segments (Figures 26, 28, 30, 32, 34, 36, and 38). However, upon examination of the validated algorithms based on A/O task measures, the predicted and observed data did not track well for Subject 7 relative to the other subjects (Figures 47, 49, 51, 53, 55, 57, 59, and 61). It is concluded that Subject 7 performed the A/O task atypically compared with the other eleven subjects employed in the validation phase. Therefore, an analysis of Algorithm I4a was conducted after the data from Subject 7 was removed. As seen in Appendix W a scatter plot of the predicted and observed data was drawn. Also contained in Appendix W is a classification matrix that does not include the data from Subject 7. The results for Algorithm I4a with and without Subject 7 data are as follows:

Including Subject 7 data: R value = 0.447, APAR (large misclassifications) = 0.93, and APAR (all misclassifications) = 0.85,

Excluding Subject 7 data: R value = 0.640, APAR (large misclassifications) = 0.97, and APAR (all misclassifications) = 0.91.

These results are used to demonstrate the consequence of the atypical A/O task performance of a single subject on overall drowsiness prediction. As can be seen in Appendix W, over half of the large misclassifications have been removed from the classification matrix when Subject 7 was excluded (see Figure 58 for the corresponding classification matrix that includes data from Subject 7).

From the examination of Subject 7 it can be concluded that the A/O task algorithms do not predict drowsiness for everyone. However, in all subjects but one, the A/O task algorithms predicted drowsiness. Also, the performance-related/driver-related algorithms performed well on all subjects no matter how the subject carried out the A/O task.

Overview

With regard to the predictability of the definitional measures of drowsiness with a new data set, results demonstrate that MASTER and PERCLOS are the most predictable, followed by EYEMEAS, NEWDEF, and AVEOBS. This order of predictability is the same as with the original data except that AVEOBS and NEWDEF are reversed. However, a reason for this reversal may be that different drowsiness raters were used in the validation experiment. (AVEOBS is the average subjective rating of three raters).

The findings of this study are very encouraging and the detection models look quite promising. It was estimated before the validation process that an average R value would be reduced by approximately 0.05 when the detection algorithms were applied to the new data. Fortunately, the average R value loss was only 0.0069 across the algorithms appearing in Appendices D and F (see Table 16).

It is concluded on the basis of the validation procedures carried out that the detection algorithms based on steering and accelerometer measures and steering, accelerometer, and lane measures are quite robust and should be used in a future on-the-road study. Even though the algorithms were developed with a certain amount of "noise" (for example, interacting with the instrument panel) they do an excellent job of drowsiness prediction when applied to new data.

PHASE FOUR

GENERAL DISCUSSION OF RESULTS

The purpose of this study was to develop the best possible algorithms and procedures for the detection of driver impairment due to fatigue and drowsiness. Upon completion of the study, it was determined that various detection algorithms could be used to classify levels of drowsiness with great success. This success was the result of the small percentages of misclassifications.

Many drowsiness-detection algorithms were developed in this study so that future implementation of a reliable on-board drowsiness-detection system would be possible. The various algorithms used slightly different sets of measures so that loss of any measure would not cause failure of the detection system. The concept of using several algorithms for the detection of drowsiness requires a microcomputer to determine if output signals from various sensors are valid. If all signals are valid, the microcomputer would use the best available algorithm for drowsiness detection. However, if one of the sensors necessary for the best algorithm is not providing a valid signal, the microcomputer would switch to the next best algorithm that does not require the invalid signal. This procedure, the "step-down" approach, can greatly increase the reliability of an impairment detection system. A "step-up" procedure can also be implemented. This procedure involves having a microcomputer regularly scan the sensors so that if an invalid signal becomes valid it would be detected. After determining that a newly validated signal is present, the microcomputer would "step-up" to the detection algorithm that employed the newly validated signal as well as the other valid signals. Hence, the primary objective of this research was to develop and validate algorithms that could be used in an on-the-road vehicle in the near future.

The main advantages of using a simulated automobile in this study were that data were collected in a controlled environment and subjects would not get hurt if they fell asleep at the wheel. However, the next logical step in the development of the detection algorithms should be a full-scale study in which an on-the-road vehicle is employed and data are collected using performance and roadway sensors located on the automobile. A full-scale study is important to test whether the developed algorithms are sufficiently robust to overcome factors such as roadway conditions and on-the-road driver behaviors. When an on-the-road study is undertaken safety must be of utmost concern.

Future manufacturers of drowsiness detection devices may have to caution consumers that a drowsiness-detection system does not take the place of common sense. Although it has been found that very high drowsiness-detection accuracy rates can be achieved, drivers should not solely rely on a drowsiness-detection device to keep them awake. A drowsiness-detection system should be used to help drivers decide when they are too drowsy to drive. Furthermore, a drowsiness-detection system should not give drivers justification to drive in situations that could be potentially dangerous due to drowsiness. For instance, drivers should not use a drowsiness-detection system as a justification for beginning a road trip at night if they are not used to night driving or for driving while deprived of the proper amount of sleep.

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APPENDIX A

Driving Habit and Sleep Habit Questionnaire

PROSPECTIVE PARTICIPANT'S QUESTIONNAIRE

1. Do you ORDINARILY wear glasses or contact lenses?

GLASSES	Yes	No
CONTACTS	Yes	No

2. What are your usual sleeping hours?

Retire Time	_____:_____	AM PM	Awake Time	_____:_____	AM PM

3. On the average, what is your depth of sleep?

Shallow	Slightly Shallow	Moderately Shallow	Deep	Very Deep

4. If you drive, please answer this question:

   How often have you had trouble staying awake while driving?

never	almost never	occasionally	moderately often	often

5. Other activities:

6. How many cups of coffee do you drink per day?

   __________________ cups per day

7. How many caffinated soft drinks (Coke, Diet Coke, Dr. Pepper, Pepsi, etc.) do you drink per day?

   _____________________ bottles, cans, and drinks (10 to 16 oz) per day (please give total of above)

8. If you are a cigarette smoker, how many cigarettes or packs do you smoke per day?

__________ cigarettes per day

or

__________ packs per day

9. If you use other smoking materials (pipe, cigar, or other), please describe what you smoke and how often.

Type: ______________________________

How often: _________________________

10. When do you ordinarily eat supper?

_____:_____ PM

11. If you snack at night, please describe what you eat and when.

What you eat: ____

When: ____

APPENDIX B

Introduction to the Study

Introduction to the Study

The purpose of this research is to investigate the relationship between driving performance and drowsiness after a period of partial sleep deprivation. The study is being conducted at the Vehicle Analysis and Simulation Laboratory, Department of Industrial and Systems Engineering, Virginia Polytechnic Institute and State University, Blacksburg. The research team consists of Steve Wreggit, Lynne Ellsworth, and Chris Kirn. The three researchers are graduate students in the Department of Industrial and Systems Engineering. Dr. Walter W. Wierwille is the principal investigator and Paul T. Norton Professor in the Department.

Your task for this study will be to sit in a automobile simulator and drive as you would normally. The simulator will move so as to mimic the motion of an actual automobile. The screen in front of you will show a roadway on which you must drive.

If you decide to participate in this study, you must awake at 7:00 A.M. or before and go through your normal daytime activities without resting or napping. Then, at about 6:00 P.M., a member of the experimental team will pick you up at your residence. This team member will buy you dinner at a fast-food restaurant. You may eat whatever you like, but you will not be permitted to drink caffinated or sugared beverages, such as coffee or coke. If you are a smoker, you will be permitted to smoke after dinner, but not thereafter. You will then be taken to the laboratory where you will be allowed to read, study, watch TV (which will be provided), or listen to your own personal headset stereo. You will not be permitted to eat, smoke, drink caffinated coffee, or caffinated soft drinks, since these may affect the outcome of the experiment. You will be permitted to drink water or non-caffinated, diet soft drinks, however. You will remain awake throughout the evening. A member of the research team will remain with you during all of this time and will prevent you from napping.

Shortly after midnight the experimental session will begin. It will last about three hours. The experimenter who remained with you will be replaced by two new experimenters. You will have a period of time (approximately 10 minutes) to get used to the simulator. After that, physiological monitoring equipment will be fitted to you and the data gathering will begin.

Physiological monitoring for the experiment involves placing two electrodes on the back of your head. They will be held in place by adhesive pads, but will be supplemented by a headband that is similar to an athletic headband to hold them in place. This headband will be fitted comfortably around the head above your ears.

In addition to the two electrodes, a small non-electrode sensor will be placed on the top of your ear. This device will be used to monitor your pulse.

Once the physiological monitoring equipment is fitted to you, it will be checked and adjusted if necessary. After that, the room lights will be dimmed and the experiment will begin. If possible, we would like for you to complete the entire data gathering experiment, which will take about 2 1/2 hours.

After completion of the experiment, the equipment will be removed from you. At this time you will be able to get out of the simulator. You will then be paid and any of your questions will answered at this time. If you participate in this experiment you must agree to let one of the experimenters drive you home since they will not be drowsy at this time.

Payment in the experiment will be $5 per hour between 6:00 P.M. and midnight, and $8 per hour between midnight and 3:00 A.M. If you complete the experiment you will receive $54. If you decide to withdraw during the experiment or simply cannot continue for whatever reason, you will be paid for the time actually spent.

Once you are seated in the simulator, you must not attempt to leave the simulator until you have given the experimenters a chance to disconnect the physiological monitoring equipment from you and guide you in exiting. You must let the experimenters know if you must terminate the experiment and give them an opportunity to disconnect and guide you.

Initially, we will ask you to take a simple vision test and fill out a brief questionnaire on your normal sleeping/waking patterns and your normal eating/drinking/smoking (if any) patterns. If you qualify, we will then schedule you for the experiment.

There are some minor risks and discomforts to which you will be exposed in this experiment. They are outlined in the attached informed consent form, which you should read carefully.

APPENDIX C

Participant's Informed Consent Form for the Drowsy Driving Experiment

Participant's Informed Consent

1. You are being asked to volunteer to be a subject in a research project whose purpose and description are contained in the document Introduction to the Study, which you have already read.

2. There are some minor risks and discomforts to which you expose yourself in volunteering for this research. The risks are:

   - The risk of possible irritation to your skin where the electrodes are adhesively attached. Such irritation might be caused by the adhesive, by the conductive gel, or by the process of removal. Irritation can be minimized by careful washing immediately following participation.

   - The risk of possible interference with your next day's activities caused by less than a full night's sleep. This risk can be minimized by sleeping longer than usual in the morning following your participation.

   - The risk of injury if you attempt to leave the simulator without the help of the investigators. Please inform one of the investigators if you feel that you must leave the simulator. The simulator will be stopped, and monitoring equipment will be removed and you will then be guided out of the simulator.

   The discomforts are:

   - The possible discomfort associated with wearing the electrodes and ear sensor. They may cause some itching or sensations of having something sticking on your skin.

   - The possible discomfort associated with trying to drive while tired or drowsy.

   - The possible discomfort associated with sitting in one seat for a long period of time.

   - Possible motion sickness due to the movement of the simulator

3. The data gathered in this experiment will be treated with anonymity. Shortly after you have participated, your name will be separated from your data. Videotapes will be kept in a locked room and will be erased when no longer needed.

4. While there are no direct benefits to you from this research (other than payment), you may find the experiment interesting. Your participation and that of other volunteers should make it possible to better understand the effects of mild sleep deprivation on performance.

5. You should not volunteer for participation in this experiment if you are under 18 years old, if you are pregnant, if you are not in good health, or if you have any other

condition which would adversely affect you by staying up until approximately 3:15 AM.

6. You should know that the principle investigator of the research project and the research team will answer any questions you may have about your participation, and you should not sign this consent form until you are satisfied that you understand all of the previous descriptions and conditions.

   You should further be aware that you may contact Dr. Janet M. Johnson, Chairman of the University's Institutional Review Board, if you have questions or concerns about this experiment. Her phone numbers are 231-6077 and 231-6168.

7. You should know that at any time you are free to withdraw from participation in this research program without penalty for any reason.

8. You will be paid at a rate of $5.00 per hour before midnight and $8.00 per hour thereafter. If you complete your participation, you will be paid $54.00. Payment will be made shortly after you have finished your participation.

9. You agree to allow one of the experimenters to drive you home following the experiment.

I have read and understand the scope of this research and I have no other questions. I hereby give my consent to participate, but I understand that I may stop participation if I choose to do so.

Signature ___________________________________

Date ___________________

APPENDIX D

Multiple Regression/Discriminant Analysis Results —

Steering and Accelerometer Measures Only

Table D1a: Multiple Regression and Discriminant Analysis of AVEOBS Using Steering and Accelerometer.

Regression Summary for Dependent Variable: AVEOBS

R= 0.74732 R^2<= 0.55849 Adjusted R^2<= 0.54791
F(7,292)=52.768 p<0.0000 Std.Error of estimate: 16.765

	BETA	St. Err. of BETA	B	St. Err. of B	t(292)	p-level
Intercpt			29.060127	1.597	18.200	0.000
ACCVAR	-0.155	0.068	-1.738049	0.763	-2.278	0.023
INTACDE	-0.207	0.058	-33.279385	9.389	-3.544	0.000
ACEXEED	0.117	0.050	290.205383	124.826	2.325	0.021
STVELV	-0.238	0.089	-0.197639	0.074	-2.670	0.008
LGREV	0.561	0.078	14.484322	2.010	7.207	0.000
MDREV	0.537	0.065	3.120561	0.378	8.264	0.000
THRSHLD	0.213	0.044	50.180883	10.407	4.822	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.56698 approx. F (5,294)=44.907 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.583	0.973	8.161	0.005	0.804	0.196	0.278606
LGREV	0.749	0.757	94.326	0.000	0.687	0.313	-0.903910
MDREV	0.580	0.978	6.650	0.010	0.539	0.461	-0.307965
SMREV	0.589	0.963	11.268	0.000	0.139	0.861	-0.784064
THRSHLD	0.608	0.933	21.073	0.000	0.119	0.881	-1.138062
Eigenval							0.763719
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.66333	DROWSY p=0.33667
Observed	AWAKE	91.960	183	16
	DROWSY	68.317	32	69
	Total	84.000	215	85

Classification Functions

	AWAKE	DROWSY
INTACDE	-1.047737	-4.378622
LGREV	-0.007797	2.115660
MDREV	0.256941	0.396834
SMREV	-0.076773	0.033193
THRSHLD	-4.018040	16.049034
Constant	-1.003523	-4.322106

Table D1b: Discriminant Analysis of AVEOBS Using Steering and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 5; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.49161 approx. F (10,586)=24.977 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.524	0.938	9.607	0.000	0.782	0.218	0.384260
LGREV	0.685	0.718	57.628	0.000	0.700	0.300	-0.892782
MDREV	0.519	0.947	8.201	0.000	0.546	0.454	-0.379560
SMREV	0.516	0.953	7.170	0.000	0.137	0.863	-0.739455
THRSHLD	0.528	0.930	10.971	0.000	0.118	0.882	-1.059666
Eigenval							0.972426
Cum.Prop							0.968837

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.55667	QUESTION p=0.18000	DROWSY p=0.26333
Observed	AWAKE	94.611	158	4	5
	QUESTION	5.556	33	3	18
	DROWSY	72.152	15	7	57
	Total	72.667	206	14	80

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACDE	-0.675572	-4.801996	-6.197370
LGREV	-0.070233	0.960653	2.679256
MDREV	0.238677	0.449434	0.441393
SMREV	-0.076184	-0.061070	0.060290
THRSHLD	-4.278009	2.924841	19.525524
Constant	-1.074850	-3.786887	-5.360465

Table D2a: Multiple Regression and Discriminant Analysis of EYEMEAS Using Steering and Accelerometer.

Regression Summary for Dependent Variable: EYEMEAS

R= 0.76374 $R^2 \le= 0.58330$ Adjusted $R^2 \le= 0.57621$
F(5,294)=82.309 p<0.0000 Std.Error of estimate: 903.39

	BETA	St. Err. of BETA	B	St. Err. of B	t(294)	p-level
Intercpt			1387.759286	72.612	19.112	0.000
ACCVAR	-0.231	0.045	-143.787224	27.808	-5.171	0.000
STVELV	0.292	0.076	13.520694	3.513	3.849	0.000
LGREV	0.358	0.075	515.535062	107.976	4.775	0.000
NMRHOLD	-0.316	0.057	-77.465944	13.874	-5.584	0.000
THRSHLD	0.362	0.049	4745.192996	640.466	7.409	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: EYEMEA_2 (2 grps)
Wilks' Lambda: 0.52067 approx. F (5,294)=54.131 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.557	0.934	20.771	0.000	0.668	0.332	-0.454127
STVELV	0.542	0.961	11.952	0.000	0.327	0.673	0.499434
LGREV	0.532	0.979	6.191	0.013	0.354	0.646	0.348545
NMRHOLD	0.592	0.880	40.191	0.000	0.455	0.545	-0.742754
THRSHLD	0.610	0.854	50.276	0.000	0.523	0.477	0.763374
Eigenval							0.920593
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.70333	DROWSY p=0.29667
Observed	AWAKE	91.469	193	18
	DROWSY	65.169	31	58
	Total	83.667	224	76

Classification Functions

	AWAKE	DROWSY
ACCVAR	0.165941	-0.261138
STVELV	0.009520	0.050441
LGREV	0.530422	1.435792
NMRHOLD	0.100267	-0.196132
THRSHLD	-0.118338	15.185064
Constant	-0.653275	-4.213998

Table D2b: Discriminant Analysis of EYEMEAS Using Steering and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 5; Grouping: EYEMEA_3 (3 grps)
Wilks' Lambda: 0.48054 approx. F (10,586)=25.934 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.512	0.938	9.607	0.000	0.672	0.328	-0.416036
STVELV	0.501	0.960	6.123	0.002	0.334	0.666	0.479481
LGREV	0.499	0.963	5.621	0.004	0.367	0.633	0.428272
NMRHOLD	0.538	0.893	17.516	0.000	0.456	0.544	-0.660637
THRSHLD	0.579	0.829	30.119	0.000	0.522	0.478	0.797991
Eigenval							1.040681
Cum.Prop							0.981380

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.67333	QUESTION p=0.06333	DROWSY p=0.26333
Observed	AWAKE	93.564	189	0	13
	QUESTION	5.263	9	1	9
	DROWSY	65.823	26	1	52
	Total	80.667	224	2	74

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCVAR	0.160576	-0.014154	-0.278234
STVELV	0.009696	0.029675	0.053997
LGREV	0.496750	1.722761	1.691286
NMRHOLD	0.095451	-0.009417	-0.199537
THRSHLD	-0.255759	12.871964	17.219448
Constant	-0.665043	-4.868148	-4.780627

Table D3a: Multiple Regression and Discriminant Analysis of NEWDEF Using Steering and Accelerometer.

Regression Summary for Dependent Variable: NEWDEF

R= 0.67680277 R^2 ≤= 0.45806199 Adjusted R^2 ≤= 0.44696429
F(6,293)=41.275 p<0.00000 Std.Error of estimate: 1.2767

	BETA	St. Err. of BETA	B	St. Err. of B	t(293)	p-level
Intercpt			-0.217278	0.121	-1.799	0.073
ACCDEV	0.223	0.086	0.641149	0.246	2.608	0.010
INTACDE	-0.260	0.072	-2.887980	0.800	-3.612	0.000
STVELV	0.423	0.074	0.024208	0.004	5.710	0.000
MDREV	-0.258	0.073	-0.103054	0.029	-3.517	0.000
SMREV	-0.329	0.065	-0.042640	0.008	-5.040	0.000
NMRHOLD	-0.518	0.082	-0.156914	0.025	-6.316	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 4; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.65844 approx. F (4,295)=38.257 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,295)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.682	0.965	10.650	0.001	0.923	0.077	-0.332450
STVELV	0.725	0.908	29.822	0.000	0.606	0.394	0.665890
SMREV	0.704	0.935	20.369	0.000	0.411	0.589	-0.677887
NMRHOLD	0.692	0.952	14.985	0.000	0.311	0.689	-0.674317
Eigenvalue							0.518744
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.73000	DROWSY p=0.27000
Observed	AWAKE	92.237	202	17
	DROWSY	51.852	39	42
	Total	81.333	241	59

Classification Functions

	AWAKE	DROWSY
INTACDE	0.551132	-2.931861
STVELV	0.023435	0.065159
SMREV	-0.036122	-0.119124
NMRHOLD	-0.000187	-0.202697
Constant	-0.578980	-3.777506

Table D3b: Discriminant Analysis of NEWDEF Using Steering and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.52481 approx. F (12,584)=18.512 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.536	0.978	3.226	0.041	0.257	0.743	0.405634
INTACDE	0.561	0.936	9.968	0.000	0.337	0.663	-0.619979
STVELV	0.588	0.892	17.644	0.000	0.439	0.561	0.693085
MDREV	0.572	0.918	13.054	0.000	0.380	0.620	-0.207209
SMREV	0.561	0.936	10.059	0.000	0.410	0.590	-0.613141
NMRHOLD	0.563	0.932	10.667	0.000	0.299	0.701	-0.670315
Eigenval							0.714509
Cum.Prop							0.865156

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.64333	QUESTION p=0.17000	DROWSY p=0.18667
Observed	AWAKE	91.710	177	8	8
	QUESTION	21.569	34	11	6
	DROWSY	60.714	17	5	34
	Total	74.000	228	24	48

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCDEV	0.135183	1.247651	1.570711
INTACDE	-1.211851	-7.362267	-9.609085
STVELV	-0.006093	-0.007040	0.058029
MDREV	0.331800	0.594367	0.174890
SMREV	-0.034121	-0.075598	-0.135023
NMRHOLD	0.070601	0.073074	-0.222268
Constant	-1.028510	-4.133420	-5.458323

Table D4a: Multiple Regression and Discriminant Analysis of PERCLOS Using Steering and Accelerometer.

Regression Summary for Dependent Variable: PERCLOS

R= 0.78910 R^2<= 0.62268 Adjusted R^2<= 0.61626
F(5,294)=97.038 p<0.0000 Std.Error of estimate: 0.06065

	BETA	St. Err. of BETA	B	St. Err. of B	t(294)	p-level
Intercpt			0.014132	0.005	2.974	0.003
INTACDE	-0.134	0.038	-0.084597	0.024	-3.488	0.000
LGREV	0.395	0.050	0.040055	0.005	7.845	0.000
STEXED	0.146	0.042	74.427007	21.231	3.506	0.000
NMRHOLD	-0.427	0.054	-0.007378	0.000	-7.985	0.000
THRSHLD	0.450	0.047	0.416209	0.044	9.491	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: PERCLO_2 (2 grps)
Wilks' Lambda: 0.52200 approx. F (5,294)=53.843 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.530	0.985	4.331	0.038	0.288	0.712	-0.324895
INTACDE	0.557	0.937	19.740	0.000	0.351	0.649	0.612624
LGREV	0.605	0.863	46.580	0.000	0.688	0.312	-0.645023
NMRHOLD	0.564	0.926	23.415	0.000	0.446	0.554	0.588040
THRSHLD	0.599	0.871	43.482	0.000	0.521	0.479	-0.718944
Eigenval							0.915703
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	92.641	214	17
	DROWSY	59.420	28	41
	Total	85.000	242	58

Classification Functions

	AWAKE	DROWSY
ACCDEV	1.133141	2.369298
INTACDE	-2.822173	-11.930291
LGREV	0.853914	2.676193
NMRHOLD	0.085229	-0.164328
THRSHLD	0.381324	16.122311
Constant	-0.594085	-5.459984

Table D4b: Discriminant Analysis of PERCLOS Using Steering and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 4; Grouping: PERCLO_3 (3 grps)
Wilks' Lambda: 0.41662 approx. F (8,588)=40.372 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.436	0.957	6.682	0.001	0.855	0.145	0.294490
LGREV	0.560	0.743	50.760	0.000	0.781	0.219	-0.748856
NMRHOLD	0.484	0.861	23.686	0.000	0.454	0.546	0.719981
THRSHLD	0.520	0.801	36.601	0.000	0.486	0.514	-0.836450
Eigenval							1.385987
Cum.Prop							0.995706

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.68333	QUESTION p=0.14667	DROWSY p=0.17000
Observed	AWAKE	94.634	194	5	6
	QUESTION	18.182	20	8	16
	DROWSY	64.706	12	6	33
	Total	78.333	226	19	55

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACDE	0.305028	-2.916322	-5.452146
LGREV	0.907734	2.964773	3.793787
NMRHOLD	0.074773	-0.150542	-0.340462
THRSHLD	-0.502005	13.069915	23.929153
Constant	-0.584879	-4.558358	-7.182536

Table D5a: Multiple Regression and Discriminant Analysis of MASTER Using Steering and Accelerometer.

Regression Summary for Dependent Variable: MASTER

$R= 0.80116$ $R^2 \leq 0.64185$ Adjusted $R^2 \leq 0.63452$
$F(6,293)=87.518$ $p<0.0000$ Std.Error of estimate: 2.1481

	BETA	St. Err. of BETA	B	St. Err. of B	t(293)	p-level
Intercpt			-2.374181	0.206	-11.503	0.000
INTACDE	-0.188	0.038	-4.325066	0.875	-4.942	0.000
LGREV	0.448	0.054	1.651363	0.198	8.340	0.000
MDREV	0.149	0.051	0.123422	0.042	2.930	0.004
STEXED	0.090	0.041	1672.678369	751.930	2.225	0.027
NMRHOLD	-0.314	0.054	-0.196918	0.034	-5.821	0.000
THRSHLD	0.357	0.047	11.974089	1.579	7.582	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 4; Grouping: MASTER_2 (2 grps)
Wilks' Lambda: 0.55341 approx. $F(4,295)=59.515$ $p<0.0000$

	Wilks' Lambda	Partial Lambda	F-remove (1,295)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.585	0.946	16.968	0.000	0.857	0.143	0.377083
LGREV	0.650	0.851	51.666	0.000	0.733	0.267	-0.674560
NMRHOLD	0.610	0.907	30.107	0.000	0.458	0.542	0.672830
THRSHLD	0.632	0.875	42.105	0.000	0.525	0.475	-0.730199
Eigenval							0.806985
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.75000	DROWSY p=0.25000
Observed	AWAKE	91.111	205	20
	DROWSY	57.333	32	43
	Total	82.667	237	63

Classification Functions

	AWAKE	DROWSY
INTACDE	0.350252	-4.761346
LGREV	0.962773	2.671899
NMRHOLD	0.072590	-0.187316
THRSHLD	-0.302222	14.284223
Constant	-0.546877	-4.575404

Table D5b: Discriminant Analysis of MASTER Using Steering and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 5; Grouping: MASTER_3 (3 grps)
Wilks' Lambda: 0.37165 approx. F (10,586)=37.524 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.398	0.934	10.435	0.000	0.807	0.193	0.361415
LGREV	0.503	0.739	51.809	0.000	0.680	0.320	-0.784924
MDREV	0.383	0.971	4.407	0.013	0.537	0.463	-0.116693
NMRHOLD	0.415	0.896	17.056	0.000	0.445	0.555	0.606994
THRSHLD	0.455	0.816	33.051	0.000	0.475	0.525	-0.786420
Eigenval							1.604731
Cum.Prop							0.979844

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.67333	QUESTION p=0.13667	DROWSY p=0.19000
Observed	AWAKE	95.545	193	5	4
	QUESTION	14.634	14	6	21
	DROWSY	59.649	11	12	34
	Total	77.667	218	23	59

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACDE	-1.036274	-5.189689	-8.448269
LGREV	0.346453	2.400078	3.785548
MDREV	0.322822	0.518263	0.357400
NMRHOLD	0.133253	-0.066562	-0.234402
THRSHLD	2.131355	19.782101	24.361584
Constant	-1.028401	-6.127763	-7.951914

APPENDIX E

Multiple Regression/Discriminant Analysis Results —

Steering, Accelerometer, & HPHDGDEV/VAR

Table E1a: Multiple Regression and Discriminant Analysis of AVEOBS Using Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: AVEOBS

R= 0.79341757 R^2<= 0.62951145 Adjusted R^2<= 0.61932620
F(8,291)=61.806 p<0.0000 Std.Error of estimate: 15.384

	BETA	St. Err. of BETA	B	St. Err. of B	t(291)	p-level
Intercpt			25.811553	1.597	16.159	0.000
ACCVAR	-0.275	0.045	-3.076726	0.502	-6.135	0.000
HPHDGDE	0.544	0.066	41.121858	4.986	8.248	0.000
STVELV	-0.313	0.082	-0.260478	0.069	-3.801	0.000
LGREV	0.345	0.084	8.919292	2.167	4.115	0.000
MDREV	0.658	0.068	3.822080	0.397	9.636	0.000
SMREV	0.369	0.164	0.694491	0.309	2.249	0.025
NMRHOLD	0.251	0.099	1.102279	0.434	2.538	0.012
THRSHLD	0.408	0.132	96.082518	31.101	3.089	0.002

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 7; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.52674 approx. F (7,292)=37.479 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.545	0.967	10.036	0.002	0.628	0.372	0.334301
HPHDGDE	0.565	0.932	21.227	0.000	0.457	0.543	-0.559782
STVELV	0.538	0.979	6.151	0.014	0.233	0.767	0.432953
LGREV	0.567	0.929	22.478	0.000	0.278	0.722	-0.736969
MDREV	0.551	0.955	13.669	0.000	0.376	0.624	-0.501436
SMREV	0.540	0.976	7.153	0.008	0.137	0.863	-0.606578
THRSHLD	0.551	0.956	13.427	0.000	0.118	0.882	-0.888132
Eigenval							0.898471
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.66333	DROWSY p=0.33667
Observed	AWAKE	92.965	185	14
	DROWSY	68.317	32	69
	Total	84.667	217	83

Classification Functions

	AWAKE	DROWSY
ACCVAR	-0.060125	-0.361772
HPHDGDE	3.149318	7.424867
STVELV	-0.028309	-0.060682
LGREV	-0.176312	1.701501
MDREV	0.325023	0.572079
SMREV	-0.092536	-0.000263
THRSHLD	-6.592471	10.393138
Constant	-1.178715	-5.222380

Table E1b: Discriminant Analysis of AVEOBS Using Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 7; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.43790 approx. F (14,582)=21.250 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,291)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.476	0.920	12.646	0.000	0.607	0.393	0.484416
HPHDGDE	0.481	0.911	14.171	0.000	0.463	0.537	-0.589511
STVELV	0.454	0.964	5.437	0.005	0.243	0.757	0.448150
LGREV	0.471	0.931	10.847	0.000	0.306	0.694	-0.644771
MDREV	0.464	0.944	8.682	0.000	0.379	0.621	-0.468773
NMRHOLD	0.454	0.965	5.211	0.006	0.427	0.573	0.290142
THRSHLD	0.457	0.958	6.421	0.002	0.502	0.498	-0.395872
Eigenval							1.159095
Cum.Prop							0.952606

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.55667	QUESTION p=0.18000	DROWSY p=0.26333
Observed	AWAKE	91.617	153	9	5
	QUESTION	14.815	35	8	11
	DROWSY	73.418	12	9	58
	Total	73.000	200	26	74

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCVAR	-0.021938	-0.346675	-0.563228
HPHDGDE	3.587241	5.418198	9.570934
STVELV	-0.027585	-0.026465	-0.072912
LGREV	0.033702	0.769535	2.196591
MDREV	0.379682	0.621798	0.666466
NMRHOLD	0.170244	0.202596	0.023041
THRSHLD	-0.043507	4.306496	9.433874
Constant	-1.329686	-4.222895	-6.704548

Table E2a: Multiple Regression and Discriminant Analysis of EYEMEAS Using Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: EYEMEAS

$R= 0.80895942$ $R^2 \leq= 0.65441535$ Adjusted $R^2 \leq= 0.64733853$
$F(6,293)=92.473$ $p<0.0000$ Std.Error of estimate: 824.10

	BETA	St. Err. of BETA	B	St. Err. of B	t(293)	p-level
Intercpt			978.028061	83.558	11.705	0.000
ACCDEV	-0.280	0.045	-649.353379	104.045	-6.241	0.000
HPHDGDE	0.578	0.054	2430.760513	226.274	10.743	0.000
STVELV	0.164	0.067	7.575613	3.122	2.426	0.016
MDREV	0.291	0.059	94.146763	19.222	4.898	0.000
SMREV	0.223	0.091	23.372237	9.562	2.444	0.015
THRSHLD	0.400	0.099	5242.463382	1296.794	4.043	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: EYEMEA_2 (2 grps)
Wilks' Lambda: 0.53057 approx. $F(5,294)=52.025$ $p<0.0000$

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.552	0.962	11.688	0.000	0.635	0.365	0.358166
HPHDGDE	0.579	0.916	27.102	0.000	0.583	0.417	-0.555182
STVELV	0.601	0.883	39.070	0.000	0.461	0.539	-0.736143
SMREV	0.556	0.954	14.114	0.000	0.139	0.861	-0.838863
THRSHLD	0.569	0.932	21.424	0.000	0.121	0.879	-1.095654
Eigenval							0.884780
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.70333	DROWSY p=0.29667
Observed	AWAKE	93.365	197	14
	DROWSY	62.921	33	56
	Total	84.333	230	70

Classification Functions

	AWAKE	DROWSY
ACCDEV	0.213594	-1.015269
HPHDGDE	2.490172	6.782544
STVELV	-0.004341	0.054789
SMREV	-0.120526	0.010086
THRSHLD	-12.841364	8.691820
Constant	-0.826270	-4.615117

Table E2b: Discriminant Analysis of EYEMEAS Using Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 5; Grouping: EYEMEA_3 (3 grps)
Wilks' Lambda: 0.48256 approx. F (10,586)=25.757 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.502	0.962	5.807	0.003	0.637	0.363	0.331325
HPHDGDE	0.540	0.893	17.569	0.000	0.606	0.394	-0.588566
STVELV	0.547	0.882	19.671	0.000	0.472	0.528	-0.703494
SMREV	0.501	0.962	5.748	0.004	0.144	0.856	-0.673542
THRSHLD	0.516	0.935	10.236	0.000	0.124	0.876	-1.017432
Eigenval							1.027325
Cum.Prop							0.978876

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.67333	QUESTION p=0.06333	DROWSY p=0.26333
Observed	AWAKE	95.545	193	0	9
	QUESTION	0.000	10	0	9
	DROWSY	63.291	26	3	50
	Total	81.000	229	3	68

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCDEV	0.190485	-0.128073	-1.117100
HPHDGDE	2.497319	5.040936	7.767228
STVELV	-0.003837	0.034266	0.059660
SMREV	-0.116712	-0.100653	0.007075
THRSHLD	-12.555587	-0.532039	10.093150
Constant	-0.835515	-5.103856	-5.336180

Table E3a: Multiple Regression and Discriminant Analysis of NEWDEF Using Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: NEWDEF

R= 0.70017096 R^2 <= 0.49023937 Adjusted R^2 <= 0.48156997
F(5,294)=56.548 p<0.00000 Std.Error of estimate: 1.2362

	BETA	St. Err. of BETA	B	St. Err. of B	t(294)	p-level
Intercpt			-0.529242	0.104	-5.093	0.000
INTACDE	-0.115	0.042	-1.276622	0.468	-2.726	0.007
HPHDGDE	0.400	0.063	2.080095	0.329	6.319	0.000
SMREV	-0.184	0.069	-0.023808	0.009	-2.653	0.008
STEXED	0.149	0.047	1331.188046	424.292	3.137	0.002
NMRHOLD	-0.344	0.080	-0.104043	0.024	-4.299	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.66519 approx. F (5,294)=29.596 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.679	0.980	6.091	0.014	0.961	0.039	-0.251106
HPHDGDE	0.701	0.949	15.669	0.000	0.567	0.433	0.516206
SMREV	0.693	0.960	12.327	0.000	0.350	0.650	-0.585618
STEXED	0.674	0.986	4.078	0.044	0.862	0.138	0.217696
NMRHOLD	0.697	0.955	13.955	0.000	0.288	0.712	-0.685080
Eigenval							0.503338
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.73000	DROWSY p=0.27000
Observed	AWAKE	92.237	202	17
	DROWSY	53.086	38	43
	Total	81.667	240	60

Classification Functions

	AWAKE	DROWSY
INTACDE	1.038125	-1.553293
HPHDGDE	3.211746	6.133039
SMREV	-0.014572	-0.085204
STEXED	-1007.460693	913.248230
NMRHOLD	0.045491	-0.157173
Constant	-0.699823	-3.886657

Table E3b: Discriminant Analysis of NEWDEF Using Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.52019 approx. F (12,584)=18.810 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.548	0.950	7.707	0.000	0.850	0.150	-0.345793
HPHDGDE	0.536	0.970	4.552	0.011	0.514	0.486	0.370278
STVELV	0.552	0.943	8.900	0.000	0.359	0.641	0.522877
MDREV	0.571	0.911	14.255	0.000	0.388	0.612	-0.034289
SMREV	0.534	0.974	3.917	0.021	0.341	0.659	-0.424117
NMRHOLD	0.538	0.967	5.026	0.007	0.246	0.754	-0.474713
Eigenval							0.736293
Cum.Prop							0.872939

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.64333	QUESTION p=0.17000	DROWSY p=0.18667
Observed	AWAKE	91.192	176	7	10
	QUESTION	17.647	36	9	6
	DROWSY	62.500	16	5	35
	Total	73.333	228	21	51

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACDE	-0.995124	-4.318599	-5.790993
HPHDGDE	3.705245	5.032941	6.718713
STVELV	-0.026981	-0.033440	0.022611
MDREV	0.399196	0.719868	0.339401
SMREV	0.003990	-0.024673	-0.066967
NMRHOLD	0.187727	0.219558	-0.025595
Constant	-1.286260	-4.541304	-6.198846

Table E4a: Multiple Regression and Discriminant Analysis of PERCLOS Using Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: PERCLOS

R= 0.84691010 R^2 <= 0.71725672 Adjusted R^2 <= 0.71244816
F(5,294)=149.16 p<0.0000 Std.Error of estimate: 0.05250

	BETA	St. Err. of BETA	B	St. Err. of B	t(294)	p-level
Intercpt			-0.000348	0.004	-0.078	0.938
ACCVAR	-0.128	0.035	-0.005646	0.002	-3.615	0.000
HPHDGDE	0.616	0.045	0.182652	0.013	13.600	0.000
STEXED	0.112	0.035	56.959348	18.000	3.164	0.002
NMRHOLD	-0.296	0.048	-0.005112	0.000	-6.154	0.000
THRSHLD	0.320	0.043	0.295479	0.040	7.463	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: PERCLO_2 (2 grps)
Wilks' Lambda: 0.51660 approx. F (5,294)=55.021 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.540	0.958	13.032	0.000	0.900	0.100	0.312391
HPHDGDE	0.599	0.862	47.071	0.000	0.694	0.306	-0.641278
STEXED	0.524	0.987	3.988	0.047	0.872	0.128	-0.178155
NMRHOLD	0.554	0.933	21.192	0.000	0.438	0.562	0.563673
THRSHLD	0.566	0.913	28.138	0.000	0.494	0.506	-0.605099
Eigenval							0.935730
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	95.671	221	10
	DROWSY	69.565	21	48
	Total	89.667	242	58

Classification Functions

	AWAKE	DROWSY
INTACDE	0.654594	-4.040364
HPHDGDE	3.950817	9.597035
STEXED	-896.107483	1373.980225
NMRHOLD	0.100406	-0.141412
THRSHLD	-1.905112	11.487375
Constant	-0.667754	-5.653876

Table E4b: Discriminant Analysis of PERCLOS Using Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 5; Grouping: PERCLO_3 (3 grps)
Wilks' Lambda: 0.38538 approx. F (10,586)=35.795 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.401	0.961	5.957	0.003	0.855	0.145	-0.271573
HPHDGDE	0.417	0.925	11.876	0.000	0.556	0.444	0.468791
LGREV	0.409	0.943	8.933	0.000	0.520	0.480	0.421886
NMRHOLD	0.421	0.916	13.384	0.000	0.432	0.568	-0.554878
THRSHLD	0.449	0.859	23.994	0.000	0.470	0.530	0.692941
Eigenval							1.578775
Cum.Prop							0.996075

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.68333	QUESTION p=0.14667	DROWSY p=0.17000
Observed	AWAKE	96.098	197	5	3
	QUESTION	29.545	17	13	14
	DROWSY	66.667	8	9	34
	Total	81.333	222	27	51

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACDE	0.346467	-2.816687	-5.325303
HPHDGDE	2.969316	7.139267	9.088789
LGREV	0.343208	1.607456	2.065827
NMRHOLD	0.108787	-0.068759	-0.236347
THRSHLD	-1.813319	9.917061	19.915348
Constant	-0.721030	-5.345433	-8.458155

Table E5a: Multiple Regression and Discriminant Analysis of MASTER Using Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: MASTER

R= 0.85182990 R^2 <= 0.72561418 Adjusted R^2 <= 0.72094776
F(5,294)=155.50 p<0.0000 Std.Error of estimate: 1.8770

	BETA	St. Err. of BETA	B	St. Err. of B	t(294)	p-level
Intercpt			-3.054219	0.190	-16.089	0.000
ACCVAR	-0.214	0.038	-0.342120	0.060	-5.694	0.000
HPHDGDE	0.659	0.043	7.098631	0.458	15.508	0.000
MDREV	0.243	0.043	0.201570	0.036	5.626	0.000
NMRHOLD	-0.184	0.049	-0.115595	0.031	-3.735	0.000
THRSHLD	0.245	0.042	8.230966	1.425	5.777	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: MASTER_2 (2 grps)
Wilks' Lambda: 0.54799 approx. F (5,294)=48.502 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.566	0.969	9.406	0.002	0.643	0.357	-0.326529
HPHDGDE	0.634	0.864	46.320	0.000	0.688	0.312	0.661322
MDREV	0.561	0.978	6.765	0.010	0.535	0.465	0.305015
NMRHOLD	0.580	0.944	17.358	0.000	0.407	0.593	-0.550595
THRSHLD	0.615	0.892	35.698	0.000	0.485	0.515	0.702890
Eigenval							0.824864
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.75000	DROWSY p=0.25000
Observed	AWAKE	92.444	208	17
	DROWSY	65.333	26	49
	Total	85.667	234	66

Classification Functions

	AWAKE	DROWSY
ACCVAR	-0.057629	-0.364934
HPHDGDE	2.776997	7.972469
MDREV	0.314350	0.469769
NMRHOLD	0.178152	-0.036880
THRSHLD	0.463999	14.659594
Constant	-1.149751	-5.838746

Table E5b: Discriminant Analysis of MASTER Using Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: MASTER_3 (3 grps)
Wilks' Lambda: 0.34318 approx. F (12,584)=34.408 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.369	0.931	10.796	0.000	0.619	0.381	0.410608
HPHDGDE	0.377	0.910	14.517	0.000	0.567	0.433	-0.495269
LGREV	0.370	0.929	11.201	0.000	0.487	0.513	-0.474412
MDREV	0.359	0.957	6.531	0.002	0.493	0.507	-0.211737
NMRHOLD	0.368	0.933	10.473	0.000	0.421	0.579	0.484471
THRSHLD	0.400	0.859	23.991	0.000	0.465	0.535	-0.680921
Eigenval							1.817982
Cum.Prop							0.981620

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.67333	QUESTION p=0.13667	DROWSY p=0.19000
Observed	AWAKE	95.545	193	6	3
	QUESTION	19.512	15	8	18
	DROWSY	70.175	7	10	40
	Total	80.333	215	24	61

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCVAR	-0.053561	-0.526573	-0.623293
HPHDGDE	3.438553	7.869648	10.476720
LGREV	-0.323041	1.064287	1.864411
MDREV	0.336392	0.605878	0.444069
NMRHOLD	0.172481	0.005292	-0.141537
THRSHLD	0.817324	17.140390	21.253637
Constant	-1.196504	-7.056661	-9.253569

APPENDIX F

Multiple Regression/Discriminant Analysis Results —

Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ

Table F1a: Multiple Regression and Discriminant Analysis of AVEOBS Using Steering, Accelerometer, and Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: AVEOBS

R= 0.82577937 R^2≤= 0.68191157 Adjusted R^2≤= 0.67428617
F(7,292)=89.426 p<0.0000 Std.Error of estimate: 14.230

	BETA	St. Err. of BETA	B	St. Err. of B	t(292)	p-level
Intercpt			25.645817	1.390	18.457	0.000
ACCDEV	-0.350	0.045	-14.565780	1.874	-7.773	0.000
ACEXEED	0.099	0.039	246.164352	95.978	2.565	0.011
LANDEV	1.142	0.079	21.903765	1.516	14.450	0.000
LNERRSQ	-0.667	0.065	-1.300765	0.127	-10.229	0.000
STVELV	-0.146	0.064	-0.121066	0.053	-2.268	0.024
MDREV	0.503	0.059	2.919365	0.343	8.517	0.000
THRSHLD	0.128	0.038	30.226578	9.054	3.339	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.42876 approx. F (5,294)=78.339 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.452	0.949	15.829	0.000	0.577	0.423	-0.393556
LANDEV	0.765	0.561	230.325	0.000	0.176	0.824	2.091625
LNERRSQ	0.598	0.717	116.320	0.000	0.196	0.804	-1.592054
MDREV	0.435	0.985	4.411	0.037	0.540	0.460	0.218918
THRSHLD	0.436	0.984	4.882	0.028	0.748	0.252	0.195526
Eigenval							1.332297
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.66333	DROWSY p=0.33667
Observed	AWAKE	94.975	189	10
	DROWSY	76.238	24	77
	Total	88.667	213	87

Classification Functions

	AWAKE	DROWSY
ACCDEV	-0.336750	-1.948067
LANDEV	0.743005	5.559700
LNERRSQ	-0.049657	-0.362039
MDREV	0.266623	0.397967
THRSHLD	5.035305	9.588925
Constant	-0.987455	-6.422662

Table F1b: Discriminant Analysis of AVEOBS Using Steering, Accelerometer, and Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 5; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.34815 approx. F (10,586)=40.715 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.399	0.874	21.216	0.000	0.551	0.449	-0.589602
LANDEV	0.734	0.474	162.322	0.000	0.173	0.827	2.187520
LNERRSQ	0.522	0.667	73.202	0.000	0.190	0.810	-1.662260
MDREV	0.368	0.945	8.447	0.000	0.497	0.503	0.249215
NMRHOLD	0.357	0.976	3.578	0.029	0.628	0.372	-0.071053
Eigenval							1.739154
Cum.Prop							0.972810

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.55667	QUESTION p=0.18000	DROWSY p=0.26333
Observed	AWAKE	94.012	157	7	3
	QUESTION	31.481	24	17	13
	DROWSY	72.152	7	15	57
	Total	77.000	188	39	73

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCDEV	-0.330501	-2.160101	-3.319488
LANDEV	0.893712	3.931660	7.502304
LNERRSQ	-0.037935	-0.234677	-0.453661
MDREV	0.308926	0.568376	0.480097
NMRHOLD	0.168968	0.238540	0.116090
Constant	-1.205339	-4.756139	-8.302217

Table F2a: Multiple Regression and Discriminant Analysis of EYEMEAS Using Steering, Accelerometer, and Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: EYEMEAS

R= 0.83700489 R^2<= 0.70057719 Adjusted R^2<= 0.69339924
F(7,292)=97.601 p<0.0000 Std.Error of estimate: 768.40

	BETA	St. Err. of BETA	B	St. Err. of B	t(292)	p-level
Intercpt			967.482741	73.780	13.113	0.000
ACCDEV	-0.336	0.042	-779.208055	97.170	-8.019	0.000
LNMNSQ	-0.372	0.084	-28.996034	6.559	-4.421	0.000
LANDEV	0.738	0.120	787.576776	127.703	6.167	0.000
LANEX	0.269	0.063	3048.878638	709.593	4.297	0.000
STVELV	0.157	0.062	7.247299	2.854	2.540	0.012
MDREV	0.230	0.057	74.233060	18.585	3.994	0.000
THRSHLD	0.140	0.038	1828.608058	493.389	3.706	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 7; Grouping: EYEMEA_2 (2 grps)
Wilks' Lambda: 0.46761 approx. F (7,292)=47.494 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.515	0.909	29.327	0.000	0.599	0.401	0.534995
LNMNSQ	0.481	0.972	8.368	0.004	0.189	0.811	0.525682
LANDEV	0.481	0.972	8.448	0.004	0.108	0.892	-0.699579
LANEX	0.480	0.974	7.654	0.006	0.384	0.616	-0.353511
STVELV	0.496	0.943	17.613	0.000	0.517	0.483	-0.454645
NMRHOLD	0.497	0.941	18.201	0.000	0.418	0.582	0.513467
THRSHLD	0.499	0.936	19.841	0.000	0.461	0.539	-0.509188
Eigenval							1.138553
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.70333	DROWSY p=0.29667
Observed	AWAKE	91.469	193	18
	DROWSY	70.787	26	63
	Total	85.333	219	81

Classification Functions

	AWAKE	DROWSY
ACCDEV	0.397206	-1.685018
LNMNSQ	-0.070787	-0.148162
LANDEV	1.462095	3.039012
LANEX	-0.830293	7.433044
STVELV	0.011877	0.053304
NMRHOLD	0.119051	-0.108819
THRSHLD	-1.430402	9.921589
Constant	-0.772214	-5.298689

Table F2b: Discriminant Analysis of EYEMEAS Using Steering, Accelerometer, and Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 7; Grouping: EYEMEA_3 (3 grps)
Wilks' Lambda: 0.41929 approx. F (14,582)=22.629 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,291)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.461	0.909	14.533	0.000	0.601	0.399	0.504528
LNMNSQ	0.437	0.959	6.199	0.002	0.190	0.810	0.599552
LANDEV	0.435	0.964	5.391	0.005	0.112	0.888	-0.746985
LANEX	0.435	0.965	5.352	0.005	0.400	0.600	-0.393867
STVELV	0.451	0.930	11.035	0.000	0.522	0.478	-0.484333
NMRHOLD	0.440	0.954	7.026	0.001	0.418	0.582	0.431707
THRSHLD	0.458	0.915	13.559	0.000	0.463	0.537	-0.550839
Eigenval							1.328630
Cum.Prop							0.982106

Classification Matrix

		Percent Correct	Observed AWAKE p=0.67333	QUESTION p=0.06333	DROWSY p=0.26333
Predicted	AWAKE	93.069	188	1	13
	QUESTION	5.263	9	1	9
	DROWSY	74.684	17	3	59
	Total	82.667	214	5	81

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCDEV	0.369893	-0.458756	-1.869528
LNMNSQ	-0.070019	-0.156188	-0.166058
LANDEV	1.458260	2.725270	3.362166
LANEX	-0.835605	5.934142	9.632619
STVELV	0.011832	0.047555	0.060920
NMRHOLD	0.115022	0.031429	-0.101484
THRSHLD	-1.485099	11.003536	11.922853
Constant	-0.783110	-5.497642	-6.168207

Table F3a: Multiple Regression and Discriminant Analysis of NEWDEF Using Steering, Accelerometer, and Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: NEWDEF

R= 0.73127598 R^2<= 0.53476456 Adjusted R^2<= 0.52845628
F(4,295)=84.772 p<0.0000 Std.Error of estimate: 1.1789

	BETA	St. Err. of BETA	B	St. Err. of B	t(295)	p-level
Intercpt			-0.518427	0.090	-5.740	0.000
INTACDE	-0.153	0.042	-1.693902	0.463	-3.660	0.000
LANVAR	0.255	0.055	0.031894	0.007	4.660	0.000
LANEX	0.350	0.057	4.908173	0.803	6.109	0.000
STVELV	0.250	0.052	0.014324	0.003	4.802	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 4; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.60546 approx. F (4,295)=48.058 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,295)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.635	0.954	14.227	0.000	0.853	0.147	-0.369704
LANEX	0.682	0.888	37.071	0.000	0.754	0.246	0.612780
STVELV	0.676	0.895	34.550	0.000	0.719	0.281	0.607751
THRSHLD	0.614	0.986	4.089	0.044	0.856	0.144	0.201166
Eigenval							0.651628
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.73000	DROWSY p=0.27000
Observed	AWAKE	94.064	206	13
	DROWSY	58.025	34	47
	Total	84.333	240	60

Classification Functions

	AWAKE	DROWSY
INTACDE	0.390172	-3.950971
LANEX	2.476775	13.231908
STVELV	0.019393	0.062074
THRSHLD	2.690654	6.145126
Constant	-0.539661	-4.263487

Table F3b: Discriminant Analysis of NEWDEF Using Steering, Accelerometer, and Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 4; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.51202 approx. F (8,588)=29.217 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.562	0.911	14.293	0.000	0.823	0.177	-0.472583
LANEX	0.599	0.855	24.851	0.000	0.792	0.208	0.636464
STVELV	0.565	0.906	15.254	0.000	0.444	0.556	0.591757
MDREV	0.549	0.932	10.682	0.000	0.461	0.539	0.032937
Eigenval							0.818917
Cum.Prop							0.917392

Classification Matrix

			Predicted		
		Percent	AWAKE	QUESTION	DROWSY
		Correct	p=0.64333	p=0.17000	p=0.18667
Observed	AWAKE	91.192	176	9	8
	QUESTION	5.882	40	3	8
	DROWSY	64.286	16	4	36
	Total	71.667	232	16	52

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACDE	-1.383107	-5.419239	-8.368541
LANEX	3.657680	8.731796	18.494841
STVELV	-0.012469	-0.016967	0.046650
MDREV	0.260922	0.525036	0.245484
Constant	-0.851375	-3.700277	-6.035586

Table F4a: Multiple Regression and Discriminant Analysis of PERCLOS Using Steering, Accelerometer, and Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: PERCLOS

R= 0.87159526 R^2<= 0.75967830 Adjusted R^2<= 0.75475703
F(6,293)=154.37 p<0.0000 Std.Error of estimate: .04849

	BETA	St. Err. of BETA	B	St. Err. of B	t(293)	p-level
Intercpt			-0.003	0.004053	-0.694	0.488
INTACDE	-0.109	0.030	-0.069	0.019114	-3.603	0.000
LANDEV	0.873	0.063	0.066	0.004763	13.798	0.000
LNERRSQ	-0.258	0.054	-0.002	0.000410	-4.820	0.000
STEXED	0.090	0.033	45.740	16.818827	2.720	0.007
NMRHOLD	-0.204	0.045	-0.004	0.000785	-4.494	0.000
THRSHLD	0.250	0.041	0.231	0.037904	6.098	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 6; Grouping: PERCLO_2 (2 grps)
Wilks' Lambda: 0.45353 approx. F (6,293)=58.841 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coeffiecient
INTACDE	0.482	0.941	18.215	0.000	0.875	0.125	0.349867
LANDEV	0.592	0.766	89.681	0.000	0.269	0.730	-1.261448
LNERRSQ	0.505	0.898	33.174	0.000	0.312	0.688	0.772370
STEXED	0.460	0.986	4.163	0.042	0.851	0.149	-0.173585
NMRHOLD	0.473	0.960	12.277	0.000	0.431	0.569	0.413003
THRSHLD	0.483	0.939	18.998	0.000	0.481	0.519	-0.481139
Eigenval							1.204930
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	94.805	219	12
	DROWSY	75.362	17	52
	Total	90.333	236	64

Classification Functions

	AWAKE	DROWSY
INTACDE	0.276362	-5.690438
LANDEV	1.637525	4.936619
LNERRSQ	-0.094531	-0.267244
STEXED	-159.922363	2350.023926
NMRHOLD	0.082455	-0.118603
THRSHLD	-1.223006	10.861004
Constant	-0.660627	-6.816076

Table F4b: Discriminant Analysis of PERCLOS Using Steering, Accelerometer, and Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: PERCLO_3 (3 grps)
Wilks' Lambda: 0.32167 approx. F (12,584)=37.141 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.337	0.954	7.056	0.001	0.858	0.142	0.282399
LANDEV	0.440	0.731	53.604	0.000	0.242	0.758	-1.274985
LNERRSQ	0.385	0.836	28.635	0.000	0.287	0.713	0.883192
STVELV	0.331	0.971	4.428	0.013	0.608	0.392	-0.267029
NMRHOLD	0.342	0.940	9.258	0.000	0.420	0.580	0.447207
THRSHLD	0.368	0.875	20.801	0.000	0.452	0.548	-0.633510
Eigenval							2.034168
Cum.Prop							0.988060

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.68333	QUESTION p=0.14667	DROWSY p=0.17000
Observed	AWAKE	96.098	197	7	1
	QUESTION	47.727	10	21	13
	DROWSY	72.549	7	7	37
	Total	85.000	214	35	51

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACDE	-0.052563	-4.219471	-6.562628
LANDEV	1.338052	5.070302	6.014334
LNERRSQ	-0.084787	-0.314965	-0.331528
STVELV	0.017498	0.045803	0.053958
NMRHOLD	0.098274	-0.066520	-0.218260
THRSHLD	-0.463380	12.367912	21.876457
Constant	-0.754007	-6.812154	-10.177960

Table F5a: Multiple Regression and Discriminant Analysis of MASTER Using Steering, Accelerometer, and Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: MASTER

R= 0.88641410 R^2 ≤= 0.78572996 Adjusted R^2 ≤= 0.77908020
F(9,290)=118.16 p<0.0000 Std.Error of estimate: 1.6701

	BETA	St. Err. of BETA	B	St. Err. of B	t(290)	p-level
Intercpt			-2.982588	0.170	-17.551	0.000
ACCVAR	-0.163	0.047	-0.259953	0.075	-3.466	0.000
INTACDE	-0.091	0.042	-2.087452	0.972	-2.147	0.033
LANDEV	0.757	0.101	2.069666	0.275	7.515	0.000
LANEX	0.174	0.059	5.049306	1.719	2.938	0.004
LNERRSQ	-0.298	0.061	-0.082919	0.017	-4.886	0.000
STVELV	0.116	0.052	0.013713	0.006	2.205	0.028
MDREV	0.161	0.049	0.133662	0.040	3.307	0.001
NMRHOLD	-0.100	0.046	-0.062747	0.029	-2.189	0.029
THRSHLD	0.168	0.039	5.636318	1.315	4.287	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 6; Grouping: MASTER_2 (2 grps)
Wilks' Lambda: 0.46857 approx. F (6,293)=55.384 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.499	0.938	19.275	0.000	0.855	0.145	0.368482
LANDEV	0.555	0.845	53.883	0.000	0.223	0.777	-1.143789
LNERRSQ	0.512	0.915	27.185	0.000	0.295	0.705	0.735886
STVELV	0.479	0.979	6.242	0.013	0.549	0.451	-0.267318
NMRHOLD	0.483	0.970	9.201	0.003	0.414	0.586	0.371849
THRSHLD	0.502	0.933	20.970	0.000	0.476	0.524	-0.513810
Eigenval							1.134148
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.75000	DROWSY p=0.25000
Observed	AWAKE	94.667	213	12
	DROWSY	74.667	19	56
	Total	89.667	232	68

Classification Functions

	AWAKE	DROWSY
INTACDE	-0.019142	-5.940732
LANDEV	1.296940	4.051528
LNERRSQ	-0.083279	-0.236376
STVELV	0.017267	0.042419
NMRHOLD	0.103223	-0.067063
THRSHLD	-0.771467	11.396350
Constant	-0.721808	-6.386709

Table F5b: Discriminant Analysis of MASTER Using Steering, Accelerometer, and Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: MASTER_3 (3 grps)
Wilks' Lambda: 0.29883 approx. F (12,584)=40.360 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.324	0.921	12.484	0.000	0.669	0.331	0.411690
LANDEV	0.409	0.731	53.861	0.000	0.243	0.757	-1.261865
LNERRSQ	0.356	0.840	27.764	0.000	0.289	0.711	0.885810
STVELV	0.331	0.903	15.693	0.000	0.577	0.423	-0.471423
NMRHOLD	0.317	0.943	8.836	0.000	0.427	0.573	0.437793
THRSHLD	0.342	0.873	21.147	0.000	0.455	0.545	-0.627597
Eigenval							2.277943
Cum.Prop							0.990920

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.67333	QUESTION p=0.13667	DROWSY p=0.19000
Observed	AWAKE	96.535	195	4	3
	QUESTION	31.707	11	13	17
	DROWSY	68.421	6	12	39
	Total	82.333	212	29	59

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCVAR	0.096871	-0.377042	-0.566417
LANDEV	1.271834	4.649972	6.324396
LNERRSQ	-0.080426	-0.294875	-0.349732
STVELV	0.014523	0.076466	0.080379
NMRHOLD	0.102337	-0.099311	-0.201678
THRSHLD	-0.301978	16.493361	20.800129
Constant	-0.778173	-6.995985	-10.317619

APPENDIX G

Multiple Regression/Discriminant Analysis Results —

Steering, Accelerometer, & All Lane Measures (includes LNRTDEV/VAR)

Table G1a: Multiple Regression and Discriminant Analysis of AVEOBS Using Steering, Accelerometer, and All Lane Measures (Includes LNRTDEV/VAR).

Regression Summary for Dependent Variable: AVEOBS

R= 0.82362288 R^2<= 0.67835465 Adjusted R^2<= 0.67064397
F(7,292)=87.976 p<0.0000 Std.Error of estimate: 14.309

	BETA	St. Err. of BETA	B	St. Err. of B	t(292)	p-level
Intercpt			24.873615	1.415	17.582	0.000
ACCDEV	-0.214	0.068	-8.903722	2.840	-3.135	0.002
INTACDE	-0.130	0.057	-20.985502	9.207	-2.279	0.023
LANVAR	-0.622	0.078	-1.127665	0.141	-8.009	0.000
LANEX	0.313	0.055	63.791868	11.174	5.709	0.000
LNRTDEV	0.821	0.097	39.821286	4.706	8.461	0.000
MDREV	0.404	0.049	2.346480	0.286	8.210	0.000
THRSHLD	0.178	0.038	41.799342	8.914	4.689	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 7; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.46935 approx. F (7,292)=47.163 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.498	0.943	17.599	0.000	0.560	0.440	-0.437422
LANVAR	0.482	0.974	7.749	0.006	0.018	0.982	1.658863
LANEX	0.512	0.916	26.657	0.000	0.505	0.495	0.558943
LNERRSQ	0.503	0.932	21.226	0.000	0.024	0.976	-2.321546
LNRTDEV	0.492	0.954	14.235	0.000	0.142	0.858	0.785447
MDREV	0.482	0.973	7.972	0.005	0.523	0.477	0.309309
THRSHLD	0.488	0.962	11.537	0.000	0.759	0.241	0.307151
Eigenval							1.130621
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.66333	Predicted DROWSY p=0.33667
Observed	AWAKE	93.970	187	12
	DROWSY	76.238	24	77
	Total	88.000	211	89

Classification Functions

	AWAKE	DROWSY
ACCDEV	-0.328885	-1.978693
LANVAR	-0.147002	0.141684
LANEX	-0.845723	11.988099
LNERRSQ	0.051780	-0.367848
LNRTDEV	3.730837	7.812114
MDREV	0.232186	0.403139
THRSHLD	5.336284	11.925923
Constant	-1.129456	-6.091866

Table G1b: Discriminant Analysis of AVEOBS Using Steering, Accelerometer, and All Lane Measures (Includes LNRTDEV/VAR).

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 8; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.37370 approx. F (16,580)=23.049 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,290)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.427	0.874	20.850	0.000	0.715	0.285	-0.525405
LANVAR	0.420	0.890	17.942	0.000	0.176	0.824	-1.013995
LANEX	0.418	0.893	17.310	0.000	0.492	0.508	0.590453
LNRTDEV	0.398	0.940	9.300	0.000	0.144	0.856	0.831064
LGREV	0.387	0.967	4.967	0.008	0.471	0.529	0.337070
MDREV	0.386	0.969	4.584	0.011	0.489	0.511	0.118182
NMRHOLD	0.391	0.956	6.612	0.002	0.384	0.616	-0.304770
THRSHLD	0.396	0.944	8.626	0.000	0.478	0.522	0.434336
Eigenval							1.539902
Cum.Prop							0.966392

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.55667	QUESTION p=0.18000	DROWSY p=0.26333
Observed	AWAKE	91.018	152	10	5
	QUESTION	20.370	28	11	15
	DROWSY	77.215	8	10	61
	Total	74.667	188	31	81

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACDE	-0.780513	-7.436996	-10.318184
LANVAR	-0.065593	-0.197257	-0.292801
LANEX	0.127129	11.539376	17.767467
LNRTDEV	3.308708	6.189995	9.025315
LGREV	-0.323163	0.226843	0.975929
MDREV	0.281818	0.471669	0.340959
NMRHOLD	0.138810	0.163197	-0.047096
THRSHLD	1.379977	6.348092	13.483023
Constant	-1.295537	-4.958326	-7.667690

Table G2a: Multiple Regression and Discriminant Analysis of NEWDEF Using Steering, Accelerometer, and All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, LNRTDEV/VAR.

Regression Summary for Dependent Variable: NEW_DEF

R= 0.75681317 R^2≤= 0.57276617 Adjusted R^2≤= 0.56550029
F(5,294)=78.830 p<0.0000 Std.Error of estimate: 1.1317

	BETA	St. Err. of BETA	B	St. Err. of B	t(294)	p-level
Intercpt			-0.479424	0.091	-5.258	0.000
INTACDE	-0.126	0.041	-1.392900	0.453	-3.074	0.002
LANDEV	0.910	0.131	1.201498	0.173	6.945	0.000
LANEX	0.178	0.072	2.499510	1.015	2.464	0.014
LNRTDEV	-0.555	0.115	-1.855124	0.383	-4.840	0.000
STVELV	0.254	0.054	0.014577	0.003	4.709	0.000

Discriminant Function Analysis Summary
No. of vars in model: 5; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.60192 approx. F (5,294)=38.887 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.632	0.952	14.680	0.000	0.837	0.163	0.377757
LANDEV	0.614	0.981	5.750	0.017	0.120	0.880	-0.632987
LANEX	0.625	0.962	11.455	0.000	0.377	0.623	-0.499914
LNRTDEV	0.611	0.985	4.377	0.037	0.145	0.855	0.504248
STVELV	0.650	0.925	23.686	0.000	0.623	0.377	-0.548151
Eigenval							0.661351
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=.73000	Predicted DROWSY p=.27000
Observed	AWAKE	93.607	205	14
	DROWSY	54.321	37	44
	Total	83.000	242	58

Classification Functions

	AWAKE	DROWSY
INTACDE	0.122238	-4.346434
LANDEV	-0.745142	0.322717
LANEX	1.721854	10.561240
LNRTDEV	2.648841	0.584743
STVELV	0.008778	0.047559
Constant	-0.615929	-4.145768

Table G2b: Discriminant Analysis of NEWDEF Using Steering, Accelerometer, and All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, LNRTDEV/VAR.

Discriminant Function Analysis Summary
No. of vars in model: 7; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.47633 approx. F (14,582)=18.663 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,291)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.512	0.931	10.818	0.000	0.786	0.214	-0.410576
LANDEV	0.496	0.960	6.093	0.003	0.125	0.875	0.825024
LANEX	0.490	0.972	4.202	0.016	0.394	0.606	0.387349
LNRTDEV	0.488	0.976	3.642	0.027	0.153	0.847	-0.581192
STVELV	0.506	0.941	9.201	0.000	0.368	0.632	0.493854
MDREV	0.524	0.909	14.506	0.000	0.374	0.626	0.124413
NMRHOLD	0.491	0.969	4.628	0.011	0.624	0.376	0.022236
Eigenval							0.895071
Cum.Prop							0.892490

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=.64333	QUESTION p=.17000	DROWSY p=.18667
Observed	AWAKE	91.710	177	9	7
	QUESTION	23.529	31	12	8
	DROWSY	66.071	14	5	37
	Total	75.333	222	26	52

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACDE	-1.112064	-5.068790	-7.413975
LANDEV	-0.173073	0.627290	1.776376
LANEX	1.545601	5.520633	10.882883
LNRTDEV	2.128076	0.814138	-1.158512
STVELV	-0.022204	-0.027772	0.029647
MDREV	0.388737	0.747278	0.420584
NMRHOLD	0.173877	0.290409	0.168603
Constant	-1.234894	-4.545473	-6.578523

Table G3a: Multiple Regression and Discriminant Analysis of PERCLOS Using Steering, Accelerometer, and All Lane Measures (Includes LNRTDEV/VAR).

Regression Summary for Dependent Variable: PERCLOS

R= 0.87171579 R^2 <= 0.75988842 Adjusted R^2 <= 0.75413232
F(7,292)=132.01 p<0.0000 Std.Error of estimate: 0.04855

	BETA	St. Err. of BETA	B	St. Err. of B	t(292)	p-level
Intercpt			-0.001330	0.004	-0.300	0.764
INTACDE	-0.112	0.031	-0.071047	0.019	-3.677	0.000
LANDEV	0.998	0.099	0.075194	0.007	10.099	0.000
LNERRSQ	-0.203	0.056	-0.001553	0.000	-3.609	0.000
LNRTDEV	-0.193	0.089	-0.036819	0.017	-2.179	0.030
STVELV	0.097	0.045	0.000318	0.000	2.148	0.033
NMRHOLD	-0.181	0.047	-0.003124	0.000	-3.878	0.000
THRSHLD	0.241	0.041	0.222764	0.038	5.832	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 6; Grouping: PERCLO_2 (2 grps)
Wilks' Lambda: 0.45353 approx. F (6,293)=58.841 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.482	0.941	18.215	0.000	0.875	0.125	0.349867
LANDEV	0.592	0.766	89.681	0.000	0.269	0.730	-1.261448
LNERRSQ	0.505	0.898	33.174	0.000	0.312	0.688	0.772370
STEXED	0.460	0.986	4.163	0.042	0.851	0.149	-0.173585
NMRHOLD	0.473	0.960	12.277	0.000	0.431	0.569	0.413003
THRSHLD	0.483	0.939	18.998	0.000	0.481	0.519	-0.481139
Eigenval							1.204930
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	94.805	219	12
	DROWSY	75.362	17	52
	Total	90.333	236	64

Classification Functions

	AWAKE	DROWSY
INTACDE	0.276362	-5.690438
LANDEV	1.637525	4.936619
LNERRSQ	-0.094531	-0.267244
STEXED	-159.922363	2350.023926
NMRHOLD	0.082455	-0.118603
THRSHLD	-1.223006	10.861004
Constant	-0.660627	-6.816076

Table G3b: Discriminant Analysis of PERCLOS Using Steering, Accelerometer, and All Lane Measures (Includes LNRTDEV/VAR).

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: PERCLO_3 (3 grps)
Wilks' Lambda: 0.32167 approx. F (12,584)=37.141 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.337	0.954	7.056	0.001	0.858	0.142	0.282399
LANDEV	0.440	0.731	53.604	0.000	0.242	0.758	-1.274985
LNERRSQ	0.385	0.836	28.635	0.000	0.287	0.713	0.883192
STVELV	0.331	0.971	4.428	0.013	0.608	0.392	-0.267029
NMRHOLD	0.342	0.940	9.258	0.000	0.420	0.580	0.447207
THRSHLD	0.368	0.875	20.801	0.000	0.452	0.548	-0.633510
Eigenval							2.034168
Cum.Prop							0.988060

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.68333	QUESTION p=0.14667	DROWSY p=0.17000
Observed	AWAKE	96.098	197	7	1
	QUESTION	47.727	10	21	13
	DROWSY	72.549	7	7	37
	Total	85.000	214	35	51

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACDE	-0.052563	-4.219471	-6.562628
LANDEV	1.338052	5.070302	6.014334
LNERRSQ	-0.084787	-0.314965	-0.331528
STVELV	0.017498	0.045803	0.053958
NMRHOLD	0.098274	-0.066520	-0.218260
THRSHLD	-0.463380	12.367912	21.876457
Constant	-0.754007	-6.812154	-10.177960

APPENDIX H

Multiple Regression/Discriminant Analysis Results —

Steering, Accelerometer, All Lane Measures, & DSYAWDEV/VAR

Table H1a: Multiple Regression and Discriminant Analysis of AVEOBS Using Steering, Accelerometer, All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, LNRTDEV/VAR, and DSYAWDE/VAR

Regression Summary for Dependent Variable: AVEOBS

R= 0.82613809 R^2<= 0.68250414 Adjusted R^2<= 0.67710455
F(5,294)=126.40 p<0.0000 Std.Error of estimate: 14.168

	BETA	St. Err. of BETA	B	St. Err. of B	t(294)	p-level
Intercpt			23.445142	1.399	16.756	0.000
ACCDEV	-0.303	0.042	-12.632984	1.766	-7.153	0.000
DSYAWDE	1.375	0.094	93.055905	6.326	14.709	0.000
LANVAR	-0.896	0.085	-1.626376	0.154	-10.591	0.000
MDREV	0.360	0.049	2.092681	0.284	7.371	0.000
THRSHLD	0.141	0.038	33.159160	8.945	3.707	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 7; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.43296 approx. F (7,292)=54.633 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.456	0.950	15.478	0.000	0.664	0.336	0.365616
DSYAWDE	0.566	0.765	89.851	0.000	0.101	0.899	-2.023733
LANVAR	0.488	0.888	36.907	0.000	0.137	0.863	1.201234
LANEX	0.440	0.984	4.696	0.031	0.423	0.577	-0.256835
LNRTVAR	0.458	0.945	17.107	0.000	0.243	0.757	0.634060
NMRHOLD	0.446	0.971	8.846	0.003	0.433	0.567	0.346224
THRSHLD	0.452	0.957	13.041	0.000	0.492	0.508	-0.391533
Eigenval							1.309690
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.66333	DROWSY p=0.33667
Observed	AWAKE	94.472	188	11
	DROWSY	78.218	22	79
	Total	89.000	210	90

Classification Functions

	AWAKE	DROWSY
ACCDEV	0.187673	-1.296495
DSYAWDE	10.057834	26.063190
LANVAR	-0.128384	-0.353377
LANEX	-3.610128	2.736871
LNRTVAR	-0.201205	-0.637651
NMRHOLD	0.089412	-0.065797
THRSHLD	-0.517916	8.522822
Constant	-1.060380	-6.588022

Table H1b: Discriminant Analysis of AVEOBS Using Steering, Accelerometer, All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, LNRTDEV/VAR, and DSYAWDE/VAR

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 8; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.35812 approx. F (16,580)=24.325 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,290)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.402	0.890	17.923	0.000	0.522	0.478	-0.566705
DSYAWDE	0.393	0.912	13.938	0.000	0.015	0.985	2.822027
LANVAR	0.441	0.812	33.520	0.000	0.129	0.871	-1.533371
LANEX	0.393	0.912	13.975	0.000	0.507	0.493	0.512641
LNRTDEV	0.369	0.971	4.282	0.015	0.021	0.979	-1.163325
MDREV	0.376	0.952	7.327	0.000	0.445	0.555	0.210845
NMRHOLD	0.374	0.959	6.232	0.002	0.388	0.612	-0.330989
THRSHLD	0.370	0.968	4.832	0.009	0.451	0.549	0.339865
Eigenval							1.618886
Cum.Prop							0.960691

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.55667	QUESTION p=0.18000	DROWSY p=0.26333
Observed	AWAKE	92.814	155	7	5
	QUESTION	33.333	23	18	13
	DROWSY	78.481	8	9	62
	Total	78.333	186	34	80

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCDEV	-0.379139	-2.224684	-3.124190
DSYAWDE	7.300250	13.568735	36.636143
LANVAR	-0.092667	-0.251270	-0.452379
LANEX	-0.758241	9.923607	14.943485
LNRTDEV	-1.023532	-0.745787	-9.864303
MDREV	0.257618	0.514950	0.388690
NMRHOLD	0.150795	0.154109	-0.048290
THRSHLD	0.103574	5.054397	9.642408
Constant	-1.319560	-5.035128	-8.366038

Table H2a: Multiple Regression and Discriminant Analysis of EYEMEAS Using Steering, Accelerometer, All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, LNRTDEV/VAR, and DSYAWDE/VAR

Regression Summary for Dependent Variable: EYEMEAS

R= 0.83577782 R^2<= 0.69852457 Adjusted R^2<= 0.69023658
F(8,291)=84.282 p<0.0000 Std.Error of estimate: 772.35

	BETA	St. Err. of BETA	B	St. Err. of B	t(291)	p-level
Intercpt			980.335382	79.386	12.349	0.000
ACCDEV	-0.325	0.043	-753.055442	98.923	-7.613	0.000
DSYAWDE	0.499	0.097	1880.313123	365.265	5.148	0.000
LNMNSQ	-0.272	0.076	-21.229478	5.939	-3.575	0.000
LANEX	0.395	0.053	4477.370093	606.886	7.378	0.000
STVELV	0.202	0.062	9.375546	2.883	3.252	0.001
MDREV	0.229	0.058	74.163706	18.895	3.925	0.000
SMREV	0.248	0.086	25.938254	9.018	2.876	0.004
THRSHLD	0.403	0.093	5286.875506	1218.526	4.339	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 8; Grouping: EYEMEA_2 (2 grps)
Wilks' Lambda: 0.47690 approx. F (8,291)=39.899 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,291)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.513	0.929	22.095	0.000	0.586	0.414	0.479835
DSYAWDE	0.488	0.977	6.819	0.009	0.018	0.982	-1.571708
LNMNSQ	0.488	0.977	6.772	0.010	0.237	0.763	0.427874
LANEX	0.523	0.913	27.866	0.000	0.500	0.500	-0.578308
LNRTDEV	0.483	0.987	3.963	0.047	0.022	0.978	1.090307
STVELV	0.536	0.890	35.855	0.000	0.463	0.537	-0.673283
SMREV	0.501	0.952	14.706	0.000	0.134	0.866	-0.829613
THRSHLD	0.508	0.938	19.205	0.000	0.115	0.885	-1.016523
Eigenval							1.096889
Cum.Prop							1.000000

Classification Matrix

		Predicted		
		Percent Correct	AWAKE p=0.70333	DROWSY p=0.29667
Observed	AWAKE	92.417	195	16
	DROWSY	67.416	29	60
	Total	85.000	224	76

Classification Functions

	AWAKE	DROWSY
ACCDEV	0.117350	-1.715700
DSYAWDE	6.002943	17.928457
LNMNSQ	-0.078494	-0.140309
LANEX	-0.824765	12.443585
LNRTDEV	-0.082354	-5.903524
STVELV	-0.006330	0.053886
SMREV	-0.101706	0.042118
THRSHLD	-10.716289	11.527822
Constant	-0.981195	-5.363698

Table H2b: Discriminant Analysis of EYEMEAS Using Steering, Accelerometer, All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, LNRTDEV/VAR, and DSYAWDE/VAR

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 7; Grouping: EYEMEA_3 (3 grps)
Wilks' Lambda: 0.42686 approx. F (14,582)=22.057 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,291)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.459	0.929	11.119	0.000	0.588	0.412	0.456696
DSYAWDE	0.442	0.966	5.061	0.007	0.174	0.826	-0.573987
LNMNSQ	0.445	0.960	6.038	0.003	0.242	0.758	0.508388
LANEX	0.475	0.898	16.549	0.000	0.518	0.482	-0.592029
STVELV	0.486	0.879	20.074	0.000	0.478	0.522	-0.671469
SMREV	0.448	0.953	7.130	0.000	0.140	0.860	-0.741333
THRSHLD	0.462	0.923	12.060	0.000	0.121	0.879	-1.061100
Eigenval							1.279504
Cum.Prop							0.978799

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.67333	QUESTION p=0.06333	DROWSY p=0.26333
Observed	AWAKE	94.059	190	1	11
	QUESTION	0.000	9	0	10
	DROWSY	74.684	18	2	59
	Total	83.000	217	3	80

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCDEV	0.085973	-0.714230	-1.897378
DSYAWDE	5.856712	10.184659	10.686194
LNMNSQ	-0.077906	-0.163886	-0.156218
LANEX	-0.640842	8.322713	14.910869
STVELV	-0.005252	0.033561	0.062581
SMREV	-0.097810	-0.055841	0.052384
THRSHLD	-10.267666	5.108737	15.958216
Constant	-0.985058	-5.892430	-6.269165

Table H3a: Multiple Regression and Discriminant Analysis of NEWDEF Using Steering, Accelerometer, All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, LNRTDEV/VAR, and DSYAWDE/VAR

Regression Summary for Dependent Variable: NEWDEF

R= 0.75064186 R^2<= 0.56346320 Adjusted R^2<= 0.55603910
F(5,294)=75.897 p<0.0000 Std.Error of estimate: 1.1439

	BETA	St. Err. of BETA	B	St. Err. of B	t(294)	p-level
Intercpt			-0.484935	0.093	-5.195	0.000
INTACDE	-0.121	0.041	-1.337347	0.459	-2.912	0.004
DSYAWDE	-0.601	0.147	-2.800168	0.686	-4.082	0.000
LANDEV	0.987	0.164	1.303252	0.216	6.025	0.000
LANEX	0.157	0.074	2.198952	1.036	2.124	0.035
STVELV	0.250	0.055	0.014345	0.003	4.569	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.60190 approx. F (5,294)=38.891 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.631	0.955	13.977	0.000	0.834	0.166	0.369658
DSYAWDE	0.611	0.985	4.387	0.037	0.092	0.908	0.635006
LANDEV	0.614	0.981	5.838	0.016	0.079	0.921	-0.788973
LANEX	0.623	0.967	10.090	0.002	0.371	0.629	-0.473746
STVELV	0.651	0.925	23.862	0.000	0.619	0.381	-0.551998
Eigenval							0.661405
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.73000	DROWSY p=0.27000
Observed	AWAKE	94.521	207	12
	DROWSY	54.321	37	44
	Total	83.667	244	56

Classification Functions

	AWAKE	DROWSY
INTACDE	-0.025428	-4.398479
DSYAWDE	5.262055	1.603303
LANDEV	-1.240149	0.090914
LANEX	2.427964	10.804997
STVELV	0.007791	0.046846
Constant	-0.642104	-4.152659

Table H3b: Discriminant Analysis of NEWDEF Using Steering, Accelerometer, All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, LNRTDEV/VAR, and DSYAWDE/VAR

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.49171 approx. F (12,584)=20.736 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.526	0.935	10.226	0.000	0.786	0.214	-0.401450
DSYAWDE	0.504	0.976	3.560	0.030	0.098	0.902	-0.714849
LANDEV	0.511	0.962	5.784	0.003	0.083	0.917	0.986590
LANEX	0.503	0.977	3.476	0.032	0.390	0.610	0.355488
STVELV	0.524	0.939	9.450	0.000	0.368	0.632	0.493836
MDREV	0.527	0.933	10.478	0.000	0.439	0.561	0.117440
Eigenval							0.893362
Cum.Prop							0.923370

Classification Matrix

		Predicted			
		Percent Correct	AWAKE p=0.64333	QUESTION p=0.17000	DROWSY p=0.18667
Observed	AWAKE	92.746	179	7	7
	QUESTION	5.882	39	3	9
	DROWSY	66.071	15	4	37
	Total	73.000	233	14	53

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACDE	-1.032896	-4.798694	-7.201191
DSYAWDE	4.645586	2.092695	-1.027322
LANDEV	-0.820364	0.124428	1.510108
LANEX	1.271942	4.273834	9.922195
STVELV	-0.024101	-0.030174	0.027793
MDREV	0.268925	0.551926	0.306346
Constant	-0.994713	-3.817051	-6.323634

APPENDIX I

Multiple Regression/Discriminant Analysis Results —

A/O Task Measures Only

Table IIa: Multiple Regression and Discriminant Analysis of AVEOBS Using A/O Task Measures Only.

Regression Summary for Dependent Variable: AVEOBS

R= 0.76120463 R^2<= 0.57943250 Adjusted R^2<= 0.57076100
F(2,97)=66.820 p<0.00000 Std.Error of estimate: 19.010

	BETA	St. Err. of BETA	B	St. Err. of B	t(97)	p-level
Intercpt			32.413187	2.655	12.209	0.000
AOTIME	1.626	0.203	37.583265	4.695	8.006	0.000
NMWRONG	-0.989	0.203	-78.442494	16.106	-4.870	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 2; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.48443 approx. F (2,97)=51.619 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,97)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
AOTIME	0.693	0.699	41.824	0.000	0.134	0.866	-2.089210
NMWRONG	0.548	0.883	12.801	0.000	0.134	0.866	1.299627
Eigenval							1.064299
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.65000	DROWSY p=0.35000
Observed	AWAKE	98.462	64	1
	DROWSY	65.714	12	23
	Total	87.000	76	24

Classification Functions

	AWAKE	DROWSY
AOTIME	1.752382	6.539391
NMWRONG	-6.386669	-15.472691
Constant	-0.703602	-3.999342

Table I1b: Discriminant Analysis of AVEOBS Using A/O Task Measures Only.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 2; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.42660 approx. F (4,192)=25.490 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,96)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
AOTIME	0.647	0.660	24.765	0.000	0.139	0.861	-2.053639
NMWRONG	0.498	0.857	7.983	0.000	0.139	0.861	1.262966
Eigenval							1.291811
Cum.Prop							0.982646

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.59000	QUESTION p=0.08000	DROWSY p=0.33000
Observed	AWAKE	100.000	59	0	0
	QUESTION	0.000	6	0	2
	DROWSY	66.667	11	0	22
	Total	81.000	76	0	24

Classification Functions

	AWAKE	QUESTION	DROWSY
AOTIME	1.501528	4.762049	7.071645
NMWRONG	-5.809053	-14.237695	-16.086460
Constant	-0.768903	-3.829383	-4.487861

Table I2a: Multiple Regression and Discriminant Analysis of EYEMEAS Using A/O Task Measures Only.

Regression Summary for Dependent Variable: EYEMEAS

R= 0.76770282 R^2 <= 0.58936762 Adjusted R^2 <= 0.58090097
F(2,97)=69.611 p<0.00000 Std.Error of estimate: 881.01

	BETA	St. Err. of BETA	B	St. Err. of B	t(97)	p-level
Intercpt			1075.915540	123.040	8.744	0.000
AOTIME	1.823	0.201	1976.414956	217.568	9.084	0.000
NMWRONG	-1.235	0.201	-4592.823116	746.443	-6.153	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 2; Grouping: EYEMEA_2 (2 grps)
Wilks' Lambda: 0.59950 approx. F (2,97)=32.401 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,97)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
AOTIME	0.822	0.730	35.930	0.000	0.110	0.890	-2.473264
NMWRONG	0.695	0.863	15.436	0.000	0.110	0.890	1.762654
Eigenval							0.668057
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	90.909	70	7
	DROWSY	60.870	9	14
	Total	84.000	79	21

Classification Functions

	AWAKE	DROWSY
AOTIME	2.225076	6.745494
NMWRONG	-7.237569	-17.402830
Constant	-0.584651	-4.644484

Table I2b: Discriminant Analysis of EYEMEAS Using A/O Task Measures Only.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 2; Grouping: EYEMEA_3 (3 grps)
Wilks' Lambda: 0.55948 approx. F (4,192)=16.172 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,96)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
AOTIME	0.820	0.682	22.356	0.000	0.105	0.895	-2.621838
NMWRONG	0.681	0.821	10.467	0.000	0.105	0.895	1.953841
Eigenval							0.777075
Cum.Prop							0.992597

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.74000	QUESTION p=0.05000	DROWSY p=0.21000
Observed	AWAKE	91.892	68	0	6
	QUESTION	0.000	4	0	1
	DROWSY	66.667	7	0	14
	Total	82.000	79	0	21

Classification Functions

	AWAKE	QUESTION	DROWSY
AOTIME	2.211760	4.756310	7.543670
NMWRONG	-7.218651	-11.990040	-19.769205
Constant	-0.608737	-4.543096	-5.206276

Table I3a: Multiple Regression and Discriminant Analysis of NEWDEF Using A/O Task Measures Only.

Regression Summary for Dependent Variable: NEWDEF

R= 0.66023809 R^2 ≤= 0.43591434 Adjusted R^2 ≤= 0.41828666
F(3,96)=24.729 p<0.00000 Std.Error of estimate: 1.1826

	BETA	St. Err. of BETA	B	St. Err. of B	t(96)	p-level
Intercept			-0.550884	0.171	-3.212	0.002
AOTIME	1.538	0.238	1.899471	0.294	6.469	0.000
NMWRONG	-1.346	0.246	-5.702566	1.040	-5.482	0.000
NMNR	0.319	0.118	2.472451	0.913	2.707	0.008

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 2; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.71183 approx. F (2,97)=19.634 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,97)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
AOTIME	0.958	0.743	33.548	0.000	0.089	0.911	3.160105
NMWRONG	0.874	0.814	22.129	0.000	0.089	0.911	-2.686709
Eigenval							0.404833
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	93.506	72	5
	DROWSY	47.826	12	11
	Total	83.000	84	16

Classification Functions

	AWAKE	DROWSY
AOTIME	2.265218	6.273815
NMWRONG	-7.278434	-18.448002
Constant	-0.582756	-4.005699

Table I3b: Discriminant Analysis of NEWDEF Using A/O Task Measures Only.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 3; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.57759 approx. F (6,190)=10.000 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,95)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
AOTIME	0.873	0.662	24.273	0.000	0.081	0.919	3.174728
NMWRONG	0.842	0.686	21.772	0.000	0.070	0.930	-3.269876
NMNR	0.626	0.923	3.964	0.022	0.440	0.560	0.634552
Eigenval							0.708598
Cum.Prop							0.981578

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.66000	QUESTION p=0.18000	DROWSY p=0.16000
Observed	AWAKE	93.939	62	0	4
	QUESTION	5.556	13	1	4
	DROWSY	56.250	5	2	9
	Total	72.000	80	3	17

Classification Functions

	AWAKE	QUESTION	DROWSY
AOTIME	2.133233	5.856611	7.735622
NMWRONG	-7.939228	-21.329929	-26.113791
NMNR	2.729618	8.243458	9.053071
Constant	-0.712883	-4.012803	-5.743200

Table I4a: Multiple Regression and Discriminant Analysis of PERCLOS Using A/O Task Measures Only.

Regression Summary for Dependent Variable: PERCLOS

R= 0.80983889 R^2≤= 0.65583902 Adjusted R^2≤= 0.64508399
F(3,96)=60.980 p<0.00000 Std.Error of estimate: 0.05334

	BETA	St. Err. of BETA	B	St. Err. of B	t(96)	p-level
Intercpt			0.002801	0.008	0.362	0.718
AOTIME	1.588	0.186	0.113237	0.013	8.551	0.000
NMWRONG	-1.215	0.192	-0.297367	0.047	-6.338	0.000
NMNR	0.358	0.092	0.160588	0.041	3.899	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 3; Grouping: PERCLO_2 (2 grps)
Wilks' Lambda: 0.55854 approx. F (3,96)=25.292 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,96)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
AOTIME	0.755	0.740	33.697	0.000	0.112	0.888	2.289983
NMWRONG	0.674	0.828	19.923	0.000	0.099	0.901	-1.979060
NMNR	0.596	0.937	6.434	0.013	0.519	0.481	0.523346
Eigenval							0.790389
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	93.506	72	5
	DROWSY	56.522	10	13
	Total	85.000	82	18

Classification Functions

	AWAKE	DROWSY
AOTIME	2.260845	6.843909
NMWRONG	-8.440691	-20.925968
NMNR	2.954725	9.184144
Constant	-0.655335	-5.325547

Table I4b: Discriminant Analysis of PERCLOS Using A/O Task Measures Only.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 2; Grouping: PERCLO_3 (3 grps)
Wilks' Lambda: 0.46253 approx. F (4,192)=22.579 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,96)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
AOTIME	0.758	0.610	30.690	0.000	0.109	0.891	-2.582091
NMWRONG	0.589	0.786	13.105	0.000	0.109	0.891	1.913777
Eigenval							1.160968
Cum.Prop							0.999572

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.70000	QUESTION p=0.16000	DROWSY p=0.14000
Observed	AWAKE	95.714	67	3	0
	QUESTION	68.750	4	11	1
	DROWSY	7.143	5	8	1
	Total	79	76	22	2

Classification Functions

	AWAKE	QUESTION	DROWSY
AOTIME	2.041104	8.169561	8.202382
NMWRONG	-6.803998	-20.401579	-20.768053
Constant	-0.621099	-5.713843	-5.796528

Table I5a: Multiple Regression and Discriminant Analysis of MASTER Using A/O Task Measures Only.

Regression Summary for Dependent Variable: MASTER

R= 0.82177950 R^2 ≤= 0.67532154 Adjusted R^2 ≤= 0.66517534
F(3,96)=66.559 p<0.00000 Std.Error of estimate: 2.0785

	BETA	St. Err. of BETA	B	St. Err. of B	t(96)	p-level
Intercpt			-2.756677	0.301	-9.146	0.000
AOTIME	1.804	0.180	5.161314	0.516	10.002	0.000
NMWRONG	-1.337	0.186	-13.121917	1.828	-7.177	0.000
NMNR	0.227	0.089	4.085838	1.605	2.546	0.013

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 3; Grouping: MASTER_2 (2 grps)
Wilks' Lambda: 0.54655 approx. F (3,96)=26.549 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,96)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
AOTIME	0.760	0.719	37.434	0.000	0.112	0.888	2.345447
NMWRONG	0.661	0.827	20.107	0.000	0.101	0.899	-1.946691
NMNR	0.570	0.959	4.062	0.047	0.522	0.478	0.414173
Eigenval							0.829653
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.76000	DROWSY p=0.24000
Observed	AWAKE	93.421	71	5
	DROWSY	62.500	9	15
	Total	86.000	80	20

Classification Functions

	AWAKE	DROWSY
AOTIME	2.226697	7.038437
NMWRONG	-8.351886	-20.845928
NMNR	2.919378	7.849426
Constant	-0.660266	-5.263638

Table I5b: Discriminant Analysis of MASTER Using A/O Task Measures Only.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 2; Grouping: MASTER_3 (3 grps)
Wilks' Lambda: 0.43541 approx. F (4,192)=24.743 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,96)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
AOTIME	0.746	0.584	34.200	0.000	0.108	0.892	-2.610973
NMWRONG	0.568	0.767	14.568	0.000	0.108	0.892	1.952915
Eigenval							1.296293
Cum.Prop							0.999866

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.68000	QUESTION p=0.14000	DROWSY p=0.18000
Observed	AWAKE	97.059	66	0	2
	QUESTION	7.143	6	1	7
	DROWSY	72.222	4	1	13
	Total	80.000	76	2	22

Classification Functions

	AWAKE	QUESTION	DROWSY
AOTIME	2.005390	7.161729	9.419361
NMWRONG	-6.717440	-18.376261	-23.265741
Constant	-0.640175	-4.675595	-6.669684

APPENDIX J

Multiple Regression/Discriminant Analysis Results —

A/O Task, Steering, & Accelerometer

Table J1a: Multiple Regression and Discriminant Analysis of AVEOBS Using A/O Task, Steering, and Accelerometer.

Regression Summary for Dependent Variable: AVEOBS

R= 0.82428252 R^2 <= 0.67944168 Adjusted R^2 <= 0.66594449
F(4,95)=50.339 p<0.00000 Std.Error of estimate: 16.770

	BETA	St. Err. of BETA	B	St. Err. of B	t(95)	p-level
Intercpt			28.378480	2.475	11.468	0.000
LGREV	0.420	0.083	13.992416	2.770	5.051	0.000
THRSHLD	0.158	0.060	47.804225	18.310	2.611	0.010
AOTIME	1.074	0.213	24.817971	4.930	5.034	0.000
NMWRONG	-0.659	0.191	-52.274586	15.112	-3.459	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.32011 approx. F (5,94)=39.930 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,94)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LGREV	0.469	0.682	43.736	0.000	0.458	0.542	-1.010186
SMREV	0.390	0.821	20.472	0.000	0.121	0.879	-1.475492
THRSHLD	0.409	0.782	26.199	0.000	0.126	0.874	-1.598158
AOTIME	0.367	0.872	13.829	0.000	0.117	0.883	-1.267977
NMWRONG	0.356	0.899	10.607	0.002	0.115	0.885	1.137048
Eigenval							2.123953
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.65000	DROWSY p=0.35000
Observed	AWAKE	98.462	64	1
	DROWSY	80.000	7	28
	Total	92.000	71	29

Classification Functions

	AWAKE	DROWSY
LGREV	0.313209	5.219165
SMREV	-0.044867	0.307743
THRSHLD	-5.270141	45.098858
AOTIME	1.338357	5.442612
NMWRONG	-5.111845	-16.341705
Constant	-0.783741	-6.506215

Table J1b: Discriminant Analysis of AVEOBS Using A/O Task, Steering, and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.22112 approx. F (12,184)=17.274 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,92)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACVA	0.245	0.904	4.871	0.010	0.766	0.234	-0.408974
STVELV	0.277	0.797	11.684	0.000	0.308	0.692	-0.522823
LGREV	0.326	0.678	21.882	0.000	0.350	0.650	1.059150
NMRHOLD	0.275	0.803	11.311	0.000	0.602	0.398	-0.523183
AOTIME	0.244	0.907	4.717	0.011	0.106	0.894	1.099778
NMWRONG	0.241	0.916	4.221	0.018	0.101	0.899	-1.059043
Eigenval							2.546658
Cum.Prop							0.902508

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.59000	QUESTION p=0.08000	DROWSY p=0.33000
Observed	AWAKE	98.305	58	1	0
	QUESTION	50.000	4	4	0
	DROWSY	75.758	7	1	25
	Total	87.000	69	6	25

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACVA	1.183557	-2.804829	-9.080936
STVELV	0.018473	0.140233	-0.059769
LGREV	-0.084659	-1.366042	5.838956
NMRHOLD	0.096476	0.382042	-0.311761
AOTIME	1.209608	2.447558	5.414878
NMWRONG	-4.259454	-4.105935	-16.223684
Constant	-0.869674	-5.964736	-7.304262

Table J2a: Multiple Regression and Discriminant Analysis of EYEMEAS Using A/O Task, Steering, and Accelerometer.

Regression Summary for Dependent Variable: EYEMEAS

R= 0.82421567 R^2<= 0.67933147 Adjusted R^2<= 0.66582964
F(4,95)=50.314 p<0.00000 Std.Error of estimate: 786.69

	BETA	St. Err. of BETA	B	St. Err. of B	t(95)	p-level
Intercept			994.858062	118.453	8.399	0.000
ACCVAR	-0.201	0.065	-125.476665	40.955	-3.064	0.003
LGREV	0.468	0.092	731.273017	143.902	5.082	0.000
AOTIME	1.233	0.216	1336.956315	234.454	5.702	0.000
NMWRONG	-0.952	0.191	-3539.096372	708.424	-4.996	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: EYEMEA_2 (2 grps)
Wilks' Lambda: 0.48659 approx. F (5,94)=19.836 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,94)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.559	0.870	14.072	0.000	0.671	0.329	-0.614828
LGREV	0.564	0.863	14.935	0.000	0.501	0.499	0.730026
NMRHOLD	0.509	0.956	4.367	0.039	0.612	0.388	-0.375924
AOTIME	0.525	0.927	7.456	0.008	0.087	0.913	1.285876
NMWRONG	0.534	0.911	9.139	0.003	0.103	0.897	-1.294938
Eigenval							1.055103
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	92.208	71	6
	DROWSY	65.217	8	15
	Total	86.000	79	21

Classification Functions

	AWAKE	DROWSY
ACCVAR	0.209848	-0.475790
LGREV	0.370266	2.816801
NMRHOLD	0.075987	-0.122563
AOTIME	1.884351	4.837925
NMWRONG	-5.914922	-15.300076
Constant	-0.776590	-5.699695

Table J2b: Discriminant Analysis of EYEMEAS Using A/O Task, Steering, and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 4; Grouping: EYEMEA_3 (3 grps)
Wilks' Lambda: 0.45107 approx. F (8,188)=11.490 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,94)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.497	0.908	4.788	0.010	0.731	0.269	-0.482360
LGREV	0.539	0.836	9.203	0.000	0.542	0.458	0.714253
AOTIME	0.532	0.847	8.470	0.000	0.090	0.910	1.661194
NMWRONG	0.517	0.872	6.916	0.002	0.099	0.901	-1.449441
Eigenval							1.117545
Cum.Prop							0.959685

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.74000	QUESTION p=0.05000	DROWSY p=0.21000
Observed	AWAKE	93.243	69	1	4
	QUESTION	40.000	3	2	0
	DROWSY	66.667	6	1	14
	Total	85.000	78	4	18

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCVAR	0.161711	-0.106101	-0.408717
LGREV	0.454512	3.414553	2.869707
AOTIME	1.707686	2.444239	5.957290
NMWRONG	-6.030131	-8.018044	-17.630079
Constant	-0.748612	-6.330108	-6.268356

Table J3a: Multiple Regression and Discriminant Analysis of NEWDEF Using A/O Task, Steering, and Accelerometer.

Regression Summary for Dependent Variable: NEWDEF

R= 0.73963532 R^2 <= 0.54706041 Adjusted R^2 <= 0.51259761
F(7,92)=15.874 p<0.00000 Std.Error of estimate: 1.0825

	BETA	St. Err. of BETA	B	St. Err. of B	t(92)	p-level
Intercept			-0.238213	0.193	-1.234	0.220
MDREV	-0.369	0.115	-0.151417	0.047	-3.224	0.002
SMREV	-1.091	0.262	-0.133558	0.032	-4.166	0.000
NMRHOLD	-0.464	0.179	-0.140279	0.054	-2.597	0.011
THRSHLD	-0.666	0.199	-10.795369	3.232	-3.340	0.001
AOTIME	1.299	0.270	1.604040	0.333	4.814	0.000
NMWRONG	-1.127	0.278	-4.775541	1.176	-4.061	0.000
NMNR	0.263	0.129	2.042848	0.998	2.047	0.044

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 4; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.59326 approx. F (4,95)=16.283 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,95)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
SMREV	0.654	0.906	9.805	0.002	0.794	0.206	-0.538186
STEXED	0.665	0.892	11.478	0.001	0.845	0.155	0.560167
AOTIME	0.672	0.883	12.546	0.000	0.079	0.921	1.905566
NMWRONG	0.628	0.944	5.600	0.020	0.078	0.922	-1.326402
Eigenval							0.685601
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	94.805	73	4
	DROWSY	65.217	8	15
	Total	88.000	81	19

Classification Functions

	AWAKE	DROWSY
SMREV	-0.011240	-0.094666
STEXED	-1002.254517	7194.425293
AOTIME	2.418972	5.564639
NMWRONG	-7.613266	-14.789371
Constant	-0.602286	-4.793881

Table J3b: Discriminant Analysis of NEWDEF Using A/O Task, Steering, and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.29374 approx. F (12,184)=12.958 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,92)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LGREV	0.382	0.770	13.763	0.000	0.451	0.549	0.691785
MDREV	0.363	0.810	10.773	0.000	0.504	0.496	-0.140898
SMREV	0.321	0.915	4.296	0.016	0.432	0.568	-0.579212
NMRHOLD	0.331	0.888	5.826	0.004	0.218	0.782	0.160086
AOTIME	0.369	0.796	11.779	0.000	0.060	0.940	2.349546
NMWRONG	0.362	0.812	10.622	0.000	0.072	0.928	-2.096960
Eigenval							1.418139
Cum.Prop							0.776646

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.66000	QUESTION p=0.18000	DROWSY p=0.16000
Observed	AWAKE	92.424	61	0	5
	QUESTION	88.889	2	16	0
	DROWSY	75.000	2	2	12
	Total	89.000	65	18	17

Classification Functions

	AWAKE	QUESTION	DROWSY
LGREV	-0.135744	0.393868	3.805454
MDREV	0.342584	0.645617	-0.051079
SMREV	0.031079	-0.068691	-0.113301
NMRHOLD	0.221926	0.619018	0.072669
AOTIME	1.848105	6.905422	6.888566
NMWRONG	-4.296284	-15.262124	-21.599892
Constant	-1.148001	-7.416992	-8.021034

Table J4a: Multiple Regression and Discriminant Analysis of PERCLOS Using A/O Task, Steering, and Accelerometer.

Regression Summary for Dependent Variable: PERCLOS

R= 0.83585799 R^2 <= 0.69865857 Adjusted R^2 <= 0.68262977
F(5,94)=43.588 p<0.00000 Std.Error of estimate: 0.05044

	BETA	St. Err. of BETA	B	St. Err. of B	t(94)	p-level
Intercpt			0.002620	0.008	0.341	0.734
ACCVAR	-0.182	0.064	-0.007485	0.003	-2.843	0.005
LGREV	0.302	0.093	0.031048	0.010	3.259	0.002
AOTIME	1.234	0.211	0.087985	0.015	5.839	0.000
NMWRONG	-1.028	0.199	-0.251580	0.049	-5.173	0.000
NMNR	0.313	0.092	0.140206	0.041	3.419	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: PERCLO_2 (2 grps)
Wilks' Lambda: 0.50065 approx. F (5,94)=18.751 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,94)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.533	0.939	6.108	0.015	0.738	0.262	0.406842
LGREV	0.549	0.912	9.017	0.003	0.529	0.471	-0.575806
AOTIME	0.565	0.886	12.150	0.000	0.093	0.907	-1.572435
NMWRONG	0.561	0.893	11.295	0.001	0.089	0.911	1.552278
NMNR	0.523	0.958	4.117	0.045	0.479	0.521	-0.418865
Eigenval							0.997410
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	93.506	72	5
	DROWSY	69.565	7	16
	Total	88.000	79	21

Classification Functions

	AWAKE	DROWSY
ACCVAR	0.145532	-0.292322
LGREV	0.415715	2.340825
AOTIME	1.825176	5.360366
NMWRONG	-7.036216	-18.037041
NMNR	1.905772	7.506567
Constant	-0.763448	-6.040749

Table J4b: Discriminant Analysis of PERCLOS Using A/O Task, Steering, and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 4; Grouping: PERCLO_3 (3 grps)
Wilks' Lambda: 0.33740 approx. F (8,188)=16.957 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,94)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LGREV	0.410	0.822	10.158	0.000	0.758	0.242	0.594373
THRSHLD	0.403	0.838	9.102	0.000	0.801	0.199	0.516686
AOTIME	0.439	0.768	14.188	0.000	0.097	0.903	1.909483
NMWRONG	0.394	0.857	7.836	0.000	0.105	0.895	-1.440423
Eigenval							1.863327
Cum.Prop							0.981503

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.70000	QUESTION p=0.16000	DROWSY p=0.14000
Observed	AWAKE	94.286	66	3	1
	QUESTION	43.750	4	7	5
	DROWSY	28.571	3	7	4
	Total	77.000	73	17	10

Classification Functions

	AWAKE	QUESTION	DROWSY
LGREV	0.801848	3.137479	3.907572
THRSHLD	0.877282	12.321609	21.113268
AOTIME	1.665262	7.322662	7.552281
NMWRONG	-6.187399	-19.006716	-19.691170
Constant	-0.721927	-7.429980	-8.975574

Table J5a: Multiple Regression and Discriminant Analysis of MASTER Using A/O Task, Steering, and Accelerometer.

Regression Summary for Dependent Variable: MASTER

R= 0.87627383 R^2 <= 0.76785583 Adjusted R^2 <= 0.75550773
F(5,94)=62.184 p<0.00000 Std.Error of estimate: 1.7761

	BETA	St. Err. of BETA	B	St. Err. of B	t(94)	p-level
Intercept			-2.881094	0.268	-10.742	0.000
ACCVAR	-0.141	0.057	-0.232185	0.094	-2.468	0.015
LGREV	0.480	0.079	1.980192	0.325	6.093	0.000
THRSHLD	0.165	0.053	6.213407	1.973	3.150	0.002
AOTIME	1.262	0.185	3.611810	0.530	6.820	0.000
NMWRONG	-0.889	0.163	-8.729733	1.601	-5.453	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: MASTER_2 (2 grps)
Wilks' Lambda: 0.44527 approx. F (5,94)=23.421 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,94)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.472	0.944	5.581	0.020	0.802	0.198	-0.354850
LGREV	0.528	0.844	17.362	0.000	0.604	0.396	0.682169
THRSHLD	0.473	0.940	5.948	0.017	0.812	0.188	0.363440
AOTIME	0.502	0.887	11.940	0.000	0.094	0.906	1.470675
NMWRONG	0.479	0.929	7.226	0.009	0.106	0.894	-1.099411
Eigenval							1.245820
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.76000	DROWSY p=0.24000
Observed	AWAKE	94.737	72	4
	DROWSY	83.333	4	20
	Total	92.000	76	24

Classification Functions

	AWAKE	DROWSY
INTACDE	-0.015768	-5.784316
LGREV	0.809142	3.379486
THRSHLD	0.808509	10.597390
AOTIME	1.691076	5.388272
NMWRONG	-6.266117	-14.912718
Constant	-0.698461	-6.697973

Table J5b: Discriminant Analysis of MASTER Using A/O Task, Steering, and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: MASTER_3 (3 grps)
Wilks' Lambda: 0.25121 approx. F (12,184)=15.260 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,92)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.280	0.898	5.240	0.007	0.676	0.324	-0.429902
LGREV	0.381	0.659	23.796	0.000	0.558	0.442	0.902072
NMRHOLD	0.272	0.923	3.845	0.025	0.437	0.563	-0.477101
THRSHLD	0.308	0.815	10.452	0.000	0.548	0.452	0.663847
AOTIME	0.297	0.845	8.423	0.000	0.094	0.906	1.460960
NMWRONG	0.298	0.844	8.481	0.000	0.104	0.896	-1.412985
Eigenval							2.859584
Cum.Prop							0.989139

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.68000	QUESTION p=0.14000	DROWSY p=0.18000
Observed	AWAKE	95.588	65	2	1
	QUESTION	42.857	4	6	4
	DROWSY	77.778	0	4	14
	Total	85.000	69	12	19

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCVAR	0.182839	-0.210936	-0.671618
LGREV	0.401334	4.087619	6.708566
NMRHOLD	0.072825	-0.158701	-0.369506
THRSHLD	-0.696336	20.652964	26.397820
AOTIME	1.883609	6.609716	7.865027
NMWRONG	-5.976651	-18.710373	-23.685942
Constant	-0.810997	-7.057717	-11.713280

APPENDIX K

Multiple Regression/Discriminant Analysis Results —

A/O Task, Steering, Accelerometer, & HPHDGDEV/VAR

Table K16a: Multiple Regression and Discriminant Analysis of AVEOBS Using A/O Task, Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: AVEOBS

R= 0.91661383 R^2<= 0.84018092 Adjusted R^2<= 0.82613089
F(8,91)=59.799 p<0.00000 Std.Error of estimate: 12.099

	BETA	St. Err. of BETA	B	St. Err. of B	t(91)	p-level
Intercpt			15.589950	2.385	6.536	0.000
INTACDE	-0.165	0.052	-29.766723	9.275	-3.209	0.002
HPHDGDE	0.993	0.086	92.957098	8.059	11.535	0.000
MDREV	0.302	0.074	2.316050	0.565	4.100	0.000
SMREV	0.455	0.166	1.041070	0.380	2.740	0.007
NMRHOLD	0.310	0.110	1.754872	0.623	2.817	0.006
THRSHLD	0.528	0.129	160.298090	39.185	4.091	0.000
NMWRONG	0.258	0.093	20.429394	7.376	2.770	0.007
NMNR	-0.292	0.077	-42.388078	11.195	-3.786	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.23980 approx. F (5,94)=59.600 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,94)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
HPHDGDE	0.561	0.427	125.885	0.000	0.459	0.541	1.281416
MDREV	0.274	0.877	13.219	0.000	0.676	0.324	-0.489701
NMRHOLD	0.270	0.887	12.020	0.000	0.569	0.431	-0.512114
THRSHLD	0.291	0.823	20.163	0.000	0.517	0.483	0.670197
NMNR	0.256	0.938	6.170	0.015	0.662	0.338	-0.349846
Eigenval							3.170192
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.65000	DROWSY p=0.35000
Observed	AWAKE	98.462	64	1
	DROWSY	85.714	5	30
	Total	94.000	69	31

Classification Functions

	AWAKE	DROWSY
HPHDGDE	3.636473	29.604374
MDREV	0.243148	-0.245466
NMRHOLD	0.165290	-0.280188
THRSHLD	-0.106725	25.699036
NMNR	-1.852901	-9.187920
Constant	-1.286278	-9.701411

Table K1b: Discriminant Analysis of AVEOBS Using A/O Task, Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.17464 approx. F (12,184)=21.358 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,92)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
HPHDGDE	0.262	0.667	22.954	0.000	0.317	0.683	1.034548
LGREV	0.187	0.932	3.365	0.039	0.371	0.629	0.343991
MDREV	0.198	0.883	6.117	0.003	0.685	0.315	-0.449863
NMRHOLD	0.220	0.793	12.039	0.000	0.477	0.523	-0.543661
THRSHLD	0.218	0.802	11.338	0.000	0.484	0.516	0.702323
NMNR	0.195	0.896	5.345	0.006	0.632	0.368	-0.418028
Eigenval							3.793200
Cum.Prop							0.951190

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.59000	QUESTION p=0.08000	DROWSY p=0.33000
Observed	AWAKE	93.220	55	3	1
	QUESTION	62.500	2	5	1
	DROWSY	90.909	1	2	30
	Total	90.000	58	10	32

Classification Functions

	AWAKE	QUESTION	DROWSY
HPHDGDE	7.980360	29.190191	33.194534
LGREV	-1.868425	-2.833258	0.591968
MDREV	0.289903	0.186952	-0.225714
NMRHOLD	0.266240	0.460500	-0.291083
THRSHLD	-2.741467	4.609221	27.770416
NMNR	-1.120421	-8.994053	-11.009107
Constant	-1.528726	-8.467973	-11.420537

Table K2a: Multiple Regression and Discriminant Analysis of EYEMEAS Using A/O Task, Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: EYEMEAS

R= 0.85466301 R^2 <= 0.73044886 Adjusted R^2 <= 0.71909934
F(4,95)=64.359 p<0.00000 Std.Error of estimate: 721.27

	BETA	St. Err. of BETA	B	St. Err. of B	t(95)	p-level
Intercpt			704.102922	121.440	5.798	0.000
ACCVAR	-0.205	0.058	-128.261142	36.313	-3.532	0.000
HPHDGDE	0.780	0.112	3425.095000	490.617	6.981	0.000
AOTIME	0.548	0.248	593.880347	269.068	2.207	0.030
NMWRONG	-0.555	0.194	-2065.652616	720.767	-2.866	0.005

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 2; Grouping: EYEMEA_2 (2 grps)
Wilks' Lambda: 0.51913 approx. F (2,97)=44.925 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,97)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.585	0.887	12.371	0.000	0.870	0.130	0.519879
HPHDGDE	0.983	0.528	86.633	0.000	0.870	0.130	-1.061728
Eigenval							0.926296
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	90.909	70	7
	DROWSY	78.261	5	18
	Total	88.000	75	25

Classification Functions

	AWAKE	DROWSY
ACCVAR	0.171452	-0.371761
HPHDGDE	3.225975	13.314791
Constant	-0.728585	-5.905890

Table K2b: Discriminant Analysis of EYEMEAS Using A/O Task, Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 3; Grouping: EYEMEA_3 (3 grps)
Wilks' Lambda: 0.46904 approx. F (6,190)=14.571 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,95)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.524	0.895	5.570	0.005	0.801	0.199	0.502534
HPHDGDE	0.533	0.881	6.432	0.002	0.331	0.669	-0.728497
LGREV	0.500	0.938	3.140	0.048	0.299	0.701	-0.400827
Eigenval							1.020515
Cum.Prop							0.948698

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.74000	QUESTION p=0.05000	DROWSY p=0.21000
Observed	AWAKE	91.892	68	1	5
	QUESTION	0.000	3	0	2
	DROWSY	61.905	5	3	13
	Total	81.000	76	4	20

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCVAR	0.237625	-0.037856	-0.329346
HPHDGDE	5.723155	5.390780	13.999780
LGREV	-1.126452	2.100520	-0.076488
Constant	-0.828805	-6.233108	-6.233814

Table K3a: Multiple Regression and Discriminant Analysis of PERCLOS Using A/O Task, Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: PERCLOS

R= 0.86837901 R^2<= 0.75408210 Adjusted R^2<= 0.73537096
F(7,92)=40.301 p<0.00000 Std.Error of estimate: 0.04606

	BETA	St. Err. of BETA	B	St. Err. of B	t(92)	p-level
Intercpt			0.000846	0.008	0.100	0.921
HPHDGDE	0.522	0.120	0.150704	0.035	4.350	0.000
MDREV	-0.259	0.072	-0.006131	0.002	-3.615	0.000
SMREV	-0.317	0.088	-0.002238	0.000	-3.585	0.000
NMRHOLD	-0.259	0.111	-0.004520	0.002	-2.332	0.022
AOTIME	0.795	0.244	0.056684	0.017	3.263	0.002
NMWRONG	-0.746	0.219	-0.182529	0.054	-3.402	0.000
NMNR	0.224	0.095	0.100139	0.043	2.346	0.021

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 4; Grouping: PERCLO_2 (2 grps)
Wilks' Lambda: 0.48782 approx. F (4,95)=24.936 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,95)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
HPHDGDE	0.644	0.757	30.483	0.000	0.546	0.454	0.932436
MDREV	0.528	0.924	7.818	0.006	0.692	0.308	-0.463035
SMREV	0.566	0.862	15.244	0.000	0.341	0.659	-0.889156
NMRHOLD	0.521	0.935	6.554	0.012	0.271	0.729	-0.681408
Eigenval							1.049941
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	94.805	73	4
	DROWSY	78.261	5	18
	Total	91.000	78	22

Classification Functions

	AWAKE	DROWSY
HPHDGDE	3.970316	13.360326
MDREV	0.260152	-0.039006
SMREV	0.044978	-0.123827
NMRHOLD	0.267679	-0.075547
Constant	-1.234925	-6.351795

Table K3b: Discriminant Analysis of PERCLOS Using A/O Task, Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 5; Grouping: PERCLO_3 (3 grps)
Wilks' Lambda: 0.29879 approx. F (10,186)=15.428 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,93)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACEXEED	0.321	0.932	3.384	0.038	0.692	0.308	-0.085672
HPHDGDE	0.496	0.602	30.685	0.000	0.581	0.419	1.010153
MDREV	0.341	0.876	6.555	0.002	0.610	0.390	-0.384629
SMREV	0.374	0.799	11.708	0.000	0.299	0.701	-0.881928
NMRHOLD	0.330	0.905	4.854	0.010	0.275	0.725	-0.628597
Eigenval							1.952703
Cum.Prop							0.936011

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.70000	QUESTION p=0.16000	DROWSY p=0.14000
Observed	AWAKE	97.143	68	2	0
	QUESTION	81.250	2	13	1
	DROWSY	64.286	1	4	9
	Total	90.000	71	19	10

Classification Functions

	AWAKE	QUESTION	DROWSY
ACEXEED	-12.899197	-92.780426	9.376826
HPHDGDE	4.249324	18.386621	19.849680
MDREV	0.276624	0.179537	-0.230724
SMREV	0.049442	-0.070451	-0.236322
NMRHOLD	0.272794	0.041800	-0.281975
Constant	-1.273693	-8.276262	-9.632964

Table K4a: Multiple Regression and Discriminant Analysis of MASTER Using A/O Task, Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: MASTER

R= 0.90259020 R^2 <= 0.81466907 Adjusted R^2 <= 0.80481105
F(5,94)=82.640 p<0.00000 Std.Error of estimate: 1.5870

	BETA	St. Err. of BETA	B	St. Err. of B	t(94)	p-level
Intercept			-3.650396	0.268	-13.600	0.000
ACCVAR	-0.138	0.049	-0.227671	0.081	-2.804	0.006
HPHDGDE	0.782	0.093	9.067579	1.082	8.381	0.000
THRSHLD	0.184	0.047	6.894818	1.766	3.904	0.000
AOTIME	0.592	0.207	1.692730	0.592	2.859	0.005
NMWRONG	-0.497	0.162	-4.878993	1.589	-3.070	0.003

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 3; Grouping: MASTER_2 (2 grps)
Wilks' Lambda: 0.48074 approx. F (3,96)=34.564 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,96)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.512	0.940	6.159	0.015	0.912	0.088	-0.356736
HPHDGDE	0.965	0.498	96.781	0.000	0.822	0.178	1.084382
THRSHLD	0.512	0.939	6.267	0.014	0.822	0.178	0.378824
Eigenval							1.080117
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.76000	DROWSY p=0.24000
Observed	AWAKE	93.421	71	5
	DROWSY	83.333	4	20
	Total	91.000	75	25

Classification Functions

	AWAKE	DROWSY
INTACDE	0.297495	-5.102292
HPHDGDE	4.276692	15.455751
THRSHLD	3.099833	12.600318
Constant	-0.710810	-6.815035

Table K4b: Discriminant Analysis of MASTER Using A/O Task, Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 4; Grouping: MASTER_3 (3 grps)
Wilks' Lambda: 0.29784 approx. F (8,188)=19.560 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,94)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
HPHDGDE	0.393	0.758	15.012	0.000	0.508	0.492	0.826001
THRSHLD	0.357	0.834	9.325	0.000	0.779	0.221	0.533321
AOTIME	0.323	0.923	3.927	0.023	0.078	0.922	1.187757
NMWRONG	0.318	0.936	3.194	0.045	0.095	0.905	-0.979102
Eigenval							2.310124
Cum.Prop							0.993847

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.68000	QUESTION p=0.14000	DROWSY p=0.18000
Observed	AWAKE	97.059	66	1	1
	QUESTION	50.000	1	7	6
	DROWSY	77.778	0	4	14
	Total	87.000	67	12	21

Classification Functions

	AWAKE	QUESTION	DROWSY
HPHDGDE	6.935243	18.298317	21.991030
THRSHLD	2.748327	20.331028	21.118731
AOTIME	0.231872	3.437217	4.701204
NMWRONG	-3.484212	-11.414469	-14.501349
Constant	-1.105129	-8.389692	-11.725960

APPENDIX L

Multiple Regression/Discriminant Analysis Results —
A/O Task, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ

Table L1a: Multiple Regression and Discriminant Analysis of EYEMEAS Using A/O Task, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: EYEMEAS

R= 0.87358113 $R^2 \leq$ = 0.76314400 Adjusted $R^2 \leq$ = 0.75054528
F(5,94)=60.573 p<0.00000 Std.Error of estimate: 679.70

	BETA	St. Err. of BETA	B	St. Err. of B	t(94)	p-level
Intercpt			722.916341	118.094	6.122	0.000
LANDEV	0.766	0.164	884.545734	188.947	4.681	0.000
LANEX	0.295	0.109	2828.348448	1045.824	2.704	0.008
LNERRSQ	-0.310	0.103	-57.852024	19.216	-3.011	0.003
AOTIME	0.486	0.236	526.837773	256.208	2.056	0.043
NMWRONG	-0.471	0.183	-1750.466828	679.207	-2.577	0.012

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 2; Grouping: EYEMEA_2 (2 grps)
Wilks' Lambda: 0.48856 approx. F (2,97)=50.772 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,97)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LANDEV	0.513	0.953	4.766	0.031	0.391	0.609	-0.483664
LANEX	0.523	0.934	6.896	0.010	0.391	0.609	-0.575808
Eigenval							1.046836
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	93.506	72	5
	DROWSY	65.217	8	15
	Total	87.000	80	20

Classification Functions

	AWAKE	DROWSY
LANDEV	1.569662	2.929090
LANEX	-7.943101	5.636083
Constant	-0.643255	-5.906140

Table L1b: Discriminant Analysis of EYEMEAS UsingA/O Task, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 3; Grouping: EYEMEA_3 (3 grps)
Wilks' Lambda: 0.42874 approx. F (6,190)=16.696 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,95)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LANDEV	0.625	0.686	21.744	0.000	0.316	0.684	1.346134
LNERRSQ	0.465	0.921	4.065	0.020	0.313	0.687	-0.234569
NMNR	0.468	0.916	4.365	0.015	0.555	0.445	-0.328305
Eigenval							1.106521
Cum.Prop							0.911647

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.74000	QUESTION p=0.05000	DROWSY p=0.21000
Observed	AWAKE	93.243	69	1	4
	QUESTION	20.000	3	1	1
	DROWSY	76.190	3	2	16
	Total	86.000	75	4	21

Classification Functions

	AWAKE	QUESTION	DROWSY
LANDEV	1.962021	5.184563	5.901431
LNERRSQ	-0.159233	-0.569526	-0.225064
NMNR	-1.606848	3.672332	-6.745735
Constant	-0.751623	-6.852998	-7.269858

Table L2a: Multiple Regression and Discriminant Analysis of NEWDEF UsingA/O Task, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: NEWDEF

R= 0.76780464 R^2 <= 0.58952396 Adjusted R^2 <= 0.57224076
F(4,95)=34.110 p<0.00000 Std.Error of estimate: 1.0141

	BETA	St. Err. of BETA	B	St. Err. of B	t(95)	p-level
Intercept			-0.598772	0.147	-4.066	0.000
LANEX	0.623	0.104	6.809401	1.142	5.962	0.000
AOTIME	0.557	0.262	0.687537	0.324	2.125	0.036
NMWRONG	-0.812	0.229	-3.439021	0.969	-3.547	0.000
NMNR	0.356	0.101	2.758593	0.785	3.516	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 3; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.53842 approx. F (3,96)=27.433 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,96)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LANVAR	0.575	0.937	6.459	0.013	0.308	0.692	0.665488
LANEX	0.613	0.879	13.220	0.000	0.418	0.582	0.791650
NMWRONG	0.609	0.884	12.547	0.000	0.465	0.535	-0.733487
Eigenval							0.857271
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	96.104	74	3
	DROWSY	56.522	10	13
	Total	87.000	84	16

Classification Functions

	AWAKE	DROWSY
LANVAR	0.123663	0.324015
LANEX	0.334395	15.770572
NMWRONG	-2.063402	-6.500807
Constant	-0.463520	-5.176169

Table L2b: Discriminant Analysis of NEWDEF UsingA/O Task, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.34083 approx. F (12,184)=10.931 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,92)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LANVAR	0.387	0.881	6.205	0.003	0.055	0.945	-1.612840
LANEX	0.403	0.845	8.448	0.000	0.328	0.672	-0.889186
LNERRSQ	0.401	0.850	8.124	0.000	0.091	0.909	1.661102
AOTIME	0.391	0.871	6.788	0.002	0.047	0.953	-0.940890
NMWRONG	0.428	0.796	11.809	0.000	0.055	0.945	1.837618
NMNR	0.389	0.876	6.493	0.002	0.277	0.723	-0.642542
Eigenval							1.487553
Cum.Prop							0.892344

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.66000	QUESTION p=0.18000	DROWSY p=0.16000
Observed	AWAKE	92.424	61	5	0
	QUESTION	38.889	9	7	2
	DROWSY	68.750	0	5	11
	Total	79.000	70	17	13

Classification Functions

	AWAKE	QUESTION	DROWSY
LANVAR	0.187031	0.246992	1.000859
LANEX	1.465241	13.772647	27.268097
LNERRSQ	-0.178205	-0.530643	-1.008849
AOTIME	1.625992	6.031645	3.200035
NMWRONG	-7.250081	-23.933344	-20.787352
NMNR	2.688737	13.576695	11.697421
Constant	-0.781261	-4.919376	-9.688525

Table L3a: Multiple Regression and Discriminant Analysis of PERCLOS Using A/O Task, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: PERCLOS

R= 0.87487717 R^2 <= 0.76541006 Adjusted R^2 <= 0.75027522
F(6,93)=50.573 p<0.00000 Std.Error of estimate: 0.04474

	BETA	St. Err. of BETA	B	St. Err. of B	t(93)	p-level
Intercpt			-0.004308	0.007	-0.648	0.519
LANVAR	0.924	0.246	0.009506	0.003	3.749	0.000
LANEX	0.310	0.105	0.195697	0.066	2.964	0.004
LNERRSQ	-0.641	0.174	-0.007871	0.002	-3.683	0.000
AOTIME	0.548	0.236	0.039067	0.017	2.326	0.022
NMWRONG	-0.591	0.197	-0.144499	0.048	-3.002	0.003
NMNR	0.286	0.095	0.127975	0.042	3.014	0.003

Discriminant Function Analysis Summary (Single Threshold)

No. of vars in model: 6; Grouping: PERCLO_2 (2 grps)
Wilks' Lambda: 0.44198 approx. F (6,93)=19.570 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,93)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LANVAR	0.469	0.942	5.717	0.019	0.061	0.939	-1.301808
LANEX	0.475	0.931	6.927	0.010	0.333	0.667	-0.610398
LNERRSQ	0.517	0.855	15.726	0.000	0.091	0.909	1.687017
AOTIME	0.470	0.941	5.795	0.018	0.062	0.938	-1.297527
NMWRONG	0.480	0.921	7.958	0.006	0.074	0.926	1.382453
NMNR	0.482	0.917	8.450	0.005	0.336	0.664	-0.666144
Eigenval							1.262553
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	94.805	73	4
	DROWSY	69.565	7	16
	Total	89.000	80	20

Classification Functions

	AWAKE	DROWSY
LANVAR	0.163313	0.655437
LANEX	1.184243	15.290865
LNERRSQ	-0.178081	-0.866059
AOTIME	1.932486	5.214530
NMWRONG	-7.895635	-18.918489
NMNR	3.199378	13.220840
Constant	-0.719288	-7.229722

Table L3b: Discriminant Analysis of PERCLOS Using A/O Task, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 4; Grouping: PERCLO_3 (3 grps)
Wilks' Lambda: 0.28005 approx. F (8,188)=20.907 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,94)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LANDEV	0.395	0.710	19.232	0.000	0.232	0.768	1.353689
LNERRSQ	0.368	0.760	14.840	0.000	0.264	0.736	-1.024863
AOTIME	0.317	0.882	6.262	0.003	0.068	0.932	1.308077
NMWRONG	0.305	0.919	4.150	0.019	0.092	0.908	-1.047731
Eigenval							2.069127
Cum.Prop							0.926789

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.70000	QUESTION p=0.16000	DROWSY p=0.14000
Observed	AWAKE	95.714	67	1	2
	QUESTION	56.250	2	9	5
	DROWSY	42.857	4	4	6
	Total	82.000	73	14	13

Classification Functions

	AWAKE	QUESTION	DROWSY
LANDEV	2.501519	7.680431	8.212624
LNERRSQ	-0.184801	-0.838919	-0.541683
AOTIME	0.660078	6.259761	3.110298
NMWRONG	-4.348678	-16.615555	-11.808404
Constant	-1.055058	-10.254856	-10.567143

Table L4a: Multiple Regression and Discriminant Analysis of MASTER Using A/O Task, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: MASTER

R= 0.90263733 R^2<= 0.81475415 Adjusted R^2<= 0.80695433
F(4,95)=104.46 p<0.00000 Std.Error of estimate: 1.5783

	BETA	St. Err. of BETA	B	St. Err. of B	t(95)	p-level
Intercpt			-3.771515	0.260	-14.481	0.000
LANDEV	1.036	0.119	3.159046	0.363	8.697	0.000
LNERRSQ	-0.299	0.090	-0.147233	0.044	-3.312	0.001
AOTIME	0.505	0.208	1.445821	0.595	2.431	0.017
NMWRONG	-0.458	0.160	-4.497845	1.575	-2.856	0.005

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 2; Grouping: MASTER_2 (2 grps)
Wilks' Lambda: 0.47705 approx. F (2,97)=53.167 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,97)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LANDEV	0.765	0.624	58.563	0.000	0.288	0.712	-1.579942
LNERRSQ	0.529	0.903	10.464	0.002	0.288	0.712	0.803525
Eigenval							1.096220
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.76000	DROWSY p=0.24000
Observed	AWAKE	93.421	71	5
	DROWSY	70.833	7	17
	Total	88.000	78	22

Classification Functions

	AWAKE	DROWSY
LANDEV	2.046470	6.502067
LNERRSQ	-0.196822	-0.500974
Constant	-0.746683	-7.079002

Table L4b: Discriminant Analysis of MASTER UsingA/O Task, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 2; Grouping: MASTER_3 (3 grps)
Wilks' Lambda: 0.31537 approx. F (4,192)=37.473 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,96)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LANDEV	0.647	0.488	50.422	0.000	0.331	0.669	-1.503278
LNERRSQ	0.360	0.876	6.803	0.002	0.331	0.669	0.727681
Eigenval							2.153909
Cum.Prop							0.997512

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.68000	QUESTION p=0.14000	DROWSY p=0.18000
Observed	AWAKE	97.059	66	1	1
	QUESTION	28.571	4	4	6
	DROWSY	77.778	2	2	14
	Total	84.000	72	7	21

Classification Functions

	AWAKE	QUESTION	DROWSY
LANDEV	2.203151	7.209744	9.622219
LNERRSQ	-0.199467	-0.526410	-0.618538
Constant	-0.800725	-6.947665	-11.436691

APPENDIX M

Multiple Regression/Discriminant Analysis Results —

A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ

Table M1a: Multiple Regression and Discriminant Analysis of AVEOBS Using A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: AVEOBS

R= 0.92242554 R^2<= 0.85086887 Adjusted R^2<= 0.83411256
F(10,89)=50.779 p<0.00000 Std.Error of estimate: 11.818

	BETA	St. Err. of BETA	B	St. Err. of B	t(89)	p-level
Intercpt			15.963364	2.328	6.858	0.000
ACCVAR	-0.138	0.064	-1.842311	0.860	-2.141	0.035
INTACVA	-0.164	0.062	-34.727814	13.128	-2.645	0.010
ACEXEED	0.203	0.056	541.630065	150.711	3.594	0.000
LANDEV	1.232	0.119	30.341040	2.939	10.322	0.000
LNERRSQ	-0.608	0.087	-2.420610	0.345	-7.016	0.000
MDREV	0.291	0.069	2.231506	0.528	4.226	0.000
SMREV	0.351	0.165	0.803440	0.377	2.131	0.036
NMRHOLD	0.272	0.112	1.537376	0.635	2.421	0.018
THRSHLD	0.362	0.128	109.833220	38.687	2.839	0.006
AOTIME	0.186	0.086	4.308043	1.988	2.167	0.033

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.24032 approx. F (5,94)=59.430 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,94)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LANDEV	0.478	0.503	92.862	0.000	0.241	0.759	1.648319
LNERRSQ	0.310	0.776	27.208	0.000	0.267	0.733	-1.052256
MDREV	0.277	0.866	14.524	0.000	0.670	0.330	-0.512853
SMREV	0.258	0.931	6.981	0.010	0.336	0.664	-0.520075
NMRHOLD	0.265	0.906	9.732	0.002	0.296	0.704	-0.645473
Eigenval							3.161150
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.65000	DROWSY p=0.35000
Observed	AWAKE	100.000	65	0
	DROWSY	85.714	5	30
	Total	95.000	70	30

Classification Functions

	AWAKE	DROWSY
LANDEV	1.259495	10.038605
LNERRSQ	-0.072611	-0.729878
MDREV	0.306352	-0.204633
SMREV	0.061520	-0.090106
NMRHOLD	0.317023	-0.243660
Constant	-1.368326	-9.454410

Table M1b: Discriminant Analysis of AVEOBS Using A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 5; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.17526 approx. F (10,186)=25.829 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,93)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACVA	0.203	0.864	7.308	0.001	0.591	0.409	-0.513435
ACEXEED	0.192	0.911	4.550	0.013	0.604	0.396	0.192060
LANDEV	0.455	0.386	74.117	0.000	0.259	0.741	1.713712
LNERRSQ	0.242	0.725	17.619	0.000	0.274	0.726	-1.098931
NMRHOLD	0.196	0.895	5.445	0.006	0.818	0.182	-0.133824
Eigenval							3.836082
Cum.Prop							0.955221

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.59000	QUESTION p=0.08000	DROWSY p=0.33000
Observed	AWAKE	96.610	57	2	0
	QUESTION	62.500	2	5	1
	DROWSY	87.879	1	3	29
	Total	91.000	60	10	30

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACVA	-1.422426	-13.332219	-16.866276
ACEXEED	47.240036	211.366241	117.035233
LANDEV	2.375351	8.997732	13.198526
LNERRSQ	-0.194254	-0.724373	-0.968835
NMRHOLD	0.155844	0.403001	0.004767
Constant	-1.016599	-8.665701	-12.800876

Table M2a: Multiple Regression and Discriminant Analysis of PERCLOS Using A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: PERCLOS

R= 0.90194474 R^2<= 0.81350432 Adjusted R^2<= 0.80147234
F(6,93)=67.612 p<0.00000 Std.Error of estimate: 0.03989

	BETA	St. Err. of BETA	B	St. Err. of B	t(93)	p-level
Intercpt			0.002139	0.005	0.404	0.687
INTACDE	-0.172	0.048	-0.095701	0.027	-3.591	0.000
LANVAR	1.058	0.196	0.010893	0.002	5.389	0.000
LANEX	0.464	0.097	0.292813	0.061	4.771	0.000
LNERRSQ	-0.747	0.149	-0.009166	0.002	-5.000	0.000
SMREV	-0.223	0.046	-0.001577	0.000	-4.803	0.000
NMNR	0.146	0.071	0.065595	0.032	2.071	0.041

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 7; Grouping: PERCLO_2 (2 grps)
Wilks' Lambda: 0.34711 approx. F (7,92)=24.721 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,92)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.424	0.819	20.349	0.000	0.747	0.253	-0.609536
LANVAR	0.378	0.919	8.147	0.005	0.069	0.931	1.345210
LANEX	0.420	0.826	19.399	0.000	0.268	0.732	0.997004
LNERRSQ	0.435	0.798	23.302	0.000	0.088	0.912	-1.875457
SMREV	0.400	0.868	13.979	0.000	0.342	0.658	-0.768170
NMRHOLD	0.362	0.958	4.026	0.048	0.273	0.727	-0.484698
NMNR	0.366	0.949	4.954	0.028	0.484	0.516	0.402195
Eigenval							1.880927
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	97.403	75	2
	DROWSY	91.304	2	21
	Total	96.000	77	23

Classification Functions

	AWAKE	DROWSY
INTACDE	1.460604	-10.978581
LANVAR	0.298721	0.919416
LANEX	-1.105944	27.017481
LNERRSQ	-0.202289	-1.135807
SMREV	-0.006829	-0.202024
NMRHOLD	0.083787	-0.242988
NMNR	-1.536722	5.848468
Constant	-0.508232	-7.926101

Table M2b: Discriminant Analysis of PERCLOS Using A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 7; Grouping: PERCLO_3 (3 grps)
Wilks' Lambda: 0.24481 approx. F (14,182)=13.274 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,91)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.272	0.901	4.989	0.009	0.807	0.193	-0.399198
LANVAR	0.293	0.837	8.883	0.000	0.077	0.923	1.715349
LANEX	0.279	0.877	6.382	0.003	0.390	0.610	0.664119
LNERRSQ	0.323	0.758	14.495	0.000	0.093	0.907	-1.847598
SMREV	0.312	0.785	12.489	0.000	0.324	0.676	-0.960498
NMRHOLD	0.263	0.930	3.430	0.037	0.270	0.730	-0.594170
AOTIME	0.272	0.899	5.084	0.008	0.384	0.616	0.244776
Eigenval							2.503423
Cum.Prop							0.937841

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.70000	QUESTION p=0.16000	DROWSY p=0.14000
Observed	AWAKE	98.571	69	1	0
	QUESTION	68.750	2	11	3
	DROWSY	64.286	1	4	9
	Total	89.000	72	16	12

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACDE	1.038848	-5.196058	-9.381308
LANVAR	0.280595	1.055709	1.314435
LANEX	-0.142636	18.341709	23.163958
LNERRSQ	-0.179170	-1.220622	-1.211802
SMREV	0.002481	-0.212105	-0.294452
NMRHOLD	0.078656	-0.265079	-0.434689
AOTIME	-0.452224	1.321898	-0.334329
Constant	-0.569359	-7.370385	-10.655139

Table M3a: Multiple Regression and Discriminant Analysis of MASTER Using A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: MASTER

R= 0.93610768 R^2<= 0.87629758 Adjusted R^2<= 0.86542265
F(8,91)=80.580 p<0.00000 Std.Error of estimate: 1.3177

	BETA	St. Err. of BETA	B	St. Err. of B	t(91)	p-level
Intercpt			-3.437887	0.232	-14.806	5.747
ACCDEV	-0.184	0.042	-1.137985	0.263	-4.312	4.082
LANDEV	0.847	0.139	2.583601	0.425	6.076	2.814
LANEX	0.368	0.095	9.32896	2.429	3.839	0.000
LNERRSQ	-0.455	0.080	-0.224127	0.039	-5.622	2.047
THRSHLD	0.133	0.044	5.008195	1.659	3.018	0.003
AOTIME	0.509	0.181	1.456495	0.519	2.805	0.006
NMWRONG	-0.571	0.149	-5.613957	1.466	-3.828	0.000
NMNR	0.192	0.074	3.458096	1.331	2.596	0.0109

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 8; Grouping: MASTER_2 (2 grps)
Wilks' Lambda: 0.37131 approx. F (8,91)=19.260 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,91)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.390	0.950	4.715	0.032	0.703	0.296	0.333777
LANDEV	0.391	0.948	4.955	0.028	0.125	0.874	-0.808903
LANEX	0.405	0.915	8.451	0.004	0.222	0.777	-0.779571
LNERRSQ	0.458	0.810	21.245	1.313	0.219	0.780	1.170042
THRSHLD	0.396	0.936	6.185	0.014	0.653	0.346	-0.393664
AOTIME	0.392	0.946	5.115	0.026	0.058	0.941	-1.200297
NMWRONG	0.398	0.932	6.627	0.011	0.070	0.929	1.233438
NMNR	0.39	0.936	6.167	0.014	0.297	0.702	-0.582579
Eigenval							1.693148
Cum.Prop							1

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.76000	DROWSY p=0.24000
Observed	AWAKE	96.052	73	3
	DROWSY	79.166	5	19
	Total	92	78	22

Classification Functions

	AWAKE	DROWSY
ACCDEV	0.138438	-1.578106
LANDEV	3.014327	5.849370
LANEX	-8.839536	12.318947
LNERRSQ	-0.143821	-0.694238
THRSHLD	-2.236395	10.124423
AOTIME	0.539720	4.057468
NMWRONG	-4.444826	-15.753779
NMNR	0.527474	10.434045
Constant	-1.167411	-8.847171

Table M3b: Discriminant Analysis of MASTER Using A/O Task, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 8; Grouping: MASTER_3 (3 grps)
Wilks' Lambda: 0.19630 approx. F (16,180)=14.142 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,90)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.221	0.884	5.857	0.004	0.659	0.340	0.391355
LANDEV	0.226	0.866	6.947	0.001	0.168	0.831	-1.005126
LANEX	0.227	0.862	7.199	0.001	0.281	0.718	-0.747973
LNERRSQ	0.255	0.768	13.519	7.348	0.246	0.753	1.095714
THRSHLD	0.227	0.862	7.192	0.001	0.609	0.390	-0.464545
AOTIME	0.212	0.924	3.696	0.028	0.067	0.932	-1.144939
NMWRONG	0.215	0.910	4.438	0.014	0.074	0.925	1.237651
NMNR	0.218	0.897	5.130	0.007	0.298	0.701	-0.421837
Eigenval							3.513401
Cum.Prop							0.964667

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.68000	QUESTION p=0.14000	DROWSY p=0.18000
Observed	AWAKE	95.588	65	2	1
	QUESTION	85.714	1	12	1
	DROWSY	72.222	0	5	13
	Total	90	66	19	15

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCDEV	0.0258060	-0.796808	-3.416983
LANDEV	3.1274228	7.421971	9.461820
LANEX	-7.8056926	7.721285	30.139028
LNERRSQ	-0.1559245	-0.659190	-1.010483
THRSHLD	-2.1160304	18.111047	17.664524
AOTIME	0.5731660	4.852143	5.734223
NMWRONG	-4.7271723	-14.632307	-22.878526
RAN_NMNR	0.9034909	0.911700	14.516259
Constant	-1.2149658	-8.985229	-15.899985

APPENDIX N

Multiple Regression/Discriminant Analysis Results —

Heart Measures, Steering, & Accelerometer

Table N1a: Multiple Regression and Discriminant Analysis of AVEOBS Using Heart Measures, Steering, and Accelerometer.

Regression Summary for Dependent Variable: AVEOBS

R= 0.78473933 R^2<= 0.61581582 Adjusted R^2<= 0.60928208
F(5,294)=94.252 p<0.0000 Std.Error of estimate: 15.585

	BETA	St. Err. of BETA	B	St. Err. of B	t(294)	p-level
Intercpt			26.093305	1.531	17.041	0.000
MNHRT	-0.333	0.042	-1.707128	0.214	-7.960	0.000
INTACDE	-0.265	0.039	-42.751330	6.259	-6.831	0.000
LGREV	0.324	0.049	8.369556	1.255	6.667	0.000
MDREV	0.539	0.053	3.128311	0.310	10.091	0.000
THRSHLD	0.122	0.043	28.715999	10.099	2.843	0.005

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 6; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.51978 approx. F (6,293)=45.117 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNHRT	0.567	0.917	26.610	0.000	0.738	0.262	-0.484561
INTACDE	0.542	0.959	12.453	0.000	0.783	0.217	-0.329377
LGREV	0.642	0.810	68.619	0.000	0.677	0.323	0.763698
MDREV	0.548	0.948	16.144	0.000	0.482	0.518	0.475194
SMREV	0.533	0.976	7.342	0.007	0.137	0.863	0.608539
THRSHLD	0.540	0.963	11.122	0.000	0.115	0.885	0.812550
Eigenval							0.923898
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.66333	DROWSY p=0.33667
Observed	AWAKE	92.965	185	14
	DROWSY	71.287	29	72
	Total	85.667	214	86

Classification Functions

	AWAKE	DROWSY
MNHRT	-0.155054	-0.366737
INTACDE	-1.780444	-6.111641
LGREV	-0.117811	1.855450
MDREV	0.328375	0.565791
SMREV	-0.088561	0.005312
THRSHLD	-7.174017	8.584438
Constant	-1.194653	-5.391342

Table N1b: Discriminant Analysis of AVEOBS Using Heart Measures, Steering, and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 5; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.43627 approx. F (10,586)=30.120 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNHRT	0.524	0.833	29.417	0.000	0.758	0.242	-0.636669
INTACDE	0.500	0.873	21.287	0.000	0.805	0.195	-0.529061
LGREV	0.545	0.800	36.613	0.000	0.692	0.308	0.728829
MDREV	0.471	0.926	11.791	0.000	0.462	0.538	0.436241
NMRHOLD	0.451	0.966	5.089	0.007	0.661	0.339	-0.117391
Eigenval							1.188279
Cum.Prop							0.961578

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.55667	QUESTION p=0.18000	DROWSY p=0.26333
Observed	AWAKE	90.419	151	9	7
	QUESTION	12.963	33	7	14
	DROWSY	75.949	10	9	60
	Total	72.667	194	25	81

Classification Functions

	AWAKE	QUESTION	DROWSY
MNHRT	-0.150088	-0.310567	-0.501240
INTACDE	-1.405234	-6.882165	-9.954392
LGREV	0.189223	1.294625	2.640916
MDREV	0.383910	0.671934	0.640410
NMRHOLD	0.141352	0.212407	0.070669
Constant	-1.291386	-4.574429	-6.849136

Table N2a: Multiple Regression and Discriminant Analysis of EYEMEAS Using Heart Measures, Steering, and Accelerometer.

Regression Summary for Dependent Variable: EYEMEAS

R= 0.77231594 R^2 <= 0.59647191 Adjusted R^2 <= 0.58820854
F(6,293)=72.183 p<0.0000 Std.Error of estimate: 890.51

	BETA	St. Err. of BETA	B	St. Err. of B	t(293)	p-level
Intercpt			1322.406105	74.632	17.719	0.000
MNHRT	-0.133	0.043	-37.927142	12.265	-3.092	0.002
ACCVAR	-0.227	0.044	-141.712204	27.420	-5.168	0.000
STVELV	0.363	0.078	16.818101	3.623	4.642	0.000
LGREV	0.292	0.077	420.363751	110.798	3.794	0.000
NMRHOLD	-0.299	0.056	-73.221203	13.745	-5.327	0.000
THRSHLD	0.309	0.051	4050.114787	670.157	6.044	0.000

Discriminant Function Analysis Summary (Single Threshold)

No. of vars in model: 5; Grouping: EYEMEA_2 (2 grps)
Wilks' Lambda: 0.51952 approx. F (5,294)=54.381 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNHRT	0.532	0.977	6.856	0.009	0.816	0.184	0.241051
ACCVAR	0.553	0.940	18.670	0.000	0.682	0.318	0.426974
STVELV	0.639	0.813	67.606	0.000	0.607	0.393	-0.800380
NMRHOLD	0.596	0.872	43.235	0.000	0.462	0.538	0.759603
THRSHLD	0.594	0.875	42.149	0.000	0.494	0.506	-0.727055
Eigenval							0.924845
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.70333	DROWSY p=0.29667
Observed	AWAKE	92.891	196	15
	DROWSY	61.798	34	55
	Total	83.667	230	70

Classification Functions

	AWAKE	DROWSY
MNHRT	-0.099511	-0.205088
ACCVAR	0.176259	-0.226211
STVELV	0.025555	0.091284
NMRHOLD	0.100238	-0.203583
THRSHLD	-1.254279	13.354656
Constant	-0.713663	-4.370838

Table N2b: Discriminant Analysis of EYEMEAS Using Heart Measures, Steering, and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: EYEMEA_3 (3 grps)
Wilks' Lambda: 0.46850 approx. F (12,584)=22.435 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNHRT	0.481	0.975	3.754	0.025	0.771	0.229	0.205527
ACCVAR	0.499	0.939	9.483	0.000	0.672	0.328	0.408959
STVELV	0.494	0.949	7.917	0.000	0.302	0.698	-0.573273
LGREV	0.479	0.978	3.252	0.040	0.344	0.656	-0.345587
NMRHOLD	0.521	0.899	16.439	0.000	0.454	0.546	0.631576
THRSHLD	0.538	0.870	21.760	0.000	0.486	0.514	-0.717690
Eigenval							1.075433
Cum.Prop							0.974227

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.67333	QUESTION p=0.06333	DROWSY p=0.26333
Observed	AWAKE	93.564	189	0	13
	QUESTION	5.263	9	1	9
	DROWSY	59.494	28	4	47
	Total	79.000	226	5	69

Classification Functions

	AWAKE	QUESTION	DROWSY
MNHRT	-0.088887	-0.241859	-0.178409
ACCVAR	0.159931	-0.015911	-0.279530
STVELV	0.018003	0.052278	0.070670
LGREV	0.296130	1.176877	1.288611
NMRHOLD	0.101821	0.007914	-0.186752
THRSHLD	-1.604295	9.202616	14.512727
Constant	-0.733406	-5.374292	-5.056039

Table N3a: Multiple Regression and Discriminant Analysis of NEWDEF Using Heart Measures, Steering, and Accelerometer.

Regression Summary for Dependent Variable: NEWDEF

R= 0.71090150 R^2<= 0.50538095 Adjusted R^2<= 0.49352364
F(7,292)=42.622 p<0.00000 Std.Error of estimate: 1.2218

	BETA	St. Err. of BETA	B	St. Err. of B	t(292)	p-level
Intercpt			0.050335	0.126	0.399	0.690
MNSQHRT	0.249	0.047	0.000571	0.000	5.285	0.000
ACCDEV	0.218	0.082	0.626425	0.235	2.663	0.008
INTACDE	-0.237	0.069	-2.626463	0.767	-3.425	0.000
STVELV	0.404	0.071	0.023138	0.004	5.696	0.000
MDREV	-0.364	0.073	-0.145508	0.029	-4.988	0.000
SMREV	-0.463	0.067	-0.059957	0.009	-6.865	0.000
NMRHOLD	-0.632	0.081	-0.191527	0.025	-7.767	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.64813 approx. F (5,294)=31.922 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.658	0.984	4.675	0.031	0.828	0.172	-0.231803
INTACDE	0.672	0.965	10.650	0.001	0.923	0.077	0.328110
STVELV	0.699	0.927	23.123	0.000	0.583	0.417	-0.596387
SMREV	0.704	0.921	25.162	0.000	0.352	0.648	0.797870
NMRHOLD	0.688	0.942	18.098	0.000	0.295	0.705	0.747057
Eigenval							0.542893
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.73000	DROWSY p=0.27000
Observed	AWAKE	94.521	207	12
	DROWSY	50.617	40	41
	Total	82.667	247	53

Classification Functions

	AWAKE	DROWSY
MNSQHRT	-0.000663	-0.000149
INTACDE	0.594525	-2.922110
STVELV	0.027943	0.066172
SMREV	-0.014273	-0.114214
NMRHOLD	0.034650	-0.194869
Constant	-0.680226	-3.782619

Table N3b: Discriminant Analysis of NEWDEF Using Heart Measures, Steering, and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 7; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.48684 approx. F (14,582)=18.009 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,291)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.525	0.928	11.349	0.000	0.757	0.243	-0.380996
ACCDEV	0.498	0.978	3.307	0.038	0.257	0.743	-0.412413
INTACDE	0.518	0.940	9.288	0.000	0.337	0.663	0.602542
STVELV	0.544	0.894	17.195	0.000	0.439	0.561	-0.628224
MDREV	0.522	0.933	10.433	0.000	0.357	0.643	0.289510
SMREV	0.543	0.896	16.876	0.000	0.337	0.663	0.820608
NMRHOLD	0.531	0.916	13.332	0.000	0.273	0.727	0.799309
Eigenval							0.798307
Cum.Prop							0.848782

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.64333	QUESTION p=0.17000	DROWSY p=0.18667
Observed	AWAKE	91.710	177	10	6
	QUESTION	29.412	31	15	5
	DROWSY	58.929	15	8	33
	Total	75.000	223	33	44

Classification Functions

	AWAKE	QUESTION	DROWSY
MNSQHRT	-0.001269	-0.000095	-0.000214
ACCDEV	0.060877	1.242064	1.558184
INTACDE	-1.186971	-7.360394	-9.604890
STVELV	-0.005602	-0.007004	0.058112
MDREV	0.415783	0.600682	0.189048
SMREV	0.009745	-0.072299	-0.127628
NMRHOLD	0.156154	0.079507	-0.207844
Constant	-1.349487	-4.135234	-5.467446

APPENDIX O

Multiple Regression/Discriminant Analysis Results —

Heart Measures, Steering, Accelerometer, & HPHDGDEV/VAR

Table O1a: Multiple Regression and Discriminant Analysis of AVEOBS Using Heart Measures, Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: AVEOBS

R= 0.81319337 R^2<= 0.66128346 Adjusted R^2<= 0.65077157
F(9,290)=62.908 p<0.0000 Std.Error of estimate: 14.735

	BETA	St. Err. of BETA	B	St. Err. of B	t(290)	p-level
Intercpt			23.887354	1.574	15.178	0.000
MNSQHRT	-0.222	0.043	-0.007413	0.001	-5.216	0.000
ACCVAR	-0.280	0.043	-3.138637	0.481	-6.532	0.000
HPHDGDE	0.434	0.067	32.778163	5.036	6.509	0.000
STVELV	-0.208	0.081	-0.173372	0.068	-2.560	0.011
LGREV	0.297	0.081	7.684155	2.089	3.678	0.000
MDREV	0.700	0.066	4.065998	0.383	10.622	0.000
SMREV	0.332	0.157	0.625530	0.296	2.113	0.035
NMRHOLD	0.231	0.095	1.016728	0.416	2.442	0.015
THRSHLD	0.331	0.127	77.839324	29.994	2.595	0.010

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 7; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.51400 approx. F (7,292)=39.442 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.538	0.956	13.540	0.000	0.707	0.293	-0.359092
ACCVAR	0.533	0.965	10.602	0.001	0.627	0.373	-0.339130
HPHDGDE	0.531	0.968	9.627	0.002	0.458	0.542	0.378841
LGREV	0.545	0.943	17.673	0.000	0.389	0.611	0.549378
MDREV	0.540	0.951	14.900	0.000	0.442	0.558	0.475158
SMREV	0.527	0.976	7.126	0.008	0.137	0.863	0.597483
THRSHLD	0.534	0.963	11.222	0.000	0.117	0.883	0.806647
Eigenval							0.945525
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.66333	DROWSY p=0.33667
Observed	AWAKE	94.472	188	11
	DROWSY	72.277	28	73
	Total	87.000	216	84

Classification Functions

	AWAKE	DROWSY
MNSQHRT	-0.000855	-0.001876
ACCVAR	-0.070048	-0.383963
HPHDGDE	2.034583	5.002924
LGREV	-0.566343	0.869672
MDREV	0.316221	0.556381
SMREV	-0.091720	0.001520
THRSHLD	-7.554695	8.271316
Constant	-1.246747	-5.564073

Table O1b: Discriminant Analysis of AVEOBS Using Heart Measures, Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 8; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.41083 approx. F (16,580)=20.306 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,290)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.438	0.938	9.555	0.000	0.660	0.340	0.404187
ACCVAR	0.450	0.913	13.820	0.000	0.603	0.397	0.496002
HPHDGDE	0.432	0.951	7.539	0.000	0.435	0.565	-0.432865
STVELV	0.420	0.979	3.085	0.047	0.231	0.769	0.272718
LGREV	0.437	0.939	9.342	0.000	0.306	0.694	-0.585207
MDREV	0.445	0.924	11.923	0.000	0.362	0.638	-0.560551
NMRHOLD	0.426	0.964	5.392	0.005	0.426	0.574	0.290799
THRSHLD	0.422	0.974	3.815	0.023	0.491	0.509	-0.304100
Eigenval							1.299154
Cum.Prop							0.956779

Classification Matrix

		Predicted			
		Percent Correct	AWAKE p=0.55667	QUESTION p=0.18000	DROWSY p=0.26333
Observed	AWAKE	89.222	149	14	4
	QUESTION	18.519	34	10	10
	DROWSY	75.949	10	9	60
	Total	73.000	193	33	74

Classification Functions

	AWAKE	QUESTION	DROWSY
MNSQHRT	-0.000706	-0.001501	-0.002194
ACCVAR	-0.043261	-0.391979	-0.629459
HPHDGDE	2.971678	4.110352	7.658929
STVELV	-0.020411	-0.011223	-0.050629
LGREV	-0.004813	0.687706	2.076961
MDREV	0.416374	0.699755	0.780436
NMRHOLD	0.165849	0.193258	0.009389
THRSHLD	-0.878267	2.532937	6.841023
Constant	-1.414579	-4.606107	-7.523584

Table O2a: Multiple Regression and Discriminant Analysis of NEWDEF Using Heart Measures,Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: NEWDEF

$R= 0.76139901$ $R^2 \leq= 0.57972845$ Adjusted $R^2 \leq= 0.57112221$
$F(6,293)=67.361$ $p<0.0000$ Std.Error of estimate: 1.1243

	BETA	St. Err. of BETA	B	St. Err. of B	t(293)	p-level
Intercpt			-0.490522	0.095	-5.183	0.000
MNSQHRT	0.333	0.042	0.000765	0.000	7.899	0.000
INTACDE	-0.125	0.038	-1.384945	0.426	-3.249	0.001
HPHDGDE	0.538	0.060	2.798022	0.313	8.942	0.000
SMREV	-0.231	0.063	-0.029926	0.008	-3.650	0.000
STEXED	0.094	0.044	843.933088	390.810	2.159	0.032
NMRHOLD	-0.260	0.073	-0.078825	0.022	-3.544	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.62320 approx. $F(5,294)=35.551$ $p< 0.0000$

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.674	0.924	24.159	0.000	0.771	0.229	0.511248
INTACDE	0.639	0.976	7.239	0.008	0.957	0.043	-0.258193
HPHDGDE	0.699	0.891	35.809	0.000	0.541	0.459	0.729678
SMREV	0.660	0.944	17.506	0.000	0.344	0.656	-0.658202
NMRHOLD	0.646	0.965	10.635	0.001	0.287	0.713	-0.568061
Eigenval							0.604616
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.73000	DROWSY p=0.27000
Observed	AWAKE	93.151	204	15
	DROWSY	55.556	36	45
	Total	83.000	240	60

Classification Functions

	AWAKE	DROWSY
MNSQHRT	-0.000217	0.000979
INTACDE	1.078047	-1.842300
HPHDGDE	2.790673	7.316452
SMREV	-0.010899	-0.097906
NMRHOLD	0.044877	-0.139302
Constant	-0.695687	-4.080601

Table O2b: Discriminant Analysis of NEWDEF Using Heart Measures, Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 7; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.46164 approx. F (14,582)=19.614 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,291)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.535	0.863	23.172	0.000	0.626	0.374	0.635209
INTACDE	0.481	0.959	6.148	0.002	0.850	0.150	-0.307097
HPHDGDE	0.532	0.867	22.225	0.000	0.497	0.503	0.748152
MDREV	0.482	0.958	6.347	0.002	0.512	0.488	0.034222
SMREV	0.490	0.941	9.090	0.000	0.321	0.679	-0.619504
STEXED	0.475	0.972	4.249	0.015	0.857	0.143	0.076347
NMRHOLD	0.483	0.955	6.811	0.001	0.246	0.754	-0.508175
Eigenval							0.909299
Cum.Prop							0.871368

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.64333	QUESTION p=0.17000	DROWSY p=0.18667
Observed	AWAKE	92.228	178	8	7
	QUESTION	29.412	32	15	4
	DROWSY	64.286	12	8	36
	Total	76.333	222	31	47

Classification Functions

	AWAKE	QUESTION	DROWSY
MNSQHRT	-0.001024	0.000607	0.000919
INTACDE	-1.129690	-4.385265	-5.674697
HPHDGDE	1.769421	5.150110	8.400496
MDREV	0.381340	0.577360	0.349746
SMREV	0.025610	-0.033979	-0.086165
STEXED	-919.717834	-2907.282959	835.371399
NMRHOLD	0.215709	0.218354	-0.050076
Constant	-1.404368	-4.573317	-6.302748

Table O3a: Multiple Regression and Discriminant Analysis of PERCLOS Using Heart Measures, Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: PERCLOS

R= 0.85077205 R^2 ≤= 0.72381308 Adjusted R^2 ≤= 0.71815738
F(6,293)=127.98 p<0.0000 Std.Error of estimate: 0.05198

	BETA	St. Err. of BETA	B	St. Err. of B	t(293)	p-level
Intercept			0.000925	0.004	0.207	0.836
MNSQHRT	0.093	0.035	0.000012	0.000	2.637	0.009
ACCVAR	-0.138	0.035	-0.006091	0.002	-3.916	0.000
HPHDGDE	0.651	0.047	0.193125	0.014	13.917	0.000
STEXED	0.099	0.035	50.264987	18.000	2.793	0.006
NMRHOLD	-0.283	0.048	-0.004884	0.000	-5.906	0.000
THRSHLD	0.346	0.044	0.319515	0.040	7.939	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: PERCLO_2 (2 grps)
Wilks' Lambda: 0.50536 approx. F (5,294)=57.553 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.536	0.942	17.952	0.000	0.851	0.149	0.369805
HPHDGDE	0.530	0.954	14.156	0.000	0.469	0.531	-0.445024
LGREV	0.524	0.965	10.617	0.001	0.452	0.548	-0.394693
NMRHOLD	0.533	0.949	15.930	0.000	0.429	0.571	0.491928
THRSHLD	0.550	0.918	26.243	0.000	0.497	0.503	-0.577623
Eigenval							0.978788
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	93.506	216	15
	DROWSY	69.565	21	48
	Total	88.000	237	63

Classification Functions

	AWAKE	DROWSY
INTACDE	0.305551	-5.378713
HPHDGDE	3.049563	7.056975
LGREV	0.368222	1.521054
NMRHOLD	0.107772	-0.108068
THRSHLD	-1.710164	11.365042
Constant	-0.676164	-5.963956

Table O3b: Discriminant Analysis of PERCLOS Using Heart Measures, Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 5; Grouping: PERCLO_3 (3 grps)
Wilks' Lambda: 0.38538 approx. F (10,586)=35.795 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.401	0.961	5.957	0.003	0.855	0.145	-0.271573
HPHDGDE	0.417	0.925	11.876	0.000	0.556	0.444	0.468791
LGREV	0.409	0.943	8.933	0.000	0.520	0.480	0.421886
NMRHOLD	0.421	0.916	13.384	0.000	0.432	0.568	-0.554878
THRSHLD	0.449	0.859	23.994	0.000	0.470	0.530	0.692941
Eigenval							1.578775
Cum.Prop							0.996075

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.68333	QUESTION p=0.14667	DROWSY p=0.17000
Observed	AWAKE	96.098	197	5	3
	QUESTION	29.545	17	13	14
	DROWSY	66.667	8	9	34
	Total	81.333	222	27	51

Classification Functions

	AWAKE	QUESTION	DROWSY
INTACDE	0.346467	-2.816687	-5.325303
HPHDGDE	2.969316	7.139267	9.088789
LGREV	0.343208	1.607456	2.065827
NMRHOLD	0.108787	-0.068759	-0.236347
THRSHLD	-1.813319	9.917061	19.915348
Constant	-0.721030	-5.345433	-8.458155

Table O4a: Multiple Regression and Discriminant Analysis of MASTER Using Heart Measures, Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: MASTER

R= 0.85402081 R^2 ≤= 0.72935154 Adjusted R^2 ≤= 0.72380926
F(6,293)=131.60 p<0.0000 Std.Error of estimate: 1.8674

	BETA	St. Err. of BETA	B	St. Err. of B	t(293)	p-level
Intercpt			-2.941838	0.197	-14.937	0.000
MNSQHRT	0.074	0.037	0.000350	0.000	2.011	0.045
ACCVAR	-0.213	0.037	-0.340152	0.060	-5.690	0.000
HPHDGDE	0.688	0.045	7.408347	0.481	15.411	0.000
MDREV	0.214	0.046	0.176998	0.038	4.697	0.000
NMRHOLD	-0.183	0.049	-0.114878	0.031	-3.731	0.000
THRSHLD	0.263	0.043	8.819823	1.447	6.094	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: MASTER_2 (2 grps)
Wilks' Lambda: 0.54799 approx. F (5,294)=48.502 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.566	0.969	9.406	0.002	0.643	0.357	-0.326529
HPHDGDE	0.634	0.864	46.320	0.000	0.688	0.312	0.661322
MDREV	0.561	0.978	6.765	0.010	0.535	0.465	0.305015
NMRHOLD	0.580	0.944	17.358	0.000	0.407	0.593	-0.550595
THRSHLD	0.615	0.892	35.698	0.000	0.485	0.515	0.702890
Eigenval							0.824864
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.75000	DROWSY p=0.25000
Observed	AWAKE	92.444	208	17
	DROWSY	65.333	26	49
	Total	85.667	234	66

Classification Functions

	AWAKE	DROWSY
ACCVAR	-0.057629	-0.364934
HPHDGDE	2.776997	7.972469
MDREV	0.314350	0.469769
NMRHOLD	0.178152	-0.036880
THRSHLD	0.463999	14.659594
Constant	-1.149751	-5.838746

Table O4b: Discriminant Analysis of MASTER Using Heart Measures, Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: MASTER_3 (3 grps)
Wilks' Lambda: 0.34318 approx. F (12,584)=34.408 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCVAR	0.369	0.931	10.796	0.000	0.619	0.381	0.410608
HPHDGDE	0.377	0.910	14.517	0.000	0.567	0.433	-0.495269
LGREV	0.370	0.929	11.201	0.000	0.487	0.513	-0.474412
MDREV	0.359	0.957	6.531	0.002	0.493	0.507	-0.211737
NMRHOLD	0.368	0.933	10.473	0.000	0.421	0.579	0.484471
THRSHLD	0.400	0.859	23.991	0.000	0.465	0.535	-0.680921
Eigenval							1.817982
Cum.Prop							0.981620

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.67333	QUESTION p=0.13667	DROWSY p=0.19000
Observed	AWAKE	95.545	193	6	3
	QUESTION	19.512	15	8	18
	DROWSY	70.175	7	10	40
	Total	80.333	215	24	61

Classification Functions

	AWAKE	QUESTION	DROWSY
ACCVAR	-0.053561	-0.526573	-0.623293
HPHDGDE	3.438553	7.869648	10.476720
LGREV	-0.323041	1.064287	1.864411
MDREV	0.336392	0.605878	0.444069
NMRHOLD	0.172481	0.005292	-0.141537
THRSHLD	0.817324	17.140390	21.253637
Constant	-1.196504	-7.056661	-9.253569

APPENDIX P

Multiple Regression/Discriminant Analysis Results —

Heart Measures, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ

Table P1a: Multiple Regression and Discriminant Analysis of AVEOBS Using Heart Measures, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: AVEOBS

R= 0.83812453 R^2 ≤= 0.70245272 Adjusted R^2 ≤= 0.69635960
F(6,293)=115.29 p<0.0000 Std.Error of estimate: 13.739

	BETA	St. Err. of BETA	B	St. Err. of B	t(293)	p-level
Intercpt			24.418514	1.363	17.920	0.000
MNSQHRT	-0.216	0.039	-0.007187	0.001	-5.582	0.000
ACCDEV	-0.318	0.041	-13.265948	1.717	-7.728	0.000
LANDEV	0.943	0.075	18.089590	1.438	12.577	0.000
LNERRSQ	-0.575	0.065	-1.120548	0.127	-8.838	0.000
MDREV	0.524	0.049	3.045297	0.283	10.749	0.000
THRSHLD	0.081	0.038	19.058550	8.986	2.121	0.035

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.42369 approx. F (5,294)=79.979 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.436	0.972	8.457	0.004	0.756	0.244	0.253344
ACCDEV	0.453	0.936	20.098	0.000	0.593	0.407	0.432536
LANDEV	0.704	0.602	194.355	0.000	0.171	0.829	-2.010284
LNERRSQ	0.569	0.744	101.023	0.000	0.192	0.808	1.520864
MDREV	0.433	0.978	6.535	0.011	0.493	0.507	-0.276512
Eigenval							1.360190
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.66333	DROWSY p=0.33667
Observed	AWAKE	95.477	190	9
	DROWSY	77.228	23	78
	Total	89.333	213	87

Classification Functions

	AWAKE	DROWSY
MNSQHRT	-0.001024	-0.001887
ACCDEV	-0.535753	-2.325107
LANDEV	0.568151	5.245740
LNERRSQ	-0.036433	-0.337955
MDREV	0.313422	0.481048
Constant	-1.089964	-6.747672

Table P1b: Discriminant Analysis of AVEOBS Using Heart Measures, Steering, Accelerometer , LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 5; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.33759 approx. F (10,586)=42.256 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.357	0.947	8.273	0.000	0.746	0.254	0.330765
ACCDEV	0.388	0.870	21.797	0.000	0.551	0.449	0.587149
LANDEV	0.610	0.554	118.017	0.000	0.170	0.830	-2.003394
LNERRSQ	0.471	0.717	57.962	0.000	0.189	0.811	1.515538
MDREV	0.368	0.917	13.306	0.000	0.484	0.516	-0.463304
Eigenval							1.887841
Cum.Prop							0.986550

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.55667	QUESTION p=0.18000	DROWSY p=0.26333
Observed	AWAKE	94.611	158	5	4
	QUESTION	31.481	26	17	11
	DROWSY	75.949	8	11	60
	Total	78.333	192	33	75

Classification Functions

	AWAKE	QUESTION	DROWSY
MNSQHRT	-0.001024	-0.001769	-0.002493
ACCDEV	-0.505749	-2.436290	-3.599016
LANDEV	0.576822	3.413285	6.892024
LNERRSQ	-0.035088	-0.226616	-0.429359
MDREV	0.303935	0.594823	0.661832
Constant	-1.156770	-4.859373	-9.379151

Table P2a: Multiple Regression and Discriminant Analysis of NEWDEF Using Heart Measures, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: NEWDEF

R= 0.77391733 R^2 <= 0.59894803 Adjusted R^2 <= 0.59212742
F(5,294)=87.814 p<0.0000 Std.Error of estimate: 1.0965

	BETA	St. Err. of BETA	B	St. Err. of B	t(294)	p-level
Intercept			-0.294132	0.090	-3.263	0.001
MNSQHRT	0.273	0.040	0.000626	0.000	6.859	0.000
INTACDE	-0.161	0.039	-1.791874	0.431	-4.161	0.000
LANVAR	0.311	0.052	0.038847	0.006	6.027	0.000
LANEX	0.422	0.054	5.930241	0.762	7.783	0.000
STVELV	0.134	0.051	0.007674	0.003	2.611	0.009

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.57940 approx. F (5,294)=42.684 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.605	0.957	13.223	0.000	0.741	0.259	-0.371566
INTACDE	0.607	0.955	13.826	0.000	0.853	0.147	0.353809
LANEX	0.673	0.861	47.621	0.000	0.689	0.311	-0.693778
STVELV	0.629	0.921	25.082	0.000	0.702	0.298	-0.516050
THRSHLD	0.600	0.965	10.542	0.001	0.727	0.273	-0.336487
Eigenval							0.725913
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.73000	DROWSY p=0.27000
Observed	AWAKE	93.607	205	14
	DROWSY	64.198	29	52
	Total	85.667	234	66

Classification Functions

	AWAKE	DROWSY
MNSQHRT	-0.000688	0.000265
INTACDE	0.421760	-3.963158
LANEX	0.963625	13.815719
STVELV	0.022590	0.060841
THRSHLD	0.782598	6.881301
Constant	-0.637129	-4.277996

Table P2b: Discriminant Analysis of NEWDEF Using Heart Measures, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 7; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.43001 approx. F (14,582)=21.824 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,291)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.492	0.874	20.921	0.000	0.666	0.334	-0.542122
INTACDE	0.457	0.941	9.128	0.000	0.786	0.214	0.379209
LANDEV	0.449	0.957	6.489	0.002	0.323	0.677	-0.505845
LANEX	0.445	0.967	4.959	0.008	0.396	0.604	-0.399847
STVELV	0.452	0.951	7.514	0.000	0.365	0.635	-0.267490
MDREV	0.458	0.940	9.345	0.000	0.411	0.589	-0.080221
SMREV	0.455	0.945	8.546	0.000	0.810	0.190	0.250857
Eigenval							1.054301
Cum.Prop							0.888710

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.64333	QUESTION p=0.17000	DROWSY p=0.18667
Observed	AWAKE	91.710	177	9	7
	QUESTION	31.373	27	16	8
	DROWSY	66.071	9	10	37
	Total	76.667	213	35	52

Classification Functions

	AWAKE	QUESTION	DROWSY
MNSQHRT	-0.001010	0.000619	0.000749
INTACDE	-0.775819	-4.460144	-7.010856
LANDEV	0.121209	0.805848	1.379725
LANEX	-0.314798	3.795406	10.232653
STVELV	-0.016041	-0.034912	0.020543
MDREV	0.369583	0.643699	0.356529
SMREV	-0.033391	-0.094261	-0.072875
Constant	-1.259992	-4.427496	-6.713489

Table P3a: Multiple Regression and Discriminant Analysis of PERCLOS Using Heart Measures, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: PERCLOS
$R= 0.87391549$ $R^2 \le= 0.76372828$ Adjusted $R^2 \le= 0.75806423$
$F(7,292)=134.84$ $p<0.0000$ Std.Error of estimate: 0.04816

	BETA	St. Err. of BETA	B	St. Err. of B	t(292)	p-level
Intercpt			-0.001811	0.004	-0.447	0.655
MNSQHRT	0.072	0.032	0.000009	0.000	2.237	0.026
INTACDE	-0.107	0.030	-0.067556	0.019	-3.557	0.000
LANDEV	0.905	0.064	0.068138	0.005	14.041	0.000
LNERRSQ	-0.272	0.054	-0.002081	0.000	-5.076	0.000
STEXED	0.081	0.033	41.227515	16.826	2.450	0.015
NMRHOLD	-0.195	0.045	-0.003362	0.000	-4.296	0.000
THRSHLD	0.273	0.042	0.252764	0.039	6.503	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 6; Grouping: PERCLO_2 (2 grps)
Wilks' Lambda: 0.45353 approx. F (6,293)=58.841 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.482	0.941	18.215	0.000	0.875	0.125	0.349867
LANDEV	0.592	0.766	89.681	0.000	0.269	0.730	-1.261448
LNERRSQ	0.505	0.898	33.174	0.000	0.312	0.688	0.772370
STEXED	0.460	0.986	4.163	0.042	0.851	0.149	-0.173585
NMRHOLD	0.473	0.960	12.277	0.000	0.431	0.569	0.413003
THRSHLD	0.483	0.939	18.998	0.000	0.481	0.519	-0.481139
Eigenval							1.204930
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	94.805	219	12
	DROWSY	75.362	17	52
	Total	90.333	236	64

Classification Functions

	AWAKE	DROWSY
INTACDE	0.276362	-5.690438
LANDEV	1.637525	4.936619
LNERRSQ	-0.094531	-0.267244
STEXED	-159.922363	2350.023926
NMRHOLD	0.082455	-0.118603
THRSHLD	-1.223006	10.861004
Constant	-0.660627	-6.816076

Table P3b: Discriminant Analysis of PERCLOS Using Heart Measures, Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: PERCLO_3 (3 grps)
Wilks' Lambda: 0.32390 approx. F (12,584)=36.845 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.331	0.977	3.393	0.035	0.790	0.210	-0.165494
INTACDE	0.336	0.964	5.480	0.005	0.882	0.118	0.247598
LANDEV	0.530	0.611	92.797	0.000	0.258	0.742	-1.494399
LNERRSQ	0.404	0.803	35.899	0.000	0.286	0.714	0.983753
NMRHOLD	0.349	0.928	11.298	0.000	0.430	0.570	0.494072
THRSHLD	0.372	0.871	21.529	0.000	0.424	0.576	-0.659123
Eigenval							1.988854
Cum.Prop							0.983698

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.68333	QUESTION p=0.14667	DROWSY p=0.17000
Observed	AWAKE	95.122	195	9	1
	QUESTION	47.727	13	21	10
	DROWSY	68.627	9	7	35
	Total	83.667	217	37	46

Classification Functions

	AWAKE	QUESTION	DROWSY
MNSQHRT	-0.000233	-0.000042	0.000700
INTACDE	0.334571	-3.196538	-5.344937
LANDEV	1.513109	5.708472	7.003439
LNERRSQ	-0.088383	-0.333392	-0.365126
NMRHOLD	0.079738	-0.109273	-0.261017
THRSHLD	-1.835600	10.357380	21.593470
Constant	-0.708965	-6.423586	-9.743718

APPENDIX Q

Multiple Regression/Discriminant Analysis Results —

Heart Measures, Steering, Accelerometer, & All Lane Measures

(includes LNRTDEV/VAR)

Table Q1a: Multiple Regression and Discriminant Analysis of AVEOBS Using Heart Measures, Steering, Accelerometer, and All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, and LNRTDEV/VAR.

Regression Summary for Dependent Variable: AVEOBS

R= 0.81553534 R^2 ≤= 0.66509790 Adjusted R^2 ≤= 0.65823983
F(6,293)=96.980 p<0.0000 Std.Error of estimate: 14.576

	BETA	St. Err. of BETA	B	St. Err. of B	t(293)	p-level
Intercept			22.617721	1.478	15.304	0.000
MNSQHRT	-0.202	0.042	-0.006730	0.001	-4.770	0.000
ACCDEV	-0.298	0.044	-12.427610	1.816	-6.842	0.000
LANVAR	-0.540	0.082	-0.979829	0.149	-6.570	0.000
LNRTDEV	0.921	0.094	44.673273	4.562	9.793	0.000
MDREV	0.538	0.053	3.123821	0.308	10.143	0.000
THRSHLD	0.149	0.040	34.982291	9.396	3.723	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 8; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.45231 approx. F (8,291)=44.046 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,291)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.460	0.984	4.753	0.030	0.773	0.227	0.194887
ACCDEV	0.474	0.955	13.740	0.000	0.647	0.353	0.356806
LANEX	0.481	0.940	18.514	0.000	0.491	0.509	-0.471744
LNERRSQ	0.510	0.887	37.128	0.000	0.238	0.762	0.932025
LNRTDEV	0.480	0.943	17.753	0.000	0.154	0.846	-0.824469
LGREV	0.465	0.974	7.869	0.005	0.450	0.550	-0.326891
NMRHOLD	0.470	0.963	11.088	0.000	0.425	0.575	0.397217
THRSHLD	0.472	0.957	12.961	0.000	0.465	0.535	-0.409315
Eigenval							1.210888
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.66333	DROWSY p=0.33667
Observed	AWAKE	93.970	187	12
	DROWSY	75.248	25	76
	Total	87.667	212	88

Classification Functions

	AWAKE	DROWSY
MNSQHRT	-0.000166	-0.000793
ACCDEV	0.348478	-1.044224
LANEX	-1.088779	10.120784
LNERRSQ	-0.088520	-0.262865
LNRTDEV	3.748508	8.182010
LGREV	0.127593	1.094549
NMRHOLD	0.074275	-0.096946
THRSHLD	0.039010	9.126862
Constant	-0.896046	-5.713709

Table Q1b: Discriminant Analysis of AVEOBS Using Heart Measures, Steering, Accelerometer, and All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, and LNRTDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 9; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.34877 approx. F (18,578)=22.262 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,289)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.368	0.947	8.115	0.000	0.650	0.350	-0.355626
ACCDEV	0.395	0.884	18.964	0.000	0.510	0.490	-0.584515
LANEX	0.393	0.887	18.326	0.000	0.510	0.490	0.585918
LNERRSQ	0.380	0.917	13.084	0.000	0.229	0.771	-0.747643
LNRTDEV	0.362	0.963	5.597	0.004	0.155	0.845	0.612969
LGREV	0.366	0.953	7.061	0.001	0.449	0.551	0.388545
MDREV	0.382	0.913	13.812	0.000	0.394	0.606	0.550790
SMREV	0.366	0.953	7.098	0.000	0.133	0.867	0.688366
THRSHLD	0.369	0.946	8.291	0.000	0.113	0.887	0.850630
Eigenval							1.766068
Cum.Prop							0.979716

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.55667	QUESTION p=0.18000	DROWSY p=0.26333
Observed	AWAKE	93.413	156	8	3
	QUESTION	27.778	25	15	14
	DROWSY	78.481	8	9	62
	Total	77.667	189	32	79

Classification Functions

	AWAKE	QUESTION	DROWSY
MNSQHRT	-0.000765	-0.001443	-0.002310
ACCDEV	-0.428908	-2.395681	-3.376772
LANEX	-0.174372	10.697702	18.807301
LNERRSQ	-0.046654	-0.158320	-0.231367
LNRTDEV	2.377613	4.760613	6.873842
LGREV	-0.517324	0.021511	1.109208
MDREV	0.298375	0.622714	0.707494
SMREV	-0.077527	-0.035217	0.090466
THRSHLD	-5.826659	3.903042	19.653296
Constant	-1.339320	-5.172844	-8.815205

Table Q2a: Multiple Regression and Discriminant Analysis of NEWDEF Using Heart Measures, Steering, Accelerometer, and All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, and LNRTDEV/VAR.

Regression Summary for Dependent Variable: NEWDEF

R= 0.80171875 R^2 <= 0.64275295 Adjusted R^2 <= 0.63667732
F(5,294)=105.79 p<0.0000 Std.Error of estimate: 1.0348

	BETA	St. Err. of BETA	B	St. Err. of B	t(294)	p-level
Intercept			-0.263432	0.084	-3.149	0.002
MNSQHRT	0.328	0.036	0.000753	0.000	9.172	0.000
INTACDE	-0.111	0.037	-1.231712	0.407	-3.024	0.003
LANDEV	0.987	0.119	1.303961	0.158	8.272	0.000
LANEX	0.178	0.066	2.492371	0.927	2.690	0.008
LNRTDEV	-0.386	0.103	-1.289530	0.344	-3.746	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 6; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.56697 approx. F (6,293)=37.297 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,293)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.630	0.899	32.749	0.000	0.769	0.231	-0.549544
INTACDE	0.585	0.968	9.548	0.002	0.875	0.125	0.288604
LNMNSQ	0.596	0.951	15.233	0.000	0.193	0.807	0.769285
LANDEV	0.627	0.904	31.031	0.000	0.117	0.883	-1.374379
LANEX	0.576	0.984	4.758	0.030	0.347	0.653	-0.326097
SMREV	0.578	0.980	5.833	0.016	0.863	0.137	0.228546
Eigenval							0.763761
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.73000	DROWSY p=0.27000
Observed	AWAKE	93.151	204	15
	DROWSY	60.494	32	49
	Total	84.333	236	64

Classification Functions

	AWAKE	DROWSY
MNSQHRT	-0.000230	0.001216
INTACDE	1.035852	-2.633012
LNMNSQ	-0.073941	-0.167256
LANDEV	1.491553	3.983209
LANEX	-1.155188	5.041178
SMREV	-0.022452	-0.056408
Constant	-0.712249	-4.641619

Table Q2b: Discriminant Analysis of NEWDEF Using Heart Measures, Steering, Accelerometer, and All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, and LNRTDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 7; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.43001 approx. F (14,582)=21.824 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,291)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.492	0.874	20.921	0.000	0.666	0.334	-0.542122
INTACDE	0.457	0.941	9.128	0.000	0.786	0.214	0.379209
LANDEV	0.449	0.957	6.489	0.002	0.323	0.677	-0.505845
LANEX	0.445	0.967	4.959	0.008	0.396	0.604	-0.399847
STVELV	0.452	0.951	7.514	0.000	0.365	0.635	-0.267490
MDREV	0.458	0.940	9.345	0.000	0.411	0.589	-0.080221
SMREV	0.455	0.945	8.546	0.000	0.810	0.190	0.250857
Eigenval							1.054301
Cum.Prop							0.888710

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.64333	QUESTION p=0.17000	DROWSY p=0.18667
Observed	AWAKE	91.710	177	9	7
	QUESTION	31.373	27	16	8
	DROWSY	66.071	9	10	37
	Total	76.667	213	35	52

Classification Functions

	AWAKE	QUESTION	DROWSY
MNSQHRT	-0.001010	0.000619	0.000749
INTACDE	-0.775819	-4.460144	-7.010856
LANDEV	0.121209	0.805848	1.379725
LANEX	-0.314798	3.795406	10.232653
STVELV	-0.016041	-0.034912	0.020543
MDREV	0.369583	0.643699	0.356529
SMREV	-0.033391	-0.094261	-0.072875
Constant	-1.259992	-4.427496	-6.713489

APPENDIX R

Multiple Regression/Discriminant Analysis Results —

Heart Measures, Steering, Accelerometer, All Lane Measures, & DSYAWDEV/VAR

Table R1a: Multiple Regression and Discriminant Analysis of AVEOBS Using Heart Measures, Steering, Accelerometer, All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, and LNRTDEV/VAR, and DSYAWDEV/VAR.

Regression Summary for Dependent Variable: AVEOBS

R= 0.83659612 R^2<= 0.69989306 Adjusted R^2<= 0.69374753
F(6,293)=113.89 p<0.0000 Std.Error of estimate: 13.798

	BETA	St. Err. of BETA	B	St. Err. of B	t(293)	p-level
Intercpt			22.140716	1.399	15.826	0.000
MNSQHRT	-0.167	0.040	-0.005552	0.001	-4.120	0.000
ACCDEV	-0.307	0.041	-12.803321	1.721	-7.441	0.000
DSYAWDE	1.197	0.101	80.994105	6.821	11.874	0.000
LANVAR	-0.774	0.088	-1.405062	0.159	-8.842	0.000
MDREV	0.450	0.052	2.616009	0.304	8.597	0.000
THRSHLD	0.104	0.038	24.601866	8.956	2.747	0.006

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 7; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.43296 approx. F (7,292)=54.633 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,292)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACCDEV	0.456	0.950	15.478	0.000	0.664	0.336	0.365616
DSYAWDE	0.566	0.765	89.851	0.000	0.101	0.899	-2.023733
LANVAR	0.488	0.888	36.907	0.000	0.137	0.863	1.201234
LANEX	0.440	0.984	4.696	0.031	0.423	0.577	-0.256835
LNRTVAR	0.458	0.945	17.107	0.000	0.243	0.757	0.634060
NMRHOLD	0.446	0.971	8.846	0.003	0.433	0.567	0.346224
THRSHLD	0.452	0.957	13.041	0.000	0.492	0.508	-0.391533
Eigenval							1.309690
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.66333	DROWSY p=0.33667
Observed	AWAKE	94.472	188	11
	DROWSY	78.218	22	79
	Total	89.000	210	90

Classification Functions

	AWAKE	DROWSY
ACCDEV	0.187673	-1.296495
DSYAWDE	10.057834	26.063190
LANVAR	-0.128384	-0.353377
LANEX	-3.610128	2.736871
LNRTVAR	-0.201205	-0.637651
NMRHOLD	0.089412	-0.065797
THRSHLD	-0.517916	8.522822
Constant	-1.060380	-6.588022

Table R1b: Discriminant Analysis of AVEOBS Using Heart Measures, Steering, Accelerometer, All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, and LNRTDEV/VAR, and DSYAWDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 7; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.35079 approx. F (14,582)=28.618 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,291)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.364	0.962	5.669	0.004	0.669	0.331	0.295819
ACCDEV	0.405	0.866	22.576	0.000	0.529	0.471	0.614781
DSYAWDE	0.417	0.841	27.569	0.000	0.081	0.919	-1.743591
LANVAR	0.374	0.938	9.649	0.000	0.128	0.872	0.864941
LANEX	0.369	0.951	7.494	0.000	0.433	0.567	-0.402082
LNRTVAR	0.378	0.927	11.374	0.000	0.231	0.769	0.679778
MDREV	0.370	0.947	8.084	0.000	0.409	0.591	-0.383878
Eigenval							1.762846
Cum.Prop							0.982280

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.55667	QUESTION p=0.18000	DROWSY p=0.26333
Observed	AWAKE	94.012	157	6	4
	QUESTION	25.926	26	14	14
	DROWSY	78.481	8	9	62
	Total	77.667	191	29	80

Classification Functions

	AWAKE	QUESTION	DROWSY
MNSQHRT	-0.000785	-0.001479	-0.002047
ACCDEV	-0.527176	-2.595922	-3.630444
DSYAWDE	5.995864	13.608090	24.415079
LANVAR	-0.080331	-0.204571	-0.287313
LANEX	-2.303933	6.961622	10.431764
LNRTVAR	-0.116376	-0.319487	-0.730500
MDREV	0.235009	0.500937	0.514493
Constant	-1.260673	-5.145245	-9.440132

Table R2a: Multiple Regression and Discriminant Analysis of NEWDEF Using Heart Measures, Steering, Accelerometer, All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, and LNRTDEV/VAR, and DSYAWDEV/VAR.

Regression Summary for Dependent Variable: NEWDEF

R= 0.79725288 R^2 <= 0.63561216 Adjusted R^2 <= 0.62941509
F(5,294)=102.57 p<0.0000 Std.Error of estimate: 1.0451

	BETA	St. Err. of BETA	B	St. Err. of B	t(294)	p-level
Intercept			-0.278989	0.086	-3.256	0.001
MNSQHRT	0.330	0.036	0.000757	0.000	9.123	0.000
INTACDE	-0.110	0.037	-1.218973	0.413	-2.948	0.003
DSYAWDE	-0.373	0.132	-1.735445	0.614	-2.828	0.005
LANDEV	0.993	0.150	1.311707	0.198	6.637	0.000
LANEX	0.166	0.067	2.326238	0.944	2.465	0.014

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.59934 approx. F (5,294)=39.308 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,294)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.646	0.928	22.924	0.000	0.889	0.111	-0.450578
INTACDE	0.621	0.966	10.435	0.001	0.885	0.115	0.310959
DSYAWVAR	0.609	0.985	4.584	0.033	0.443	0.557	0.294225
LANDEV	0.639	0.938	19.430	0.000	0.199	0.801	-0.882255
LANEX	0.611	0.980	5.926	0.016	0.325	0.675	-0.389556
Eigenval							0.668498
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.73000	DROWSY p=0.27000
Observed	AWAKE	96.804	212	7
	DROWSY	49.383	41	40
	Total	84.000	253	47

Classification Functions

	AWAKE	DROWSY
MNSQHRT	-0.000477	0.000632
INTACDE	1.035687	-2.662630
DSYAWVAR	-0.211160	-0.566237
LANDEV	0.602868	2.099265
LANEX	-0.114184	6.811004
Constant	-0.560184	-3.866084

Table R2b: Discriminant Analysis of NEWDEF Using Heart Measures, Steering, Accelerometer, All Lane Measures Including LANDEV/VAR, LNMNSQ, LANEX, LNERRSQ, and LNRTDEV/VAR, and DSYAWDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 7; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.42721 approx. F (14,582)=22.031 p<0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,291)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.497	0.859	23.812	0.000	0.644	0.356	-0.591545
INTACDE	0.447	0.957	6.597	0.002	0.852	0.148	0.309460
DSYAWVAR	0.445	0.961	5.944	0.003	0.506	0.494	0.381225
LANDEV	0.538	0.795	37.605	0.000	0.332	0.668	-1.094833
STVELV	0.448	0.954	6.954	0.001	0.366	0.634	-0.215149
MDREV	0.453	0.943	8.717	0.000	0.409	0.591	-0.076747
SMREV	0.453	0.944	8.653	0.000	0.810	0.190	0.259410
Eigenval							1.065891
Cum.Prop							0.889032

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.64333	QUESTION p=0.17000	DROWSY p=0.18667
Observed	AWAKE	93.782	181	7	5
	QUESTION	29.412	28	15	8
	DROWSY	64.286	10	10	36
	Total	77.333	219	32	49

Classification Functions

	AWAKE	QUESTION	DROWSY
MNSQHRT	-0.001005	0.000747	0.000919
INTACDE	-0.820046	-4.084108	-5.856231
DSYAWVAR	-0.011672	-0.431164	-0.650200
LANDEV	0.112347	1.573104	2.856761
STVELV	-0.015999	-0.037231	0.015922
MDREV	0.368326	0.632593	0.350107
SMREV	-0.033402	-0.094991	-0.074072
Constant	-1.259870	-4.503894	-6.742176

APPENDIX S

Multiple Regression/Discriminant Analysis Results —

A/O Task and Heart Measures

Table S1a: Multiple Regression and Discriminant Analysis of NEWDEF Using A/O Task and Heart Measures.

Regression Summary for Dependent Variable: NEWDEF

R= 0.77375393 R^2<= 0.59869515 Adjusted R^2<= 0.58179811
F(4,95)=35.432 p<0.00000 Std.Error of estimate: 1.0027

	BETA	St. Err. of BETA	B	St. Err. of B	t(95)	p-level
Intercpt			-0.177403	0.157	-1.127	0.262
MNSQHRT	0.493	0.079	0.001031	0.000	6.208	0.000
AOTIME	1.471	0.202	1.816592	0.249	7.287	0.000
NMWRONG	-1.018	0.215	-4.311826	0.910	-4.738	0.000
NMNR	0.341	0.100	2.647352	0.775	3.417	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 3; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.67724 approx. F (3,96)=15.251 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,96)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.712	0.951	4.903	0.029	0.641	0.359	0.484773
AOTIME	0.914	0.741	33.515	0.000	0.089	0.911	3.003753
NMWRONG	0.793	0.854	16.347	0.000	0.087	0.913	-2.273958
Eigenval							0.476586
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	93.506	72	5
	DROWSY	47.826	12	11
	Total	83.000	84	16

Classification Functions

	AWAKE	DROWSY
MNSQHRT	-0.001071	-0.000012
AOTIME	2.138201	6.272367
NMWRONG	-8.201278	-18.458525
Constant	-0.785889	-4.005725

Table S1b: Discriminant Analysis of NEWDEF Using A/O Task and Heart Measures.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 4; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.44441 approx. F (8,188)=11.751 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,94)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.578	0.769	14.086	0.000	0.564	0.436	-0.828739
AOTIME	0.705	0.630	27.573	0.000	0.077	0.923	-2.990381
NMWRONG	0.610	0.729	17.495	0.000	0.070	0.930	2.680649
NMNR	0.497	0.893	5.607	0.005	0.426	0.574	-0.683858
Eigenval							1.128753
Cum.Prop							0.951895

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.66000	QUESTION p=0.18000	DROWSY p=0.16000
Observed	AWAKE	89.394	59	3	4
	QUESTION	50.000	3	9	6
	DROWSY	56.250	4	3	9
	Total	77.000	66	15	19

Classification Functions

	AWAKE	QUESTION	DROWSY
MNSQHRT	-0.001377	0.001528	0.000891
AOTIME	1.620669	6.425329	8.067444
NMWRONG	-7.623679	-21.680048	-26.318068
NMNR	1.642223	9.449984	9.757025
Constant	-0.986788	-4.350011	-5.857993

APPENDIX T

Multiple Regression/Discriminant Analysis Results —

A/O Task, Heart Measures, Steering, & Accelerometer

Table T1a: Multiple Regression and Discriminant Analysis of AVEOBS Using A/O Task, Heart Measures, Steering, and Accelerometer.

Regression Summary for Dependent Variable: AVEOBS

R= 0.83729040 R^2 <= 0.70105522 Adjusted R^2 <= 0.68515390
F(5,94)=44.088 p<0.00000 Std.Error of estimate: 16.281

	BETA	St. Err. of BETA	B	St. Err. of B	t(94)	p-level
Intercpt			25.569385	2.633	9.711	0.000
MNSQHRT	-0.180	0.069	-0.007063	0.003	-2.607	0.011
LGREV	0.440	0.081	14.654898	2.702	5.425	0.000
THRSHLD	0.164	0.059	49.794531	17.792	2.799	0.006
AOTIME	1.070	0.207	24.736890	4.786	5.169	0.000
NMWRONG	-0.768	0.190	-60.926952	15.042	-4.051	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 6; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.33266 approx. F (6,93)=31.094 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,93)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.380	0.876	13.152	0.000	0.717	0.283	0.508715
LGREV	0.441	0.755	30.235	0.000	0.620	0.380	-0.769796
THRSHLD	0.367	0.907	9.507	0.003	0.715	0.285	-0.440979
AOTIME	0.382	0.870	13.851	0.000	0.117	0.883	-1.289999
NMWRONG	0.348	0.957	4.223	0.043	0.105	0.895	0.788495
NMNR	0.347	0.959	4.016	0.048	0.405	0.595	0.391539
Eigenval							2.006089
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.65000	DROWSY p=0.35000
Observed	AWAKE	98.462	64	1
	DROWSY	80.000	7	28
	Total	92.000	71	29

Classification Functions

	AWAKE	DROWSY
MNSQHRT	-0.001035	-0.003273
LGREV	0.718557	4.351851
THRSHLD	-0.075297	13.431870
AOTIME	1.629594	5.687620
NMWRONG	-8.095888	-15.664165
NMNR	1.746210	-4.784073
Constant	-0.977709	-7.336881

Table T1b: Discriminant Analysis of AVEOBS Using A/O Task, Heart Measures, Steering, and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 5; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.26848 approx. F (10,186)=17.297 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,93)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.297	0.903	4.998	0.009	0.765	0.235	0.410265
STVELV	0.308	0.873	6.765	0.002	0.375	0.625	0.366132
LGREV	0.353	0.761	14.625	0.000	0.410	0.590	-0.861323
AOTIME	0.324	0.829	9.587	0.000	0.108	0.892	-1.515502
NMWRONG	0.304	0.884	6.075	0.003	0.098	0.902	1.295844
Eigenval							2.226958
Cum.Prop							0.935224

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.59000	QUESTION p=0.08000	DROWSY p=0.33000
Observed	AWAKE	98.305	58	1	0
	QUESTION	12.500	7	1	0
	DROWSY	78.788	6	1	26
	Total	85.000	71	3	26

Classification Functions

	AWAKE	QUESTION	DROWSY
MNSQHRT	-0.001072	-0.000994	-0.003035
STVELV	0.009916	0.089502	-0.044058
LGREV	0.530858	0.017711	5.109155
AOTIME	1.268432	2.504633	6.665951
NMWRONG	-6.335968	-8.421473	-20.191818
Constant	-1.010371	-5.190659	-7.938440

Table T2a: Multiple Regression and Discriminant Analysis of AVEOBS Using A/O Task, Heart Measures, Steering, and Accelerometer.

Regression Summary for Dependent Variable: NEWDEF

$R= 0.80979082$ $R^2 <= 0.65576118$ Adjusted $R^2 <= 0.63355222$
$F(6,93)=29.527$ $p<0.00000$ Std.Error of estimate: 0.93865

	BETA	St. Err. of BETA	B	St. Err. of B	t(93)	p-level
Intercpt			-0.009280	0.168	-0.055	0.956
MNSQHRT	0.489	0.075	0.001024	0.000	6.542	0.000
LGREV	0.309	0.101	0.549856	0.179	3.073	0.003
MDREV	-0.278	0.079	-0.114135	0.033	-3.503	0.000
AOTIME	1.402	0.228	1.731042	0.282	6.148	0.000
NMWRONG	-1.138	0.230	-4.822081	0.976	-4.939	0.000
NMNR	0.374	0.101	2.899977	0.787	3.686	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.52406 approx. $F(5,94)=17.074$ $p< 0.0000$

	Wilks' Lambda	Partial Lambda	F-remove (1,94)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.550	0.953	4.599	0.035	0.636	0.364	0.392404
LGREV	0.677	0.774	27.388	0.000	0.442	0.558	1.035714
MDREV	0.567	0.924	7.691	0.007	0.603	0.397	-0.513318
AOTIME	0.591	0.886	12.035	0.000	0.073	0.927	1.803305
NMWRONG	0.596	0.880	12.846	0.000	0.076	0.924	-1.828212
Eigenval							0.908188
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	90.909	70	7
	DROWSY	65.217	8	15
	Total	85.000	78	22

Classification Functions

	AWAKE	DROWSY
MNSQHRT	-0.001177	0.000007
LGREV	-0.025437	3.235478
MDREV	0.271322	-0.038421
AOTIME	1.039145	4.465323
NMWRONG	-4.840306	-16.224230
Constant	-1.209412	-5.534165

Table T2b: Discriminant Analysis of AVEOBS Using A/O Task, Heart Measures, Steering, and Accelerometer.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 7; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.25230 approx. F (14,182)=12.881 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,91)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.299	0.845	8.333	0.000	0.461	0.539	0.721529
LGREV	0.355	0.711	18.465	0.000	0.414	0.586	0.844321
MDREV	0.311	0.812	10.567	0.000	0.513	0.487	-0.143894
NMRHOLD	0.290	0.871	6.711	0.002	0.258	0.742	-0.017519
THRSHLD	0.291	0.868	6.928	0.002	0.578	0.422	0.592116
AOTIME	0.317	0.797	11.582	0.000	0.060	0.940	2.230115
NMWRONG	0.300	0.840	8.679	0.000	0.071	0.929	-1.849245
Eigenval							1.809522
Cum.Prop							0.814998

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.66000	QUESTION p=0.18000	DROWSY p=0.16000
Observed	AWAKE	93.939	62	1	3
	QUESTION	83.333	3	15	0
	DROWSY	75.000	1	3	12
	Total	89.000	66	19	15

Classification Functions

	AWAKE	QUESTION	DROWSY
MNSQHRT	-0.002165	0.000295	0.000991
LGREV	-0.588816	0.694609	4.430888
MDREV	0.392605	0.678713	-0.012968
NMRHOLD	0.337731	0.657705	0.087756
THRSHLD	-5.382091	8.319555	15.525961
AOTIME	1.629871	7.000513	7.076466
NMWRONG	-4.734112	-15.573772	-22.025040
Constant	-1.674005	-7.459106	-8.270246

APPENDIX U

Multiple Regression/Discriminant Analysis Results —

A/O Task, Heart Measures, Steering, Accelerometer, & HPHDGDEV/VAR

Table U1a: Multiple Regression and Discriminant Analysis of AVEOBS Using A/O Task, Heart |Measures, Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: AVEOBS

$R= 0.91827943$ $R^2 \leq= 0.84323711$ Adjusted $R^2 \leq= 0.82945575$
$F(8,91)=61.187$ $p<0.00000$ Std.Error of estimate: 11.983

	BETA	St. Err. of BETA	B	St. Err. of B	t(91)	p-level
Intercpt			14.295824	2.499	5.721	0.000
MNSQHRT	-0.181	0.059	-0.007103	0.002	-3.070	0.003
INTACDE	-0.179	0.050	-32.212558	9.065	-3.553	0.000
HPHDGDE	0.892	0.074	83.511252	6.946	12.023	0.000
MDREV	0.253	0.067	1.939562	0.516	3.762	0.000
NMRHOLD	0.194	0.079	1.098879	0.446	2.466	0.016
THRSHLD	0.186	0.055	56.472263	16.682	3.385	0.001
NMWRONG	0.259	0.092	20.530661	7.301	2.812	0.006
NMNR	-0.332	0.078	-48.232265	11.252	-4.287	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 5; Grouping: AVEOBS_2 (2 grps)
Wilks' Lambda: 0.23980 approx. F (5,94)=59.600 $p< 0.0000$

	Wilks' Lambda	Partial Lambda	F-remove (1,94)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
HPHDGDE	0.561	0.427	125.885	0.000	0.459	0.541	1.281416
MDREV	0.274	0.877	13.219	0.000	0.676	0.324	-0.489701
NMRHOLD	0.270	0.887	12.020	0.000	0.569	0.431	-0.512114
THRSHLD	0.291	0.823	20.163	0.000	0.517	0.483	0.670197
NMNR	0.256	0.938	6.170	0.015	0.662	0.338	-0.349846
Eigenval							3.170192
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.65000	DROWSY p=0.35000
Observed	AWAKE	98.462	64	1
	DROWSY	85.714	5	30
	Total	94.000	69	31

Classification Functions

	AWAKE	DROWSY
HPHDGDE	3.636473	29.604374
MDREV	0.243148	-0.245466
NMRHOLD	0.165290	-0.280188
THRSHLD	-0.106725	25.699036
NMNR	-1.852901	-9.187920
Constant	-1.286278	-9.701411

Table U1b: Discriminant Analysis of AVEOBS Using A/O Task, Heart Measures, Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: AVEOBS_3 (3 grps)
Wilks' Lambda: 0.17464 approx. F (12,184)=21.358 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,92)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
HPHDGDE	0.262	0.667	22.954	0.000	0.317	0.683	1.034548
LGREV	0.187	0.932	3.365	0.039	0.371	0.629	0.343991
MDREV	0.198	0.883	6.117	0.003	0.685	0.315	-0.449863
NMRHOLD	0.220	0.793	12.039	0.000	0.477	0.523	-0.543661
THRSHLD	0.218	0.802	11.338	0.000	0.484	0.516	0.702323
NMNR	0.195	0.896	5.345	0.006	0.632	0.368	-0.418028
Eigenval							3.793200
Cum.Prop							0.951190

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.59000	QUESTION p=0.08000	DROWSY p=0.33000
Observed	AWAKE	93.220	55	3	1
	QUESTION	62.500	2	5	1
	DROWSY	90.909	1	2	30
	Total	90.000	58	10	32

Classification Functions

	AWAKE	QUESTION	DROWSY
HPHDGDE	7.980360	29.190191	33.194534
LGREV	-1.868425	-2.833258	0.591968
MDREV	0.289903	0.186952	-0.225714
NMRHOLD	0.266240	0.460500	-0.291083
THRSHLD	-2.741467	4.609221	27.770416
NMNR	-1.120421	-8.994053	-11.009107
Constant	-1.528726	-8.467973	-11.420537

Table U2a: Multiple Regression and Discriminant Analysis of PERCLOS Using A/O Task, Heart Measures, Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: PERCLOS

R= 0.88007496 $R^2 \leq$= 0.77453194 Adjusted $R^2 \leq$= 0.75471057
F(8,91)=39.076 p<0.00000 Std.Error of estimate: 0.04434

	BETA	St. Err. of BETA	B	St. Err. of B	t(91)	p-level
Intercpt			0.013315	0.009	1.443	0.152
MNSQHRT	0.202	0.070	0.000024	0.000	2.873	0.005
HPHDGDE	0.537	0.116	0.155090	0.033	4.645	0.000
MDREV	-0.313	0.071	-0.007411	0.002	-4.379	0.000
SMREV	-0.311	0.085	-0.002197	0.000	-3.654	0.000
NMRHOLD	-0.375	0.114	-0.006548	0.002	-3.282	0.001
AOTIME	0.714	0.236	0.050935	0.017	3.024	0.003
NMWRONG	-0.683	0.212	-0.167012	0.052	-3.216	0.002
NMNR	0.282	0.094	0.126153	0.042	2.998	0.004

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 4; Grouping: PERCLO_2 (2 grps)
Wilks' Lambda: 0.48782 approx. F (4,95)=24.936 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,95)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
HPHDGDE	0.644	0.757	30.483	0.000	0.546	0.454	0.932436
MDREV	0.528	0.924	7.818	0.006	0.692	0.308	-0.463035
SMREV	0.566	0.862	15.244	0.000	0.341	0.659	-0.889156
NMRHOLD	0.521	0.935	6.554	0.012	0.271	0.729	-0.681408
Eigenval							1.049941
Cum.Prop							1.000000

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	94.805	73	4
	DROWSY	78.261	5	18
	Total	91.000	78	22

Classification Functions

	AWAKE	DROWSY
HPHDGDE	3.970316	13.360326
MDREV	0.260152	-0.039006
SMREV	0.044978	-0.123827
NMRHOLD	0.267679	-0.075547
Constant	-1.234925	-6.351795

Table U2b: Discriminant Analysis of PERCLOS Using A/O Task, Heart Measures, Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 5; Grouping: PERCLO_3 (3 grps)
Wilks' Lambda: 0.29879 approx. F (10,186)=15.428 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,93)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
ACEXEED	0.321	0.932	3.384	0.038	0.692	0.308	-0.085672
HPHDGDE	0.496	0.602	30.685	0.000	0.581	0.419	1.010153
MDREV	0.341	0.876	6.555	0.002	0.610	0.390	-0.384629
SMREV	0.374	0.799	11.708	0.000	0.299	0.701	-0.881928
NMRHOLD	0.330	0.905	4.854	0.010	0.275	0.725	-0.628597
Eigenval							1.952703
Cum.Prop							0.936011

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.70000	QUESTION p=0.16000	DROWSY p=0.14000
Observed	AWAKE	97.143	68	2	0
	QUESTION	81.250	2	13	1
	DROWSY	64.286	1	4	9
	Total	90.000	71	19	10

Classification Functions

	AWAKE	QUESTION	DROWSY
ACEXEED	-12.899197	-92.780426	9.376826
HPHDGDE	4.249324	18.386621	19.849680
MDREV	0.276624	0.179537	-0.230724
SMREV	0.049442	-0.070451	-0.236322
NMRHOLD	0.272794	0.041800	-0.281975
Constant	-1.273693	-8.276262	-9.632964

Table U3a: Multiple Regression and Discriminant Analysis of MASTER Using A/O Task, Heart Measures, Steering, Accelerometer, and HPHDGDEV/VAR.

Regression Summary for Dependent Variable: MASTER

R= 0.90881935 R^2 <= 0.82595261 Adjusted R^2 <= 0.81472375
F(6,93)=73.556 p<0.00000 Std.Error of estimate: 1.5462

	BETA	St. Err. of BETA	B	St. Err. of B	t(93)	p-level
Intercept			-3.435209	0.276	-12.455	0.000
MNSQHRT	0.130	0.053	0.000630	0.000	2.455	0.016
ACCVAR	-0.141	0.048	-0.232834	0.079	-2.943	0.004
HPHDGDE	0.796	0.091	9.228873	1.056	8.739	0.000
THRSHLD	0.180	0.046	6.776318	1.721	3.937	0.000
AOTIME	0.552	0.202	1.577936	0.579	2.727	0.008
NMWRONG	-0.395	0.163	-3.876012	1.601	-2.421	0.017

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 3; Grouping: MASTER_2 (2 grps)
Wilks' Lambda: 0.48074 approx. F (3,96)=34.564 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,96)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
INTACDE	0.512	0.940	6.159	0.015	0.912	0.088	-0.356736
HPHDGDE	0.965	0.498	96.781	0.000	0.822	0.178	1.084382
THRSHLD	0.512	0.939	6.267	0.014	0.822	0.178	0.378824
Eigenval							1.080117
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.76000	DROWSY p=0.24000
Observed	AWAKE	93.421	71	5
	DROWSY	83.333	4	20
	Total	91.000	75	25

Classification Functions

	AWAKE	DROWSY
INTACDE	0.297495	-5.102292
HPHDGDE	4.276692	15.455751
THRSHLD	3.099833	12.600318
Constant	-0.710810	-6.815035

Table U3b: Discriminant Analysis of MASTER Using A/O Task, Heart Measures, Steering, Accelerometer, and HPHDGDEV/VAR.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 4; Grouping: MASTER_3 (3 grps)
Wilks' Lambda: 0.28911 approx. F (8,188)=20.206 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,94)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
HPHDGDE	0.498	0.580	34.003	0.000	0.529	0.471	1.069164
THRSHLD	0.373	0.775	13.675	0.000	0.649	0.351	0.672860
AOTIME	0.308	0.938	3.100	0.050	0.429	0.571	0.420425
NMNR	0.318	0.909	4.710	0.011	0.492	0.508	-0.398131
Eigenval							2.273718
Cum.Prop							0.975725

Classification Matrix

			Predicted		
		Percent Correct	AWAKE p=0.68000	QUESTION p=0.14000	DROWSY p=0.18000
Observed	AWAKE	95.588	65	2	1
	QUESTION	64.286	2	9	3
	DROWSY	61.111	0	7	11
	Total	85.000	67	18	15

Classification Functions

	AWAKE	QUESTION	DROWSY
HPHDGDE	7.886054	23.293568	26.778196
THRSHLD	3.084555	26.850864	24.909464
AOTIME	-0.892217	0.679884	0.431076
NMNR	-0.692496	-10.631020	-6.572848
Constant	-1.049934	-8.602823	-11.030434

APPENDIX V

Multiple Regression/Discriminant Analysis Results —

A/O Task, Heart Measures, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ

Table V1a: Multiple Regression and Discriminant Analysis of NEWDEF Using A/O Task, Heart Measures, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: NEWDEF

R= 0.82305014 $R^2 \leq$= 0.67741154 Adjusted $R^2 \leq$= 0.66025258
F(5,94)=39.479 p<0.00000 Std.Error of estimate: 0.90381

	BETA	St. Err. of BETA	B	St. Err. of B	t(94)	p-level
Intercpt			-0.298259	0.144	-2.070	0.041
MNSQHRT	0.381	0.075	0.000797	0.000	5.061	0.000
LANEX	0.469	0.098	5.127752	1.071	4.789	0.000
AOTIME	0.747	0.237	0.922774	0.292	3.159	0.002
NMWRONG	-0.690	0.205	-2.923041	0.870	-3.360	0.001
NMNR	0.364	0.090	2.823119	0.699	4.037	0.000

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 3; Grouping: NEWDEF_2 (2 grps)
Wilks' Lambda: 0.56084 approx. F (3,96)=25.057 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,96)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LANVAR	0.596	0.941	6.020	0.016	0.262	0.738	0.716624
LANEX	0.646	0.868	14.588	0.000	0.411	0.589	0.855264
AOTIME	0.609	0.921	8.209	0.005	0.330	0.670	-0.737348
Eigenval							0.783038
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.77000	DROWSY p=0.23000
Observed	AWAKE	97.403	75	2
	DROWSY	60.870	9	14
	Total	89.000	84	16

Classification Functions

	AWAKE	DROWSY
LANVAR	0.097345	0.303539
LANEX	0.146173	16.084366
AOTIME	-0.348404	-1.649222
Constant	-0.362959	-4.525967

Table V1b: Discriminant Analysis of NEWDEF Using A/O Task, Heart Measures, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 6; Grouping: NEWDEF_3 (3 grps)
Wilks' Lambda: 0.31064 approx. F (12,184)=12.178 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,92)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
MNSQHRT	0.387	0.803	11.279	0.000	0.523	0.477	-0.571941
LANEX	0.394	0.788	12.365	0.000	0.335	0.665	-0.855586
LNERRSQ	0.346	0.899	5.191	0.007	0.272	0.728	0.715778
AOTIME	0.410	0.757	14.728	0.000	0.052	0.948	-2.440259
NMWRONG	0.422	0.737	16.453	0.000	0.060	0.940	2.621334
NMNR	0.385	0.806	11.043	0.000	0.302	0.698	-1.008234
Eigenval							1.510715
Cum.Prop							0.842611

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.66000	QUESTION p=0.18000	DROWSY p=0.16000
Observed	AWAKE	89.394	59	4	3
	QUESTION	66.667	3	12	3
	DROWSY	68.750	1	4	11
	Total	82.000	63	20	17

Classification Functions

	AWAKE	QUESTION	DROWSY
MNSQHRT	-0.001540	0.001473	-0.000079
LANEX	5.469023	12.877739	34.302395
LNERRSQ	-0.042448	-0.362228	-0.307664
AOTIME	1.248283	7.629996	6.060547
NMWRONG	-7.588944	-26.196163	-26.826406
NMNR	2.694064	15.837375	16.971954
Constant	-1.049151	-5.123313	-8.272355

Table V2a: Multiple Regression and Discriminant Analysis of MASTER Using A/O Task, Heart Measures, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Regression Summary for Dependent Variable: MASTER

$R= 0.90965575$ $R^2 \leq= 0.82747358$ Adjusted $R^2 \leq= 0.81829664$
$F(5,94)=90.169$ $p<0.00000$ Std.Error of estimate: 1.5312

	BETA	St. Err. of BETA	B	St. Err. of B	t(94)	p-level
Intercpt			-3.549782	0.266	-13.328	0.000
MNSQHRT	0.138	0.052	0.000670	0.000	2.633	0.010
LANDEV	1.059	0.116	3.230413	0.353	9.140	0.000
LNERRSQ	-0.317	0.088	-0.156263	0.043	-3.611	0.000
AOTIME	0.473	0.202	1.352647	0.578	2.340	0.021
NMWRONG	-0.353	0.161	-3.461397	1.578	-2.194	0.031

Discriminant Function Analysis Summary (Single Threshold)
No. of vars in model: 2; Grouping: MASTER_2 (2 grps)
Wilks' Lambda: 0.47705 approx. F (2,97)=53.167 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (1,97)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LANDEV	0.765	0.624	58.563	0.000	0.288	0.712	-1.579942
LNERRSQ	0.529	0.903	10.464	0.002	0.288	0.712	0.803525
Eigenval							1.096220
Cum.Prop							1.000000

Classification Matrix

			Predicted	
		Percent Correct	AWAKE p=0.76000	DROWSY p=0.24000
Observed	AWAKE	93.421	71	5
	DROWSY	70.833	7	17
	Total	88.000	78	22

Classification Functions

	AWAKE	DROWSY
LANDEV	2.046470	6.502067
LNERRSQ	-0.196822	-0.500974
Constant	-0.746683	-7.079002

Table V2b: Discriminant Analysis of MASTER Using A/O Task, Heart Measures, LANDEV/VAR, LNMNSQ, LANEX, and LNERRSQ.

Discriminant Function Analysis Summary (Dual Threshold)
No. of vars in model: 2; Grouping: MASTER_3 (3 grps)
Wilks' Lambda: 0.31537 approx. F (4,192)=37.473 p< 0.0000

	Wilks' Lambda	Partial Lambda	F-remove (2,96)	p-level	Toler.	1-Toler. (R-Sqr.)	Standardized Coefficient
LANDEV	0.647	0.488	50.422	0.000	0.331	0.669	-1.503278
LNERRSQ	0.360	0.876	6.803	0.002	0.331	0.669	0.727681
Eigenval							2.153909
Cum.Prop							0.997512

Classification Matrix

		Percent Correct	Predicted AWAKE p=0.68000	QUESTION p=0.14000	DROWSY p=0.18000
Observed	AWAKE	97.059	66	1	1
	QUESTION	28.571	4	4	6
	DROWSY	77.778	2	2	14
	Total	84.000	72	7	21

Classification Functions

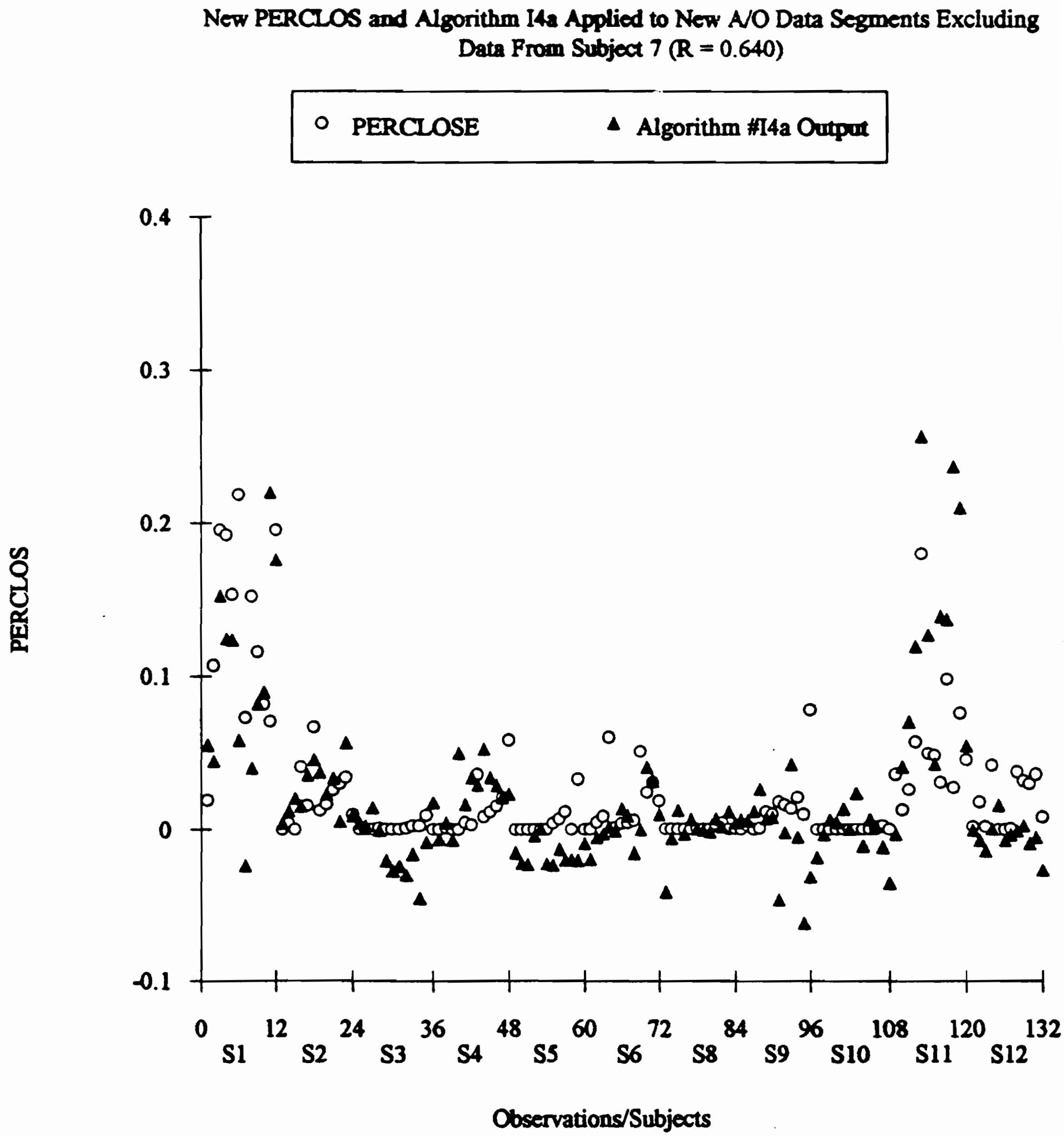
	AWAKE	QUESTION	DROWSY
LANDEV	2.203151	7.209744	9.622219
LNERRSQ	-0.199467	-0.526410	-0.618538
Constant	-0.800725	-6.947665	-11.436691

APPENDIX W

Scatter Plot and Classification Matrix for A/O Validation

With Subject 7 Data Excluded

Corresponds to Figure 57



NOTE: The first 12 points on the abscissa correspond to subject 1, the next 12 points correspond to subject 2, and so on (Subject 7 excluded).

Figure W1: Scatter Plot of PERCLOS Data -- Predicted vs. Observed

Corresponds to Figure 58

Classification Matrix Excluding Data From Subject 7

			Predicted		
	Group	% Correct	Awake	Questionable	Drowsy
New	Awake	95.80	**114**	3	2
Observed	Questionable	50.00	2	**3**	1
	Drowsy	42.86	2	2	**3**
	Total	90.91	118	8	6

PERCLOS R Value =0.6396

Apparent Accuracy Rate (large misclassifications): 0.97

Apparent Accuracy Rate (all misclassifications): 0.91

Figure W2: Classification Matrix Showing Accuracy of Algorithm I4a When Subject 7 Data are Excluded.

VITA

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