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on

AN INVESTIGATION OF THE EFFECTS OF CARBON MONOXIDE ON HUMANS IN THE DRIVING TASK

by

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PREFACE

This report presents the findings of a two-year investigation of the effects of carboxyhemoglobin (expressed as percent of hemoglobin combined with carbon monoxide) on human performance, particularly in regard to the task of driving an automobile. This study was performed under contract to the Coordinating Research Council and was financially supported by the U. S. Environmental Protection Agency, the American Petroleum Industry, and the Motor Vehicle Manufacturers Association.

The scope of this study includes three major objectives:

1. The development of methods for rapid and accurate laboratory and field measurement of carboxyhemoglobin (COHb) in man.

2. The determination of the effects of up to 20% COHb concentrations on
   a. physiological performance,
   b. complex psychophysiological and psychomotor skills, and
   c. driving skills and judgment on the highway.

3. The determination of the predictability of decrement in driving skills based upon laboratory skills testing.

The opinions, findings, and conclusions in this publication are those of the authors and not necessarily those of the sponsors.

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SUMMARY

This two-year investigation of the effects of carboxyhemoglobin on human performance involved the testing of 40 subjects on the highway with a battery of real driving situations and/or laboratory tasks related to driving skills. In all, 24 tasks were developed and over 130,000 observations taken to study human performance at carboxyhemoglobin (COHb) levels of nominally 0, 7, 14, and 20%. The first year effort was designed to study the extreme values, 0 and 20% COHb with 15 subjects while the second year was devoted to examining the lower levels (0, 7, and 14% COHb) with 25 additional subjects.

Overall the results suggest consistent patterns of performance changes with increased COHb levels. Differences observed with 20% COHb levels were directionally preserved with lower (7 and 14% COHb) levels but with smaller magnitude differences. The results, however, do not suggest a low COHb level where all performance measures are first affected. Rather, the magnitudes and directions of performance changes appear to be highly dependent on the particular task and protocols employed. As expected, laboratory dual tasks (where the subject is required to perform two tasks simultaneously) exhibited performance differences at lower COHb levels than more simple tasks. Since accidents are probably more prevalent when the attention and control demands on the driver are greatest, the dual task results may be more important than results in routine, over-learned driving situations.

Strong correlations between performance on simple laboratory tasks and COHb levels were not observed in this research. This was not unexpected since, again, simple tasks are often over-learned and compensatory subject reactions may negate possible effects.

Driving performance was categorized into three levels: visual (perception and information acquisition), control (psychomotor), and dynamic response (time delayed vehicle response). Of primary importance in this research is the heirarchy of observed COHb differences. The results of this research suggest that the largest magnitude effects with increased COHb levels occur at the early stages of information processing. Visual and psychomotor control measures, in general, were the first measures to be affected by COHb. These measures, however, are also the most variable due to large intra- and intersubject variability.

In general, no ostensible performance degradation was observed with COHb and the normal driving tasks although subtle performance losses were observed, especially in the information acquisition measures. With heavy information processing demands and/or other associated debilitating factors in driving, such as fatigue or alcohol, these subtle effects could be compounded into gross performance changes.

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CHAPTER 1

RESEARCH OVERVIEW AND BACKGROUND LITERATURE

1.1 Introduction

While a great deal is known about the human physiological response to acute carbon monoxide poisoning, considerable controversy exists regarding possible psychophysical and behavioral effects resulting from carbon monoxide exposures that produce carboxyhemoglobin (COHb) levels less than 20%. Since a variety of carbon monoxide exposure conditions can produce equivalent resultant COHb levels, the major emphasis of this study was placed on the effects of specific COHb levels, rather than the effects of certain carbon monoxide exposures.

Since automobile drivers may have a higher risk of carbon monoxide exposure from automobile exhaust than the general population, this study was designed to investigate the possible effects of COHb on driving related performance. The scope of the investigation included first the development of rapid, accurate laboratory and field COHb measurements in men. Next, relation of the various levels of COHb to physiological performance, simple and complex psychomotor skills, driving performance, and assessment of judgment degradation were studied. The complex laboratory tasks related to driving included: pursuit tracking, choice reaction time, and dual tasks (involving both pursuit tracking and choice reaction time tests performed simultaneously). The driving performance studies investigated 1) vehicle dynamics such as velocity and spacing while car following, 2) operator control movements, such as steering wheel, gas, and brake pedal applications, and 3) perceptual measures, such as driver's visual search and scan patterns measured with The Ohio State University eye-movement camera technique.

1.2 Research Strategy

Goals were set for each year of the two-year research effort. The first year effort was designed to screen those factors and tasks which may be susceptible to 20% COHb level effects. Those tests which demonstrated changes at 20% COHb were incorporated into the second year efforts with COHb levels of nominally 7 and 14%.

An equally important goal of the first year effort was the development of facilities and protocols to produce desired COHb levels in the subjects. Support personnel were trained to monitor carbon monoxide in air and blood in order to standardize methods. One important goal was maintenance of COHb levels outside the laboratory during lengthy test sessions.

Subject safety was of utmost concern, therefore for the first year studies, single blind techniques were used (only the subjects were unaware of the carbon monoxide exposure conditions). For the second year, with lower COHb levels, possible experimenter biases were eliminated with double blind techniques. Only the medical monitor and the research chemist were aware of CO concentrations in the testing.

The overall experimental design strategy for the research was to let the subjects serve as their own controls. This required that there be no transfer effects across COHb levels and test periods. It further required that there be small differential subject effects by COHb treatment. Tests were counterbalanced to guard against biases from learning and/or fatigue.

In retrospect, the use of subjects as their own controls had one significant drawback as compared to a completely randomized design. Losses of data due to weather induced cancellations, equipment failures, failures to meet required carboxyhemoglobin levels, or subjects' failures to appear for testing, limit the usual benefits from such designs. Unfortunately, these situations did occur occasionally throughout the reported testing, necessitating the use of covariate types of analyses and resulting in less powerful statistical tests. As such, many of the analyses present more conservative assessments of possible COHb effects than might be expected with more balanced designs.

1.3 Schedule of Tasks

Table 1.1 presents an overview of the two-year schedule of tasks performed both in laboratory and on the road. These tasks were sequenced in four phases representing blocks of time for continuous testing. Particular protocals, orders of administration of tasks, etc., may be found in the methodology sections for the respective phases. Table 2 presents an abbreviated list of the 24 tests employed in the various research phases.

Complete descriptions of these tasks may be found in the methodology sections of phases where employed, subject instructions for the tasks are in Appendixes A and B.

For coherence (since all subjects did not perform all tasks), the forty subjects in the research will be referred to in the test subscripted S1 through S40. S1 through S8 were studied in Phase A, S9 through S15 in Phase B, S16 through S31 in Phase C, and S32 through S40 in Phase D.

Table 1. 1

Schedule of Testing

	Phase A	Phase B	Phase C	Phase D
Lab Tasks	T1 - T11	T1 - T11	T1-7, 9-11	T1-7, 9-11
Road Tasks	T15 - T20	T12 - T20	T17 - T24	T17 - T24
Nominal COHb Levels	0, 20%	0, 20%	0, 7, 14%	0, 7, 14%
Subjects Tested	8	7	16	9

Table 1. 2

Laboratory and Road Tests Employed

Laboratory Tasks

T1 - Rail Walking
T2 - Mirror Tracing
T3 - Spatial Relations
T4 - Finger Tapping
T5 - Brightness Discrimination
T6 - Dark Adaptation
T7 - Flash Blindness
T8 - Time Estimation
T9 - Choice Reaction Time
T10 - Pursuit Tracking
T11 - Dual Task (T9 + T10)

Road Tasks

T12 - Headway Estimation & Production
T13 - Velocity Estimation & Production
T14 - Time Estimation
T15 - Constant Speed Car Following
T16 - T15 with Voluntary Occlusion
T17 - Variable Speed Car Following
T18 - T17 with Voluntary Occlusion
T19 - Open Road, 50 mph Driving
T20 - T19 with Voluntary Occlusion
T21 - Open Road, 30 mph Driving
T22 - T21 with Voluntary Occlusion
T23 - Velocity Maintenance
T24 - Leap-Frog Passing

1.4 Report Outline

The results of the two-year effort are organized into eight chapters in this report. Chapter 2 describes the administration, control, and measurement of carbon monoxide and carboxyhemoglobin (COHb) levels. Chapters 3, 4, and 6 describe the results of the first year comparing control COHb levels with 20% COHb levels. These chapters, together with Chapters 1, 2, and 8 constitute the final report for the first year.

Chapters 5 and 7 describe the laboratory and road testing results of the second year. These studies (referred to as Phases C and D) were performed with COHb levels of nominally 0, 7, and 14%. Chapter 8 presents a summary of the two year of research with conclusions and recommendations for the third year of effort now underway.

Appendix C presents the results of three minor complementary studies performed in February 1972. One study sampled transient drivers for COHb levels on the Ohio Turnpike. The second sampled truck drivers on the freeway and at a local private trucking firm, Suburban Motor Freight Company. The third study sampled student smokers and nonsmokers on the Ohio State University campus for ambient COHb levels. All three studies used an infrared measurement (Beckman Analyzer) technique.

1.5 Literature Overview

The remainder of this chapter will be devoted to an overview of the technical literature related to this research.

1.5.1 Carbon Monoxide: Effects on Man

Several investigations have indicated that the central nervous system (CNS) is apparently impaired at COHb levels as low as 3-5% (MacFarland, et al., 1944; Schulte, 1963; Beard and Wertheim, 1967; and Horvath, et al., 1971). Other investigators have not confirmed these findings (Stewart, et al., 1970; and O'Donnell, et al., 1971). Readers interested in the toxicological basis of CO uptake, and the physiological response to CO intoxication, are referred to the US-HEW 1970 report on air quality criteria for CO, and to Coburn (1970).

It is now widely accepted (Otis, 1970; Brody, 1970) that COHb competes with oxyhemoglobin (O_2Hb) at the cellular level, creating symptoms associated with anemic hypoxia. Consequently, it is not surprising that some of the behavioral effects that have been observed with CO intoxication are similar to those manifested by subjects who have been exposed to reduced partial pressures of atmospheric oxygen sufficient to produce hypoxic hypoxia.

Research has indicated that human vision is one of the first systems to be affected in hypoxic conditions, including those resulting from CO intoxication. Halperin, et al., (1969), while summarizing earlier experiments, reported an increase in visual threshold at COHb concentrations as low as 4-5%. Lilienthal and Fugitt (1946) observed that subjects exposed simultaneously to CO and a reduced oxygen environment exhibited decreased critical flicker fusion (CFF) frequencies; i.e., the frequency at which a flickering light appeared to be a steady glow. More recently, Hosko (1970) detected differences in the visual evoked response (VER) of subjects whose COHb levels were approximately 22%. At lower COHb levels, no differential VER effects would be detected. The author suggested that the changes observed in the VER represented the direct cortical response to activity in the scotopic (rod) visual system. (See below.)

A series of experiments performed by Luria and McKay (1971) indicated that changes in scotopic sensitivity occurred after a 90 minute exposure to an atmosphere containing 200 ppm CO. The study also detected changes in the VER and increases in eye fixations, eye reversals, and in the mean reading time of a standard passage of text under the influence of CO. Closer inspection of the data reveals that only two of three subjects showed increased fixations and reversals.

The exposure conditions of Luria and McKay (90 min. x 200 ppm CO) should have produced approximately 5% COHb. It is unusual to find such marked effects at this low level. Stewart, et al., (1970) reported "As COHb saturation approached 20%, changes were observed in the VER. These changes became more marked as the COHb saturation neared 30%. The VER was the most sensitive objective indicator of CO effect." (Emphasis ours.) In another chapter of the same reference, Hosko states, "The significance of these data are difficult to project since the functional relationships between VER morphology and vision remain unknown for the most part." Indeed, he attributes specific VER changes to shifts in subject attention, a far more exciting finding than a simple visual phenomenon.

Stewart, et al., (1970) employed a complete battery of psychomotor tests to study several groups of subjects intoxicated to levels up to 31.8% COHb. At lower levels of CO intoxication, no significant differences in performance could be demonstrated between control and CO conditions. At higher levels of intoxication, two subjects reportedly demonstrated a deterioration in performance on a Crawford collar and pin test, although performances on a simple reaction time task, and a time estimation task, were not significantly affected. The authors note that during this test period, marked fatigue of hands and fingers was observed.

Beard and Wertheim (1967) detected a significant decrement in the ability of humans to estimate the duration of periods of time after exposure to low concentrations of CO. This research began as the result of previous studies which identified a derangement of the time sense in animals exposed to low concentrations of CO.

Central nervous system functions responsible for cognitive behavior have been thought to be affected by COHb levels as low as 4% (Schulte, 1963). In motor skill tests, where the contribution of higher mental functions is comparably reduced, equivocal results on the effects of CO have been obtained.

O'Donnel, et al., (1971) employed a critical instability tracking task (CTT) to investigate performance during three-hour exposures to atmospheres containing 0, 50, and 125 ppm CO. Up to 13% COHb, no effects were found when compared to control, i.e., approximately 1% COHb levels. Hanks (1970) found no effect of low CO intoxication on the performance of the CTT.

The above research suggested that performance deterioration at low levels of COHb increased as the extent of participation of both higher mental processes and the visual system in the task increases. It is suggested that the mental processes responsible for psychomotor performance are affected by CO, but that simple tasks, such as those previously employed, are not sufficiently sensitive to the subtle effects of low level CO intoxication to show significant deterioration in task performance.

1.5.2 Carbon Monoxide: Effects on Driving

Ramsey (1970) investigated the effects of inhaled traffic exhaust on the performance of a simple reaction time task. Subjects drove in rush hour traffic for 90 minutes, in an atmosphere of an average 38.1 ppm CO. Reaction time of the exposed group was compared with the performance of a control group which did not participate in the driving task, and the before-and-after driving performance of the exposed group was compared. Results indicated a significant increase in reaction time of drivers and passengers over the reaction times of the control group. Results were discussed in relation to the percent reduction in blood O_2Hb, rather than the percent increase in COHb. The author admits that many factors, including CO, could have produced the results.

An investigation by Rockwell and Ray (1967) studied the effects of CO intoxication on three subject drivers who drove in normal city traffic. Several aspects of driving were affected by CO inhalation. The mean driving responses were not generally affected, but the variance of many of the performance measures increased significantly, indicating more erratic driving performance.

It is suggested that under loaded conditions, when the operator must time-share between different independent tasks, CO will reduce the operator's capability to perform several tasks simultaneously. In effect, CO intoxication will reduce the "channel capacity" of the operator's information processing system. This reduced capacity, not evident in simple tasks, should be manifest in the time-sharing situation by either decreased performance on particular tasks, or on combinations of the time-shared tasks.

Allen (1970) hypothesized that CO acts in part to destroy visual acuity, visual motor coordination, and perceptual alertness. He pointed out that any compensable visual anomaly becomes progressively less compensable under the influence of CO. This idea lends itself to the concept of a spare visual capacity. Allen also suggested that persons with measureable levels of COHb would have more asthenopia, and more binocular vision and accomodative problems than persons not exposed to CO. This suggested that fixation times for persons exposed to carbon monoxide might be increased.

The following section describes a part of driving performance; i.e., eye search and scan patterns, which offered potential as indicators of CO effects.

1.5.3 Eye-Movements and Driving*

Lack of available information concerning normal driver vision is partially due to lack of equipment and techniques to measure the visual behavior of persons outside fixed laboratory systems. One exception to this is the "eye-movement camera" equipment developed by the Systems Research Group, and described by Rockwell, et al., (1972).

The device enables the accurate determination of the eye-movement behavior of the driver to yield information regarding the driver's visual sampling behavior. The eye-movement equipment is quite adaptable and can be used under many driving conditions. Several studies have already been conducted using this eye-movement apparatus; some of the studies are described below.

Whalen (1968) studied the eye movements of drivers operating an instrumented vehicle on the open road at two velocity levels, following a car at two headway levels, passing, and in normal freeway traffic. Significant differences were found for various driving conditions when spatial temporal analyses of eye fixations were examined.

Zell (1969) used the same apparatus to study driver eye movements as a function of driving experience. His results indicated:

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*A more extensive review of vision and driving may be found in Safford (1971).

1. Drivers' spatial eye-movement patterns changed substantially as a function of experience. Spatial differences between new and experienced drivers could be detected even after the new drivers had several months' experience.

2. Differences in temporal aspects of eye movements between novice and experienced drivers were not apparent.

3. Experienced drivers tended to adjust their eye-movement patterns to driving conditions more than novice drivers; i.e., experienced drivers tended to seek information at increased distances in front of their vehicles as speeds increased. Novice drivers failed to maintain a constant preview and tended to use a fixed forward reference regardless of speed.

4. Eye-movement patterns of new and experienced drivers were not noticeably different in car-following situations, suggesting that the hazard of the lead car forced the subjects to perform in a similar manner.

In a study to determine the effects of low alcohol concentrations on driver eye movements, Belt (1969) found a significant increase in the amount of time drivers spent fixating in a $3^{o} \times 3^{o}$ area of the driving scene (measured in subtended visual angle). This indicated a "spatial" narrowing which Belt hypothesized was due to blurring or blunting of the peripheral stimuli forcing the driver to use only central vision. Belt also observed that in some instances, drivers were able to maintain "good lateral control" of their vehicles while exhibiting the narrowed compensatory eye fixation patterns, but when subjects reverted to the eye-movement pattern typical of the "normal" driver, lateral control performance was degraded. Belt found no differences in "temporal" measures of eye movements that could be related to alcohol concentrations. Some temporal differences were noticed when eye movements during "car-following" were compared with movements during "open road" driving.

Mourant (1971) found that novice drivers of a vehicle at 70 miles per hour exhibited frequent pursuit "eye movements" similar to the experienced subjects tested by Kaluger and Smith (1970) after 12 hours of driving and sleep deprivation the previous night. The experienced drivers tested by Mourant, however, did not make any pursuit eye movements. Novice drivers also showed less horizontal and vertical eye movement activity than experienced drivers.

Mourant also found that increased driving task difficulty tended to reduce the blink rate for novice drivers.

1.5.4 Secondary Task Techniques*

Considerable recent research has been done using secondary task techniques to evaluate the effects of drugs and alcohol on human performance. Moskowitz (1970) suggested that deterioration of performance on secondary (or dual) tasks might be a sensitive method; i.e., when subjects performed two simultaneous tasks or time-shared between primary and secondary tasks. Because most driving in traffic involves secondary tasks, this approach to measuring effects of CO on human performance seemed to offer considerable potential.

Rolfe (1969) defined methods used in this area of research; secondary tasks were either subsidiary or loading tasks, depending on their use in the experiment. If the subject was instructed to aim for error-free performance on the primary task at the expense of performance on the secondary task, the second task would be termed a subsidiary task. On the other hand, if the priorities were reversed, the second task would be termed a loading task. He noted that non-interference was achieved more often if the workload of the secondary task could be paced by the operator. Experimenter-paced tasks might require attention at a time when the operator could least afford it.

Knowles (1963) suggested that the secondary task should require little learning and should show little inter-subject variability. Learning could be controlled through (a) initial sessions on the secondary task, and (b) appropriate balancing within the experimental schedule. Inter- and intra-subject variability would be more difficult to control in secondary tasks. A suitable primary task would be a pursuit tracking task and a representative secondary task would contain elements of perception, decision making, and reaction time.

Allnutt, et al.,(1966) compared the tracking performance of subjects on each of two displays, while the subjects simultaneously performed visual reaction time task. Results indicated that both the reaction-time task and the primary task were sensitive measures of the differences between the two tracking displays.

One successful application of a secondary task procedure in a simulated driving condition was reported by Moskowitz (1970). Subjects operating a driving simulator were required to respond to colored lights presented adjacent to the drivers central line of sight. The secondary task was sensitive to performance deterioration at low levels of alcohol intoxication.

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*A more extensive review may be found in Attwood (1972).

Stephens and Michaels (1964) simulated two aspects of the driving task by employing both a compensatory tracking task and a visual search for recognition task. As subjects tracked a one dimensional compensatory display, they searched for target words on road signs which appeared in a road scene projected above the tracking display. Results indicated that as the complexity of either task increased, performance on both tasks deteriorated. A functional relationship between component tasks relating to consistent whole task performance was suggested.

It was the hypothesis of this research that human information processing ability would be reduced by inhalation of CO. The reduction was assumed to be minute to the extent that only when faced with processing demands that tax the system near its capacity, would the effect of CO be apparent.

1.5.5 Secondary Tasks and Driving

The ability of drivers to perform adequately under "extreme" driving conditions, or to devote time to additional tasks other than vehicle control, has been known for some time.

Different types of secondary tasks have been used several times previously to measure aspects of driving performance. Brown (1961, 1962, 1966, and 1967) suggested that one can borrow concepts from information theory to think of the driver as a communications channel with a greater capacity for dealing with information than is usually required. He also stated that unless we have some way of measuring the driver's spare capacity, any investigation is unlikely to differentiate between "concentrated effort and relaxed, overlearned skill."

Brown, et al.,(1960) measured interference between concurrent tasks of driving and using a mobile telephone, and found that engaging in the secondary task increased the "risk taking" of the subjects; i.e., while engaged in telephoning, they attempted maneuvers they had no chance of successfully completing. They also found a decrease in vehicle speed when telephoning. Subjects whose vehicle speed decreased most also showed the largest increases in "errors of judgment." The authors inferred that although the subjects drove slower to compensate for the stress imposed by driving and telephoning, they did this only to maintain their accuracy on the secondary task.

In research by Brown and Poulton (1961), "spare mental capacity" was measured by using a secondary task. The subsidiary tasks were mental arithmetic and selective attention tasks. Results indicated that the subsidiary tasks were "sensitive" enough to reveal the greater concentration required to drive in a shopping area than in a residential area.

Brown (1962) also attempted to measure the effects of "fatigue" by a subsidiary task while studying drivers before and after an eight hour shift of driving. This experiment indicated that the type of subsidiary task which is used does not appear to matter very much; however, the relationship between "cause and effect" can more easily be observed in a subsidiary task which requires frequent responses.

Brown, et al., (1967) attempted to evaluate effects of 12 hour automobile driving by measuring performance of a subsidiary task of time-interval production. Performance on the subsidiary task was consistently more variable when driving was required than on other days, but mean subsidiary task performance was apparently unrelated to the duration of driving.

CHAPTER 2

CARBON MONOXIDE: ADMINISTRATION, CONTROL, AND MEASUREMENT

Carbon monoxide (CO) was administered to subjects by two methods. All subjects were first exposed to air or CO in a dynamic flow chamber for 1.5 to 2.0 hours to produce the desired carboxyhemoglobin (COHb) level. During specified experiments, subjects remained in the chamber and continued to receive CO at a concetration sufficient to maintain the desired COHb level. For experiments involving driving, and for certain laboratory experiments, subjects were periodically "refreshed" with CO from a pressure cylinder in order to maintain the desired COHb level.

2.1 Exposure Facilities

A dynamic flow exposure chamber, constructed of vinyl coated masonite and wood after the design of Hinners (1968), was used for equilibrating subjects with CO. The cube-shaped chamber measured 2.43 M/side, with a volume of 14,350 liters. The finished chamber was sealed to a tiled floor; the seams were caulked to eliminate leaks. Two plexiglass windows were fitted on opposite walls. One window was located in the wall opposite the door to facilitate certain testing; the other was mounted in the aluminum door which afforded the only access to the chamber. The window in the door allowed the experimenter to observe the subjects during exposures. Two air-tight portholes were fitted into the door for transferring materials and taking blood samples from the subjects at various intervals during exposure. An intercom system permitted the experimenter to maintain continuous voice communication with the subject.

Dynamic flow conditions were maintained by supplying air flow through the chamber via two vents installed at diametrically opposite corners of the chamber. A vane-axle fan, installed in the exhaust duct between the chamber and the exterior of the laboratory, had the capacity to provide one air change per minute through the chamber. A rectangular mixing duct was attached in series to the intake vent of the chamber to mix room-air with CO before entering the exposure chamber. During all experiments, the chamber was operated at an air flow rate of 0.3 changes per minute. This rate provided a balance between an acceptable gas equilibration time, chamber noise level, and CO delivery rate. Pressure in the chamber was maintained at 2 to 4 mm H_2O pressure (negative to ambient) to insure the safety of laboratory personnel. The chamber was lightproof when the windows were covered.

Several safety devices were incorporated into the exposure facility to insure subject safety. A high-limit pressure transducer was installed in the CO delivery system to monitor the absolute flow of CO delivered from the storage cylinder to the chamber intake system. A second pressure transducer was installed in the chamber influent duct to measure the differential pressure between the duct and the laboratory. This differential pressure was directly related to the chamber air flow rate.

Output from the two transducers was connected in series to an electrically operated solenoid valve in the CO delivery system. If the delivery rate of CO from the cylinder exceeded a predetermined level, the first transducer interrupted flow by closing the solenoid. If the chamber air flow was decreased by power failure, significant leakage (e. g., through an open door or porthole, or a blocked intake or exhaust vent), the chamber transducer output also interrupted CO flow by closing the solenoid.

2.2 Carboxyhemoglobin "Refreshing Technique"

Subjects were administered either air, or a mixture of air and CO (1000 ppm), by mask through a demand regulator from a pressure cylinder. The quantity of gas administered was measured by passing all expired air through a Parkinson Cowan dry gas meter.

Subjects were "refreshed" at intervals of 30-45 minutes to maintain specified COHb levels. Calculations for quantity of gas to be administered were based on the interval since last administration using the Colburn (1965) formula.

2.3 Subjects

Subjects were selected from a group of volunteers who responded to a series of advertisements in local newspapers soliciting healthy males, over age 21, who were licensed drivers and were interested in problems of air pollution. Candidates completed the Cornell Medical Health Index Questionnaire and a habit inventory form (see Appendix D). Prospects that had uneventful medical histories, and who were professed non-smokers, were selected for further screening.

Prospects selected from the above group were administered standard tests for visual acuity and color blindness. If they had adequate uncorrected vision, they were given a complete physical examination by a physician before final acceptance. All successful candidates were informed of the experimental design, advised of health risks, and asked to sign a consent form (see Appendix D) before the start of the experimental series.

2.4 Experimental Scheduling

Experiments cooperatively conducted by the two research groups required careful coordination of effort for the most efficient use of 'subjects' and 'investigators' time. The exposure sequence for the experiments conducted in this study was as follows:

1. Pre-exposure Control Period: Control data were obtained for psychophysical and psychomotor performance.

2. Exposure Period: Subjects were exposed to controlled concentrations of CO in the test chamber to obtain desired COHb concentrations.

3. Post-exposure Testing Period: Psychophysical and psychomotor tests conducted during the pre-exposure control period were repeated.

4. Road Tests: Subjects were tested for driving ability. During this part of each experiment, it was necessary to "refresh" the subject periodically at roadside with CO from a storage tank to maintain the desired COHb levels.

5. Detoxification Period: Subjects were administered oxygen by mask to reduce blood levels of CO to less than 10%, COHb before release from the laboratory.

Figure 2.1 is a graphical presentation of the experimental sequence.

2.5 Carboxyhemoglobin Analyses

Blood from all subjects was routinely taken for chemical analyses of COHb. For most samples, capillary blood from a lanced digit was collected in heparinized microhematocrit tubes. Approximately 0.04 ml blood was adequate for each analysis. Blood from the cephalic vein was withdrawn from selected subjects for comparison of venous and capillary samples.

The spectrophotometric method of Commins and Lawther (1965) was evaluated for COHb determination. For this study, the method was modified as follows:

1. Introduction of a self-calibration method, as suggested by Buchwald (1969).

2. Measure of absorbance at both the bases and the peak in the Soret band to overcome the error associated with the reproducibility of wavelength in the spectrophotometer.

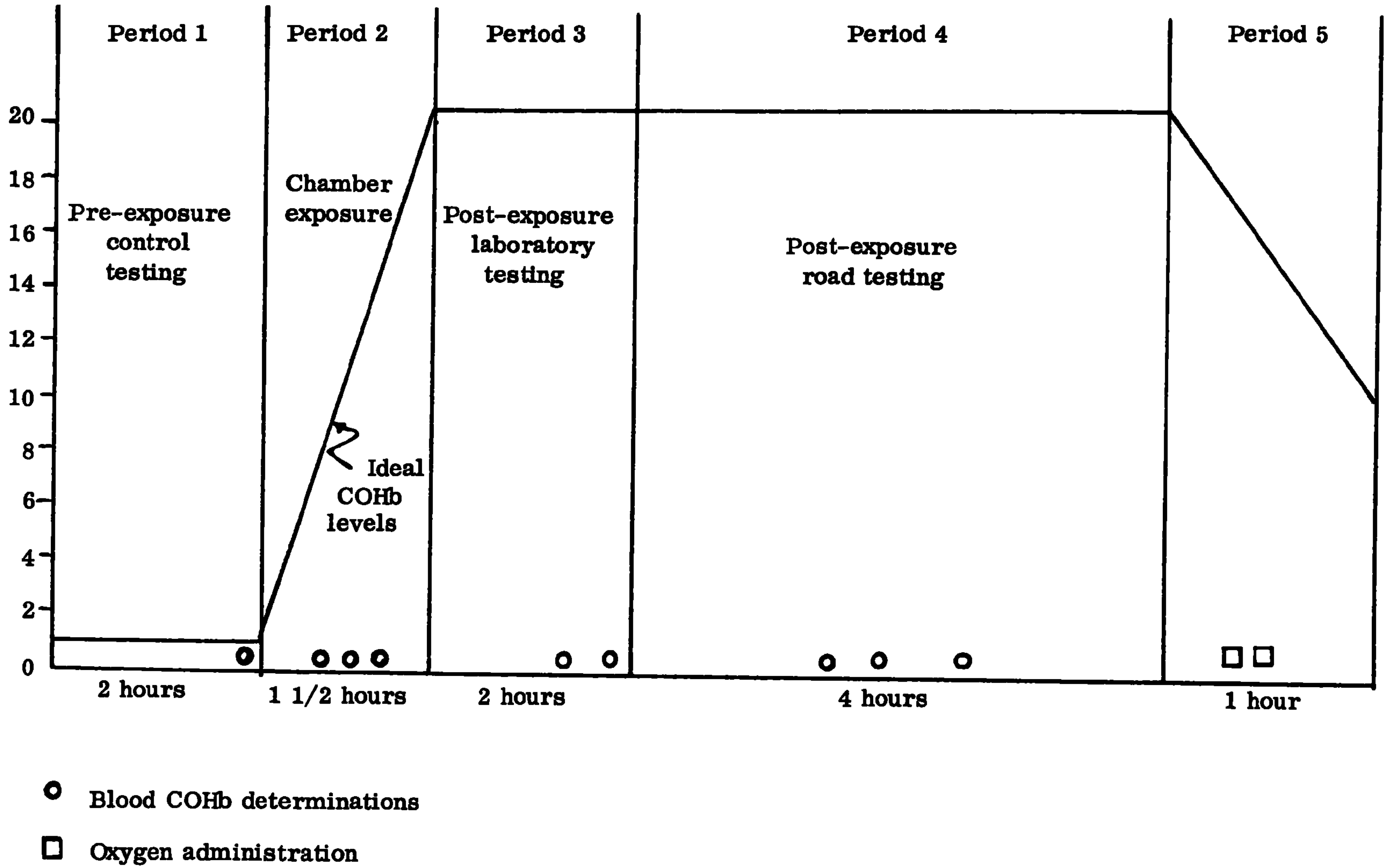

Figure 2.1.--Time sequence of events showing ideal levels for 20% COHb experiments

Radford, et al., (in press) measured the absorbance due to COHb directly at the isobestic points 413, 431, and the maxima of 421 mu. The modified method used in this research measured the difference in absorbance between COHb and an equivalent amount of oxyhemoglobin at 406, 420, and 436 mu, instead of 414, 420, and 426 mu.

The modified method was susceptible to the following sources of errors:

1. Presence of interfering pigments, such as methemoglobin, bile, salts, etc.;

2. Presence of reduced hemoglobin;

3. Dilution error caused by diluting the blood sample; and

4. Nonconformity with Beer's Law.

These problems were minimized by:

1. All subjects chosen from a select group of healthy males minimizing the possibility of interfering pigments due to illness.

2. Analysis of pre-exposure blood samples for direct comparison of pre- and post-exposure blood from each subject.

3. Dilution of blood in .04% ammonia solution. The resulting solution had a pH of about 10; under this condition, less than 1% reduced hemoglobin is present.

4. Use of gas-free solution and protection of all the solutions from air. This prevented conversion of COHb to oxyhemoglobin to minimize dilution error.

5. Determination of difference in absorbance between 100% COHb and 100% oxyhemoglobin for various blood concentrations. The blood concentration was measured by determining absorbance of 100% oxyhemoglobin at 370 mu (minima), 414 mu (maxima), and 498 mu (minima) in the Soret band.

2.6 Atmospheric Carbon Monoxide Analysis

Atmospheric concentrations of CO were measured by one of two methods. A gas chromatograph (GC) method essentially described by O'Neal, et al., (1968) was utilized for most experiments.

In practice, the gas sample containing CO was passed through a stainless steel column packed with 60-80 mesh 5A molecular sieve to separate oxygen, methane, and CO. Prepurified nitrogen was used as the carrier gas. After separation, the gases were passed through a tubular reactor containing the reduced nickel catalyst at 320° C. Hydrogen was added to the gases entering the reactor to convert CO to methane. The effluent from the reactor then passed to a flame ionization detector.

Sampling of chamber air for CO was conducted by periodic removal of aliquots in a gas syringe from a port in the effluent duct. The aliquots were injected immediately into the gas chromatograph.

For later experiments in this series, a Beckman Model 215-B infrared Analyzer was available to monitor the chamber atmosphere. Air from the sampling port in the exposure chamber was drawn through an Ascarite [R] absorption column to remove carbon dioxide, through a Drierite [R] absorption column to remove moisture, and then through the detector of the instrument using a vacuum pump. Carbon monoxide concentration was displayed on the analyzer meter in parts per million (ppm) units, and recorded continuously using a Honeywell strip chart recorder. The analyzer was calibrated before each exposure using air containing known concentrations of CO from pressure cylinders.

2.7 Carboxyhemoglobin Analysis Method Evaluation

To determine the reliability of the COHb analysis method, a series of samples of blood containing various levels of COHb were prepared, coded, and subsequently analyzed using the technique described. Seven samples of six different concentrations were tested. For this series, a single sample of heparinized human blood was divided into two portions. One portion was equilibrated with oxygen to convert all hemoglobin to oxyhemoglobin. The second portion was equilibrated with CO to convert all hemoglobin to COHb. Mixtures of the two substances were prepared to simulate COHb concentrations from 2% to 40%. Each mixture was divided into seven containers, coded, and given to a technician to analyze. Results of these tests appear in Table 2.1.

2.8 In Vivo Carboxyhemoglobin Analyses Verification

Blood samples were withdrawn in triplicate from a subject before exposure to CO, and then two, four, six, and eight hours after the start of an exposure to 200 ppm CO. The samples were analyzed using the spectrophotometric method described. Results are presented in Table 2.2.

Table 2.1

In Vitro Reproducibility Study on % COHb in Blood

Sample	Concentration					
	A	B	C	D	E	F
1	1.7	4.0	10.3	18.0	29.0	37.4
2	2.1	4.1	9.8	16.9	28.8	40.6
3	2.1	4.0	9.6	17.0	28.1	40.0
4	2.1	4.3	9.8	17.5	28.3	38.5
5	1.8	3.9	10.3	18.2	28.7	39.7
6	2.1	4.6	9.6	18.1	28.3	40.4
7	2.8	4.3	9.8	17.8	28.6	40.6
Mean	2.1	4.2	9.8	17.6	28.5	39.6
Standard Deviation	0.33	0.23	0.27	0.40	0.30	1.13

Table 2.2

In Vivo COHb Analyses Verification

Sample \ Time	Percent (%) Carboxyhemoglobin (COHb) Measured:				
	Control	2 Hours	4 Hours	6 Hours	8 Hours
1	1.39	6.96	10.6	13.9	18.5
2	1.99	7.66	11.9	13.3	18.3
3	1.43	6.86	10.8	13.4	18.6
Mean	1.60	7.16	11.1	13.5	18.4
Standard Deviation	0.11	0.62	0.70	0.32	0.17

2.9 Atmospheric Carbon Monoxide Analysis Method Evaluations

To determine the reliability of the gas chromatographic method, a series of air samples containing various concentrations of CO were prepared, coded, and subsequently tested using the techniques described. Six cylinders containing CO in concentrations from five to 10,000 ppm were utilized. Results of this series are presented in Table 2.3.

2.10 Results of Subject COHb Analyses

Results of COHb determination for each subject before exposure to wither CO or air, at the completion of exposure, and the average levels during experiments are presented in Tables 2.4 - 2.9 as follows. The levels presented for the driving experiments were the mean values (2-5 determinations) of blood samples taken immediately after "refreshment" of the subject.

Table 2.3

Results of CO Analysis of Samples Containing CO

Nominal Concentration of Samples	Number of Tests	Mean Concentration Analyzed	Standard Deviation	% Coefficient of Variation
80 ppm	12	69.8	2.35	3.37
1,000 ppm	6	914.8	23.32	2.54
10,000 ppm**	6	10,000.0	91.85	0.92
80 ppm	3	71.1	1.20	1.69
10,000 ppm**	3	10,000.0	92.76	0.93
5 ppm	9	5.14	0.097	1.89

**Primary Standard supplied by Matheson Gas Co.

Conditions

Column: 1/2" x 6', packed with 60-80 mesh 5A molecular sieve
Column Temperature: 92° C
Detector Temperature: 132° C
Carrier Gas: Nitrogen
Flow Rate: 38 ml/min.
Hydrogen Flow Rate: 30 ml/min.
Air Flow Rate: 600 ml/min.
Catalyst: Nickel on firebrick at 320° C
Retention Time: 3 minutes
Average Time of Analysis: 5 minutes

Table 2.4

Carboxyhemoglobin Levels of Phase A Subjects before and after 120 Minutes of Exposure (490 ppm) and During Driving Experiment

Subject	% COHb		
	Pre-exposure	End Exposure	Road Average
S1	2.0	---	
S2	---	18.8	NA
S3**	2.0	19.5	
S3	1.4	17.1	19.0
S4	2.0	19.5	17.1
S5	1.3	17.3	NA
S8	---	20.0	
S3	0.6	19.9	
S3	1.2	18.4	
S3	2.4	17.6	
S7	3.6	18.4	NA
S6	2.1	22.9*	20.5
Mean	1.9	19.0	18.8
Std. Dev.	0.82	1.63	---

*Two hour exposure

**Multiple entries for some subjects denote repeated testing.

Table 2.5

Carboxyhemoglobin Levels of Phase B Subjects before and after 120 Minutes Air Exposure and During Driving Experiment

Subject	% COHb		
	Pre-exposure	End Exposure	Road Average
S9	2.2	2.1	1.8
S10	1.7	2.2	NA
S11	2.5	2.1	2.6
S11	2.0	1.5	2.0
S12	2.1	2.0	NA
S12	2.4	2.1	3.2
S13	2.3	1.6	2.6
S14	3.8	2.4	2.5
S14	1.1	1.8	2.2
Mean	2.2	2.0	2.4
Std. Dev.	0.7	0.3	0.7

Table 2.6

Carboxyhemoglobin Levels of Phase B Subjects before and after 120 Minutes CO Exposure (450 ppm) and During Driving Experiment

Subject	% COHb		
	Pre-exposure	End Exposure	Road Average
S9	1.0	23.0	17.7
S10	1.5	24.6	20.1
S11	1.5	24.4	20.1
S12	1.2	21.7	19.8
S12	0.9	20.8	18.8
S13	1.3	20.8	16.0
S14	1.0	17.8	19.2
S14	1.7	15.1	16.7
Mean	1.3	20.7	18.0
Std. Dev.	0.4	3.2	2.1

Table 2.7

Carboxyhemoglobin Levels of Phase C-D Subjects before and after 90 Minutes Air Exposure and During Driving Experiment

Subject	% COHb		
	Pre-exposure	End Exposure	Road Average
S16	1.9	2.0	
S17	0.7	0.6	
S18	1.4	2.6	
S19	0.7	1.3	
S20	0.8	1.6	3.7
S21	1.4	0.9	1.1
S22	1.9	2.9	2.6
S23	0.7	1.7	1.8
S24	1.3	1.3	1.7
S25	1.6	2.2	3.5
S26	0.9	1.9	8.1
S27	1.1	---	2.7
S28	1.5	1.8	2.5
S29	1.1	1.6	1.8
S30	1.2	0.6	2.5
S31	1.9	1.4	3.8
S32	---	---	
S33	1.2	2.9	
S34	0.7	1.4	
S35	1.4	---	2.2
S36	1.4	2.3	2.7
S37	1.1	1.2	1.2
S38	1.9	2.8	2.8
S39	1.5	2.1	2.4
S40	---	1.7	1.7
Mean	1.3	1.8	2.7*(2.4**)
Std. Dev.	0.4	0.7	1.6*(0.8**)

*All subjects

**S26 deleted

Table 2.8

Carboxyhemoglobin Levels of Phases C-D Subjects before and after 90 Minutes CO Exposure (100 ppm) and During Driving Experiment

Subject	% COHb		
	Pre-exposure	End Exposure	Road Average
S16	2.0	8.9	
S17	2.1	9.3	
S18	2.1	10.8	
S19	1.7	8.9	
S20	1.6	7.5	7.6
S21	2.1	---	6.9
S22	1.4	8.0	9.9
S23	3.8	8.4	8.3
S24	1.1	7.3	7.3
S26	2.1	7.3	8.0
S27	2.5	5.9	8.1
S28	1.3	8.6	9.2
S29	1.5	8.1	8.3
S30	2.0	6.9	7.1
S31	1.3	7.9	7.5
S32	1.1	7.4	
S33	1.8	6.7	
S34	1.1	6.8	
S35	1.1	7.4	6.6
S36	1.9	8.3	6.9
S37	1.9	7.1	7.6
S38	1.6	6.7	7.3
S39	1.8	9.5	8.3
S40	1.2	7.3	8.4
Mean	1.8	7.9	7.8
Std. Dev.	0.6	1.1	0.9

Table 2.9

Carboxyhemoglobin Levels of Phase C-D Subjects before and after 90 Minutes CO Exposure (350 ppm) and During Driving Experiment

Subject	% COHb		
	Pre-exposure	End Exposure	Road Average
S16	1.4	9.4	
S17	2.1	9.3	
S18	2.1	10.8	
S19	1.7	8.9	
S20	1.0	9.1	8.4
S21	2.4	13.0	12.6
S22	2.7	12.7	12.3
S23	1.7	17.5	14.2
S24	1.6	14.4	11.7
S26	1.4	8.5	9.7
S27	1.4	12.1	11.5
S28	1.5	13.2	10.1
S29	1.4	14.6	12.4
S30	1.7	9.4	12.2
S31	2.3	11.6	10.8
S32	0.8	13.8	
S33	3.6	10.6	
S34	1.5	11.9	
S35	1.5	13.8	11.2
S36	2.1	11.7	9.4
S37	1.0	12.2	9.9
S38	2.3	12.4	12.5
S39	1.9	11.9	10.2
S40	0.9	11.1	10.7
Mean	1.8	11.8	11.2
Std. Dev.	0.6	2.2	1.5

CHAPTER 3

SIMPLE LABORATORY TESTS

3.1 Introduction

Several psychophysical and simple psychomotor tests were evaluated as part of the comprehensive plan to measure CO effects. Physiological measures of altered perception were also eliminated because of the poor experience of others. (See Michon, 1964, for discussion of this problem.)

Tests which measured coordination, concept formation, and various aspects of visual discrimination were sought. A number of tests not previously used to demonstrate CO effects were selected. These tests were sufficiently well-known so that a body of literature and range of normative values existed for each. Since any psychological test reflects mental process and not discrete anatomic function, it was reasoned that various measures, as unrelated as possible to each other, would be more likely to detect pharmacologic effects which are usually quite broad. Several well known tests including the Porteus Maze were rejected since large doses of depressants; e.g., alcohol, or stimulants; e.g., amphetamines, were required to obtain exceptional scores, and the present study was concerned with indications of minimal intoxication.

3.2 Simple Laboratory Tasks Descriptions

The simple psychophysical/psychomotor tasks used were all administered within 60 minutes, inexpensive, required no apparatus inconvenient to space considerations, and were scored by technicians with limited experience. Rapid scoring was required so that extreme scores after administration of CO could be noted immediately and used as criteria by the medical staff to limit further exposure and further testing in the driving tasks. The selected tasks were star-tracing, finger-tapping, rail-walking, Minnesota Spatial Relations Test, brightness discrimination, and dark adaptation.

3.2.1 Mirror-Drawing: Star-Tracing

This test demonstrated eye-hand coordination by requiring a subject to trace between two eight-point stars, keeping within an 1/8 inch band while watching the motion of the hand-held stylus in a mirror. Since this activity is not related to daily experience, all subjects were naive.

For this investigation, the Star-Tracing Test was scored by dividing the total distance correctly drawn; i.e., within the space between the stars, by the time required to perform the task. This test was administered before and after air or CO exposure (Nominal 20% COHb) for a total of 12 times to three subjects.

3.2.2 Finger-Tapping

Subjects used a telegraph key to tap as rapidly as possible for one minute to evaluate fine muscle coordination before and after air or CO exposure. Impaired performance of this task reflected "traffic control problems in the central nervous system," Michon (1964). For example, if stimuli were too complex for immediate transmittal, queuing and timing would be necessary and frequently led to performance irregularity. For an investigation of tapping as a measure of CO effects, the gross score (number of taps) over one minute was accepted without further analysis of tapping pattern (regularity). The test was administered to six subjects during Phase A.

3.2.3 Rail-Walking

This stationary balancing test with simple instructions, easy scoring, and modest space requirements seemed ideal for inclusion in the CO study.

The Rail-Walking Test, as originally described (Heath, 1949), consisted of walking three wooden rails: 9' x 4", 9' x 2", and 6' x 1", of sufficient height to prevent contact of feet with the floor. Each rail was graded in units of feet, and was walked barefoot, heel-to-toe, by each subject three times. Because of the difference in degree of difficulty of each rail, the raw score for the three rails was weighted 1 - 2 - 4. Thus, the total possible score is (1 x 27) + (2 x 27) + (4 x 18), or 153 points. Heath standardized the test on 1,013 troops selected from a non-special unit which would be regarded as an average cross section of the white male population of Army age. The mean rail-walking score for that group was 130.73 points with a standard deviation of 19.63 points. The author notes that the poorly coordinated, and some special types of the retarded, can be identified by this test. A distinct limitation is failure to differentiate well at the upper levels of locomotor coordination; i.e., above average and superior.

Subjects participating in the carbon monoxide investigation were able to complete the Rail-Walking Test as described with little or no error. Therefore, the test was revised to include an additional rail, 5/8" wide, 10' long, and 4" high. An arbitrary weighting of score was 6.4 x 30 = 192, for a perfect score on this rail.

Data were recorded in unassisted distance each subject walked barefoot. One practice trial was given and the next three trials were recorded. Few subjects were able to walk the length of the rail without losing balance even under control conditions. This test was carried out both before and after CO exposure. Data were collected on 120 trials given to eight different subjects.

3.2.4 Minnesota Spatial Relations Test

The Minnesota Spatial Relations Test was chosen to evaluate the capacity of CO to alter speed and accuracy in comprehension and manipulation of objects of different sizes and shapes. This test, first published in 1930, consisted of four form boards each containing 58 variously shaped cutouts. One set of blocks was used with Boards A and B, another with Boards C and D. The small forms were placed into the appropriate holes in the boards as rapidly as possible. Test score was the time, in seconds, to perform four tasks: (1) move the blocks from Board A to B, (2) B to A, (3) C to D, and (4) D to C. All the blocks were in their correct position before the subject could move on to the next board.

The test was administered in the chamber prior to, and again following, exposure to CO. This test was taken by six different subjects 34 times.

3.2.5 Brightness Discrimination

Recognition of objects is based on perception of brightness difference. This is important to driving, since an obstacle may appear either as a darker or a lighter object compared to the horizon or alternate background.

Measurement of the ability to match the intensity of two light sources is one way to assess this contrast sensitivity.

In this study, measurement of contrast sensitivity (brightness discrimination) was measured at several wavelengths to maximize the possibility of finding some degradation in contrast sensitivity under the influence of CO.

In the first series, subjects were required to match brightness of eight pairs of colored lights while seated in the lightproof exposure chamber. Thirty minutes dark adaptation preceded each session.

The light box was mounted on the chamber wall 7-1/2" from the seated subject. Each target was a 1-1/2" diameter circular filter placed 1" from the edge of the duplicate. The target represented 1^{o} of visual arc. Incandescent light was passed through Rohm and Haas plexiglas filters to produce the test colors as follows:

Colors	Wavelength (Nanometer)
Red I	700
Red II	680
Orange	640
Yellow	600
Green	540
Violet	450
Blue	420
White	---

The paired lights were turned on by the experimenter, and the control target set at control voltage to give 35 millilamberts illumination. The subject then matched the brightness of the experimental target by turning the potentiometer of his hand-held control box. Voltage differences between the two targets were recorded for each of the colors to the nearest thousandth volt on a digital recording voltmeter.

Two red filters were used because:

1. the eye does not detect the red light as well as some of the others (Bernberg, 1960), and
2. the red light is used extensively on the automobile.

Four subjects were tested on all eight colors after CO or air exposures for the Nominal 20% COHb series.

During later series, tests included only Red I, Green, and White test lights. Thirteen subjects were tested at each exposure level in the later series.

3.2.6 Dark Adaptation

The Dark Adaptation Tests of Baker (1949), and Wald and Clark (1937), were modified for this investigation.

Each subject was seated in the lightproof exposure chamber 30 minutes prior to testing to allow near-maximum rhodopsin regeneration.

At the end of this time, a 90% reflectance screen, placed 7-1/2' from the subject, was illuminated at 90 millilamberts. After five minutes of bright light adaptation, the projection screen was darkened and the subject was requested to identify the dim light target, either a square, circle, triangle, or diamond. When the subject was able to identify the target, he signaled and the target light was changed and reduced in intensity. Levels of intensity ranged from 8×10^{-3} millilamberts to 2×10^{-5} millilamberts. Up to 16 steps could be tested in the 1000 second test period.

Six subjects were tested after exposure to air or CO during the first series of experiments, (Nominal 20% COHb). Fourteen subjects were tested during Phase C-D after exposure to air or CO (nominal 7% COHb and 14% COHb).

3.3 Results

3.3.1 Mirror-drawing - Star-tracing

The post-exposure testing of the reversed star-tracing showed no increased tremulousness after CO exposure (nominal 20% COHb), and most of the subjects improved at each subsequent trial on this particular task. No further analyses were conducted on these data.

3.3.2 Finger-tapping

Results of the Finger-tapping test conducted on six subjects are presented in Table 3.1. Inspection of the data showed that CO has no effect on finger-tapping performance. This test was not used for the later series of experiments.

Table 3.1

Results of Finger-tapping Performance Test

Experiment	Taps/Min.	
	Mean	Std. Dev.
Control	349.3	54.8
Nominal 20% COHb	352.2	52.5

3.3.3 Rail-walking

Results of the Rail-walking Test, performed as originally described on the first series of five subjects, appear in Table 3.2. The maximum score for this test was 153. All score means were within 5% of the maximum attainable score. This test was not used for subsequent experiments.

Table 3.2

Results of Rail-walking Test

Phase A Subjects

Experiment	Mean Rail-walking Performance	
	Mean	Std. Dev.
Control	153.0	0
Nominal 20% COHb	147.0	8.6

Results of the Modified Rail-walking Test used in the second series of subjects appear in Table 3.3. The maximum score for this test was 192. Although there were differences in the mean scores for this series, none were significant or related to CO exposure.

Table 3.3

Results of Modified Rail-walking Test

Phase B Subjects

Experiment	Mean Rail-walking Performance (Standard Deviation)	
	Mean	Std. Dev.
Control	134.4	48.2
Nominal 20% COHb	152.0	32.4

3.3.4 Spatial Relations Test

Results of the Spatial Relations Test conducted on five subjects in Phase A are presented in Table 3.4. Inspection of the data suggests the CO may have had an effect in performance. However, in this series, all control experiments were conducted before the nominal 20% COHb experiments. Therefore, the differences observed in Table 3.4 must be attributed to learning.

Table 3.4

Results of Spatial Relations Test

Phase A Subjects

Experiment	Board	Mean Spatial Relations Performance Time: Seconds	
		Mean	Std. Dev.
Control	A	173.4	71.7
	B	161.8	42.3
	C	200.0	94.1
	D	192.2	75.4
	Total	727.4	227.9
Nominal 20% COHb	A	144.5	25.9
	B	146.4	19.1
	C	167.2	45.9
	D	151.6	32.5
	Total	609.8	113.2

3.3.5 Brightness Discrimination

Results of the Brightness Discrimination Test on four subjects in Phase A using all eight colors appear in Table 3.5. Results are presented as deviation from control voltage, expressed in percent. In all colors except yellow, there appear to be an increase in difference from the control lamp and an increased variance.

Table 3.5

Results of Brightness Discrimination Test

Phase A

Light Source	% Difference from Control Lamp (Standard Deviation)	
	Control	Nominal 20% COHb
Red I	7.35 (3.19)	7.60 (4.78)
Red II	3.60 (3.18)	6.72 (6.81)
Orange	3.98 (1.71)	6.66 (6.13)
Yellow	7.68 (3.95)	4.98 (3.03)
Green	2.78 (2.16)	6.45 (4.72)
Violet	3.98 (2.15)	4.66 (3.83)
Blue	3.50 (2.64)	4.24 (3.59)
White	3.59 (2.77)	3.79 (2.83)

Statistical analyses of the mean percent difference data from Table 3.4 are presented in Table 3.6. For these analyses, the variance was assumed to be a function of COHb level (C), and the light source (S).

Table 3.6

Analysis of Variance
of Brightness Discrimination Data

Source	DF	Sum of Squares	Mean Squares
Total	15	43.45	-
C	1	4.47	4.47
S	7	23.56	3.36
C x S	7	15.92	2.20

When all light sources were included in the analyses, no statistical significance ($p < .75$) could be assigned to the observed effect. However, if the data for the yellow light source are excluded from consideration, the observed differences between control and 20% nominal COHb become highly significant ($p > .95$). This analyses appears in Table 3.7.

Table 3.7

Analysis of Variance of Brightness Discrimination Data
Disregarding Yellow Light Source

Source	DF	Sum of Squares	Mean Squares
Total	13	35.38	-
C	1	9.18	9.18
S	6	19.63	3.27
C x S	6	6.56	1.09

Analysis of variance of the standard deviation calculated from the control and the 20% COHb data using the eight light sources is presented in Table 3.8. Again, the standard deviation was assumed to be a function of COHb level and of the different light sources.

Table 3.8

Analysis of Variance of Standard Deviation

Source	DF	Sum of Squares	Mean Squares
Total	15	30.15	-
CO	1	12.20	12.20
LS	7	6.96	.99
CO x LS	7	10.99	1.57

Analyses of the differences in standard deviation between control and nominal 20% COHb, including all light sources, indicates that there is a highly significant ($p > .99$) increase in variance due to the CO exposure.

It should be noted that increases were observed in both mean difference from control voltage and in the standard deviation between the control experiment and the 20% COHb experiment except for the yellow light. There is no obvious explanation for the apparent discrepency in the results from the yellow light source.

Results of the Brightness Discrimination Test conducted for subsequent experiments on subjects in Phases C and D at control and nominal 7% and 14% COHb, appear in Table 3.9. These results are presented as deviation from control voltage expressed in percent. Inspection of these data indicated that no differences in contrast sensitivity could be attributed to elevated COHb in this series. No statistical analysis were conducted on these data.

Table 3.9

Results of Brightness Discrimination Test

Phases C - D

Light Source	Mean Percent Difference From Control Lamp (Standard Deviation)		
	Control COHb	Nominal 7% COHb	Nominal 14% COHb
Red I	5.37 (4.45)	4.70 (2.99)	4.42 (4.16)
Green	8.65 (5.82)	8.24 (4.93)	9.87 (6.30)
White	4.15 (3.55)	5.63 (3.82)	3.57 (3.03)

3.3.6 Dark Adaptation

Results of the dark adaptation test conducted on subjects during this investigation demonstrated that there is considerable inter- and intra-subject variability in performance of this test. Figure 3.1 presents an example of the intra-subject variation observed on S-19 during a series of control trials. Figure 3.2 presents an example of the inter-subject variation using the most representative curves from a series of three trials on each of the subjects.

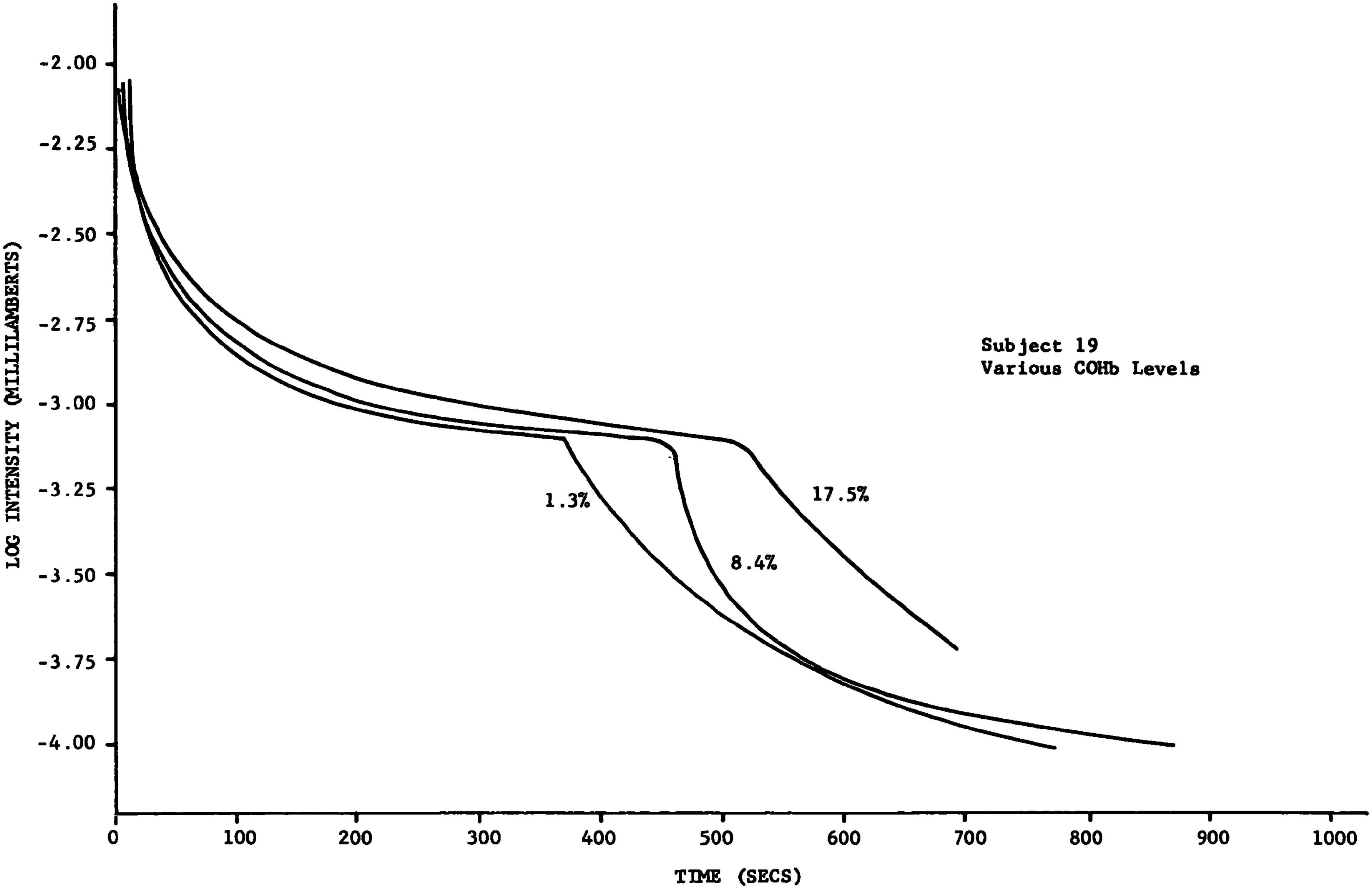

Figure 3.1.--Dark Adaptation Curves.

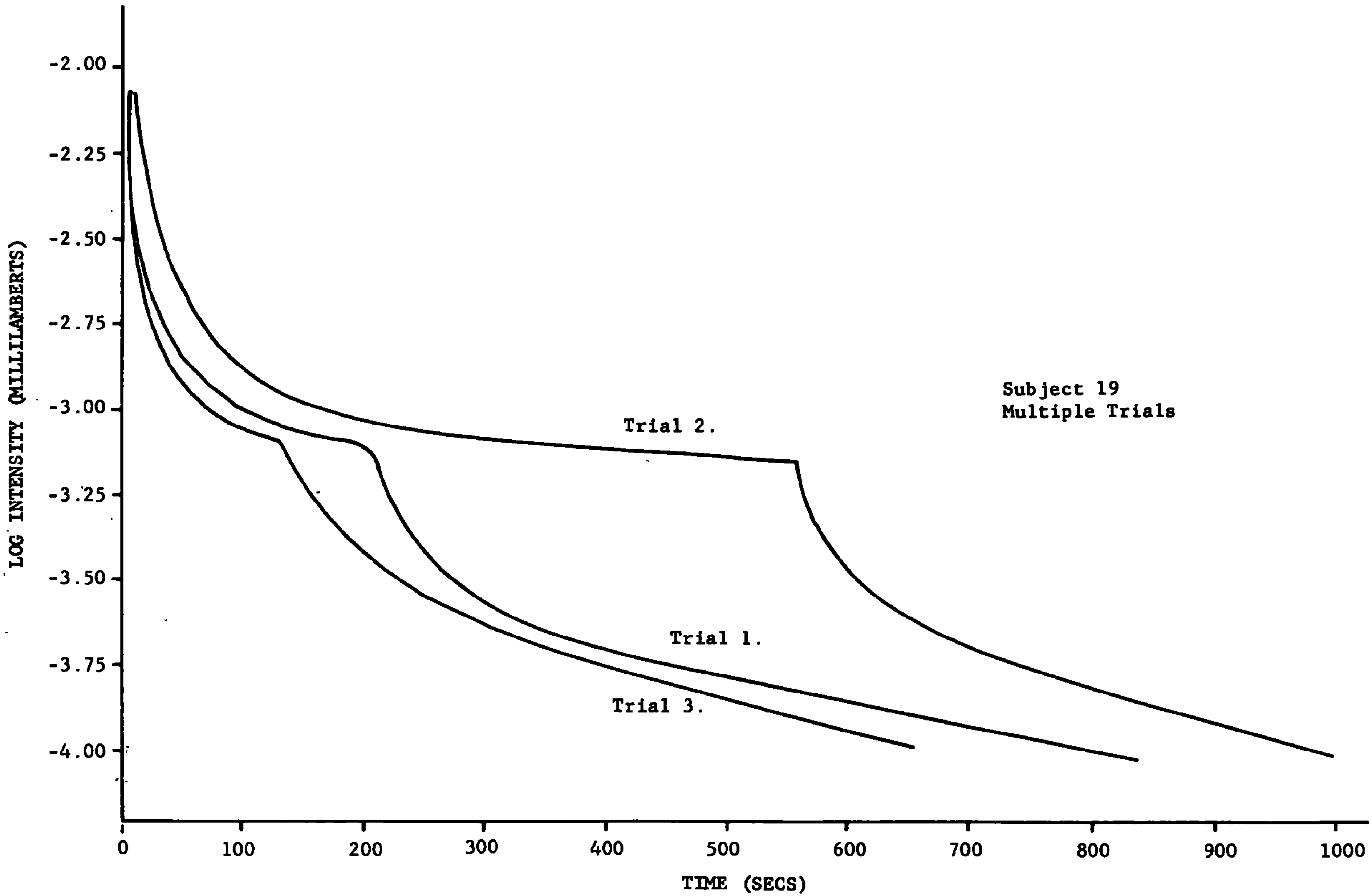

Figure 3.2.--Dark Adaptation Curves.

The inter- and intra-subject variability in this test exceeded the differences observed as a result of CO exposure. An example of the effect that CO exposure had on subject performance is presented in Figure 3.3. The data used in Figure 3.3 are the most representative curves selected from three trials at each exposure level tested. Most subjects tested demonstrated a pattern similar to the data presented in Figure 3.3. No quantitative analyses were attempted on these results.

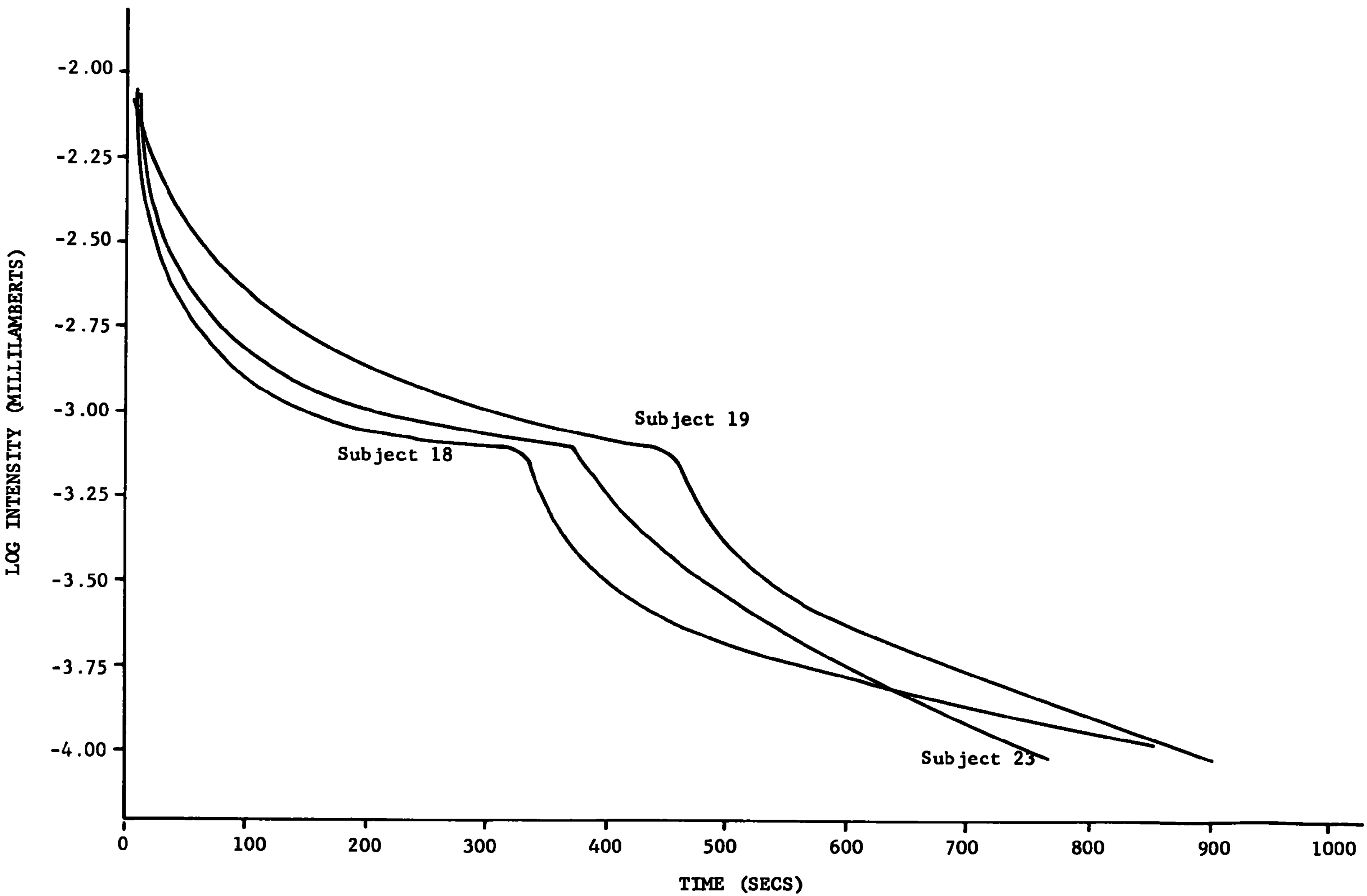

Figure 3.3.--Dark Adaptation Curves.

CHAPTER 4

COMPLEX LABORATORY TASKS WITH 20% COHb

During the first year of this research (Phases A and B) complex psychomotor tests were designed to initially ascertain performance effects due to large differences in COHb (0 and 20%). These tests and the subsequent results are reported in this section of the report.

The distinction between Phases A and B is only to designate two different groups of subjects. The test protocols were for all practical purposes the same. The initial set of studies (Phase A) should be viewed as preliminary tests to shakedown the methodology and provide group overall effects prior to Phase B.

4.1 Description of Tasks

4.1.1 Time Estimation Task

During the trials, subjects performed three time estimation tasks. For the first of these, subjects were presented with an example tone, 4 seconds in duration, in their earphones. They were instructed to press their pushbutton each time they felt that four seconds had elapsed. The trial lasted 100 seconds.

At the start of the next trial subjects were presented with a tone two seconds in duration. They were instructed to press their pushbutton each time they felt that two seconds had elapsed. This trial lasted 50 seconds. The final time estimation trial was 200 seconds long. Subjects were first presented with a tone eight seconds in duration and then instructed to press their pushbuttons once every eight seconds.

The performance measures for this task included:

1. average time estimates, over 25 estimates, and
2. sample variances of the time estimates.

4.1.2 Choice Reaction Time Tests

Subjects responded selectively to numbers projected on the screen at 1.5 second intervals. The numbers appeared at four different locations on the screen; right or left of the oscilloscope face and centered at visual angles of three or nine degrees to the subject's central line of sight. Each stimulus subtended a visual angle of 50 minutes. Subjects responded to the same set of seven numbers, arranged in a different random order on each trial. The numbers were divided into three sets of size one, two, and four stimuli. The members of each set occurred equally often on each trial.

A target number was first presented. Thereafter, a set of one, two, and four figures was presented on either side of the scope. If the target number was presented in either set, the subject was instructed to respond using that button on the steering wheel corresponding to whether the target was left or right of the scope.

The performance measure for this task was choice reaction time(CRT) recorded as a function of stimulus set size and location (angle from line of sight).

4.1.3 Tracking Task

This was a one dimensional (horizontal) tracking task. The target moved across the oscilloscope face in a random fashion at various sweep rates. Target reversal rates were randomly developed in an electronic signal generator. The subject operated the cursor on the scope by means of the steering wheel and attempted to superimpose the cursor on the target (see Appendix A). Tracking complexity was achieved by changing sweep rates.

The measures of performance for this task were:

1. MAE - mean absolute tracking error - the mean of the absolute deviation of the cursor from the target, and

2. tracking time lag (in seconds) - the cross correlation function between the input tracking function (target) and the subjects output function (cursor). This is merely the average lag between target movement and cursor movement.

4.1.4 Dual Task: Tracking Plus Choice Reaction Time (CRT)

For 16, 40 second trials subjects simultaneously tracked and responded to the choice reaction time task. For ease of description these 16 trials will be termed dual task trials with four trials performed at each of four different levels of tracking complexity ranging from level zero (CRT only) through the three levels of tracking complexity (i.e., increasing target speed).

Subjects were presented with fourteen pairs of visual stimuli projected on the screen surrounding the scope face with one member of the pair located on either side of the scope face. Eight of the fourteen stimulus pairs contained a target number and a letter. The number appeared four times on one side of the scope and four times on the other. The order of presentation of target numbers was randomly chosen. The subject's task was to press the button on the same side of the steering wheel as the side of the scope face on which the number appeared. Stimulus duration was one second and interstimulus intervals were chosen randomly between 1.0 and 2.5 seconds.

The performance measures for this dual task were:

1. MAE (defined above),
2. CRT (choice reaction time),
3. errors in stimuli detection, and
4. time lag in tracking (defined above).

4.2 Test Schedules

During the Phase A test period, six subjects performed in three separate experimental sessions, one session on each of three different days. During the first session, subjects were introduced to the tasks. They practiced the pursuit tracking portion and were familiarized with the choice reaction time (CRT) and combined tracking plus choice reaction time tasks. On each of the two remaining sessions, subjects breathed the experimental atmospheres before participating in the testing.

The followingorder of tasks was followed throughout the experimentation:

Trials	Time Duration	Task
1-3	40 seconds	Tracking Only
4	100 seconds	Time Estimation (4 second intervals)
5	50 seconds	Time Estimation (2 second intervals)
6	200 seconds	Time Estimation (8 second intervals)
7-14	40 seconds	Tracking plus Choice Reaction Time or Choice Reaction Time Only
15-16	40 seconds	Tracking plus Time Estimation (4 second intervals)
17-24	40 seconds	Tracking plus Choice Reaction Time or Choice Reaction Time Only
25-27	40 seconds	Tracking Only

For the second series of tests (Phase B), six additional subjects were tested with the two treatment conditions (nominally 0 and 20% COHb). Table 4.1 illustrates the subject scheduling over the six calendar days of testing. Each subject participated in four laboratory test sessions, two before chamber exposure and two after. In addition, three of the six subjects were tested on each of two other days after a driving experiment which lasted approximately two hours.

Table 4.1

Phase B Subject Schedule

Time	Treatment	Air Day 1*	CO Day 2	CO Day 3	Air Day 4	Air Day 5	CO Day 6
6-8 am	Pre-exposure session	S9 S14	S9 S14	S11 S13	S11 S13	S10 S12	S10 S12
8-10 am	Treatment	S9 S11 S14	S9 S11 S14	S10 S11 S13	S10 S11 S13	S10 S12 S13	S10 S12 S13
10-12 am	Post-exposure	S9 S14	S9 S14	S11 S13	S11 S13	S10 S12	S10 S12
1-2 pm	Experimental session after driving	S11	S11	S10	S10	S13	S13

*Days denote calendar days of testing.

4.3 Phase A Results

The major results of the Phase A psychomotor experiment are summarized as follows:

1. No significant differences ($p < .75$) were observed in either CRT or MAE data as a result of 20% COHb intoxication for individual tasks.

2. A significant ($p > .90$) increase in tracking time lag was observed due to 20% COHb for the dual task. This increase in crosscorrelation in a continuous tracking task has been compared to an increase in reaction time in discrete tasks.

3. Time estimation performance was slightly affected ($p > .75$) by 20% COHb intoxication, however, considerable interference effects between tasks were observed when tracking and time estimation were performed simultaneously.

4. Mean absolute errors (MAE) increased significantly ($p > .99$) as level of tracking complexity increased. These increases were even more pronounced in the dual task.

5. Choice reaction times (CRT) did not significantly ($p < .75$) increase as tracking complexity increased in the dual task.

4.3.1 Discussion of Results

With two exceptions (points 2 and 3), the above results suggest that the majority of the performance indices investigated in this preliminary study failed to deteriorate significantly under the effects of 20% COHb levels. Summary data for the two performance measures affected by COHb level, pursuit tracking lag and time estimation, are presented in Tables 4.2 and 4.3, respectively.

The increase in the tracking time lag under the effects of 20% COHb levels verified the hypothesis that the subjects' response to a change in the direction of the tracking sensor would be increased with carboxyhemoglobin. The result is viewed as cautious support for the models proposed by Garvey (1960).

A significant reduction in the mean of the time estimates was demonstrated over the combined data in the time estimation task. The literature does not report a precedent for this result, although, close observation of the data in Stewart, et al. (1970) indicates that in 39 of the 48 categories of time estimation which were tested at elevated CO atmospheres, mean normalized time estimates were below the mean normalized time estimate for the control condition.

Table 4.2

Average Time Lag (msec.), Dual Task, Low Complexity

Subject	AIR	CO	Δ = CO - AIR
S2	267	242	-25
S3	200	326	126
S5	125	143	18
S6	204	275	71
S8	77	209	132

In many instances during the CRT analyses, the trend toward deteriorated performance under elevated COHb levels did not materialize into a significant effect because of the 'noise' (variability inherent in the CRT data). While a large percent of the intra-subject variability indicated in the CRT data is probably due to the secondary nature of the CRT task, substantial variation must have been the result of performance on a relatively novel task. In the latter tests, the detection and control of the learning factors became a necessity.

4.4 Phase B Results

The results of these laboratory studies can be divided into two categories:

1. those which measured effects of experimental control variables, and
2. those which measured the effects of 20% COHb.

In the former category are such factors as learning (or day) effects, size of the stimulus set, tracking complexity, visual angle, and before versus after driving performance. It will be assumed for purposes of this section of the report that the effects of these control variables are of interest only as they relate to possible 20% COHb effects. A more detailed analyses of these variables may be found in Attwood (1972).

Upon analyzing the results of the Phase B data, it was observed that subjects S9 and S14 exhibited large "novel learning" effects which were attributed to experimenter biases in starting the Phase B data collection (subjects S9 and S14 were the first subjects tested). Rather than inflate the residual error variances of this factor screening experiment, these two subjects were eliminated from the analyses which follow.

Table 4.3

Summary Statistics of Time Estimation Data - Five Subjects

Subject	Statistic*	TIME ESTIMATION AIR 2 sec	AIR 4 sec	AIR 8 sec	CO 2 sec	CO 4 sec	CO 8 sec
S8	n	16	16	16	NA[ω]	12	NA
	$\bar{x}$	264	6.56	7.30		4.18	
	s	.35	.72	.49		.33	
S4	n	NA	NA	NA	16	16	16
	$\bar{x}$				1.83	4.77	8.3
	s				.26	.49	.65
S5	n	NA	NA	NA	16	16	16
	$\bar{x}$				2.34	4.77	6.52
	s				.188	.49	.65
S6	n	16	16	15	16	16	16
	$\bar{x}$	3.19	5.43	11.8	2.62	5.19	10.2
	s	.61	.15	1.3	.5	.406	1.87
S3	n	16	16	15	16	16	16
	$\bar{x}$	2.67	7.06	11.89	2.28	3.58	7.74
	s	.27	1.18	1.69	.28	.39	1.37

* n = number of samples
$\bar{x}$ = mean time estimate
s = sample variance of time estimates

ω NA = data not available

The data for the remaining four subjects were analyzed with fixed subject effects models. As a result, all statistical tests for 20% COHb effects on performance showed significant effects for $p > .95$. The reader should recognize that these "statistically significant" results cannot necessarily be extrapolated beyond the four subjects of this particular phase. However, treatment of subjects as "fixed effects" is not uncommon in exploratory factor screening research of this kind. The validity and interpretation of the resulting interaction effects (subjects by COHb level, for example) will be postponed to Phases C and D with a larger sample size (16 subjects).

4.4.1 Choice Reaction Times

The choice reaction times for the three subjects who also participated in the driving studies, averaged across all data for tasks 9 and 11 (CRT only and dual task), were compared for 20% COHb differences and before versus after driving differences. The means for these choice reaction time data are presented in Figure 4.1.

This figure illustrates a mild degradation in choice reaction times (increases) with 20% COHb exposure. This COHb effect was slightly affected by the "fatigue" of driving with the COHb effect somewhat smaller after participation in the driving studies.

The additional effects of loading (task 1 versus task 11) and size of the stimulus set are illustrated in Figure 4.2. This figure shows (for the "after driving" data) the additional increases in choice reaction times attributable to the dual task loading and increased size of the stimulus set. It is interesting to note that there are no consistent interactions between the COHb level and set size or task difficulty which would be represented by lack of parallel in the four lines.

4.4.2 Mean Absolute Error Scores

Similarly, the mean absolute error scores for the three subjects were analyzed before and after driving as presented in Figure 4.3. This figure also shows a mild degradation (increases) in scores for the 20% COHb condition. These increases do not appear to be dependent on the before versus after driving differences (no lack of parallel). Figure 4.4 shows the dual task mean absolute errors were highly dependent on level of tracking complexity but there were no synergistic or interactive COHb by complexity effects.

Figure 4.5 depicts how four subjects (S10 through S13) traded off the primary and secondary tasks when exposed to CO as compared to air. Subjects S10 and S11 maintained primary task performance (MAE not affected) but demonstrated COHb effects in CRT. Subjects S12 and S13 allowed both MAE

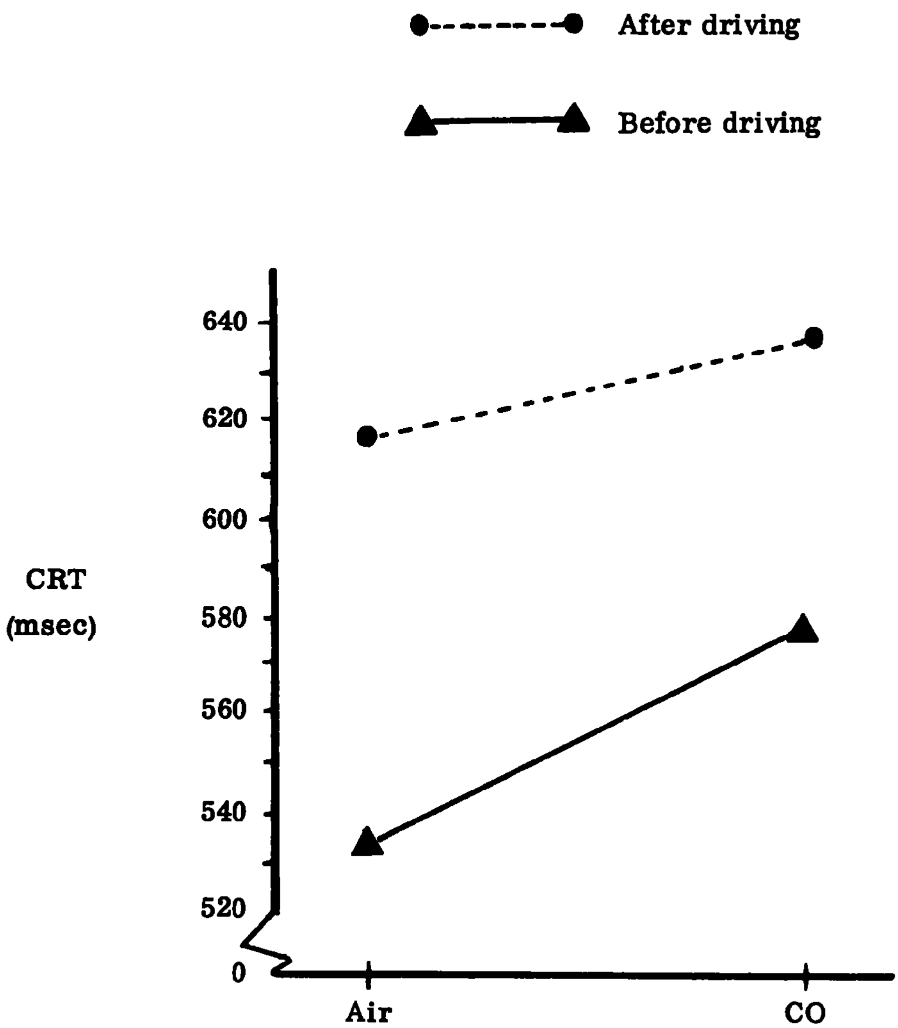

Figure 4. 1. --Mean choice reaction time (CRT) as a function of the AIR-CO treatment and the before- versus after-driving condition

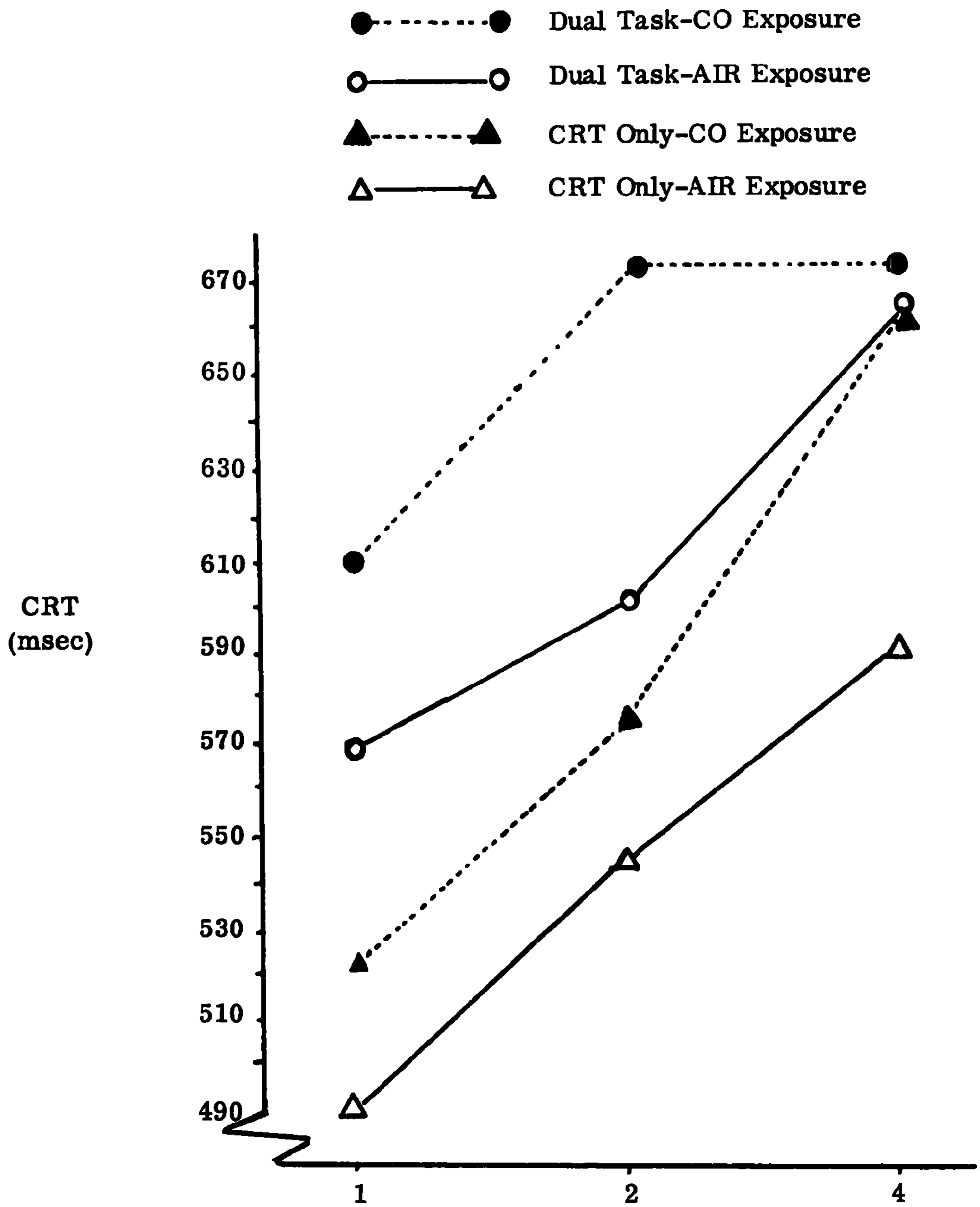

Figure 4.2.--Mean choice reaction time (CRT) as a function of the size of stimulus set, COHb level, and dual-task or CRT-only condition

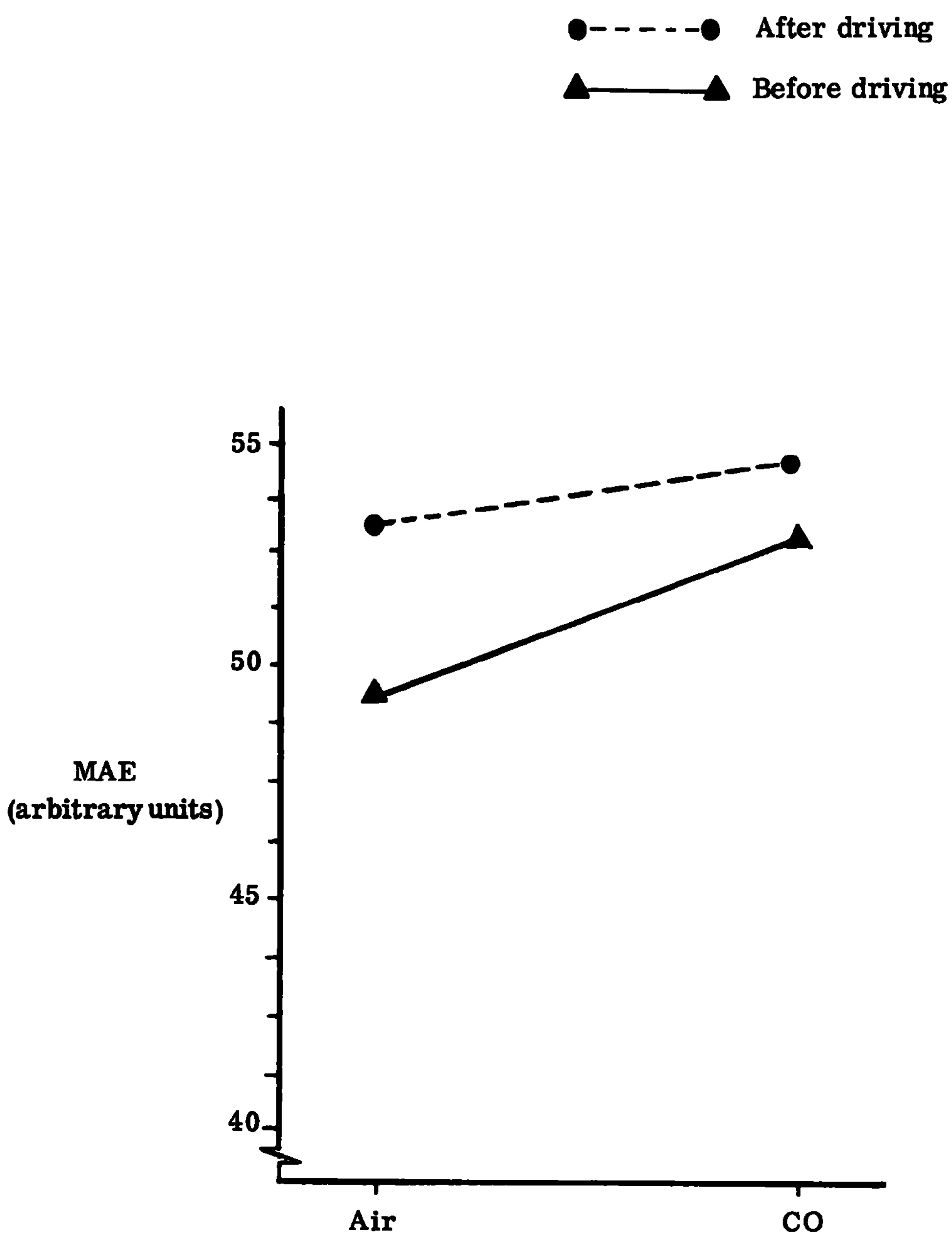

Figure 4.3.--Average mean absolute tracking error (MAE) as a function of the air-CO treatment and the before- versus after-driving condition

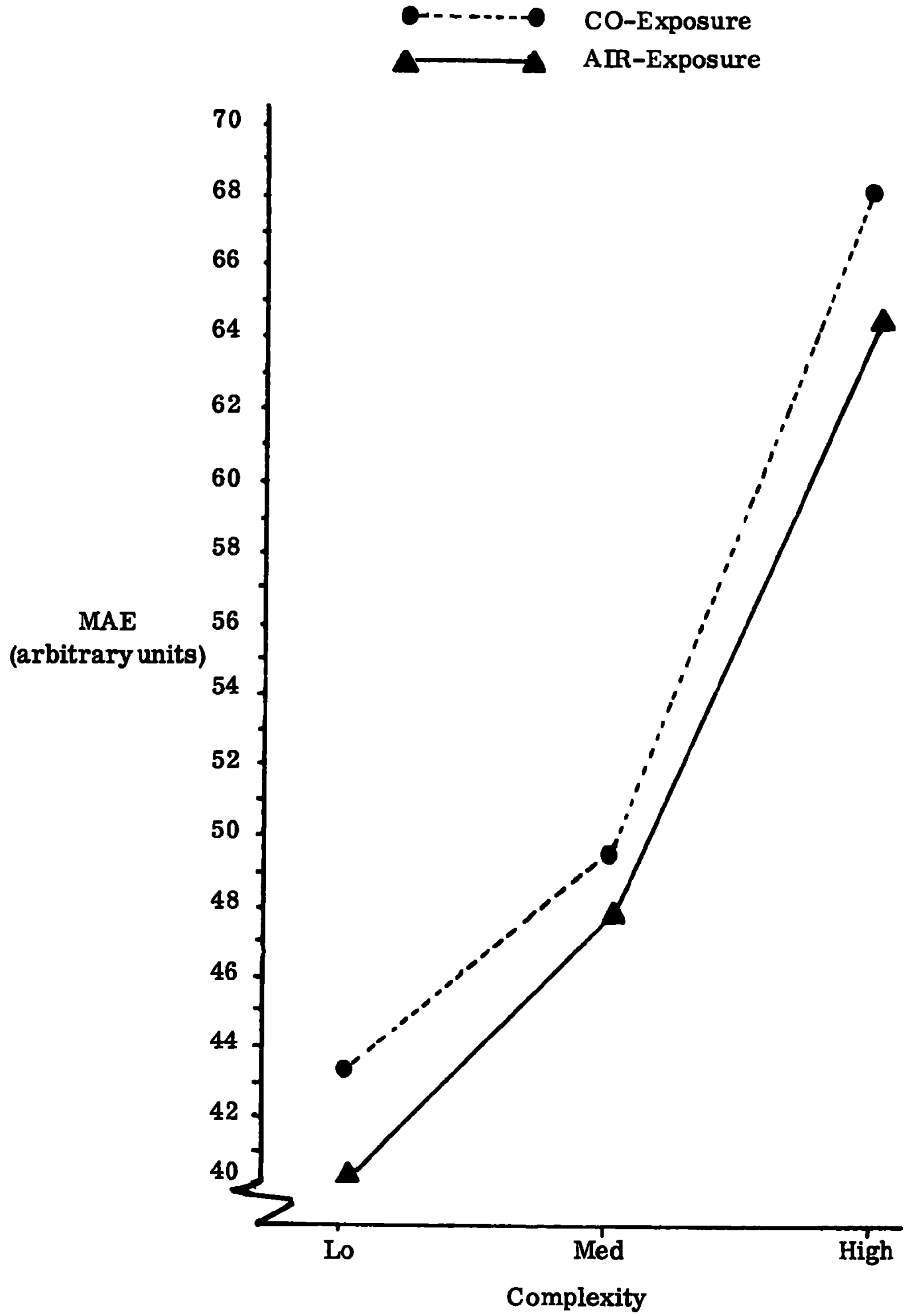

Figure 4.4.--Average mean absolute tracking error (MAE) as a function of the level of tracking complexity and air-CO exposure

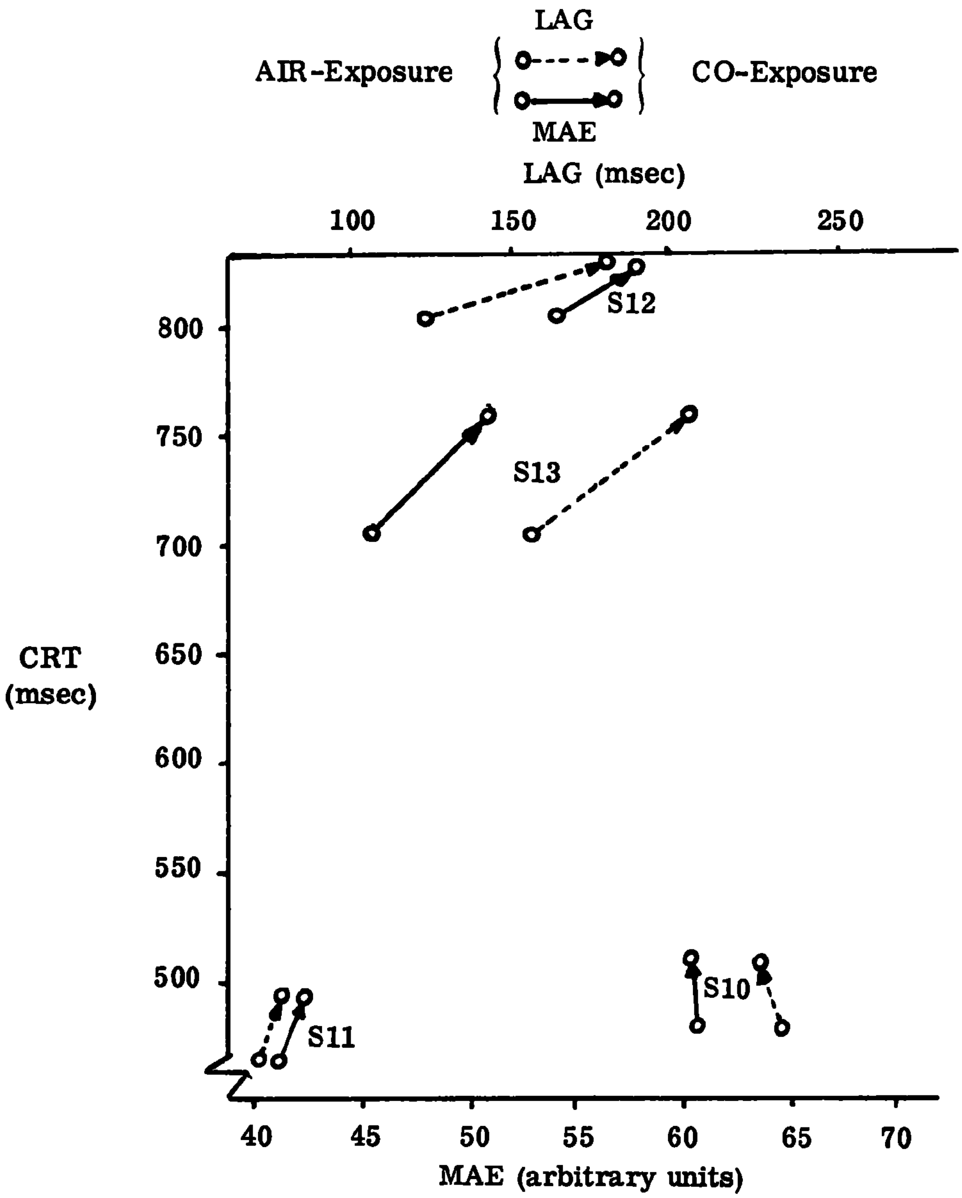

Figure 4.5.--Mean choice reaction time (CRT) versus average mean absolute tracking error (MAE) and mean tracking time-lag (LAG)

and CRT performance to become deteriorated due to CO effects over air. The results suggest that subjects do not always maintain primary task performance (MAE) at the expense of secondary task performance (CRT). Dual task research often indicates that despite instructions, subjects will often choose their own strategy (rarely a cognitive decision). The important point is that subjects, although not aware of the air versus CO condition, suffered performance loss under CO in one or both of the tasks.

4.4.3 Tracking Time Lags

Lag time effects (i.e., the time between target and cursor movement) were much the same as MAE results. These corresponding trade-offs between lag times and mean absolute errors for the same four subjects are illustrated in Figure 4.6. As a single dimensional response, the mean tracking time lags as functions of tracking complexity and COHb level are presented in Figure 4.7. Notice in this case, the apparent COHb effect coupled with an interaction effect of COHb with complexity. The magnitude of the COHb effect was diminished with increased tracking complexity levels.

4.5 Summary of Phase B Results

The data from the Phase B tests suggest that mild decrements in performance of the time shared psychomotor task (T11) can be expected with 20% COHb levels. Performance of the choice reaction task (T9) alone was also observed to deteriorate somewhat with 20% COHb levels. In contrast, performance did not deteriorate with 20% COHb levels in the pursuit tracking task, T10, when it was performed alone (Figure not presented).

This inconsistency of individual tasks to demonstrate 20% COHb effects confirmed the necessity for considering dualtask techniques in the future Phases C and D. The subjects were observed to trade-off performance on the tracking task for performance on the choice reaction time task as the tracking task became more complex. This behavior seemed to be an attempt to optimize total task performance by attending less to the most difficult (tracking) task and more to the CRT task even though the subjects had been instructed otherwise.

It is also important to observe the consistent (additive) effect on performance of all the tasks due to driving exposure. There was no evidence of a synergistic degradation in performance after driving with 20% COHb.

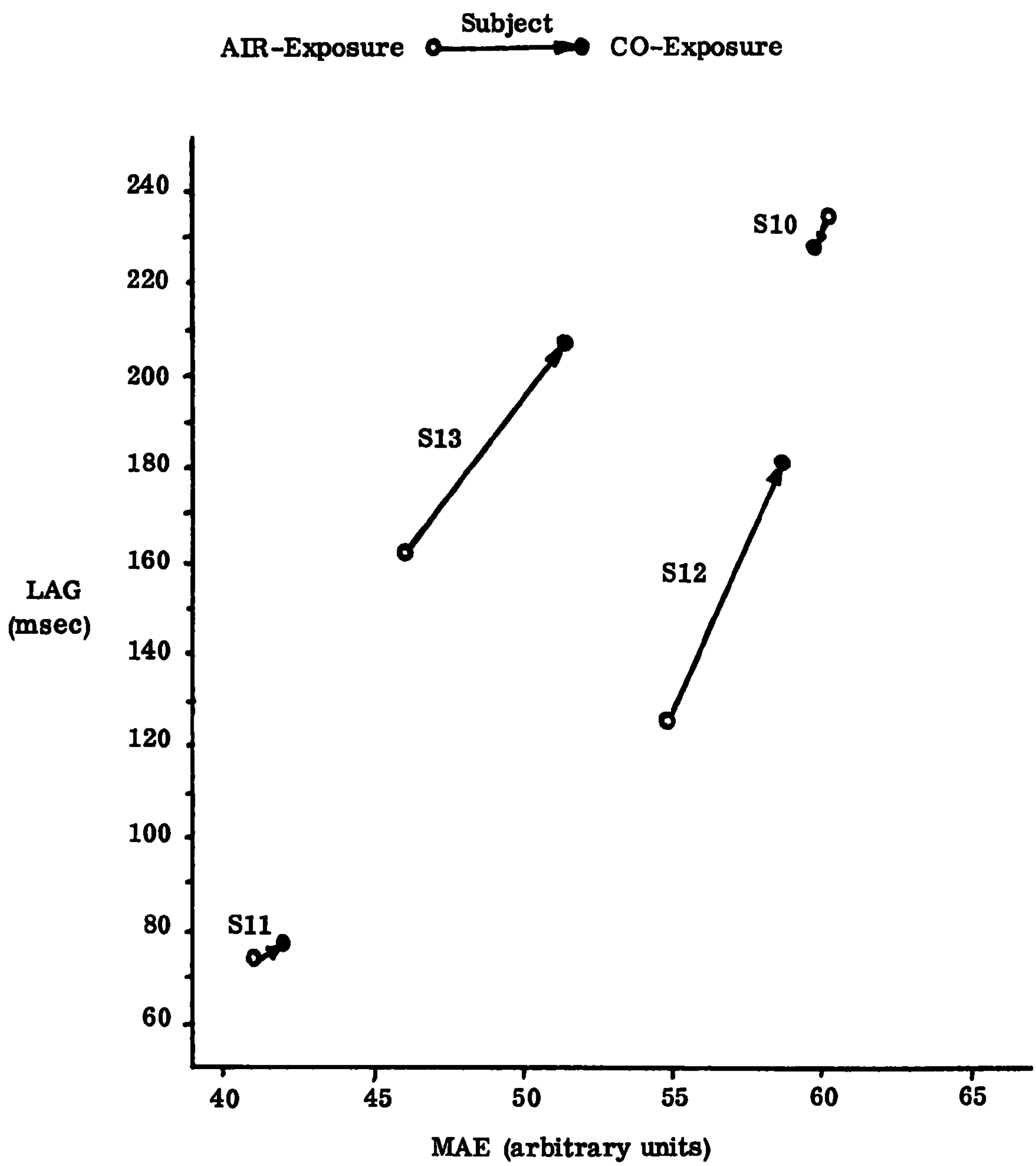

Figure 4.6.--Mean tracking time-lag (LAG) versus average mean absolute tracking error (MAE)

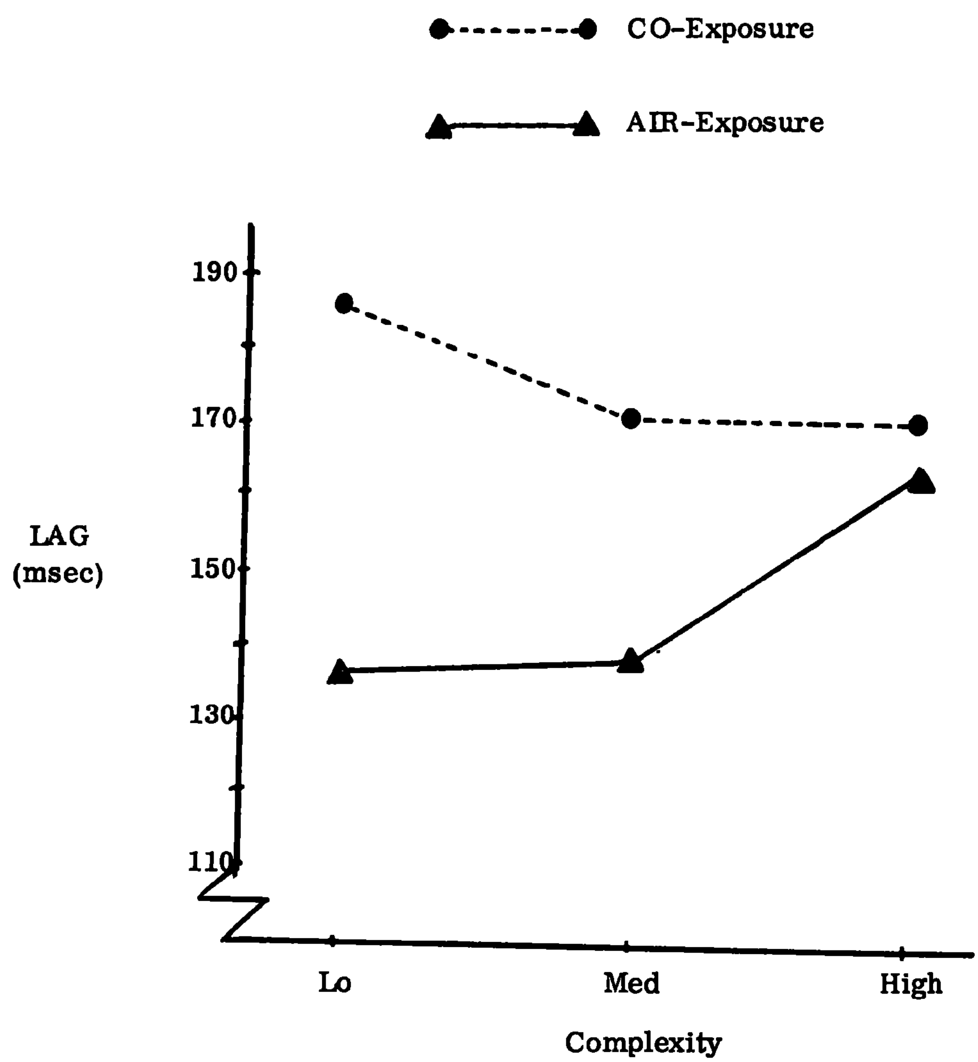

Figure 4.7.--Mean tracking time-lag (LAG) as a function of the level of tracking complexity and the air and CO exposure

CHAPTER 5

COMPLEX LABORATORY TASKS WITH 7 AND 14% COHb

During the second year of this research, the previously discussed psychomotor tests (developed in year 1) were again employed to ascertain whether noticed COHb effects with 20% levels would be preserved with lower levels of nominally 7% and 14% COHb.

Complete descriptions of the tasks employed may be found in Chapter 4 while instrumentation and subject instructions may be found in Appendix A. Since the majority of the effects of 20% COHb (Phases A and B) were found in dual task loading (T11), the analyses of the following section are confined to the dual task data of Phases C and D.

5.1 Results

Of primary importance in this series of tests was the possible deterioration of performance in the dual task since this was found at 20% COHb levels. Data for 15 subjects from two phases (Phases C and D) were combined for analysis of choice reaction times and mean absolute errors for the dual task.

Table 5.1 presents an analysis of variance for the choice response times observed as a function of COHb level (M) (treated nominally as 0, 7, and 14%). This analysis shows no significant effect ($p < .75$) due to COHb level. This is due to a large differential subject by COHb (S x M) error. As might be expected with choice reaction times, the CRT complexity (stimulus set size, C) did significantly affect performance ($p > .99$), while MAE complexity (tracking complexity, T) did not ($p < .75$). Also, there were no apparent COHb by tracking complexity (M x T) or COHb by stimulus set size (M x C) effects ($p < .75$ for both).

Table 5.2 presents a similar analysis for mean absolute error scores. Again, subjects are most variable. No significant ($p < .75$) effects are evidenced due to COHb level due to a large apparent interactive subject by COHb level (S x M) effect ($p > .99$). Also, as expected, there is a highly significant ($p > .99$) relation between tracking complexity (T) and mean absolute error scores, with negligible effect due to stimulus set size ($p < .75$). Finally, there is no evidence of differential COHb by tracking complexity (M x T) or stimulus set size (M x C) effects ($p < .75$ for both).

Table 5.1

Analysis of Variance of Choice Reaction Time, Phases C and D, 15 Subjects

Source	df	SS	MS	F	p
Subjects (S)	14	9.81×10^6	7.0×10^5	82	>.99
COHb (M)	2	36,639	18,319	<1	<.75
S x M	28	1.4×10^6	48,169	5.6	>.99
Tracking Complexity (T)	2	9,046	4,523	<1	<.75
Stimulus Set Size (C)	2	664,048	332,024	39	>.99
T x C	4	125,998	31.499	3.7	>.99
M x T	4	38,641	9,660	1.1	<.75
M x C	4	15,129	3,782	<1	<.75
Residual	344	2.937×10^6	8,537		
Total	404	1.499×10^7			

Table 5.2

Analysis of Variance of Mean Absolute Error, Phases C and D, 15 Subjects

Source	df	SS	MS	F	p
Subjects (S)	14	55,498	3,964	106	>.99
COHb (M)	2	327	163	< 1	<.75
S x M	28	5,194	186	4.97	>.99
Tracking Complexity (T)	2	15,223	7,611	203	>.99
Stimulus Set Size (C)	2	32	16	< 1	<.75
T x C	4	69	17	< 1	<.75
M x T	4	150	38	1.02	<.75
M x C	4	133	33	< 1	<.75
Residual	344	12,872	37.4		

The existence of a large subject by COHb level interactions suggest four possible explanations (in both the choice reaction time and mean absolute error data):

1. there are fixed learning effects (day effects) confounding this interaction effect,
2. S x M is really random day to day variation by subjects,
3. there are groupings of subjects who predictably exhibit either better or worse performance, or
4. combinations of the above.

To examine the first possibility, the data were analyzed with the model:

$$E\ (\text{performance}) = \mu + S_i + D_j + b_0\text{COHb} + b_1(\text{COHb})^2.$$

For this model, the expected performance is a function of some mean (μ), subject effect (S), day or learning effect (D), and linear and quadratic COHb effects. For analysis purposes, data for the nine combinations of tracking complexity and stimulus set size were averaged by subject and day. COHb level was treated quantitatively by actual level observed. Analyses of variances for this model for choice reaction times and mean absolute errors are presented in Tables 5.3 and 5.4, respectively. Neither analysis indicates a significant learning (or day) effect, so suggestion 1 does not explain the large subject by COHb (S x M) interaction.

Table 5.3

Analysis of Variance of Choice Reaction Time Data
Adjusting for Learning Effects

Source	df	SS	MS	F	p
Subjects	14	1.4	.100	17.8	>.99
Days	2	10.7×10^{-4}	$.54\times10^{-3}$	<1	<.75
CO	1	4.9×10^{-3}	4.9×10^{-3}	<1	<.75
CO^2	1	3.4×10^{-3}	3.4×10^{-3}	<1	<.75
Residual	25	.140	5.6×10^{-3}		
Total	43	1.548			

Table 5.4

Analysis of Variance of Mean Absolute Errors
Adjusting for Learning Effects

Source	df	SS	MS	F	p
Subjects	14	2803	200.2	8.4	>.99
Days	2	75	37.5	1.6	<.75
CO	1	137	137	5.8	>.95
CO^2	1	30	30	1.26	<.75
Residual	25	595	23.8		
Total	43	3641			

To examine the data for possible groupings of subjects who predictably exhibit better or worse performance with COHb, each S x M (subject by COHb) interaction effect (14 x 2 = 28 effects) were determined with the pooled data.

These effects are presented in Table 5.5. By chance, we would expect 1.4 of the interactions under choice reaction time to be outside ± .062 (two standard deviations) or under mean absolute error outside ± 4.1. These critical values are circled in the table illustrating the lack of assignable groupings to subject by COHb effects. Thus, it may be concluded that the large subject by COHb effects found in Tables 5.1 and 5.2 may be more accurately viewed as random, day to day, variation of subjects (i.e., intra-subject variability).

Figure 5.1 illustrates the inconsistency of the COHb level effects on choice reaction times in the dual tasks. There is an apparent reduction in choice reaction times from the 0% to 7% COHb conditions (perhaps a relaxing effect) followed by an increase in reaction times from the 7% to the 14% COHb condition. Further, any COHb effects appear to be highly dependent of the level of tracking complexity with the effects most pronounced in the high complexity case. Figure 5.2 illustrates similar results for CRT performance related to stimulus set size and COHb level. In this case, however, there were no apparent COHb by set size interactions (no lack of parallel).

Mean absolute error scores for the three levels of tracking complexity in the dual task (T11) are presented in Figure 5.3. In this case, there were slight linear increases in errors with COHb levels (see Table 5.4).

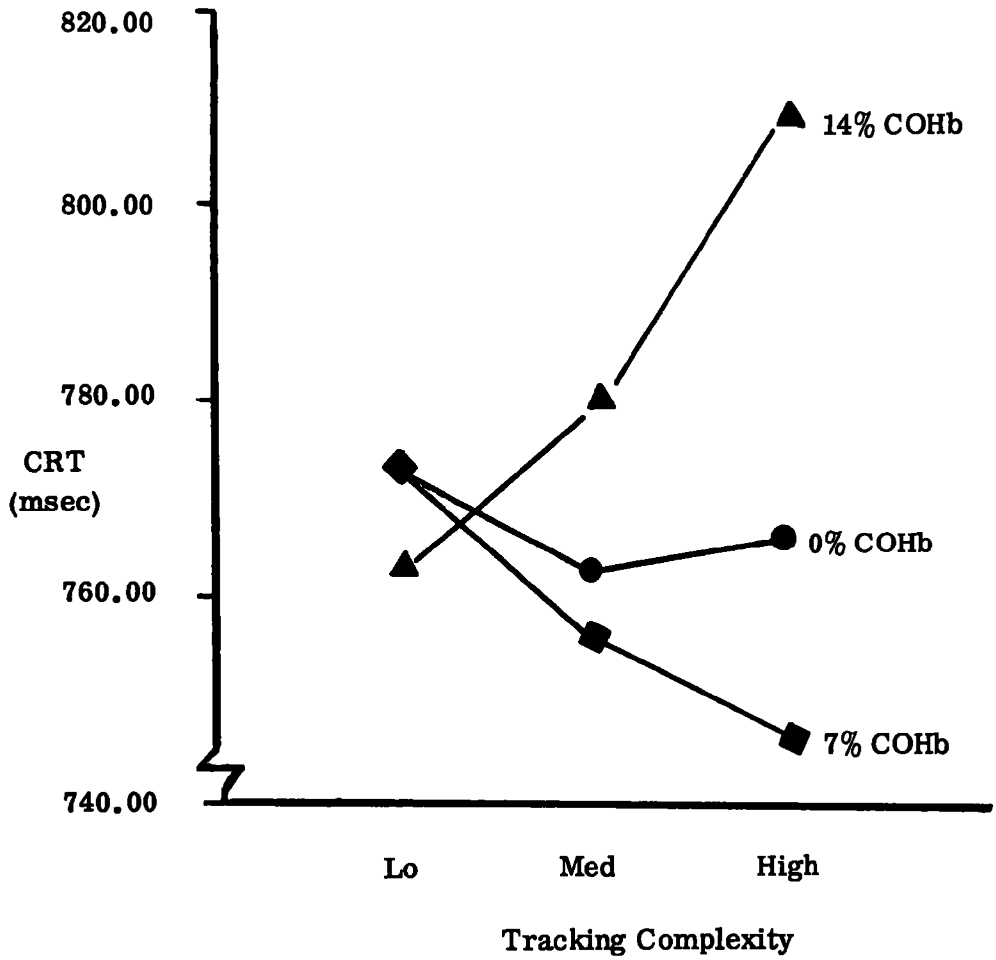

Figure 5.1.--Mean CRT latency as a function of COHb level and tracking complexity

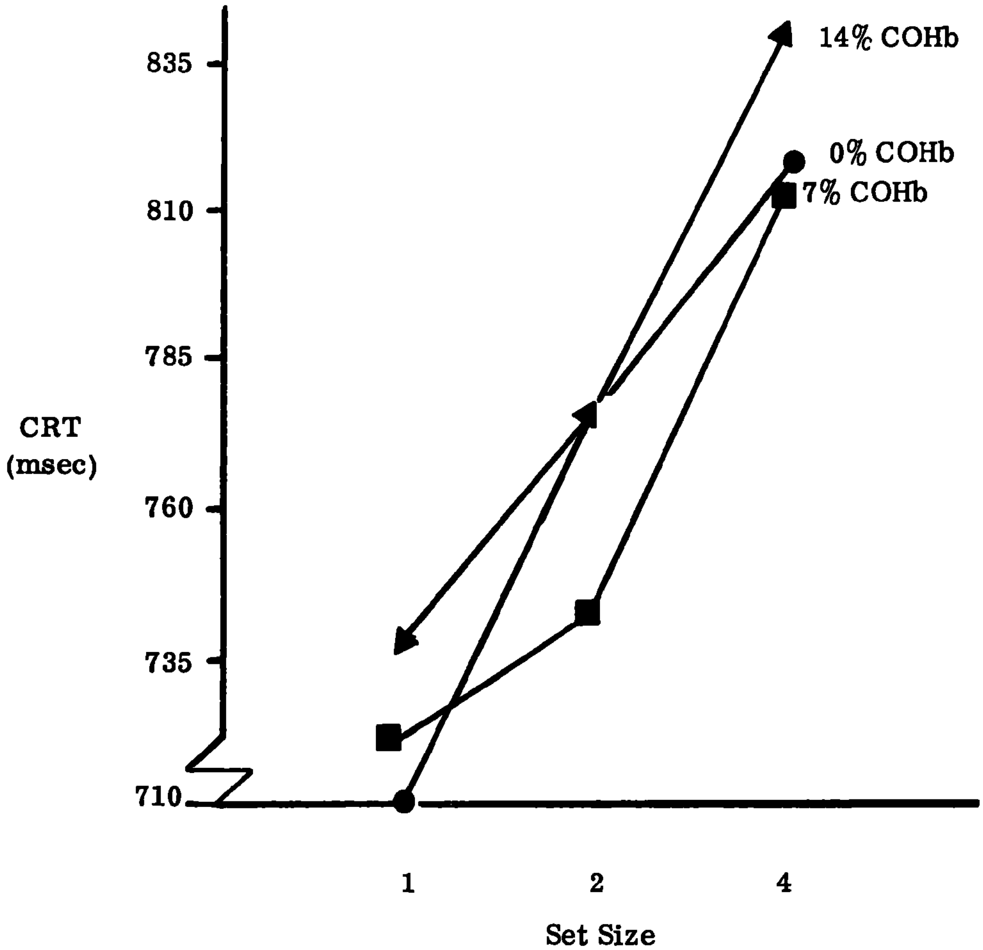

Figure 5.2.--Mean CRT latency as a function of COHb level and stimulus uncertainty

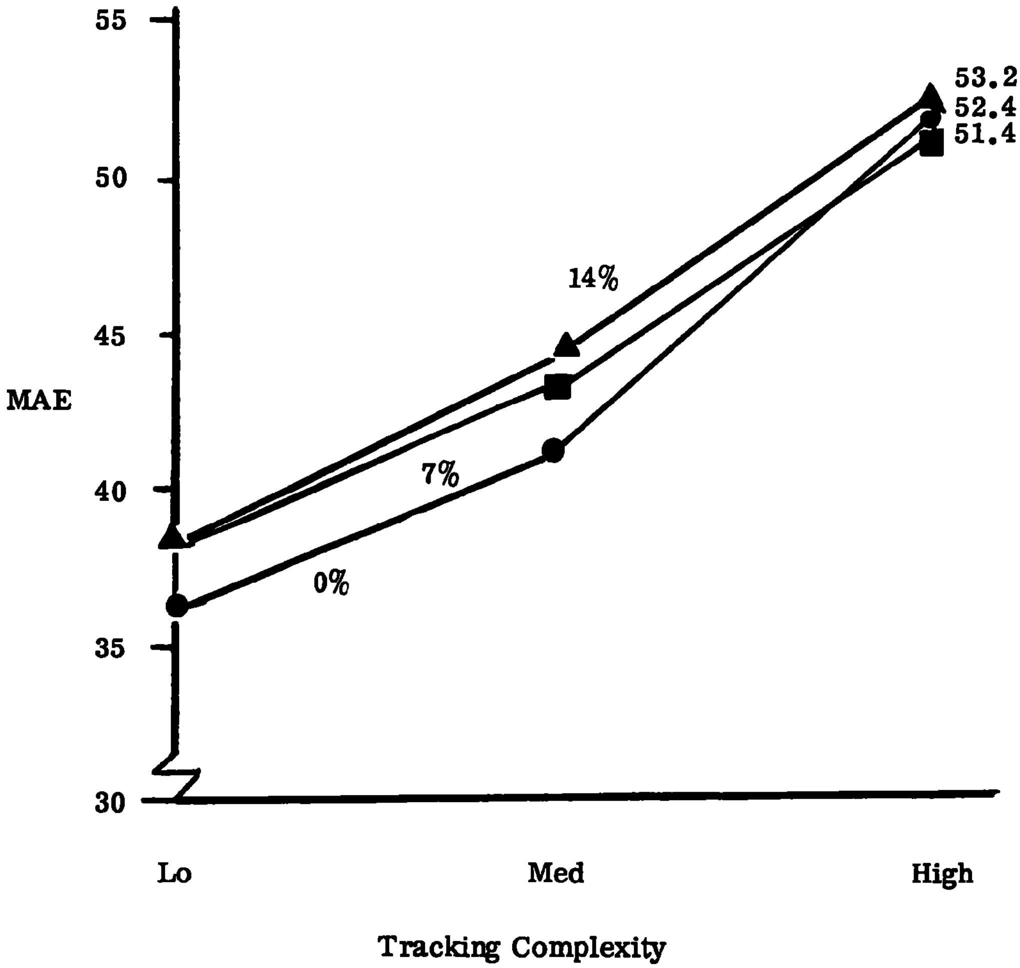

Figure 5.3.--Mean absolute tracking error as a function of the level of tracking complexity and COHb

Table 5.5

Subject by COHb Interactions

	Choice Reaction Time		Mean Absolute Error	
	COHb		COHb	
Subject*	Linear	Quadratic	Linear	Quadratic
1	+ .0795	+ .0405	+ 2.85	+ 1.45
2	- .0550	- .0393	+ 2.70	+ 0.57
3	- .0915	+ .0768	- 7.55	+ 3.35
4	- .0720	+ .0283	- 7.45	- 4.02
5	+ .0140	+ .0037	- 3.15	+ 0.42
6	- .0300	- .0043	+ 0.70	- 2.32
7	+ .0140	+ .0173	- 2.20	+ 0.27
8	- .0170	+ .0093	- 8.90	+ 3.47
9	- .0520	- .0150	- 2.70	- 1.63
10	+ .0610	- .0347	- 3.25	+ 1.32
11	- .0270	+ .0090	+ 0.25	- 0.25
12	+ .0415	- .0052	- 0.40	- 1.27
13	+ .0330	+ .0083	- 1.55	+ 1.12
14	+ .0570	+ .0163	+ 2.30	- 0.17

*Arbitrary subject designation, not corresponding to subject identifiers (i.e., S16-S40).

This is an example of "an effect" which is statistically significant for fixed effects subjects but negligible for random effects subjects (see Table 5.2). Since the data did not suggest an assignable cause to the subject by COHb level interactions, we must assume no real COHb effect exists for nominal 7 and 14% COHb levels.

This non-statistically significant COHb effect is again illustrated in Figure 5.4 in relation to stimulus set size for the dual task data. There was no significant interaction between COHb level and stimulus set size (see Table 5.2) as might be improperly inferred from the apparent lack of parallel in the lines of this figure.

5.2 Summary of Phases C and D

The data collected in these phases with lower COHb levels (nominally 7 and 14%) did not show statistically significant ($p < .75$) effects on reaction times or tracking error scores due to COHb exposure. The lack of "statistical significance" may be attributed to the treatment of subjects as random effects. Analyses treating subjects as fixed effects were performed on the data of Phases C and D with some resulting "COHb effects" significant for $p > .99$.

This apparent paradox was resolved by attempting to find assignable cause for subject by COHb interactions. Since none were formed, it must be concluded that any minor COHb differences are less than the "noise" of intra-subject variability and as such require more careful experimental control for statistical significance. However, since the effects are on the same order of magnitude as intra-subject variation, they may be of less practical significance.

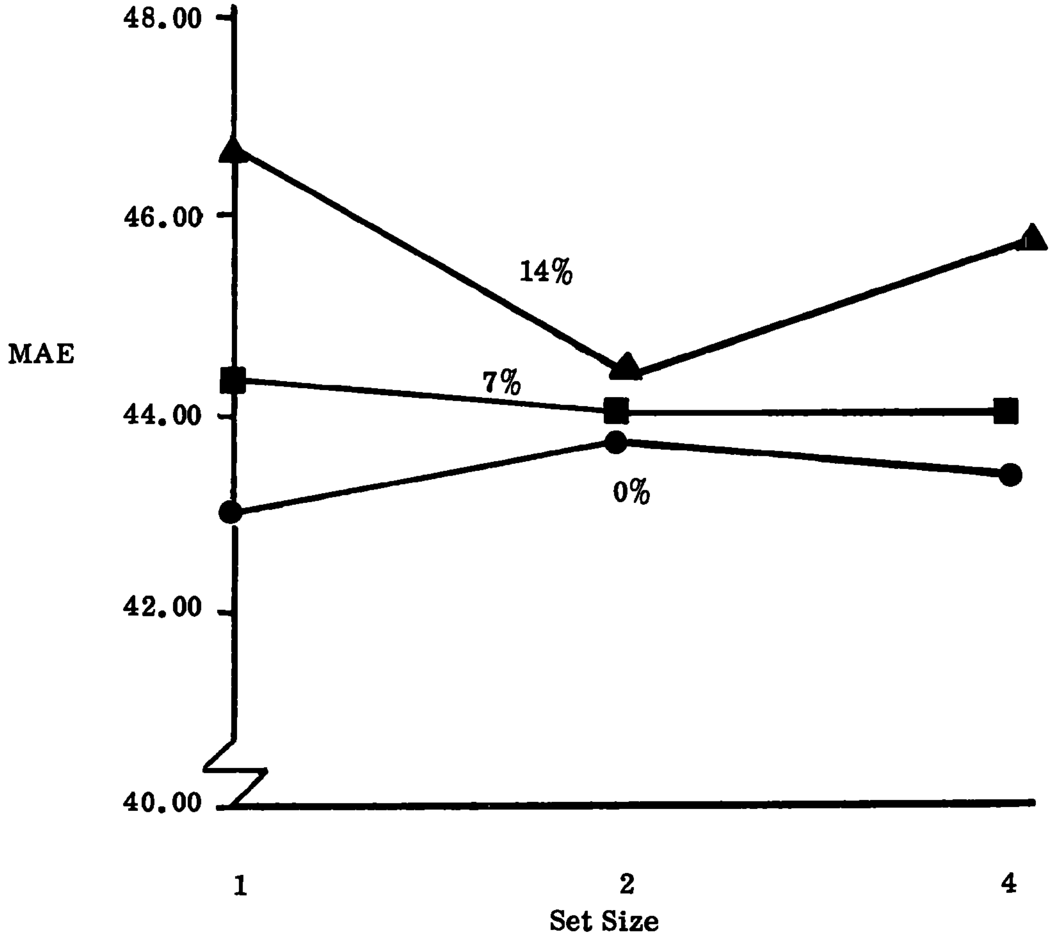

Figure 5.4.--Mean absolute tracking error as a function of COHb level and stimulus uncertainty

CHAPTER 6

DRIVING TASKS WITH 20% COHb

This section describes the series of road tests conducted to determine the effects of nominally 20% COHb on the visual sampling and vehicular control performance of 12 drivers. Of particular interest was the effect of 20% COHb on the ability of 6 drivers to engage in a secondary task of voluntary visual occlusion while driving (Phase A). The additional 6 drivers (Phase B) were tested for similar purposes, except a cognitive loading task was introduced to replace the voluntary visual occlusions. These latter drivers were also tested to determine the effects of 20% COHb on their ability to estimate and produce prescribed target headways and velocities, and to estimate time while driving.

6.1 Independent Variables

The following independent variables were included in the experimental design.

I. Task Loading

1. open road driving at fifty miles per hour,
2. car following--with the lead car maintaining a constant velocity of fifty miles per hour, and
3. car following--with the lead car exhibiting a variable velocity with an average velocity of fifty miles per hour.

II-A. Secondary Loading - 6 Phase A Subjects

1. control--full, unhindered vision, and
2. voluntary visual occlusion--subjects voluntarily closed their eyes whenever possible.

II-B. Secondary Loading - 6 Phase B Subjects

1. control--no cognitive task, and
2. cognitive load--mental arithmetic.

III. COHb Level

1. control--no carbon monoxide administered, and
2. treatment--carbon monoxide in a quantity sufficient to produce nominally 20% COHb.

These independent variables are arrayed in a matrix in Figure 6.1. Each subject utilized in this experimental design participated in six separate tests for each level of COHb employed. The T15 through T20 notation is used to denote the six combinations of task difficulty and secondary loading. Subject instructions for these six tasks are presented in Appendix B.

6.2 Dependent Variables

During both series of tests the following performance measures were taken:

1. mean velocity and velocity variance,
2. gas and brake pedal actuations,
3. steering wheel reversals,
4. mean headway and headway variance over time while car following,
5. relative velocity variance; variability of rate of closure and separation of two vehicles while car following, and
6. visual behavior.

The visual behavior data obtained for each task, subject, and COHb level included:

1. Eye spot fixation location and "look" duration: TV tapes obtained in the experiment were analyzed for each separate "look" at an object or area in the scene and its duration. For purposes of this research the duration of a "look" was defined as the period of time beginning with the appearance of the eye spot on an object or area of interest and ending with the disappearance of the eye spot from that object or area. A "look", therefore, consisted of one or more visual fixations.

2. Variance of duration of "looks" in various visual modes (closed, looking ahead, viewing speedometer, and viewing mirrors).

3. Percent of time the driver spent in various visual modes.

4. Frequency and duration of blinks.

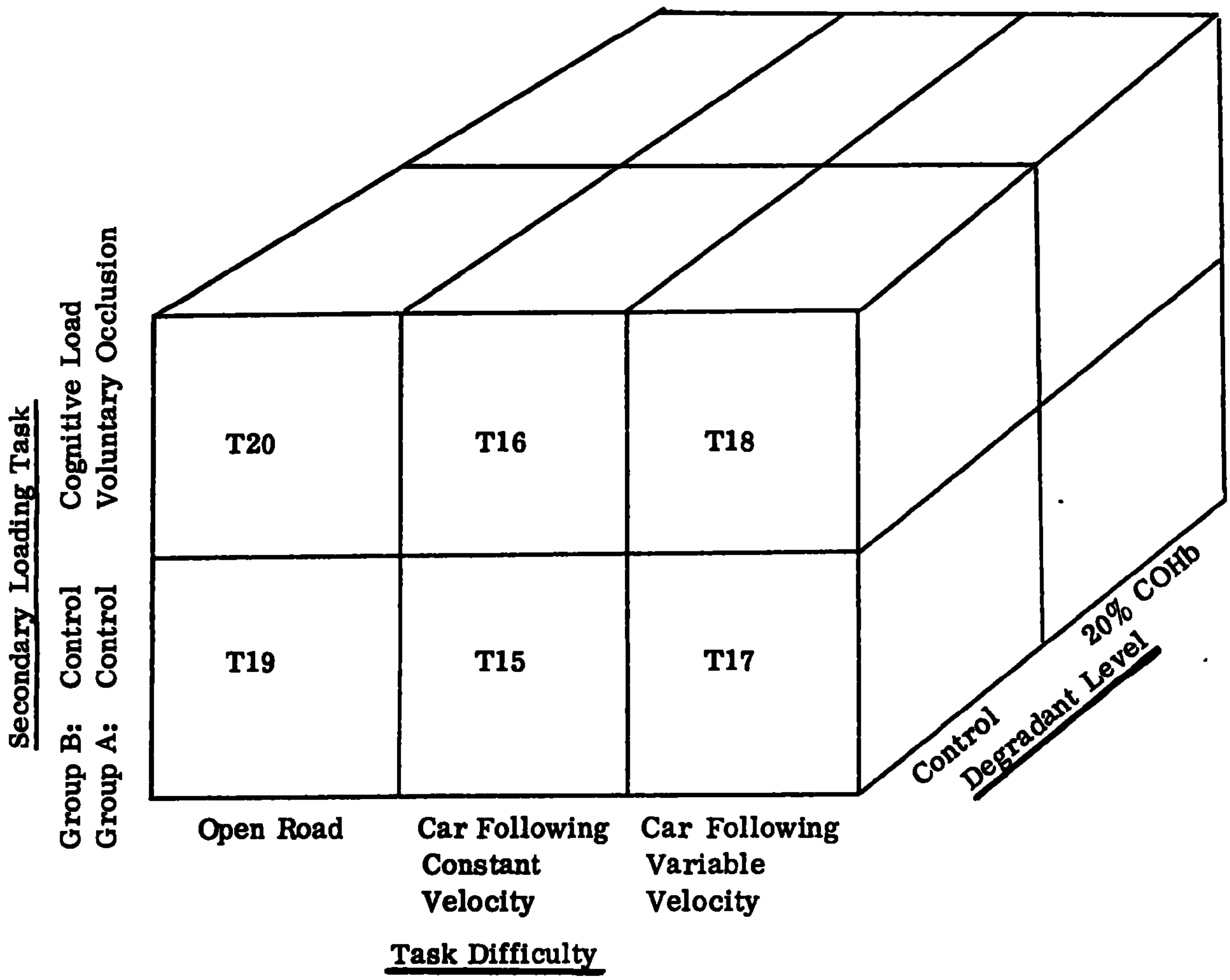

Figure 6.1.--Matrix of independent variables for two groups of six subjects (Phases A and B)

6.3 Equipment

6.3.1 Instrumented Vehicle (1970 Chrysler)

The main instrumented vehicle used in this research (i.e., the vehicle which was driven by the research subjects in all experiments) was a 1970 Chrysler Newport, 4 door sedan.

This vehicle was modified to enable the following parameters to be recorded and monitored:

1. velocity,
2. gas pedal position,
3. brake pedal actuation,
4. headway (using the "yo-yo", described later)
5. relative velocity (using the "yo-yo"), and
6. driver eye movements (using the Systems Research Group's eye-movement equipment, described later).

The above parameters were recorded on a Honeywell model 2206 Visicorder Oscillograph recorder mounted in the vehicle. An auxiliary power brake which was capable of being actuated by the right front seat passenger (the "safety man") was also installed in the vehicle.

6.3.2 Other Instrumented Vehicles

Two other instrumented vehicles were used in this research primarily as lead vehicles in the car-following tasks. These included a 1965 Plymouth station wagon and a 1969 Buick Electra sedan. Both of these vehicles, as well as the 1970 Chrysler described above, were equipped with two-way FM radio transmitter-receivers to enable intervehicular communication.

6.3.3 Oscillograph Recorder

The recorder used in the instrumented vehicle was a Honeywell Model 2206 Visicorder, a portable direct writing oscillograph recorder, capable of recording up to 12 channels of information.

6.3.4 Headway and Relative Velocity Measurement Equipment

Headway (the distance between a lead car and the following instrumented vehicle) and relative velocity were measured in the instrumented vehicle with a device, often referred to as a "yo-yo" which utilizes a 10-inch diameter drum mounted on the front of the instrumented vehicle on which is wound up to

1,000 feet of thin stainless steel wire. One end of the wire on the drum is fastened to the rear of the lead vehicle and the rest is wound on the drum of the yo-yo. The wire is kept in tension by a clutch faced rotating disc powered by a McCulloch Model 49C two stroke gasoline engine. Rotary potentiometers are used to determine how far the drum has turned on its axis and hence, the headway between the two vehicles while a Weston tachometer generator is used to determine the rate at which the drum turns and therefore, enables the realtive velocity between the two vehicles to be determined.

6.3.5 Other Sensors

Several other sensors were mounted on the instrumented vehicle to enable various items of information about vehicle control movements and vehicle performance to be determined. These included:

1. a potentiometer for measuring gas pedal position,
2. a pressure sensitive switch for determining brake pedal actuation, and
3. a tachometer generator attached to the vehicle transmission to enable vehicle velocity to be determined.

6.3.6 Television Eye-Marker System

A major instrumentation system used in this research was a television eye-marker system. This system is basically composed of closed circuit television components connected in such a manner that it is possible to simultaneously photograph and record the scene in front of an automobile driver and a small dot of light indicating the point on that scene on which the driver is foveally fixating.

The stability of the eye-movement recording device is due primarily to the helmet worn by each subject participating in the research. This helmet consists of a light-weight epoxy outer shell and a light-weight polyurethane inner shell molded to fit the subject's head. This helmet is attached to the subject's head and is stabilized using a "bite bar" with a custom molded dental impression connected to the helmet via adjustable side braces. This helmet enables the weight of the attached "eye marker" equipment to be distributed uniformly over the driver's skull.

A Shibaden model HV-50S television camera is attached to the left side of the helmet mounted on the subject's head and is used to photograph the roadway in front of the driver.

A lens system mounted on the right side of the helmet picks up the reflection of a light, also positioned on the right side of the helmet, off the cornea of the subject driver's right eye. This corneal reflection is transmitted by a coherent fiber optic cable to a Shibaden model HV-15 closed circuit TV camera mounted on the floor of the instrumented vehicle where it is photographed.

A third television camera, a Shibaden model HV-15, photographs a picture of the driver's eye and the face of an accurate electric clock with a digital readout in increments of 50 milliseconds. A more complete description of this television eye-marker system may be found in Rockwell, et al., (1972).

6.4 Results

The results of the various analyses performed on the data collected with the first group (Phase A) of subjects are presented in this section of the report.

6.4.1 Spare Capacity Analysis

Of primary importance in this series of tests was the determination of the spare visual capacity of the drivers for the various drivers for various driving situations considered in the experiments and the effects of 20% carboxyhemoglobin on this spare capacity.

Requiring the subject to voluntarily occlude his vision (close his eyes) was used as a means to determine his spare visual capacity. Voluntary visual occlusions were recorded for the three tasks: open road driving, constant car following, and variable car following. Spare capacity will be defined as the percentage of time that a driver kept his eyes closed for each task.

An analysis of spare visual capacity by subject and trial is presented in Table 6.1. As can be seen from this table, subjects' abilities differed but performance was fairly stable for each subject. Task difficulty also had an effect on spare capacity. As can be seen from the table, only 8 out of 14 possible 20% COHb versus 0% COHb comparisons indicated a reduction in spare capacity available to the subject with increased COHb.

An analysis of variance for spare capacity, percent occlusion time, showed effects due to tasks and decrement associated with the 20% COHb level were marginally significant ($p > .75$). Though not statistically significant, there was an obvious trend (reduction) in average spare visual capacity. Table 6.2 illustrates the changes in spare capacity averaged across subjects.

Table 6.1

Spare Capacity as a Function of Percent of Time that Subjects Kept their Eyes Closed (voluntarily occluded their vision)

Subject	S_2		S_3		S_4		S_5		S_6		S_7	
Task \ Gas	Air	CO	Air	CO	Air	CO	Air	CO	Air	CO	Air	CO
T15: Constant Car Following	82.0	80.9	81.1	55.2	26.0	NA	35.0	44.2	60.9	46.4	54.4	56.1
T17: Variable Car Following	87.1	79.7	81.1	NA	21.6	NA	35.1	36.3	36.1	25.5	54.5	60.1
T19: Open Road	75.4	83.4	86.1	62.6	15.4	NA	49.4	57.5	58.3	42.3	61.3	58.7

NA: Not Available

Table 6.2

Spare Capacity as a Function of the Percent of Time that Subject Drivers Were Able to Close Their Eyes (Occlude Their Vision) While Driving

Test	Gas + Mode	Air	CO	% change
T16	Constant Car Following	62.7	56.6	~ 10%
T18	Variable Car Following	59.0	50.4	~ 15%
T20	Open Road	66.1	60.4	~ 10%

6.4.2 Occlusion Time and Open Time Analyses

For the voluntary occlusion tasks (T16, T18, T20), the mean and variance of occlusion and open periods was claculated.

Open periods (any time eyes were not closed) may be considered time required to obtain information while occluded time is the interlook interval in which no visual information is obtained from the environment in front of the driver.

Analyses of variance for these measures indicated:

1. differences in the mean occlusion time due to subjects and tasks ($p > .99$), but no significant ($p < .75$) changes with 20% COHb, and

2. differences in mean "open" periods were significantly higher for 20% COHb conditions than for air conditions ($p > .75$). (See Table 6.3.)

Table 6.3

Mean "Open" Time
(seconds)

Subject	S_2		S_3		S_5		S_6		S_7	
Task \ Gas	Air	CO	Air	CO	Air	CO	Air	CO	Air	CO
T15: Constant Car Following	0.68	0.73	3.69	4.40	0.54	1.76	1.80	3.41	3.81	3.23
T17: Perturbated Car Following	0.39	0.66	2.38	3.88	0.44	NA	4.05	4.48	1.69	1.61
T19: Open Road	1.22	0.63	2.33	2.76	0.39	0.50	1.79	3.67	2.52	2.78

6.4.3 Means and Variances of "Look" Durations

The average time spent looking at the highway was determined for each subject, task, and COHb level.

Means and variances of these "looks" were computed for nonocclusion tasks (T15, T17, T19). The mean duration of looks were compared across CO levels for each subject and task and the percentage of these comparisons that were longer with CO than with air was computed. This data is summarized in the matrix of Table 6.4. As can be seen from the table, 18 out of 29 of these percentages ($p > .95$) were greater than 50%. This indicates that under COHb, the subjects spent more time per look obtaining information from the objects and areas in their environment.

A similar analysis was performed on the variances of the "look" duration times. It was found that 48.3% of the values were greater than 50% while 24.5% were less than 50%. This indicated that the variability of "look" times under 20% COHb levels for all categories (except blinks, out of view, speedometer and rear mirror) was greater than under air.

Table 6.4

Percentage of Time that the Mean Duration Time for "Looks" at Different Objects or Areas Greater Under CO than Under Air

Task \ Subject	S2	S3	S5	S6	S7
T15	100%	--	67%	45%	57%
T16	100%	67%	83%	50%	86%
T17	0%	50%	60%	40%	67%
T18	67%	100%	67%	40%	67%
T19	80%	100%	70%	29%	75%
T20	0%	100%	50%	50%	50%

6.4.4 Visual Information Acquisition in Car Following

Table 6.5 presents data for the number of visual fixations made on the lead car in car-following tests for each subject at both levels of COHb. Table 6.6 presents data for the number of visual fixations made in all other categories except "lead car".

As can be seen from these tables CO was associated with increased looks at the lead car to obtain information about position. This is particularly evident in the data on Task 18 where the subject's spare visual capacity was eliminated through occlusion. CO also had the effect of reducing the number of looks that were made on other categories and areas away from the lead car. Again this was particularly apparent when the excess visual capacity was eliminated through occlusion.

The data included in Table 6.5 was subjected to a three factor analyses of variance. Differences due to tasks and subject were both significant ($p > .95$) and differences between levels of carbon monoxide were significant for $p > .90$.

The data of Table 6.6 was also subjected to a similar analysis which indicated differences due to the subjects ($p > .90$) and COHb level ($p > .75$). Differences due to the task difficulty were not found to be statistically significant ($p < .75$). Interactions involving the presence or absence of CO (i.e., the trial by "environment" and the subject by "environment" interaction) were marginally significant ($p = .75$). This analysis indicates a need for increased foveal concentration on the lead car due to the presence of COHb.

6.4.5 Blink Analysis

Eye blink rates have been found by researchers to be related to the stress associated with a task. Poulton and Gregory (1952) found that blink rate varied inversely with the difficulty of a tracking task (i.e., increased difficulty in the tracking resulted in a decreased blink rate).

Eye blinks were recorded and analyzed in this research study. For purposes of analysis, the data from Tasks 16, 18, and 20 was deleted since these tasks required the subjects to engage in voluntary visual occlusions. The data are displayed in Table 6.7. A three factor analyses of variance was performed on these blink rate data. Reductions in blink rate associated with carbon monoxide were found to be significant ($p > .99$) differences due to subjects and tasks were also significant ($p > .99$ and $p = .75$, respectively). Test by subject interactions and subject by COHb interactions were also found to be significant ($p > .99$).

Table 6.5

Number of Looks at the Lead Car

Subject	S_2		S_3		S_5		S_6		S_7	
Task \ Gas	Air	CO	Air	CO	Air	CO	Air	CO	Air	CO
T17: Variable Car Following Normal Vision	73	56	98	124	66	68	83	103	47	53
T18: Perturbated Car Following Occlusions	30	68	67	103	57	56	47	78	52	48
TOTALS	103	124	165	227	123	124	130	181	99	101

Table 6.6

Number of Looks at Categories Other than Lead Car

Subject	S_2		S_3		S_5		S_6		S_7	
Task \ Gas	Air	CO	Air	CO	Air	CO	Air	CO	Air	CO
T17: Variable Car Following Normal Vision	23	38	6	8	53	25	20	23	2	3
T18: Varible Car Following Occlusion	38	1	2	2	70	3	13	13	2	12
TOTALS	61	39	8	10	123	28	33	36	4	15

Table 6.7

Blink Rate Analysis
(Rate = Average per 3 minute period)

Subject / Task \ Gas	S_2		S_3		S_5		S_6		S_7	
	Air	CO	Air	CO	Air	CO	Air	CO	Air	CO
T15: Constant Car Following	14	24	73*	37*	61	52	82	53	88	28
T17: Variable Car Following	20	40	76	52	36	34	70	47	48	11
T19: Open Road	17*	32*	71	23	85	91	88	62	26	22
TOTALS	51	96	220	112	182	177	240	162	152	61

* Average value computed for analysis purposes.

These blink rates are, as mentioned, primarily indicators of stress and by themselves do not indicate performance decrement. They are, however, useful for comparing different conditions which a driver might be subjected to.

6.4.6 Gas and Brake Pedal Movements

Two control related variables which were considered in this series of experiments were the gas pedal actuation behavior and the brake pedal actuation behavior of the drivers. It was hypothesized that the number of brake applications and the number of gas pedal releases (periods of time in which the driver took his foot off the gas) as well as the number of gas pedal reversals would be related to task difficulty, secondary task loading, and differences in the level of the COHb.

The number of gas pedal reversals (i.e., measured by the number of times that the slope of the gas pedal trace changed sign) exhibited by the subjects in each of the tasks was obtained. Table 6.8 summarizes this data for combined subjects. As can be seen from the data, the measure of gas pedal reversals seems to be a measure that is sensitive to task difficulty, loading, and the presence of COHb. The results of a three-factor analysis of variance indicated that gas pedal reversals were significantly different for the two CO levels ($p > .975$). Tasks and the presence or absence of spare capacity also showed significant effects ($p > .99$). One interaction, the task by "loading" interaction, was found to be significant ($p > .95$). The other two interactions, test by CO and CO by loading were of marginal significance ($p = .75$).

Table 6.8

Gas Pedal Reversals Summary for all Subjects Combined
(reversals per 3 minute period)

	Air		20% COHb	
	Normal Vision	Occluded Vision	Normal Vision	Occluded Vision
T15: Constant Car Following	65.6	38.2	57.5	26.8
T17: Perturbated Car Following	65.7	44.0	64.0	39.2
T19: Open Road	16.8	12.7	21.5	7.5
Column Total	148.1	84.9	143.0	73.5
Combined Total	233.0		216.5	

6.4.7 Headway Analysis

The mean headways exhibited by the subjects while car following were derived and an analysis of variance performed to test for effects due to differences in COHb levels. The analysis failed to indicate any differences due to CO ($p < .75$) when all subjects were aggregated. Some interesting trends were apparent in the data, however, for individual subject's differences between CO and air.

It was found that under elevated carbon monoxide levels, subjects drove with shorter mean headways for "variable car following" tests than they did for "constant car following" tests. (Eight out of ten comparisons of "variable car following headway means" with "constant car following headway means" indicated this tendency.) This is the opposite of what was found under the control condition and could be interpreted as a failure to compensate for increased task difficulty under CO (see Table 6.9).

6.5 Phase B Analyses

The analyses of Phase B road tests indicated that the secondary cognitive loading tasks did not produce the sensitivity to performance that found from the secondary voluntary occlusions in Phase A.

Since no eye-movement data was collected in Phase B, emphasis was placed on driver input measures. No statistical difference in the speed and accuracy of the cognitive tasks were noted with respect to CO, although the trend was that subjects completed fewer cognitive tasks under 20% COHb. Gas and brake pedal applications did not appear to be sensitive to 20% COHb.

It was surprising to note little change in the psychophysical tests of time, velocity, and head production (estimation) between the air and CO conditions. Laboratory tests confirmed the lack of time estimation changes due to 20% COHb. The same intervals, 2, 4, and 8 seconds were employed both in the lab and on the road.

Table 6.9

Mean Headway Analysis
(Headway in feet separation)

Subject	S_2		S_3		S_5		S_6		S_7	
Task \ Gas	Air	CO	Air	CO	Air	CO	Air	CO	Air	CO
T15: Constant Car Following Normal Vision	47.5-	66.4	47.5+	33.05	84.1+	57.4	132.3-	166.0	76.3-	163.9
T16: Constant Car Following Voluntary Occlusion	125.7+	123.5	55.3+	42.38	137.6-	249.4	246.6-	393.1	114.9+	99.1
T17: Perturbated Car Following Normal Vision	87.8+	59.5	45.6+	19.62	115.7+	45.0	130.2-	150.7	61.2+	53.3
T18: Perturbated Car Following Voluntary Occlusion	180.8+	79.8	68.5+	56.58	147.4-	294.6	198.6+	152.7	97.8+	87.7
	HEADWAY MEANS									

Note: (+) sign indicates longer headway under air

In general, it may be argued that effects due to 20% COHb are subtle in driving and show up only when subjects are realistically secondary task loaded. Perceptual changes, however, are more readily sensitive to CO as might be expected. These perceptual effects can be compensated for by the driver provided he has time to adapt. If task loading is applied, apparently his adaptation is impaired and CO effects become more apparent. This was noted with respect to gas pedal reversals, for example, in Phase A.

6.6 Summary of Results

The major results of these Phase A and B experiments are presented below.

1. The measure of visual spare capacity (i.e., the percentage of time that a driver was able to keep his eyes closed) was found to be sensitive to 20% carboxyhemoglobin and task difficulty. Both were associated with decreases in spare capacity ($p > .75$ for both).

2. Twenty percent carboxyhemoglobin levels were associated with increases in the "mean eye open" time in occlusion tasks ($p > .75$).

3. Twenty percent carboxyhemoglobin was related to increased mean "look" durations (i.e., the length of time the driver looked at an object or area in his field of view) for automobile drivers ($p > .95$).

4. Variance of "look" times also increased with 20% CO ($p > .95$).

5. Carbon monoxide was also associated with an increase in the frequency of visual fixations on the lead car in car following which at the same time caused a decrease in the frequency of fixations on objects or areas other than the lead car ($p > .90$).

6. Blink rates which were measured in the experiments were found to reflect the stress associated with 20% COHb and task loading ($p > .99$ for both).

7. Control actuation was also found to be sensitive to independent variables of interest. With respect to gas pedal reversals, task difficulty increased the number of observed reversals while 20% COHb levels and the elimination of spare capacity resulted in a reduction in the number of gas pedal reversals ($p > .99$, $p > .975$, $p > .99$, respectively).

CHAPTER 7

DRIVING TASKS WITH 7 AND 14% COHb

This chapter describes the series of road tests conducted to determine the possible effects of COHb at nominally three levels (0%, 7%, and 14%) on the visual sampling and vehicular control performance of 18 additional drivers.

7.1 Equipment

The equipment used in this testing was identical to that of Phases A and B. The description of the equipment and their capability will not be reiterated here but may be found in Chapter 6.

7.2 Independent Variables

In Phases C and D, eighteen drivers were tested on each of three test days, usually separated by one week. On each test day, each subject performed eight tests (denoted T17-T24), over a two-hour period of driving. As shown in Figure 7.1, subjects were paired for CO treatments by day. For example, subjects 29 and 23 were together administered carbon monoxide sufficient to produce 7% COHb on the second day (D2) they were tested. Subject 29 was tested in the morning on the road tests so he is further typed AM. Subject 23 performed lab tests in the morning so to examine possible "fatigue" differences when tested on the road in the afternoon; he is typed PM.

Basically, the tasks employed in both Phases C and D may be summarized as follows:

T17 - variable car following, average speed 50 mph, test driver with normal vision *

T18 - variable car following, average speed 50 mph, test driver asked to voluntarily close his eyes whenever possible

T19 - open-road driving, target speed 50 mph, test driver with normal vision

T20 - open-road driving, target speed 50 mph, test driver voluntary visual occlusion

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*Normal vision refers to drivers employing normal search and scan patterns for the task at hand.

Subjects

Phase D	Phase C	Type	Nominal CO Level 0%	7%	14%
S39	S26	AM	D_1	D_3	D_2
S36	S20	PM			
S38	S27	AM	D_2	D_1	D_3
S35	S21	PM			
S40	S29	AM	D_3	D_2	D_1
S37	S23	PM			
	S28	AM	D_3	D_1	D_2
	S22	PM			
	S31	AM	D_2	D_3	D_1
	S25	PM			
	S30	AM	D_1	D_2	D_3
	S24	PM			

Tasks 17-24

Figure 7.1.--Road Protocol for Phases C and D

T21 - open-road driving, target speed 30 mph, test driver with normal vision

T22 - open-road driving, target speed 30 mph, test driver voluntary visual occlusion

T23 - open-road driving, target speed 50 mph, test driver denied use of speedometer

T24 - leap frog passing

A more complete description of the tasks and subject instructions may be found in Appendix B.

It may be helpful to the reader to view these tasks in a lattice as illustrated in Figure 7.2.

	NORMAL VISION	VOLUNTARY OCCLUSION	NO SPEEDOMETER
VARIABLE CAR FOLLOWING AVG. 50 MPH	T17	T18	
OPEN ROAD 50 MPH	T19	T20	T23
OPEN ROAD 30 MPH	T21	T22	
LEAPFROG PASSING	T24		

Figure 7.2.--Lattice of tasks employed in Phases C and D

To explain the variability in the dependent variables of interest due to the tasks, most of the macro analyses employed six comparisons of these task variables:

OCCL30 = T22 - T21 (occlusion effect @ 30 mph)

OCCL50 = T20 - T19 (occlusion effect @ 50 mph)

OCCLCF = T18 - T17 (occlusion effect in car following)

30VS50 = T19 + T20 - T21 - T22 (effect of target speed 50 - 30)

ORVSCF = T17 + T18 - T19 - T20 (difference between car following and open-road driving)

SPEEDO = T23 - T20 (difference due to lack of speedometer information).

The first five comparisons are, of course, orthogonal to one another, and thus effects are estimated independently.

7.3 Dependent Variables

The primary response or dependent variables of interest apriori for tasks 17 through 23 included:

1. mean velocity (V BAR),
2. standard deviation of velocity (S_V),
3. mean headway (H BAR),
4. standard deviation of headway (S_H),
5. relative velocity standard deviation (S_{RV}),
6. gas pedal deflection rate (G),
7. brake pedal activation rate (B),
8. steering wheel reversal rate (S),

"Look" time:

9. mean,
10. standard deviation,
11. percent,

"Occluded" time:

12. mean,
13. standard deviation,
14. percent,

15. mirror usage, and
16. speedometer usage.

For purposes of analysis, these dependent variables are categorized into three sets. Measures 1 through 5 represent Vehicle Responses, not under direct, immediate control of the driver, but rather time delayed measures of vehicle dynamics. Measures 6 through 8, will be referred to as the Driver Control responses, measured as frequencies or rates per minute of testing. Finally, measures 9 through 16 represent the observed visual behavior of the driver in information acquisition and perceptual demand, and thus, will be called Visual Information measures.

These latter Visual Information performance measures require explanation. The mean look times and occluded times are measures of the average duration per occurrence of time spent in either mode. Mean look time is the average time from first glanding at an object in the visual scene ahead until leaving the scene to look at, say, the speedometer or rear view mirrors. The standard deviation is, then, a measure of the variability of these times (consistency), and percent is the fraction of the total time spent in each mode:

$$\text{(i. e.,}\ \frac{\text{Mean x Number of Occurrences}}{\text{Total Time}} = \text{Percent}/100)$$

The speedometer and mirror usages were also documented by mean duration, standard deviation of looks, percentage of time, and total number of occurrences. Unfortunately, these responses are highly related to task demand, other traffic in the vicinity, etc., and were very low frequency events.

7.4 Task 24 - Dependent and Independent Variables

The final task employed in this research will be called Leapfrog passing. This task was developed to examine the freeway passing behavior of the subject drivers. The drivers were instructed to drive at about 60 mph while an auxillary research vehicle passed, got about 1,000 feet ahead, and then slowed down. The subjects were instructed to pass the car and return to the right hand lane in their normal manner and the procedure was repeated for 20 trials.

This free running task took about 45 minutes to execute 20 trials. The target speed of the auxillary research vehicle was either 30 mph and 50 mph prior to the pass (random presentation), and interferences due to other traffic was documented and trials deleted.

The dependent, response variables included:

1. mean velocity and standard deviation of velocity,

2. gas pedal and steering wheel reversals,

3. lane change rate (LCR) and variation in lane change rate (S_{LCR}),

4. visual activity (frequency of looks at rearview mirrors prior to lane change and during pass, and time between last mirror look and lane change).

These visual measures were acquired without the use of the eye-movement camera system. The number of looks at the mirrors as well as the time between last looking at a mirror and changing lanes were viewed as additional measures of perceived risk or risk acceptance. The independent variables of interest included possible:

1. subject effects,

2. day (or learning) effects, and

3. COHb effects (linear CO and quadratic CO^2).

7.5 Models and Notation

The models of driver behavior and the analytic approaches of the next section differ from analysis to analysis. This is due in part to the fact that the results presented are, in themselves, summaries of more comprehensive analyses too numerous to report here. To avoid the necessity for repeating the implied model for every response and analysis, this section outlines the principal analytic models.

The implied model of driver performance in the macro-experimental design of Phases C and D may be expressed as,

Model I-A (Latin Square)

$$Y_{ijklm} = \mu + S_i + T_j + CO_k + D_l + G_m + S \times T_{ij} + CO \times T_{jk} + D \times T_{jl} + \epsilon_{ijklm}$$

where

Y = the observed response

μ = some overall constant mean

S_i = the effect due to subject $i = 1, \ldots, I$

T_j = the effect due to task $j = 1, \ldots, J$

CO_k = the effect due to COHb at level k, $k = 1, 2, 3$

D_l = the effect due to day $l = 1, 2, 3$

G_m = the effect due to group $m = 1$, AM
2, PM

Three differential (or interaction effects of interest are $S \times T_{ij}$ effect of subject i on task j.

$CO \times T_{jk}$ effect of COHb level k with task k

$D \times T_{jl}$ effect of day l with task k (differential learning)

ϵ_{ijklm} = the error associated with the assumed model including other interactions which are assumed negligible.

Had the experiment been free of missing observations and COHb levels sufficiently close to nominal values to be treated qualitatively (low, medium, and high), the interpretation of results could have been performed with Model I-A and standard analyses of variance. However, with nonorthogonal (missing) data secondary analyses were required. In this case with a new Model I-B.

Model I-B

$$Y_{ijklm} = \mu + S_i + T_j + CO_k + D_l + G_m + \epsilon_{ijklm}$$

Some of the performance variables of this research were not affected by groups (morning versus afternoon implying adequacy of Model I-C.

Model I-C

$$Y_{ijk} = \mu + S_i + T_j + CO_k + D_l + \epsilon_{ijklm}$$

In addition, with some performance measures it was suspected that $CO \times T_{jk}$ may be large (i.e., the effect of COHb on the performance measure was different depending on the specific task). To facilitate pictorial presentation of this factor with nonorthogonal data, a third model was proposed for each task.

Model I-D

$$Y_{ik} = \mu + S_i + CO_k + \epsilon_{ik} \quad \text{(for each task 17-24)}$$

One other model which was employed for clarification of underlying assumptions of the hypotheses tested assumed again that Days (l) and Groups (m) did not affect the response variables, but that alternate interactive or differential effects may be present as defined in Model II.

Model II

$$Y_{ijk} = \mu + S_i + T_j + CO_k + S \times T_{ij} + S \times CO_{ik} + T \times CO_{jk} + \epsilon_{ijk}$$

The reader may observe that this model is not directly testable under the Latin Square design, but was considered for possible elucidation of large residual error variances in the other models. This model requires fully balanced, orthogonal data so further subsets of the data base were used.

To summarize these models and the parameters included, the following table may be helpful.

Table 7.1

Models Employed in Data Analysis for Phase C and D Road Tests

Testing for effects due to	I-A	I-B	I-C	I-D	II
μ	X	X	X	X	X
S_i	X	X	X	X	X
T_j	X	X	X	Each	X
CO_k	X	X	X	X	X
D_l	X	X	X		
G_m	X	X			
SxT_{ij}	X				X
$COxT_{jk}$	X				X
DxT_{jl}	X				X
$SxCO_{ik}$-					

7.6 Results

This section reports a detailed analysis for each of the dependent variables of interest in Phases C and D of the road testing in this research. The order of presentation is the same as listed in the previous methodology section.

The number of subjects examined in the analyses that follow vary primarily due to missing observations. There were a variety of reasons for missing observations (i.e., equipment failure, subject illness, weather). Data which was not complete across COHb levels for a particular subject and set of tasks was eliminated from the statistical analyses.

In addition, due to inaccuracies between the observed and target COHb levels, all of the analyses for Models I-A, I-B, I-C, and I-D treat COHb as a continuous, quantitative variable using actual observed values. Model II was employed only in cases of very large residual errors with Models I-A, I-B, I-C, and I-D, treating COHb qualitatively [LO(0), MED (7), HI (14)].

7.6.1 Mean Velocity (V_{BAR})

The instantaneous velocity of the research vehicle was recorded continuously throughout all of the testing. The first measure of interest is mean or average velocity for the various tasks. Sampling velocity at five second intervals produced 36 data points per three minute task trial which were then averaged.

Data for eight subjects, free of missing observations, from Phase C were used to examine the additive Model I-B:

$$V_{BAR} = \mu + S_i + T_j + CO_k + D_l + G_m + \epsilon_{ijklm}$$

An analysis of variance (Table 7.2) for this model showed an obvious effect due to tasks. Tasks 17, 19, 21, and 23 were significantly different ($p > .999$) explaining differences in mean velocity due to target speed, car following versus open road driving, and with speedometer versus without. Effects due to occlusion (Task 21 versus 22, for example) were not significant ($p < .5$). There were no apparent effects due to groups (morning versus afternoon) nor were there any significant differences between day 2 and day 3 speeds. Day 1, however, showed significantly ($p > .99$) faster speeds than day 2 or day 3. ($D_1 = D_2 + .5$ mph) suggesting a possible novel learning or familiarization effect on day 1. The subjects were homogenous in mean velocity and no significant differences were observed.

There was a significant ($p > .90$) effect due to COHb level, composed primarily of a quadratic component, with a residual error for the full model of

σ_{ϵ} = 1.55 mph. Further analyses examining those tasks which were significantly different in the previous analysis are presented in Figure 7.3. This figure demonstrates a quadratic COHb effect and also suggests a possible subtle COHb x Task interaction.

Table 7.2

ANOVA for Mean Velocity, Full Data
(8 Subjects, 7 Tasks, 3 Days, 3 COHb Levels)

Source	df	MS	F	Sig
TASK	6	2420.0	1000.0	
OCCL30	(1)	2.9		
OCCL50	(1)	8.1	3.4	p > .90
OCCLCF	(1)	1.0		
30VS50	(1)	9102.4	3793.0	p > .999
ORVSCF	(1)	4475.0	1865.0	p > .99
SPEEDO	(1)	931.0	388.0	p > .999
GROUP	1	0.0		
DAY	2	20.9		
$D_1 - D_2$	(1)	41.5	17.3	p > .99
$D_1 + D_2 - 2D_3$	(1)	0.3		(D_1-D_2=.5)
SUBJECTS	7	1.6		
COHb ($CO+CO^2$)	2	8.9	3.7	p > .90
CO	(1)	4.1	1.7	
CO^2	(1)	13.7	5.7	p > .95
ERROR	149	2.4		

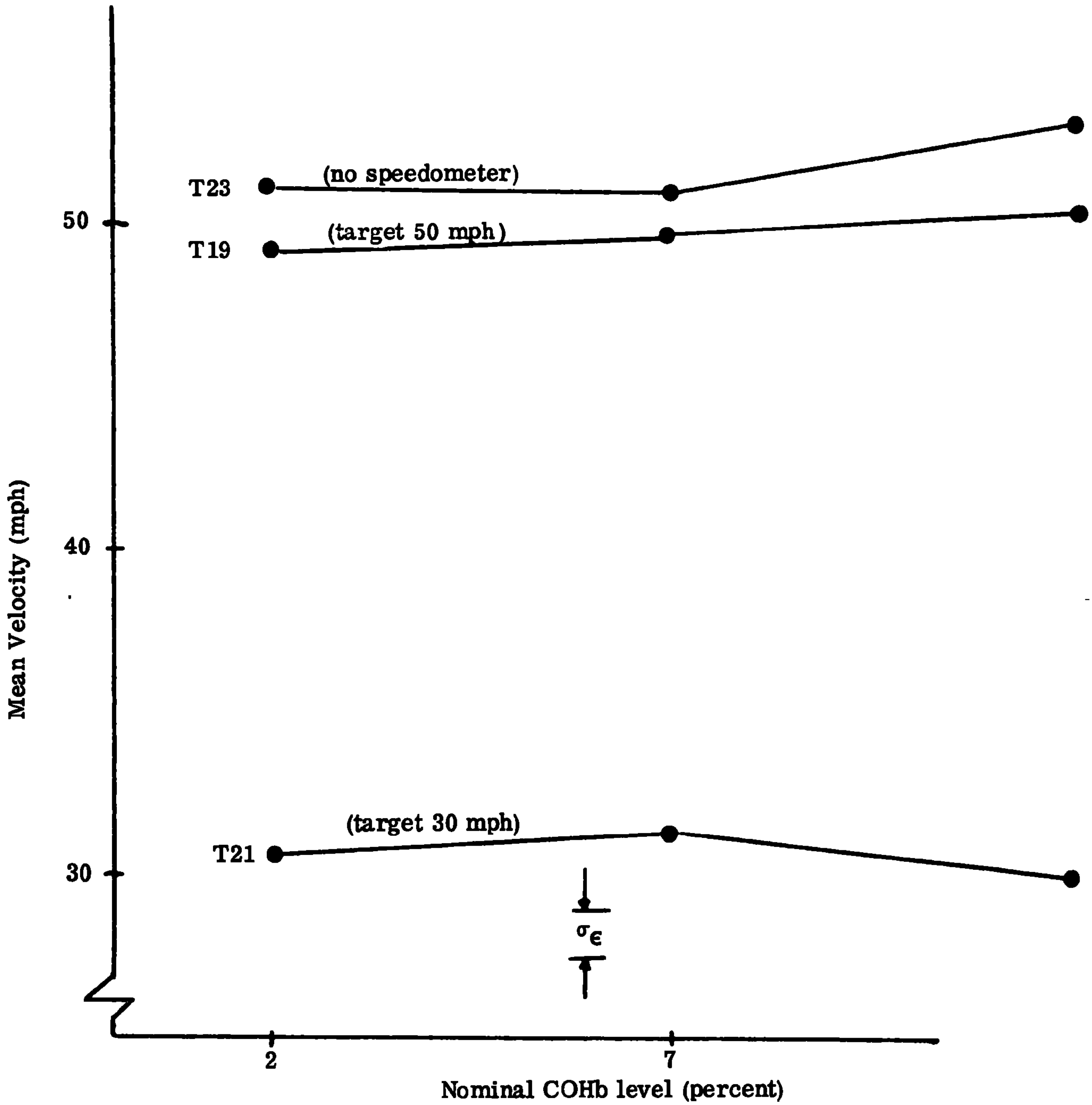


Figure 7.3.--Mean velocities for three open road driving tasks

7.6.2 Standard Deviation of Velocity (S_V)

The standard deviation of the 36 observations of instantaneous velocity for each trial was computed as a measure of driving precision. Data for 8 subjects were analyzed with Model I-B.

The results indicated no statistically significant differences between subjects or days. The tasks, too, were fairly homogeneous with the obvious exceptions of comparisons for target speed effects and open-road versus car-following differences. Variations in velocity were significantly higher in car-following compared to open-road driving at 50 mph. Also, there was a significant ($p > .999$) effect on standard deviation of velocity due to presence of speedometer information. The drivers were more variable without speedometer than with speedometer information available.

Although the COHb effect was not statistically significant ($p < .75$) in this analysis, the trends for T17, T19, and T23 which were statistically different (above) are shown in Figure 7.4. This figure suggests negative trends which may not be statistically significant due to CO x Task interactions (or Subject x CO, Subject x Task).

Since day effects were negligible, Model II was proposed for T17, T19, and T23 with 12 subjects. This analysis is supported by Table 7.3 which illustrates a mild COHb effect with Subject x CO interactions (subjects react differentially to increasing COHb levels).

Table 7.3

Average Standard Deviation of Velocities across Tasks T17, T19, T23

	Nominal COHb Level		
Subject	2%	7%	12%
S26	5.02	4.92	4.40
S20	4.71	4.95	5.69
S27	5.13	4.66	5.10
S21	3.73	4.87	4.61
S29	5.26	4.57	4.61
S23	5.42	4.69	5.18
S28	5.31	5.48	5.17
S22	4.74	4.94	4.86
S31	9.00	4.22	4.53
S25	5.40	4.52	4.93
S30	4.31	4.37	4.32
S24	4.14	4.30	3.67
Average	5.18	4.71	4.76

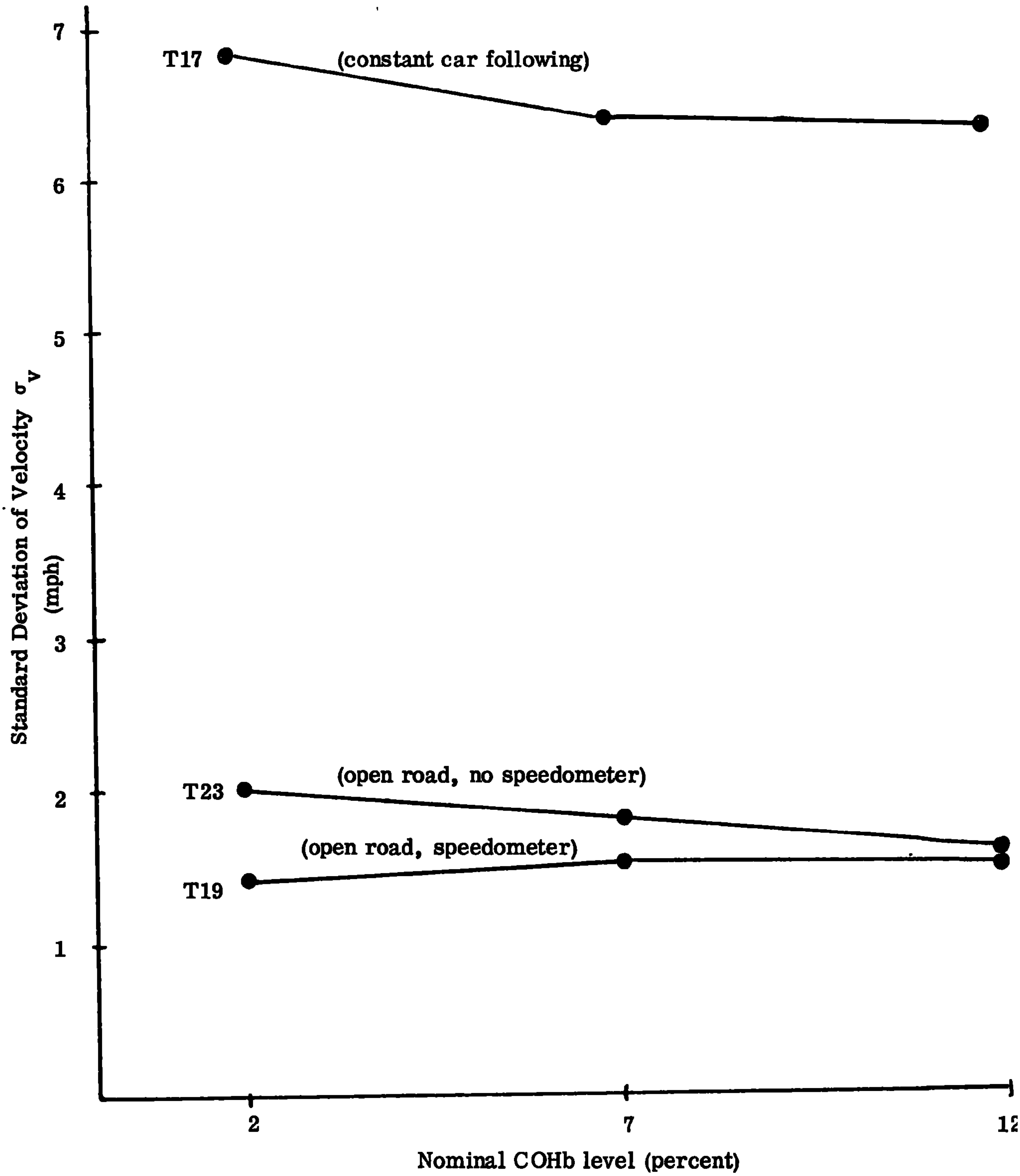


Figure 7.4.--Standard deviation of velocities for three 50 mph driving tasks

The analysis of variance for these data with Model II is presented in Table 4.

Table 7.4

ANOVA for Standard Deviation of Velocities

Source	df	MS	F	p
Subjects	11	2.16	2.74	
Task	2	247.0	312.0	
CO	2	2.44	3.09	$(p > .9)$
CO x Subject	22	2.11	2.68	$(p > .9)$
CO x Task	4	.56	<1	
Subject x Task	22	1.09	1.38	
Error	44	.79		
TOTAL	107			

7.6.3 Mean Headway (H_{BAR})

The instantaneous headway or separation of lead vehicle and following vehicle was recorded every five seconds over each task (T17, T18) of three minute duration. These 36 observations were averaged for seven subjects with full data for preliminary analysis. The results suggested obvious between-subject differences and differences between normal vision car following and occluded vision car following. On the average, the drivers maintained 20 feet larger headways when asked to voluntarily occlude their vision. Large residual errors ($\sigma_e/\mu = .30$) prompted a second analysis for each task. Data for 17 subjects were used with the model I-D:

$$H_{BAR} = \mu + S_i + CO + CO^2$$

for each task.

The results suggested a significant ($p = .85$) reduction of 15 feet in headway for the nonoccluded (T17) over the range 2% to 12% COHb. The quadratic effect (CO^2) was not significant ($p < .75$). For the occluded task, however, this reduction in headway was not monotonic as indicated by a significant quadratic CO^2 effect ($p = .90$), as illustrated in Figure 7.5.

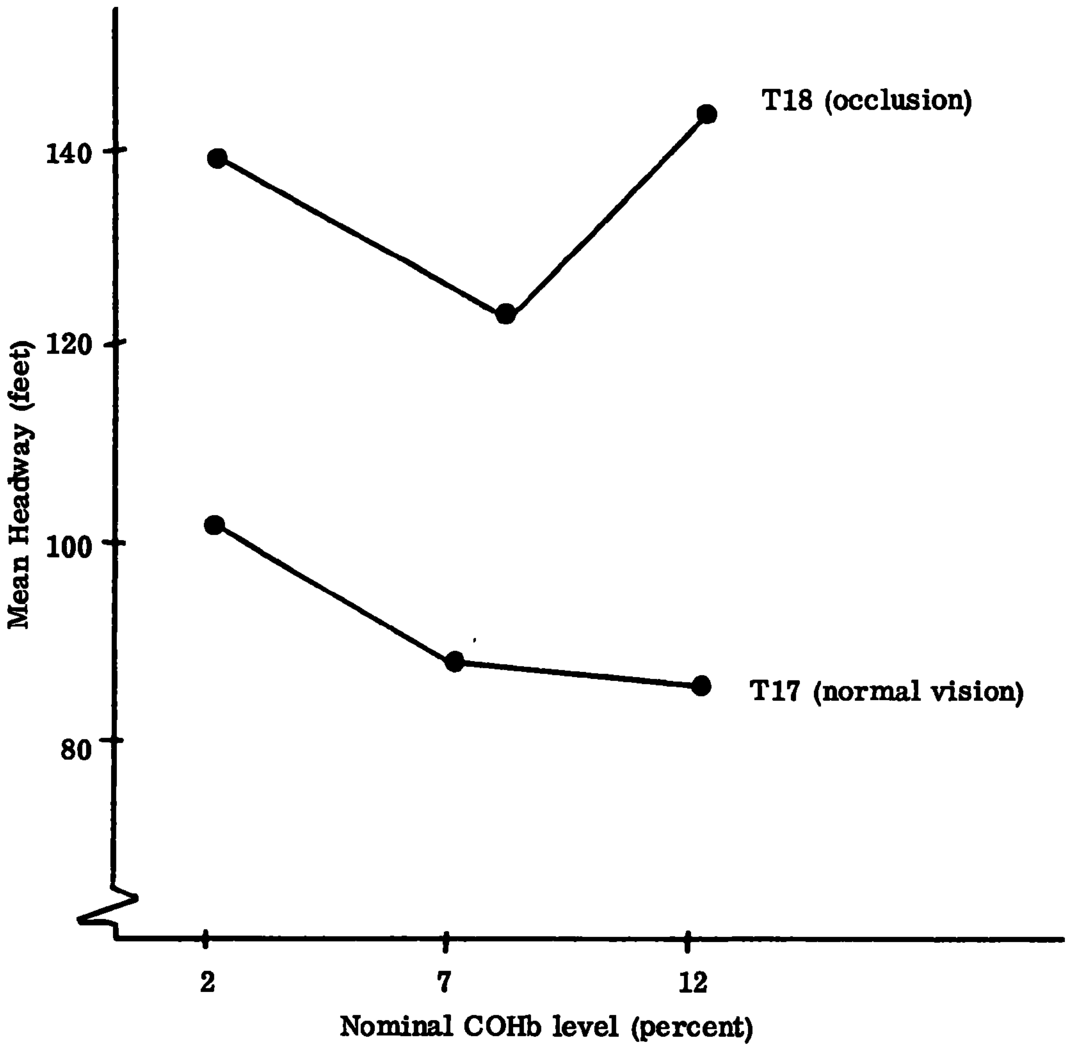


Figure 7.5.--Mean headways for car-following tasks

7.6.4 Standard Deviation of Headway (S_H)

The standard deviation of the 36 observations of instantaneous headway for each subject on each task were analyzed in identical fashion to headway. Similar trends were present with COHb as illustrated in Figure 7.6, however, the linear (CO) effects were not statistically significant ($p < .75$) but quadratic (CO^2) effects were significant ($p = .85$).

7.6.5 Relative Velocity Standard Deviation (S_{RV})

In addition to measuring headway continuously throughout the car-following tasks, the relative velocity or rate of closure and separation of the vehicles was also recorded continuously. Since this measure will average zero if the headway at the beginning equals the headway at the end of the run, mean relative velocity is probably an insensitive measure. The variation or standard deviation of relative velocity on the other hand is a measure of car-following stability.

For the two car-following tasks of this research, the measure was analyzed for seven subjects with the following results.

Source	df	MS	F
Subject	6	.96	<1
Day	2	.47	<1
Task	1	6.84	6.8
CO	2	.77	<1
Error	29	1.01	
TOTAL	40		

The overwhelming task effect ($p > .999$) of .41 ft/sec higher under occluded car following led to separation of tasks for further analysis. Using 17 subjects with Model I-D, there was still no significant CO or CO^2 effects, however, the trends are presented in Figure 7.7. Notice that with additional subjects, the average difference between occluded and nonoccluded car following more than doubled while there was no evidence of a CO x Task interaction (lack of parallel).

7.6.6 Gas Pedal Reversals (G)

Eight subjects for whom all data was available for three days and seven tasks were employed with the following results using Model I-C.

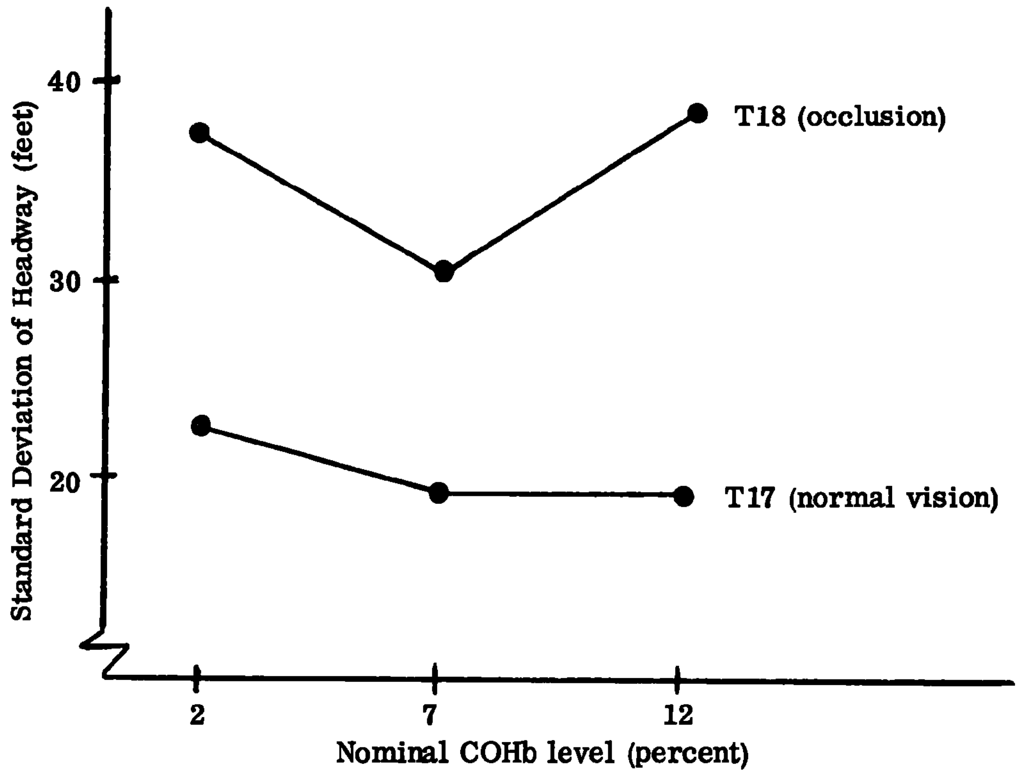


Figure 7.6.--Standard deviation of headways for car-following tasks

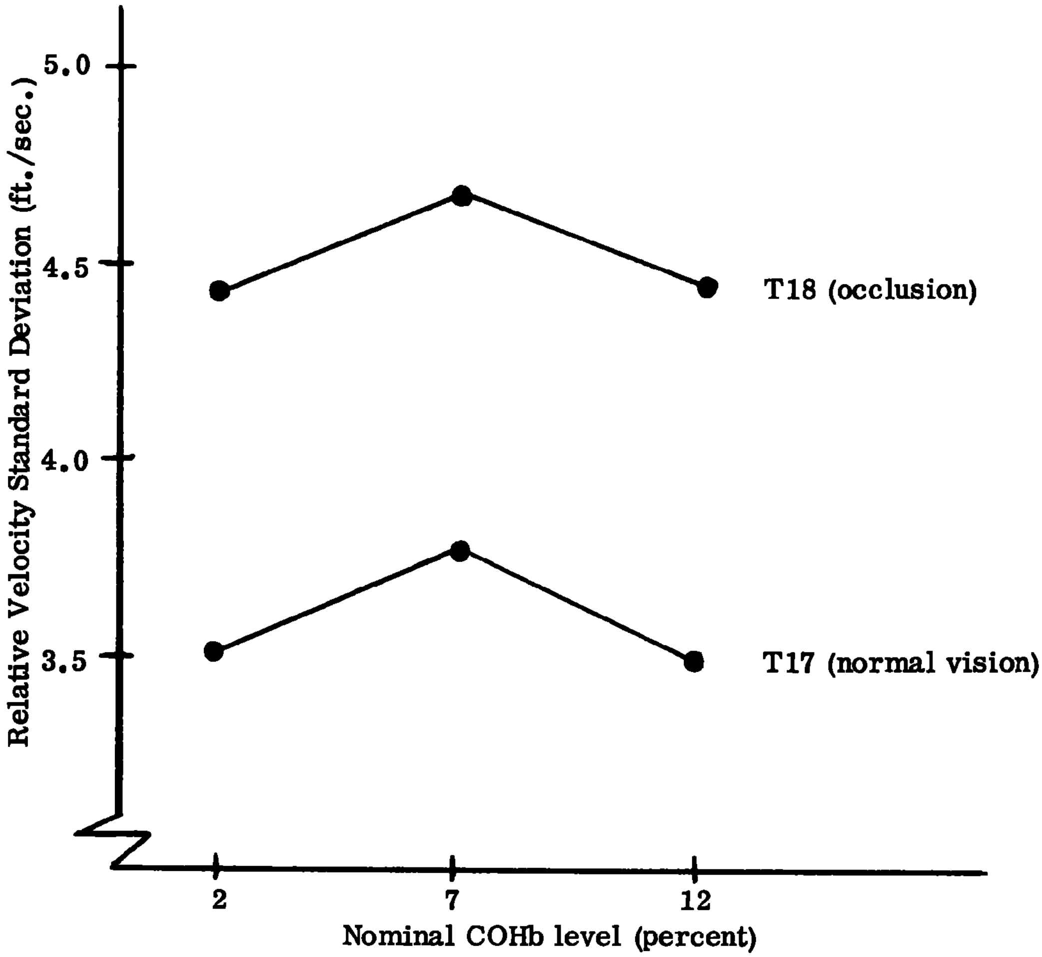


Figure 7.7.--Relative velocity standard deviations for car-following tasks

Source	df	SS	MS	F
Subjects	7	1214.8	173.5	11.8
Days	2	166.2	83.1	5.7
Tasks	6	3470.4	578.4	39.4
CO	2	6.3	3.15	1.0
Error	150	2203.3	14.69	
TOTAL	167	7061.0		

There were no obvious effects due to COHb (linear or quadratic) with this analysis. However, the possibility of COHb x Task interactions suggested that the analyses be separated by tasks and separate analyses performed. The resultant analysis is presented in graphical form in Figure 7.8.

As can be seen from the figure there is an apparent slight increases in gas pedal reversals with COHb in tasks 17 through 23 and reductions in tasks 20 and 21. The average performance across tasks increased steadily from 4.92 at 2% to 6.68 at 12% COHb, a relative increase of approximately 36 percent.

These data may be compared with those of the previous year's study as shown in Table 7.5.

Table 7.5

Gas Pedal Reversal Comparisons

	1st Year		2nd Year		
COHb Level	2%	20%	2%	7%	12%
Task					
T19	5.6	7.2	2.8	2.9	3.7
T20	4.2	2.5	2.1	2.8	1.6
T17	21.9	21.3	14.0	13.0	14.4
T18	14.7	13.1	9.8	9.3	11.9

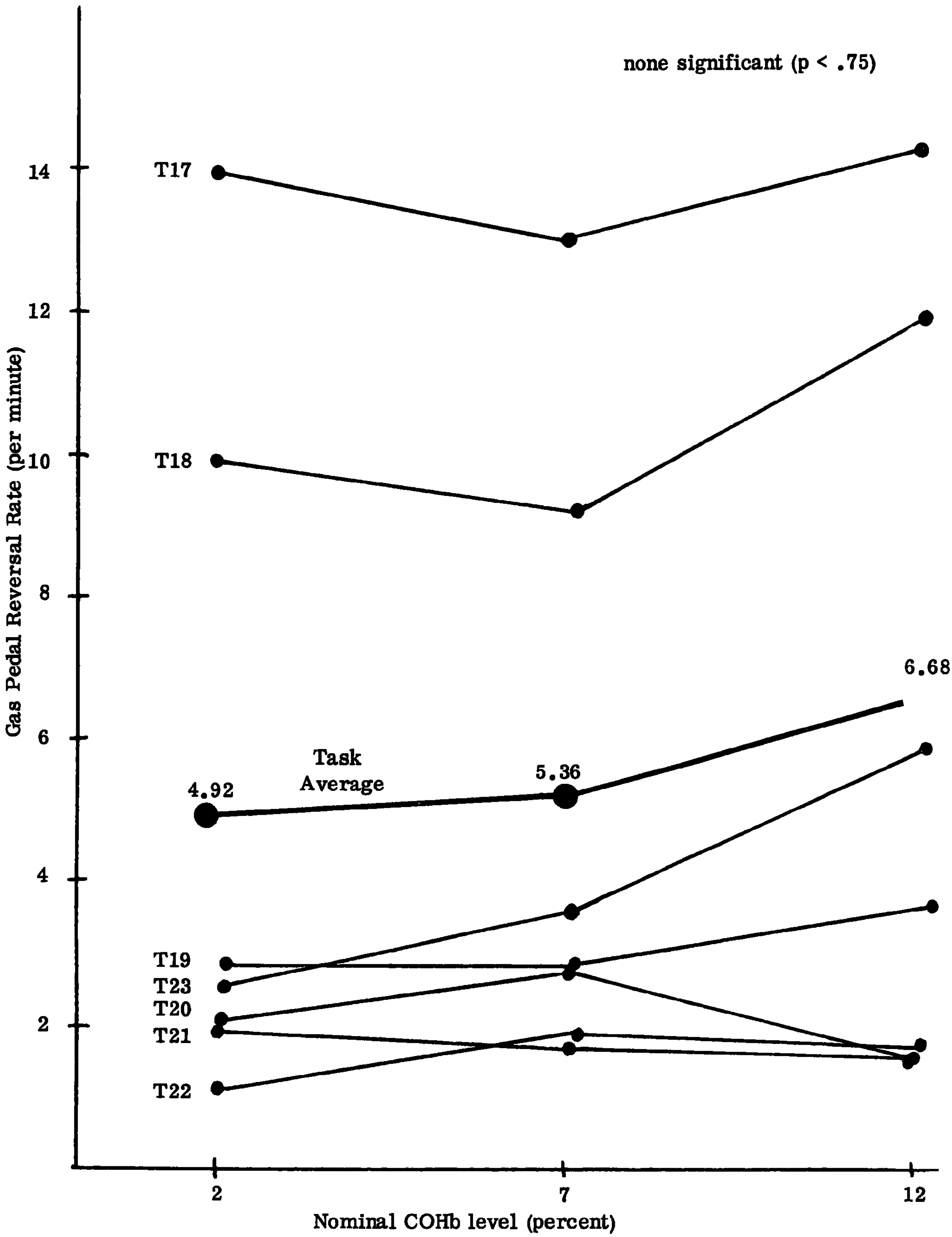


Figure 7.8.--Gas pedal reversals for Tasks 17 through 23

7.6.7 Brake Pedal Applications (B)

The brake pedal was only applied during the car following tasks (T17 and T18) and analyses were confined to eight subjects with full data for three days on both tasks with the following result:

Source	df	SS	MS	F
Subjects	7	1.43	.204	1.39
Days	2	.012	.006	<1
Task	1	.130	.130	<1
CO	2	.559	.279	1.9
CO	(1)	.379	.379	2.58 (p=.75)
CO^2	(2)	.180	.180	1.22
Error	34	5.00	.147	
TOTAL	46	7.13		

Interestingly, this preliminary analysis shows no differences between subjects, between days, or between occluded versus nonoccluded driving. This is similar to the mean velocity analysis, and again slight significant differences (p = .75) were observed due to COHb. Separating the two tasks (t17 and T18) we may diagram this effect as shown in Figure 7.9.

7.6.8 Steering Wheel Reversals (S)

Assuming no day or group (am/pm) differences, the data for six subjects under each COHb level (nominally 2, 7, and 12%) for tasks 17, 18, 19, 20 (all 50 mph) were analyzed with Model II. The resulting ANOVA is presented below:

Source	df	SS	MS	F
Subjects	5	1079.8	216.0	6.9 p > .999
Tasks	3	289.1	96.4	3.1 p > .95
CO	2	269.9	135.0	4.3 p > .975
S x T	15	1409.8	94.0	3.0 p > .995
S x CO	10	1425.9	142.6	4.5 p > .999
CO x T	6	269.2	44.9	1.4
Error	30	934.6	31.2	
TOTAL	71	5678.3		

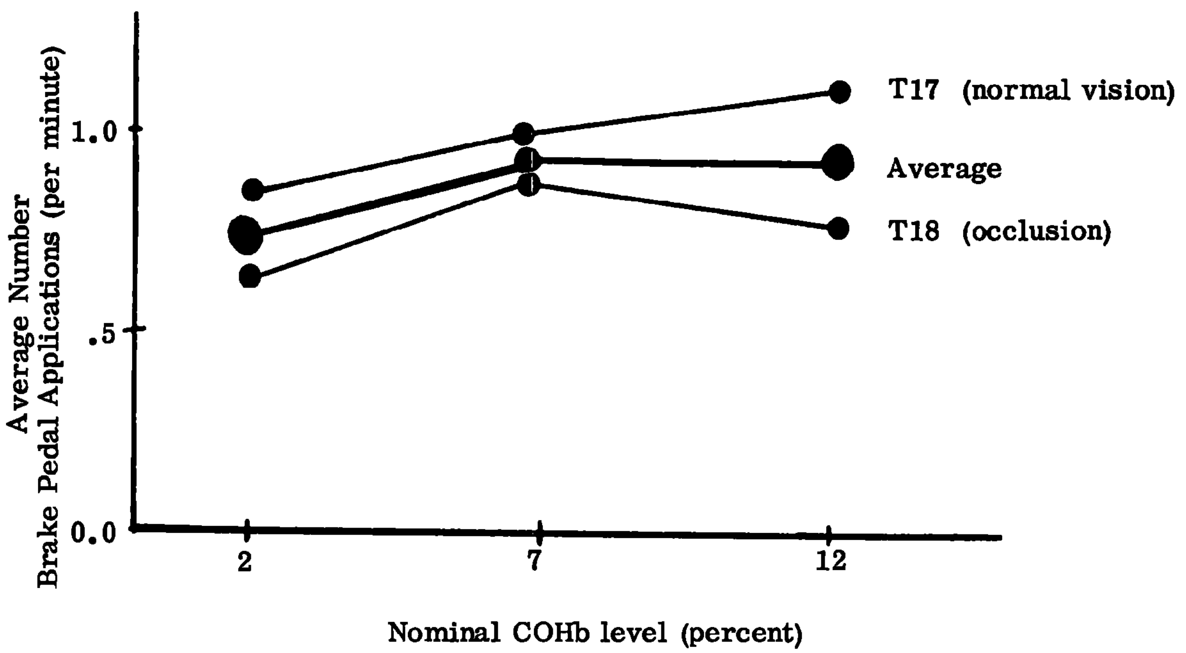


Figure 7.9.--Brake pedal applications while car following

This analysis shows significant effects due to subject and task differences in addition to a COHb effect and differential subject by COHb and subject by task effects. The COHb effect is best illustrated by Figure 7.10. The subject x COHb interactions are shown in Table 7.6.

Table 7.6

Average Steering Wheel Reversals by Subject

Subject	Nominal COHb Level 2%	7%	12%
S31	47.1	31.4	35.8
S30	34.8	17.6	24.6
S24	36.8	39.6	28.5
S38	37.7	34.4	33.7
S40	33.7	34.4	34.5
S37	26.2	37.7	32.3
Average	36.0	32.5	31.6

7.6.9 Visual Measures

A step-wise regression analysis for all visual data for the 18 Phase C and D subjects with model I-B was performed for the primary visual measures of interest. This step-wise entry process was terminated with the first observation of a "t" value less than 1.0. The resulting regression coefficients for linear (CO) and quadratic (CO^2) effects are presented in Table 7.7 with corresponding "t" statistics and significance (p) levels.

Qualitatively, these results suggest that CO intoxication was associated with higher percentages of "closed"time but less time per closure. The drivers were apparently unwilling or unable to spend long times away from the road scene. When they observed the highway, although they spent less total time on the highway, the average glance was longer suggesting more time may be necessary to retrieve information. The measures of speedometer, rear view mirror, and side view mirror usage were inconclusive.

Another measure of visual activity termed "out of view" was recorded to describe the time spent by the driver outside the central 20^{o} x 20^{o} visual angle scene, looking at such things as road signs, scenery, and other highway traffic.

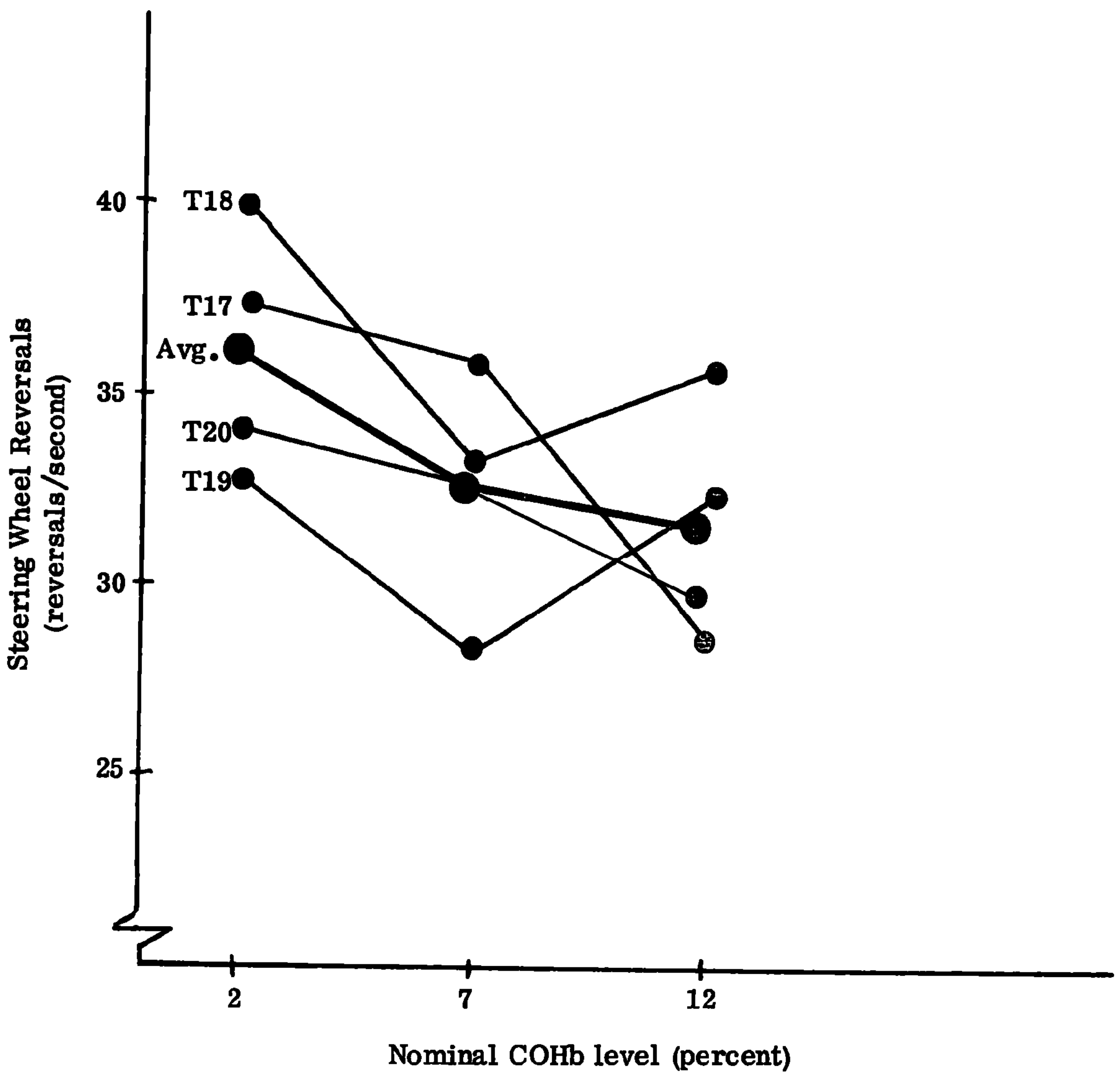


Figure 7.10.--Steering wheel reversals for 50 mph tasks

Table 7.7

Linear and Quadratic COHb Effects Summary
for Visual Measures (Phase C)

Measure	CO	t	p	CO^2	t	p
Mean Straight	0.177	2.08	>.95	-	-	-
Percent Straight	-3.85	-2.04	>.95	.481	2.55	>.975
Std. Dev. Straight	-	-	-	.107	1.57	>.80
Mean Closed	-0.088	-1.85	>.90	-	-	-
Percent Closed	2.82	1.39	>.80	-.327	-1.59	>.80
Std. Dev. Closed	-	-	-	-	-	-
Mean Speedometer	-	-	-	-	-	-
Percent Speedometer	0.169	1.04	>.70	-	-	-
Mean Side Mirror	-	-	-	-	-	-
Percent Side Mirror	-0.108	-1.55	>.80	-	-	-
Mean Out of View	-	-	-	-	-	-
Percent Out of View	-0.0048	2.6	>.975	-	-	-

" - " indicates t statistic 1.0.

CO values represent differential due to 1% COHb increase.

A reduction in this measure is sometimes called "tunnel vision" since the driver makes fewer or shorter excursions to the periphery of the visual scene. This behavior has been observed in drivers under low blood alcohol concentrations.

Out of view data revealed a mild case of perceptual narrowing with increased COHb levels ($p > .975$). However, the average excursion duration to the periphery did not change significantly with increased COHb levels.

The lack of significant quadratic effects with most visual measures in this analysis prompted deletion of the nonlinearities with CO in further analysis.

Since many of these visual measures are highly task dependent, the analyses were divided by task and employed model I-D. This allowed removal of any possible subject by Task or CO by Task interactions from the residual errors.

7.6.10 Normal Vision Driving

The driving tasks which involved normal vision (with speedometer) were: open-road driving with target speed of 30 mph (T21), open-road driving with target speed of 50 mph (T19), and driving while car following with the lead car varying speed with an overall average of 50 mph (T17). Differential effects due to CO exposure were computed over the range of actual COHb levels and analyses of variances were performed with model I-D. The results are best illustrated in Table 7.8.

Although the large unexplained residual errors (σ_ϵ) in these analyses deny statistical significance, there are several interesting trends present.

The mean duration of looks straight ahead increased in all cases with COHb. Likewise, the average look at the speedometer or rear view mirror was shorter with increased COHb levels for all three driving tasks.

A similar analysis was performed with visual measures for the occluded vision tasks; Table 7.9 illustrates magnitudes of these changes expressed as percentages of residual errors. The two predominant modes for the occluded tasks were either (a) closed (or occluded) and (b) open, looking straight ahead. Very few excursions to the periphery were made in these tasks so apparent overwhelming COHb effects actually represent small magnitude changes appearing large with respect to very small 2% COHb activity.

From this table it appears that COHb has a different effect on "up" or straight measures, depending on whether the driver is car following or on the open road. There were reductions in mean, standard deviation, and percentages "up" for both open-road driving tasks (30 and 50 mph). The (nonstatistically significant) trends for each of these measures were reversed for the car-following (loaded) task. The means and standard deviations of "down" or occluded times were less consistent across tasks. Percentages closed, however, consistently increased with COHb on all tasks, suggesting more risk acceptance behavior with COHb.

7.6.11 Perceptual Uncertainty

Examination of the occluded 50 mph task for a sample of six subjects at both control (1.5 - 2.0% COHb) and 6 - 8% COHb introduces an interesting phenomenon. If the mean look time is divided by the percent closed time and multiplied by 1000, we get a measure which reflects perceptual confidence or

Table 7.8

CO Trends for Normal Vision Tasks*

	T1 Open Road 30 mph		T3 Open Road 50 mph		T5 Variable Car Following	
	ΔCO	σ_ϵ	ΔCO	σ_ϵ	ΔCO	σ_ϵ
Mean Straight	+ 9.1	47.4	+ 106.0	185.0	+ 82.2	145.3
Percent Straight	- 5.6	21.4	+6.5	18.4	+ 2.8	6.3
Mean Speedometer	- 27.3	29.0	- 10.2	19.1	- 82.6	47.8
Percent Speedometer	+ 80.1	88.2	- 36.2	40.2	- 95.2	59.2
Mean Mirror	- 87.9	91.5	- 8.8	111.8	- 9.4	176.7
Percent Mirror	- 95.5	81.7	+ 369.0	373.1	+ 31.8	128.1

Table 7.9

CO Trends for Occluded Vision Tasks*

	T2 Open Road 30 mph		T4 Open Road 50 mph		T6 Variable Car Following	
	ΔCO	σ_ϵ	ΔCO	σ_ϵ	ΔCO	σ_ϵ
Mean "Up" Time	- 12.3	69.6	-18.1	27.7	24.7	41.4
Std. Dev. "Up Time	- 51.6	412.2	-145.2	130.5	626.8	837.3
Percent "Up" Time	- 6.5	68.9	-26.1	56.9	20.8	46.7
Mean "Down" Time	- 42.2	33.7	217.9	364.2	- 118.4	123.8
Std. Dev. "Down" Time	- 99.3	144.8	-10.5	29.2	36.8	29.1
Percent "Down" Time	+ 8.2	29.9	+92.0	185.4	+ 38.3	32.0
Percent Speedometer	230.1	409.4	325.8	464.4	- 62.5	195.1
Percent Mirrors	- 88.0	132.3	275.0	535.0	125.0	171.4

* Table values are expressed as percentage changes from low COHb level performance (nominally 2% COHb) to the 12% level performance.

the lack thereof. This measure is large when mean look time is long (suggesting visual inefficiency) or when the percent closed time is small (suggesting uncertainty about car path direction) or a combination of both. The converse of these factors produces less perceptual uncertainty. Data for six subjects is shown in Figure 7.11 for both the control and the 6 - 8 % COHb level. Note that in each case there is greater perceptual uncertainty for elevated COHb levels. The magnitude of the increase is apparently related to the initial control level. That individual subjects react differently to this unique task designed to induce spare visual capacity is not surprising. What is significant is that all subjects showed greater uncertainty at elevated COHb levels.

7.6.12 Leapfrog Passing (Task 24)

The results of the leapfrog passing task largely supported the results of the analyses for other tasks (T17 through T23). Examination of the data for 12 subjects with at least two days (of three) complete data showed that COHb levels of nominally 14% (actual average near 12%) were associated with

1. slightly lower average speeds and higher variation in speeds over the 20 trials ($p > .85$ and $p > .80$, respectively);

2. a mild reduction in the number of gas pedal reversals during the average pass ($p > .75$);

3. reductions in the number of looks at mirrors both prior to and during the average pass ($p > .95$ and $p > .85$, respectively); and

4. no significant ($p < .75$) changes in mean or standard deviation of lane change rate nor on time between mirror check and lane change.

Quantitative estimates of these COHb effects are provided in conclusion in Table 7.10. It is interesting to note the reduction in mirror usage with elevated COHb levels. This is consistent with the perceptual narrowing phenomenon suggested earlier.

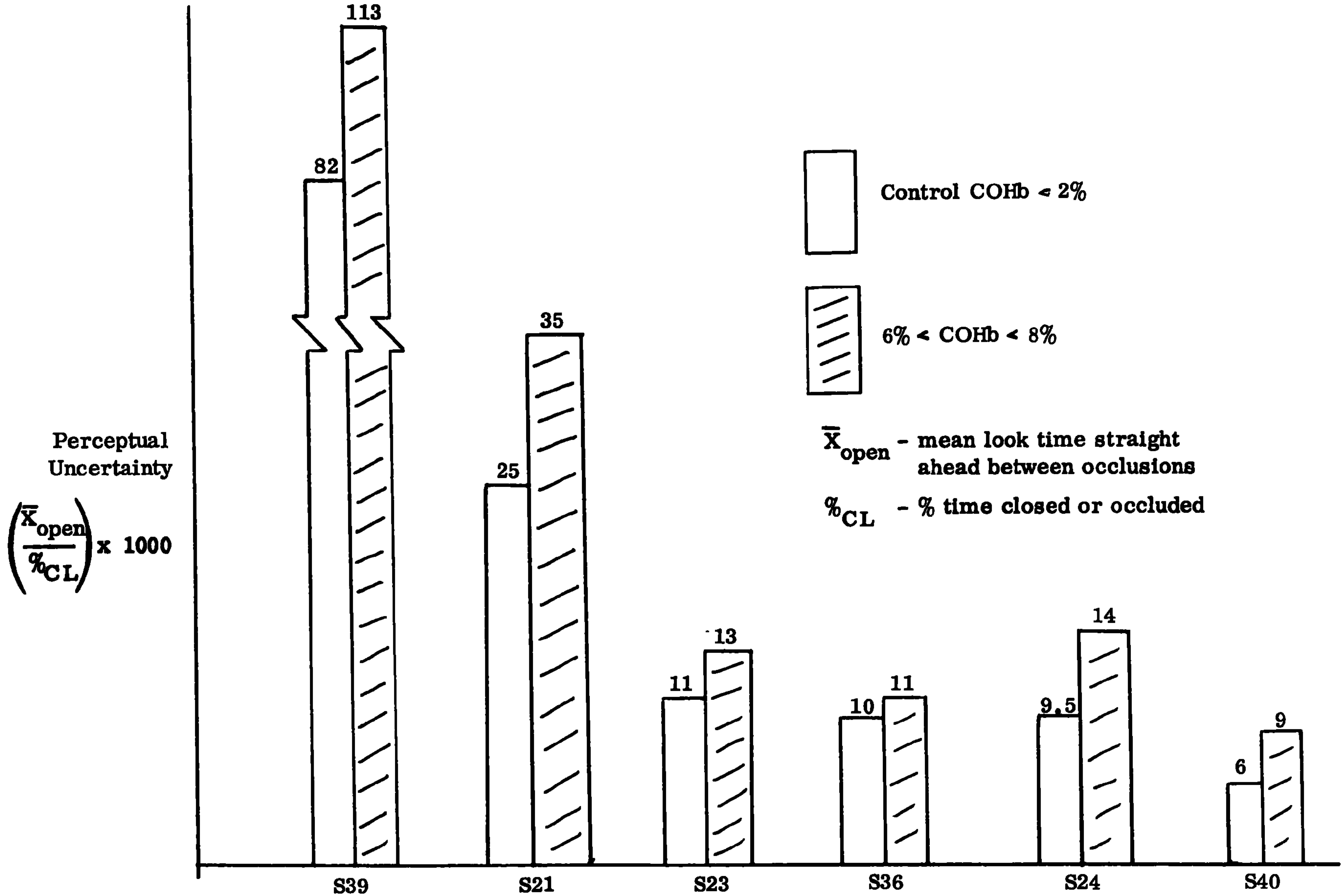


Figure 7. 11. --Perceptual uncertainties for selected subjects - Task T20

Table 7.10

COHb Effects for Leapfrog Passing Test

Measure	2% COHb	12% COHb
Mean velocity ($p > .85$)	53.7	52.2
Velocity variation ($p > .80$)	1.3	2.0
Gas pedal reversals ($p > .75$)	3.04	2.01
Number mirror looks prior to pass ($p > .95$)	6.16	4.24
Number mirror looks during pass ($p > .85$)	4.75	3.43
Lane change rate ($p < .75$) (sec.)	2.80	3.20
Std. dev. lane change rate ($p < .75$) (sec.)	1.06	0.60
Time between mirror look and lane change ($p < .75$)	0.47	1.06

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction

This study provides a challenge to the statistician by virture of the fact that (1) large inter- and intra-subject variability exist, (2) there are apparently large subject x carbon monoxide interactions (which illustrate different effects for different subjects due to carbon monoxide), (3) missing observations often forced the analysis to less powerful statistical techniques, and (4) lack of precise control over the prespecified carboxyhemoglobin levels meant that the COHb level could not be treated nominally, but instead, required covariate analysis to treat COHb conditions as a variant for each subject treatment.

Because this research is exploratory in nature it is proposed that generous significance levels be used in granting statistical significance. The authors within the report often present p values of .8 as being significant in the spirit of exploratory research. Since the p values are given for each test, the reader is free, however, to determine his own criteria for significance. It should also be noted that statistical significance is not necessarily the best test of experimental significance. Practical differences associated with mean values of performance measures at different levels of COHb must also be considered. In fact, throughout the analysis the authors treat both statistical and practical differences simultaneously. For example, a change in a visual performance measure of 100% may not be statistically significant because of large residual errors in the tests. On the other hand, an increase of 1.5 miles per hour in speed, for example, is statistically significant yet hardly of practical significance in terms of its effect on safe driving performance.

Indeed, one must recognize that with any hypothesis test, failure to reject the hypothesis of "no COHb effect" is no guarantee that no effect exists. It simply reports that for this test, significant assignable causes were not present for the specific experimental conditions employed. The researchers sought not to find differences but rather to test for both practical and statistical significant differences which might be present in the data.

8.2 Interpretation

Figure 8.1 presents the general characteristics of performance measures and their response to carbon monoxide. The complex lab tasks, despite the advantages of laboratory control, showed only moderate changes with respect to elevated COHb levels. Performance changes were found more in tracking error than in choice reaction times and more in dual tasks than with individual tasks. It should be noted that in terms of sensitivity to carbon monoxide, it was expected that vehicle dynamic measures would be least affected, driver control next affected, and perceptual measures would be most affected, and this was, in fact, found in the data. Inherent variability associated with performance also increased from the vehicle dynamics measures to the perceptual measures. At the same time safety relevance of performance decrement is probably more related to perceptual measures than vehicle dynamics because perceptual failures are usually the initiating factors in the accident chain of events.

Figure 8.2 presents some illustrative results over all tasks in the road research paradigm which clearly illustrates the dilemma of the analyses. This plot of the relative change in performance from 2 to 12% COHb in mean values of performance measures is plotted against the residual error relative to the base line (2% COHb) mean. These are graduated in broad categories of less than 10%, 10 to 50%, and greater than 50%. It should be noted that the regions of both strong statistical and practical significance were actually not found in the research. Were there to be any statistical significance in this figure, one would have to expect residual error to be less than 50% and typically about 30% of the mean value of the performance measure. This figure is interesting on two grounds. First, it should be noted that, as anticipated, vehicle dynamic measures showed minor changes in mean values and were also those variables with the smallest residual error. In the middle cells we find the control movements, and in the cells involving more than 50% change in mean value due to CO levels, we find percpetual measures. These perceptual measures are associated with large residual error, and hence, the inability to test these measures for statistical significance. These large residual errors stem from both the intra-subject variability and subject by CO interaction as well as perhaps by subtle variation introduced by days and time of day.

The trends and the magnitudes of the performance differences associated with elevated COHb levels in the perceptual measures suggest that tighter experimental controls, more precise subject instructions, replication of trials, and prescreening of subjects on tests related to driving might reduce the experimental error such that these large differences might well be explained by non-chance factors.

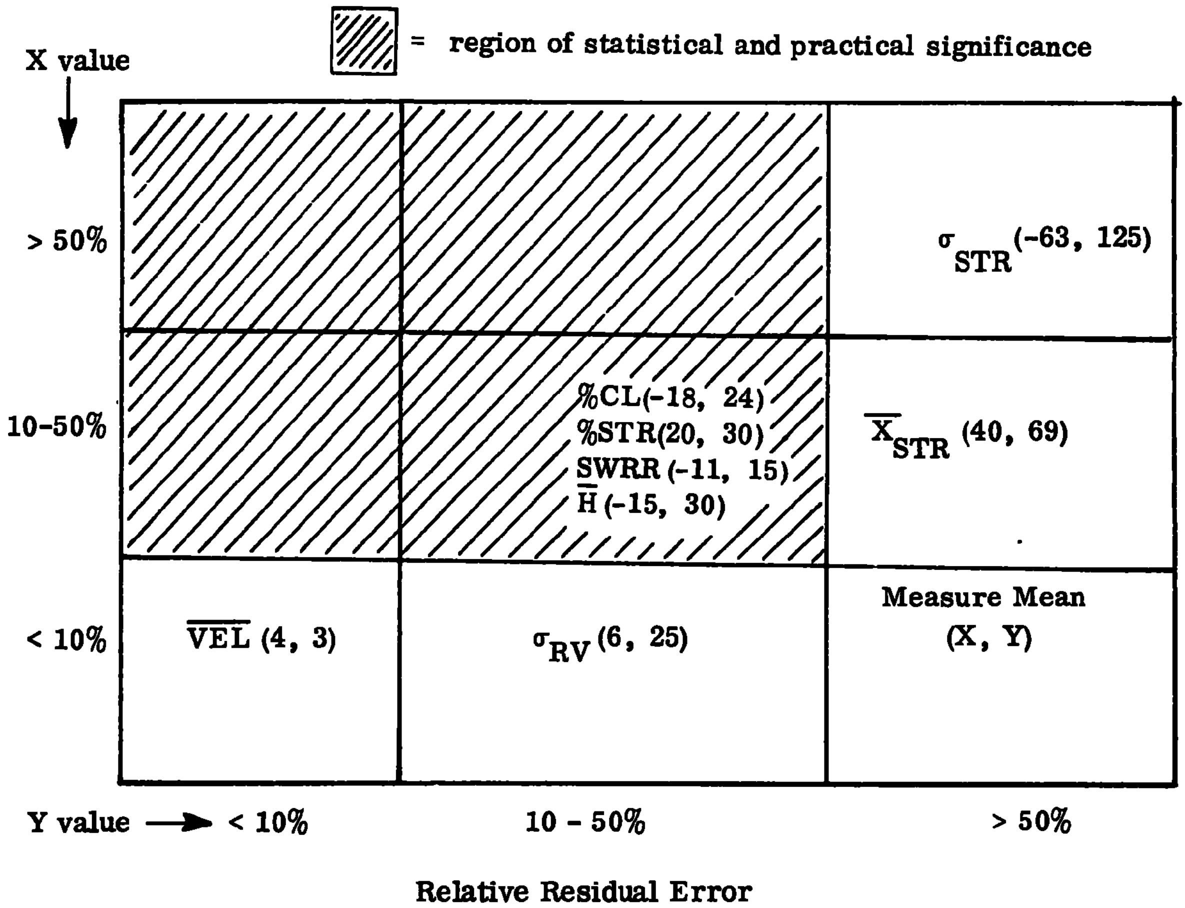
Type of Measure	Complex Lab	Vehicle Dynamics	Driver Control	Perceptual
Examples	MAE CRT	$\overline{VEL}$, σ_{VEL}, H	SWRR GPRR Brake	$\overline{X}_{ST}$, $\%_{ST}$, % Down Time
Sensitivity to CO	Moderate	Low	Moderate	High
Inherent Variability	Low	Low	Moderate	High
Safety Relevance	-	Low	Moderate	High
Statistical Significance	$p < .9$	$p < .9$	$p < .8$	$p < .75$

Figure 8.1.--General response to CO

8.3 A Proposed Conceptual Model for the Observed Experimental Differences

The analysis in this report on road performance measures has suggested some trends in driver performance with elevated COHb levels. In general, largest differences occurred in perceptual measures and the smallest in the vehicle measures (except for car-following spacing). The literature supports the findings with the visual measures (e.g., dash-light adaptation and night vision become deteriorated under elevated COHb levels). Further, the preliminary Phase A and B laboratory studies demonstrated that central processing or information processing might be the bases of any performance degradation. Current work of Moskowitz (1970) on the effect of marijuana and the work of Finkleman (1970) on noise suggests that operator capacity to time share between two tasks is affected by both the external and the internal stress mechanisms. Often performance degradation which is not found in any single measure will develop from secondary task loading (as found in driving tasks).

Figure 8.3 depicts the trends in perceptual measures with elevated COHb levels. Occluded studies permit us to study perceptual uncertainty, spare visual capacity, visual efficiency, and risk (or the time the subject would operate without information). Normal vision research tests permit us to find the average amount of time spent in looks directly ahead and the percent of time the subject concentrates on the immediate roadway environment ahead of the car. In addition, inter-signal sampling intervals in car following can also be extracted from normal vision studies. As a result of elevated COHb levels, we find an increase in perceptual uncertainty, a decrease in the spare visual capacity of the subjects (as measured by percent closed) and reduced visual efficiency in the occlusion car-following tasks. (This is only at moderate levels of COHb. See Figure 8.6.) In the normal vision tests, we find increased levels of COHb result in increases in both open-road and car following mean time straight ahead, again suggesting reduced visual efficiency and increases in percent of time spent on the road directly ahead. Figure 8.4 demonstrates the secondary task loading effect found in the lab studies and the need to separate analysis by driving task. For example, COHb apparently affects mean straight time more in car-following tasks than in open-road driving. Taken together these combined effects suggest a form of perceptual narrowing on the part of the subject, a reduced perceptual certainty, and a reduced visual efficiency. It might be noted that in each of these instances, the data of Phases A and B by and large, support the work of Phases C and D. For example, in Phase A, larger values in the percent straight visual measure were found at 20% COHb than those found at the lower COHb levels studied in Phases C and D. Reduced visual efficiency as reflected in increased open times during occluded tasks were found in the Phase A study above the levels of Phases C and D



$$X = \frac{12\%\ \text{COHb mean} - 2\%\ \text{COHb mean}}{2\%\ \text{COHb mean}} \times 100$$

$$Y = \frac{\sigma_E}{2\%\ \text{COHb mean}} \times 100$$

$\overline{X}_{STR}$ = mean look time straight ahead

$\%_{STR}$ = % of look time straight ahead

SWRR = steering wheel reversal rate

$\%_{CL}$ = % time eyes closed

σ_{STR} = STD deviation looks straight ahead

σ_{RV} = Relative Velocity STD deviation

$\overline{H}$ = mean headway

$\overline{VEL}$ = mean velocity

Figure 8. 2. --Illustrative results (all tasks)

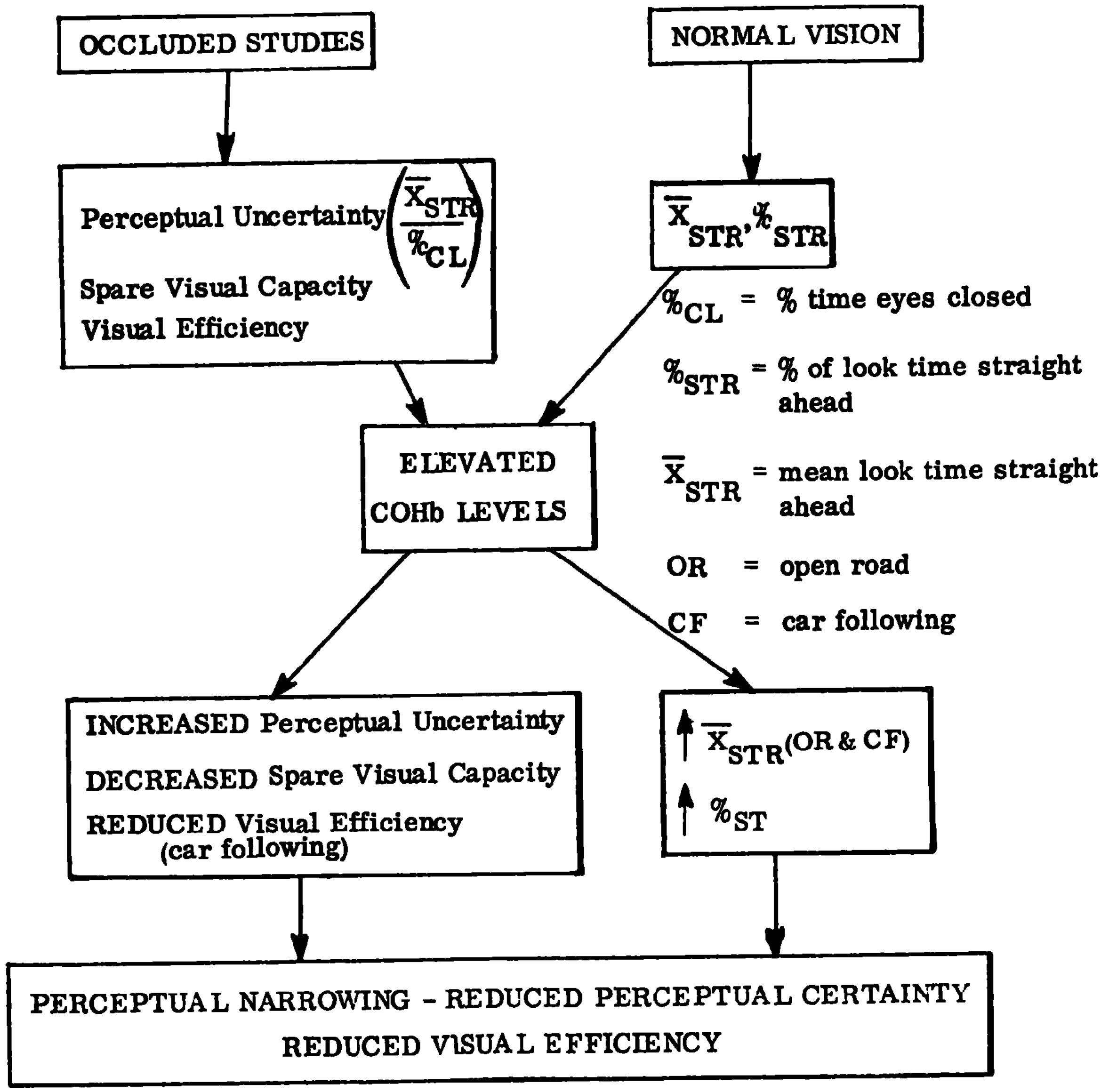


Figure 8.3.--Trends in perceptual measures

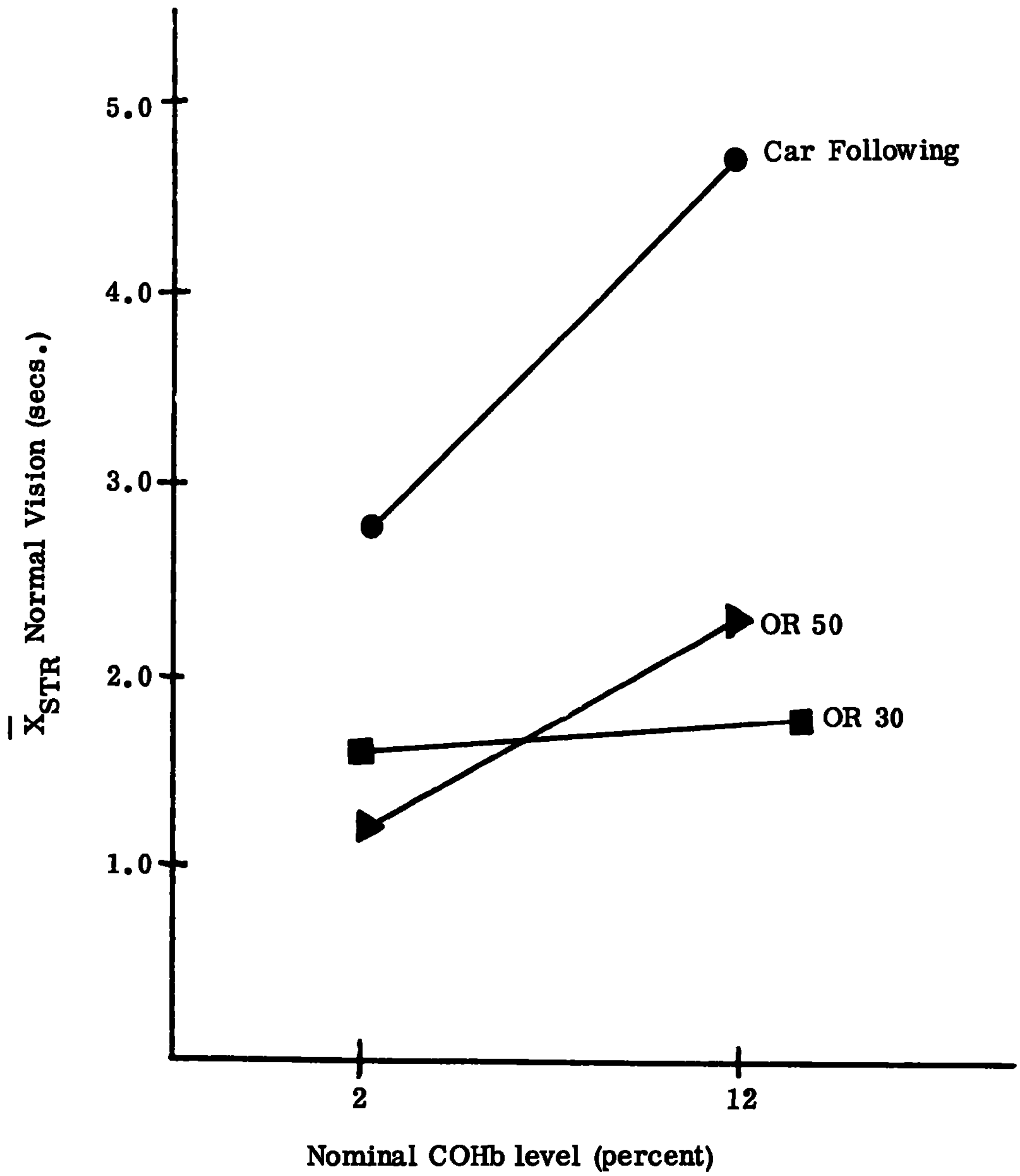


Figure 8. 4. --Mean straight looks for normal vision driving tasks

(where effects were shown only in occluded car following). The percent straight measure in both open road and car following appears to make its effect known in lower levels of COHb and there appears to be little increase in moving from the 7 to 12% region to the 20% region used in Phases A and B.

In examining the vehicle dynamics and driver control measures as a function of elevated COHb levels, it was found that steering wheel reversal rates decreased with elevated COHb levels. If carbon monoxide acts in the same way as driving fatigue, this result would be consistent with the work of Platt (1964) and others who have examined operator control movements as a function of driving time. Since brake pedal and gas pedal applications were only relevant in the car-following case, their interpretations must be tempered. It was found that in the car-following tests, elevated COHb levels led to increased gas pedal reversal rates and increased brake applications, perhaps reflecting some of the perceptual uncertainty indicated above.

In terms of car-following performance (as measured by headway and relative velocity), it is noted that there was an increase in the relative velocity variation associated with elevated COHb levels and a corresponding decrease in headway maintained at elevated COHb levels. In one sense, this is an apparent contradiction since research in the psychophysics of car following would suggest that as the driver gets closer to the car ahead, his ability to sense changes in spacing should improve simply on the basis of his Weber function. The decrease in mean headway is supported in the work of Phase A where 14 out of 20 cases showed a reduced headway. This fairly consistent reduction of headway under elevated COHb levels appears to be an anomaly not easily explainable in terms of perceptual measures described earlier. The driver's perceptual narrowing mentioned earlier may suggest that over-concentration of visual activity on the lead car would lead to lack of other cues to provide spacing information. This would explain changes in headway but not necessarily the fact that the changes were negative.

Since headway refers to elected spacing in car following, the observed reduced headways may have their locus not in perception but in risk acceptance whereby elevated COHb levels serve to relax driving inhibitions. In any event, reduced headways, lack of mirror sampling, increased perceptual uncertainty, and reduced visual efficiency, taken together, are required for decreased safety in car following (visually loaded tasks). It might be of interest in future research to examine the pattern of accidents of older cars with exhaust system failures against newer models and patterns of heavy smokers versus non-smokers.

8.4 Nonlinear Effects of Elevated COHb Levels

One of the reasons for testing subjects at three levels of COHb (controls, 7 and 14% target values) was to ascertain if ovserved effects would be linear with COHb levels. Beard (1967) and others have shown peculiar nonlinear effects of COHb levels for certain performance measures. Other investigators have found small amounts of alcohol in the blood stream can actually lead to smoother performance. This research has also demonstrated in several cases the existence of quadratic terms in the analysis. In many cases these quadratic terms are highly significant. This frequent reappearance of significant nonlinear terms presents a difficult interpretation problem. For monotonically increasing or decreasing effects, one could argue that threshold conditions are different from magnitude effects (see Figure 8.5, curve 3). Curve 1 suggests little effect until COHb levels reach a threshold level and the effects accelerate beyond that point. Curve 2 suggests early effects which taper off as COHb levels increase. Mean open time for the occluded tasks apparently follow curve 1 showing much more effect at the very high levels of COHb tested. On the other hand, percent straight measures appear to follow curve 2 since most of the changes take place at low levels of COHb and little change in performance is observed beyond the lower levels.

Figure 8.6, however, depicts pure quadratic effects found for percent closed for occluded sample driving. This curve supports the data on the six subjects presented earlier which clearly showed a reduction in percent closed in moving from the 2% to the 6 to 8% COHb level. However, when the data is examined beyond the 6 to 8% level up to the 12 to 14% level we find a reverse effect where very little difference in percent closed between 2 and 12% is observed. The covariate analyses demonstrated this clearly by suggesting no linear effect but a strong quadratic effect. It is doubtful that this effect is purely random. No physiological evidence, however, exists which could account for such relationships. Two general explanations might be possible. One, a change might occur in driver compensatory processes due to elevated COHb levels wherein the driver subjectlvely alters his adaptive process once he becomes subconsciously aware of decrement at the middle COHb level. The second explanation comes from an arousal theory which proposed that small stressor effects may alter the driver's arousal level differently from large effects. In any event, more research is needed to ascertain if these nonlinear effects are real or chance effects, and whether a causal mechanism can be found.

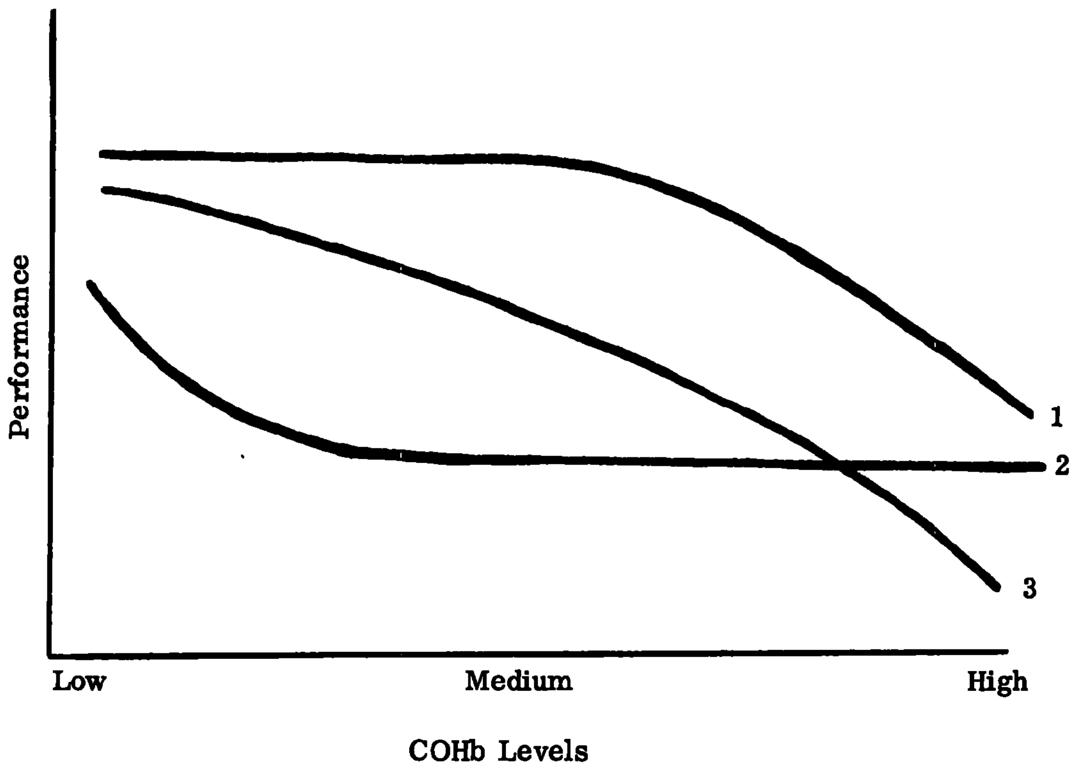


Figure 8. 5. --Possible trends in performance due to COHb levels

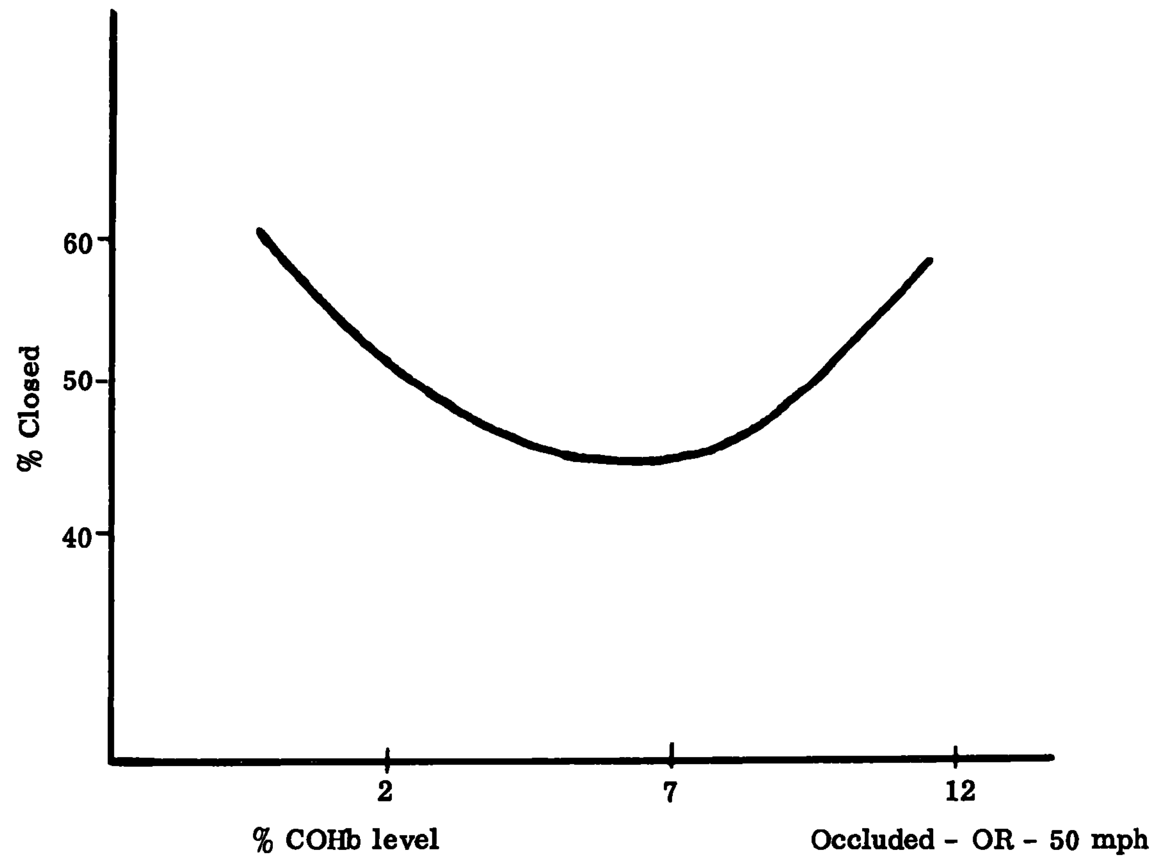


Figure 8. 6. --Example of quadratic effects

APPENDIX A

EQUIPMENT AND SUBJECT INSTRUCTIONS COMPLEX LABORATORY TASKS

The complex task for the series of experiments resulted from the simultaneous employment of two basic psychomotor tasks; one visual choice reaction time task, and the other a pursuit tracking task. This section describes the task hardware employed during the series of studies. Figure A.1 is a general schematic illustrating the equipment and its interface with the computer.

A.1 Choice Reaction Time Apparatus

The visual stimuli for the two-choice reaction time task were projected on to a screen surrounding the face of an oscilloscope from a 16 mm Data Analyst movie projector. The projector was located behind and above the subject at a distance of approximately eight feet from the screen. The screen was located approximately five feet in front of the subject.

The stimuli were white one inch letters and numbers photographed on a black matte background and projected through a 1-5/8 inch lens. At a five foot viewing distance, the stimuli subtended approximately 50 minutes of arc horizontally. The stimuli were centered approximately three degrees horizontally on either side of the subject's central line of sight.

The onset of each stimulus was detected and recorded electronically. Each frame of 16 mm film which contained an active stimulus was coded by means of white squares which were photographed in the upper corners.

Light shining through the corners was intercepted by one of three cadmium sulfide cells, implanted in a metal housing which was located several inches in front of the lens of the projector. The onset of the light triggered a low voltage pulse through the cell which activated a galvanometer on a Consolidated Electrodynamics Corporation, 50 channel oscillograph recorder. The subject viewed only the lower half of the frame of film, containing the stimulus and, consequently, was unaware of the coded light pulses.

Timing of the stimulus sequences was dictated by the frame speed of the movie film. The experimenter was alerted to the beginning and end of each trial through the onset of a light on the experimenter's console. The lamp was triggered from a third cadmium sulfide cell located between the stimulus cells.

Subjects responded to selected stimuli by pressing either of two momentary contact pushbuttons mounted on the spokes of a steering wheel. The function of the wheel will be explained in a later section.

The response voltages were recorded by a CEC oscillograph recorder.

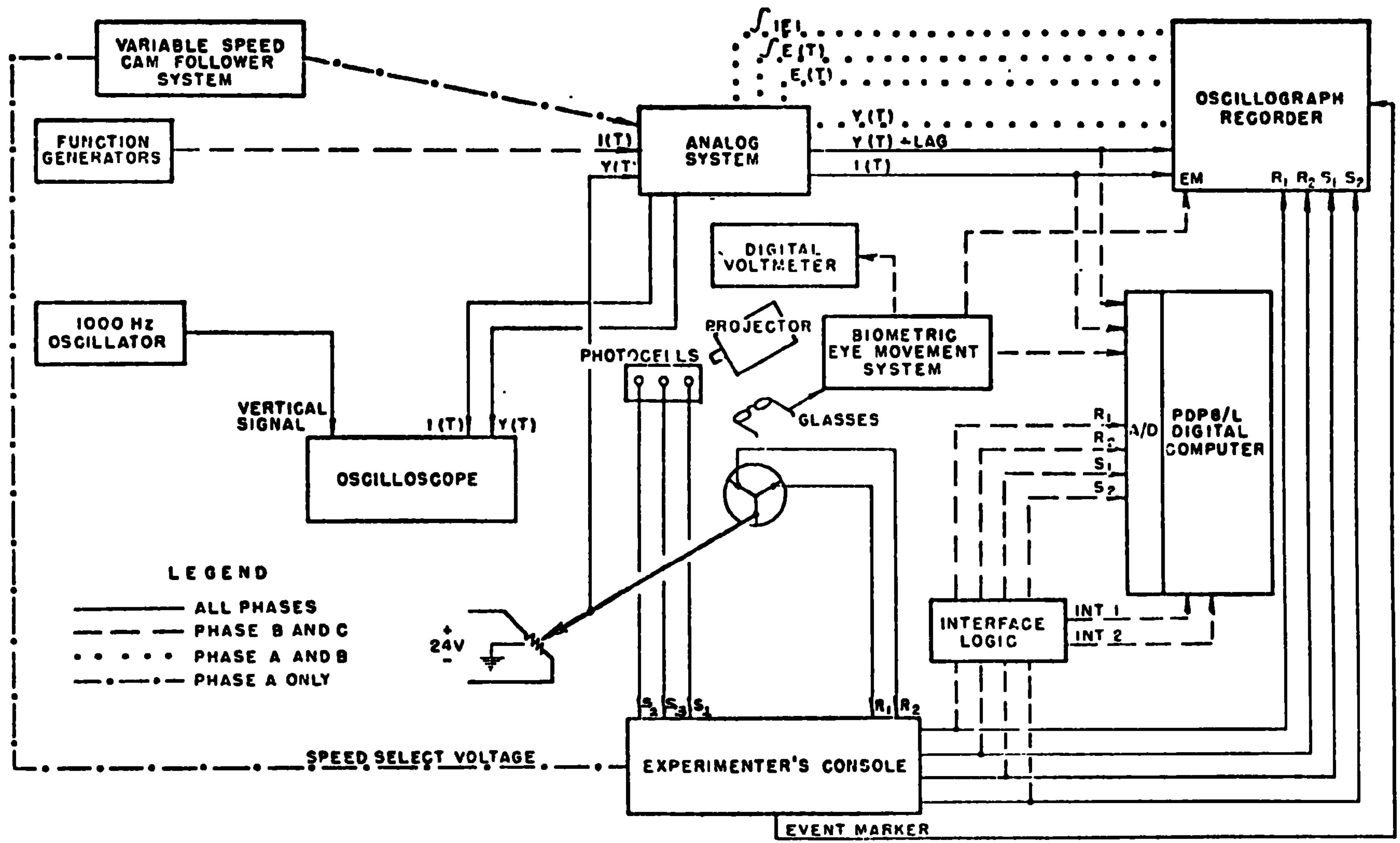


Figure A. 1. --Psychomotor task schematic

A.2 Data Collection Apparatus

The onset of each stimulus was detected and recorded electronically in the same manner as described above. However, the pulses produced by the stimuli were routed both to the CEC recorder and a Digital Equipment Corporation, PDP-8, digital computer. The use of the computer will be detailed in a later section.

A.3 Tracking Apparatus

The subject's tracking display consisted of two vertical bars of light, 3/4 inch in height, which traversed horizontally across the face of a Dummont dual-beam oscilloscope.

A 1000 Hz sinusoid was applied to the vertical axes of each beam to create the light bars. The upper bar was driven in the horizontal plane by the tracking system forcing function. The lower bar was driven in the horizontal plane by voltage resulting from the rotation of the subject's steering wheel. A weight attached to the shaft of the steering wheel returned the wheel to center when pressure was released.

A.4 Digital Computer System

Data collection and reduction for a large portion of the tests was performed by an on-line digital computer system which consisted of:

1. Digital Equipment Corporation PDP-8L digital computer equipped with a high speed paper tape reader and punch,

2. a Teletype printer and keyboard which were operated by the computer,

3. seven (7) analog-to-digital channels which transformed the analog voltages received from the tracking and choice reaction time equipment to digital data for analysis,

4. two (2) interrupt channels which triggered the internal digital logic on the occurrence of either a stimulus or response, and

5. assorted peripheral solid state logic and conditioning circuitry necessary to interface the computer with the task.

The digital computer was programmed to output the following information at the end of each 40 second trial and at the option of the experimenter:

1. mean absolute tracking error (MAE),
2. mean tracking error,
3. choice reaction time data including the time of stimulus or response onset,
4. cross correlation between the forcing function voltage (i(t) and the tracking voltage function y(t)) in the same form as each appeared on the oscilloscope,
5. autocorrelation of the error voltage, $e(t) = i(t) - y(t)$,
6. complete data dump of e(t) onto punch paper tape, and
7. subject eye-movement data.

A.5 Eye-Movement System

A commercially available Biometrics SGHV/2 eye-movement system was employed to measure the horizontal deflection of the subject's right eye during certain CRT tests. A detailed description of this system is available from the manufacturer.

During each experimental session, the subject grasped a bite bar between his teeth in order to keep his head stationary and produce accurate eye-movement measurements. The bite var was rigidly attached to a bracket which protruded from a sturdy partition.

The subject's eye movements were calibrated every three minutes by having the subject fixate on known targets spaced across the subject's field of view.

The output voltage from the Biometrics system was attached both to the CEC oscillograph recorder and an A/D channel of the digital computer.

Maximum output voltages varied both from subject to subject and within subjects on during separate experimental sessions. Voltages rarely exceeded $\pm$ 1.0 volts DC.

A.6 Subject Instructions

A.6.1 Tracking Only

The purpose of this first portion of the experiment is to test your ability to follow the movements of a visual target.

In front of you, you will notice an oscilloscope tube with two vertical lighted bars on its face. The upper vertical bar moves randomly back and forth across the face of the tube. The lower vertical bar moves only when the steering wheel in front of you is rotated.

Your task is to keep the lower bar lined up as closely as possible with the upper bar during each trial of this session.

There will be a number of short trials. Between each trial you will be given a brief rest. The end of each will be signalled by a brief tone in your earphones. The upper bar will continue to move but you will not follow it.

At the end of each rest period another tone will sound in your earphones. Begin to line up the bars immediately after hearing this tone.

Questions?

Please keep both hands on the wheel at all times even during the rest period. It is important that you grasp the wheel so that your thumbs rest lightly on the red buttons. The experimenter will inform you when this portion of the experiment is over.

The earphones are to be worn at all times during the session. They will normally play static to eliminate outside noise.

Please put on your earphones now and be prepared to begin the experiment at the sound of the tone.

A.6.2 Choice Reaction Time

This portion of the experiment will test your ability to respond to visual stimuli as rapidly as possible. The experiment is divided into a number of short trials. At the beginning of each trial, a number or a group of numbers will be projected on the screen above the oscilloscope. This number or group of numbers are the target stimuli for that trial.

Similarly, this stimulus is a 5 and you would respond with your right (left) hand pushbutton.

Advance — 3

This next stimulus is not a 5, so you would respond by pushing your left (right) hand pushbutton as rapidly as possible as soon as it appeared.

Advance — 4

Similarly, you would respond with your left (right) hand pushbutton as soon as this stimulus appeared.

Advance — 9

Similarly, this stimulus

Advance — 7

and this stimulus would require a response with your left (right) hand pushbutton.

Advance 2 frames

At the beginning of some trials, a 4-9 combination will appear above the scope.

Advance — 4-9 target

For the remainder of that trial, you will respond by pushing your right (left) hand pushbutton as rapidly as possible whenever a 4 or a 9 appear in any location on the screen. You will respond with your left (right) hand whenever any other number appears.

Advance — 4

Your task is to respond by pushing your right (left) hand pushbutton as rapidly as possible if the number that appears is the same as any of the target numbers. Whenever any other number appears, you are to push your left (right) hand pushbutton as rapidly as possible. As soon as you respond to one number another will appear.

For the remainder of the trial different numbers will be projected on either side of the oscilloscope, one after another. The numbers may appear either near the oscilloscope or farther away from the scope.

Advance 1 frame	5 target

For example, in this slide a 5 is shown as the target number. You would push your right (left) hand pushbutton as rapidly as possible each time it appeared during the trial. If any other number appeared, you would push your left (right) hand pushbutton as rapidly as possible.

Advance 1 frame	5

For example, you would push your right (left) hand pushbutton as rapidly as possible when this stimulus appeared.

Advance	5

For this stimulus you would again respond with your right (left) hand pushbutton.

Advance	5

This stimulus is a 5 also, so again you would respond with your right (left) hand pushbutton.

Advance	5

For example, in this slide a 4 appears. You would respond with your right (left) hand as rapidly as possible.

Advance	9

Similarly, when a 9 appears you would also push your right (left) hand pushbutton as rapidly as possible.

To be certain that you understand the instructions, I'll advance through the the next few slides and you tell me which pushbutton, the right or the left you would push each time a stimulus appears.

Advance	3 right (left)
Advance	9 right (left)
Advance	4 right (left)
Advance	5 left (right)
Advance	3 left (right)
Advance	0 left (right)
Advance	1 left (right)
Advance 2 frames	

At the beginning of some trials, a group of numbers consisting of a 0, 1, 3, and 7 will appear above the scope face.

Advance	01 target 37

For the remainder of that trial you will respond with your right (left) hand whenever a 0, 1, 3, or 7 appears on the screen on either side of the scope. You will respond with your left (right) hand when any other number appears.

Afain, to be certain that you understand the instructions, I'll advance through the next few slides and you tell me which pushbutton, the right or the left you would push when each stimulus appears.

Advance	0 right (left)
Advance	1 right (left)
Advance	3 right (left)
Advance	7 right (left)
Advance	5 right (left)
Advance	4 right (left)
Advance	9 right (left)

Are there any questions so far?

There will be a number of trials. At the start of each trial, you will hear a tone in your earphones and the target number or numbers will appear above the scope face.

At the end of each trial, another tone will sound. You may then take a short rest. After the rest period, another tone will sound. At that tone be prepared to begin the next trial.

When the experiment is over, you will hear a number of beeps in your earphone. At that time, remove your earphones for further instructions.

Please try to respond as fast as possible to each number, without making mistakes.

Questions?

Please keep your hands on the wheel and your thumbs resting lightly over the pushbuttons at all times during the experiment.

Put on your earphones now and be prepared to begin the trial at the sound of the tone.

A.6.3 Dual-Task

This portion of the experiment will test your ability to respond to visual signals while at the same time following the movements of a visual target.

One of your tasks will be to keep the upper and lower bars on the oscilloscope lined up as closely as possible, as you have previously done.

Your second task will be to respond to numbers projected on the screen on either side of the oscilloscope as you have also previously done.

As before, a tone will sound to alert you to the start of each trial. When the tone sounds begin to line up the bars. Do not begin to respond to stimuli until a new stimulus appears at the side of the scope face.

At the end of each trial another tone will sound in your earphones.

You may take a short rest at this time. As previously, near the end of the rest period the target stimuli for the next trial will be projected briefly over the face of the scope. When you hear the alerting tone begin to line up the bars and when a new stimulus appears at the side of the scope, begin to respond.

The experimenter will inform you when this portion of the experiment is over.

Again, please wear your earphones at all times during the experiment and keep your hands on the wheel and thumbs resting lightly over the pushbuttons at all times.

A.7 Feedback of Results

It is important during this experiment, that you perform the bar following task as well as possible. Respond as quickly as you can to the numbers when they appear, but try not to let your responses affect your performance on the bar following task. Is this clear?

During this experiment, the meter located on the console in front of you will keep you informed of your performance on the bar following or tracking task. At the end of each tracking trial, the meter will briefly present you with a score of your performance. This score will be based on a comparison of your performance on that trial and previous performance on the same task. For example, if your tracking performance is average for a trial you will receive a score of 50 on the meter. If you perform below average you will receive a score of 25. If you perform above average you will receive a score of 75. The meter will return to zero before the next trial begins. Do you understand this scoring method?

A.8 Eye-Movement Recording

The glasses you are wearing will permit us to record where you are looking at any instant. It is important, once we have calibrated the glasses, that you do not move your head. The bite-bar will ensure that your head remains stationary as long as you maintain a firm pressure on the bar with your teeth.

You will be asked to assist in calibrating the equipment several times throughout the session. For this procedure, a numbered piece of cardboard will be raised in front of you. You are asked to look directly at each of the black spots beneath the numbers as the numbers are called out.

Please do not attempt voice communication once you have the bar in your mouth, unless it is absolutely necessary.

As previously, before each trial begins, you will be presented with the master stimuli for that trial. When the alerting tone sounds begin to line up the bars. Do not begin to respond to stimuli until a new stimulus appears at the side of the scope face.

Please keep your hands on the wheel and your thumbs resting lightly over the pushbuttons at all times. You will be informed each time we wish to calibrate or when the experiment is over. Are there any questions?

Please put on your earphones now and be prepared to begin the experiment at the sound of the tone.

APPENDIX B

SUBJECT INSTRUCTIONS FOR ROAD TESTS (TASKS 12 THROUGH 24)

Task 12

Description: Headway Production Task

Subject Instructions:

During this part of the experiment, we would like to test your ability to estimate different headways or distances between cars.

Your task will be to accelerate or decelerate the vehicle and then hold it at a distance from the lead car which I will read to you. After you have produced the desired distance, please say the words "at distance." I will then immediately read off another distance which you should try also to produce. Are there any questions?

Target Headways:

Trial	Headway	Trial	Headway	Trial	Headway	Trial	Headway
1	90	11	358	21	84	31	356
2	172	12	86	22	280	32	98
3	186	13	182	23	272	33	369
4	268	14	362	24	24	34	260
5	262	15	82	25	176	35	184
6	352	16	264	26	94	36	270
7	370	17	366	27	274	37	188
8	100	18	88	28	360	38	276
9	178	19	174	29	96	39	190
10	368	20	354	30	180	40	278

Task 13

Description: Velocity production task

Subject Instructions:

During this part of the experiment, you will be driving the vehicle without the use of the speedometer. We would also like to test your ability to estimate different velocities during this part of the experiment.

Your task will be to accelerate or decelerate the vehicle and then hold it at a speed which I will read to you. After you have produced the required speed, please say the words "at speed." I will then immediately read off another speed which you should try to also produce. Are there any questions?

Target Speeds:

Trial	Velocity	Trial	Velocity	Trial	Velocity	Trial	Velocity
1	62	11	26	21	48	31	67
2	57	12	66	22	54	32	35
3	49	13	50	23	27	33	41
4	38	14	67	24	64	34	56
5	51	15	33	25	47	35	36
6	37	16	40	26	39	36	53
7	31	17	63	27	30	37	70
8	44	18	69	28	60	38	52
9	58	19	61	29	34	39	42
10	32	20	43	30	29	40	55

Task 14

Description: Time Estimation Task

Subject Instructions:

1. During this portion of the experiment, we would like you to drive the car in your normal manner. We also would like to test your ability to estimate time intervals while you are driving.

Your first task will be to estimate two second time intervals. When I say start, begin to estimate a two second interval. When you feel that two seconds have elapsed, press the button in your right hand and begin to estimate the next two second interval. Continue this task until we tell you to stop.

It is important that you attempt to judge the two second interval without counting. If you are wearing a watch, please do not use it. Are there any questions?

2. Your second task is to estimate eight second time intervals. When I say start, begin to estimate an eight second time interval. When you feel that eight seconds have elapsed, press the button in your right hand and begin to estimate the next eight second interval. Continue this task until we tell you to stop.

Again it is important that you attempt to judge the eight second interval without counting. If you are wearing a watch, please do not use it. Are there any questions?

3. Your third task is to estimate four second time intervals. When I say start, begin to estimate a four second interval. When you feel that four seconds have elapsed, press the button in your right hand and begin to estimate the next four second interval. Continue this task until we tell you to stop.

As before, it is important that you attempt to judge the four second interval without counting. If you are wearing a watch, please do not use it. Are there any questions?

Task 15

Description: Constant speed, (50 mph) car following, normal vision

Subject Instructions:

Please drive this car behind the lead car as if you were on a two-lane highway attempting to pass the lead car but were unable to because of oncoming traffic in the left lane. Are there any questions?

Task Duration: 3 minutes

Task 16

Description: Constant speed (50 mph) car following, voluntary occlusion

Subject Instructions:

Please drive this car behind the lead car as if you were on a two-lane highway attempting to pass the lead car, but were unable to do so because of oncoming traffic in the left lane.

During this part of the experiment we would like you, in addition to driving as we just described, to close your eyes whenever possible. That is, we would like you to keep your eyes shut as much as possible and when you open your eyes to keep them open for as short a time as possible. The "safety man" seated next to you will be observing your behavior and that of the other traffic near this vehicle. He will alert you by stating the word "open" if he feels that you should open your eyes. If at any time during this run you feel that you should open your eyes and keep them open, do not hesitate to do so.

Although we are asking you to keep your eyes closed as much as possible, we still expect you to maintain normal control of the vehicle and to keep the car in the right hand lane. The safety man's role will be that of alerting you to unusual occurrences that might develop.

During this run, the lead car will maintian approximately the same speed at all times. Are there any questions?

Task Duration: 3 minutes

Task 17

Description: Variable speed car following (mean speed 50 mph) normal vision

Subject Instructions: Same as T15

Task Duration: 3 minutes

Task 18

Description: Variable speed car following (mean speed 50 mph) voluntary occlusion

Subject Instructions: Same as T16 with the exception of the following at the end of the instructions

During this run, the lead vehicle will upon occasion change speeds in a gradual manner. That is, it will slow down or speed up, but it will not do so suddenly. Are there any questions?

Task 19

Description: Open road driving, target speed 50 mph, normal vision

Subject Instructions:

Please drive this car in your normal manner at about 50 mph. Please keep to the right hand side of the road whenever possible. If you desire to pass anyone, please let us know and we will tell you when it is safe to do so. Are there any questions?

Task Duration: 3 minutes

Task 20

Description: Open road driving, target speed 50 mph, voluntary visual occlusion

Subject Instructions:

Please drive this car in your normal manner at about 50 mph, and keep to the right hand side of the road whenever possible.

During this part of the experiment we would like you, in addition to driving as we just described, to close your eyes whenever possible. That is, we would like you to keep your eyes shut as much as possible and when you open your eyes to keep them open for as short a time as possible. The "safety man" seated next to you will be observing your behavior and that of the other traffic near this vehicle. He will alert you by stating the word "open" if he feels that you should open your eyes. If at any time during this run you feel that you should open your eyes and keep them open, do not hesitate to do so.

Although we are asking you to keep your eyes closed as much as possible, we still expect you to maintain normal control of the vehicle and to keep the car in the right hand lane. The safety man's role will be that of alerting you to unusual occurrences that might develop. Are there any questions?

Task Duration 3 minutes

<u>Phase B:</u> For the cognitive loading task of Phase B, the following instructions were substituted:

Please drive this car in your normal manner at about 50 mph. Please keep to the right hand side of the road whenever possible. During this part of the experiment, we would like you in addition to driving as we have just described, to perform the following task as much as possible.

The subject was then told to perform one of the following secondary tasks:

Task 1

Using the mirror mounted on the front roof pillar of the car, please read the first three numbers on the digital clock into the microphone. Then read the speed to the nearest mile; e.g., 53, 68, 64, etc., from the speedometer into the microphone. Then mentally add the two numbers together and read the sum into the microphone. After doing this, please start the task again as quickly as possible. Are there any questions?

Task 2

Using the mirror mounted on the front roof pillar of the car, please read the first three numbers on the digital clock into the microphone. Then mentally divide that number by two and read the answer into the microphone. After doing this, please start the task again as quickly as possible. Are there any questions?

Task 1 was used as a secondary task during the first replication of the series of tests. It was observed; however, that the subject kept the vehicle speed as close as he could to fifty miles per hour in order to simplify the secondary task. Task 2 was adopted for the second replication of the series of tests in order to avoid this problem.

Task Duration: 6 minutes

Task 21

Description: Open road driving, target speed 30 mph, normal vision

Subject Instructions: Same as Task 19 with "30 mph" substituted for "50 mph"

Task Duration: 3 minutes

Task 22

Description: Open road driving, target speed 30 mph, voluntary visual occlusion

Subject Instructions: Same as Task 20 with "30 mph" substituted for "50 mph"

Task Duration: 3 minutes

Task 23

Description: Velocity maintenance, target speed 50 mph, no speedometer variable

Subject Instructions:

For the next few minutes we would like for you to try to hold your speed as close to 50 mph as possible. You may use the speedometer to find 50 mph before we begin, after which we will cover up the speedometer. Are there any questions?

Task 24

Description: Leap frog passing test

Subject Instructions:

During this part of the experiment we would like for you to drive about 60 mph. The other vehicle will pass you, get some distance ahead, and then slow down. When you close in on the other vehicle we would like to pass it in your normal manner. After passing, please return to the right hand lane in your normal manner and we will repeat the test 20 times. Are there any questions?

Task Duration: approximately 45 minutes

APPENDIX C

MEASUREMENTS OF CARBOXYHEMOGLOBIN LEVELS OF FREEWAY DRIVERS

Three ancillary studies performed in conjunction with the main studies of this report are provided in this appendix. The data was collected during the winter months (January through March, 1972).

Study 1

Almost five hundred (498) drivers on the Ohio Turnpile were tested for COHb. Fifty-two (52) of these drivers were truck drivers and are reported under Study 2. A test station was established at the Portage Plaza rest area through the gracious cooperation of Messers. Allen Johnson and J. Budd Morrison of the Ohio Turnpike Commission. The test station was operated around the clock from Friday afternoon through Sunday evening on two weekends in February, 1972.

Study 2

Seventy-seven (77) truck drivers were tested for COHb levels. Twenty-five (25) of the truck drivers were employed by Suburban Motor Freight Company of Columbus, Ohio. We are grateful to the drivers and Mr. Larry Legrange for their cooperation in this study. The remaining fifty-two (52) drivers were tested at the turnpike test station of Study 1.

Study 3

One hundred and thirty (130) students and staff who had occasion to enter the Baker Industrial and Systems Engineering Building on The Ohio State University campus were tested for COHb levels.

This site was chosen for this third study to screen for effects due to smoking by screening for subjects who had not driven for over one hour prior to being tested.

Results

All COHb levels were determined using a Beckman infra-red breath-analyzer. Summary statistics for these three studies are presented in Table C.1.

Table C.1

Summary Data Table for Ancillary Studies

	Study 1 Total Ohio Turnpike Study				Study 2 Truck Study		Study 3 University Study	
	cigarette smokers	pipe and cigar smokers	non-smoker male	non-smoker female	non-smoker	smoker	non-smoker	smoker
Number of persons tested	212	22	132	80	28	49	85	45
Mean COHb level in %	4.64%	3.05%	2.11%	2.02%	2.61%	4.33%	2.05%	3.64%
Std. Dev. of COHb level	1.77%	1.86%	.38%	.35%	.99%	1.48%	.26%	1.52%
Range of COHb level	9.0%	8.0%	3.0%	2.0%	4.0%	7.0%	2.0%	6.0%
Maximum COHb level	11.0%	10.0%	4.0%	3.0%	5.0%	9.0%	4.0%	8.0%
Minimum COHb level	2.0%	2.0%	2.0%	1.0%	1.0%	2.0%	2.0%	2.0%

APPENDIX D

SUBJECT CONSENT FORM

SUBJECT PRESCREENING DATA FILE

HABIT INVENTORY FORM

CORNELL MEDICAL INDEX HEALTH QUESTIONNAIRE

DESCRIPTION OF KNOWN RISKS ASSOCIATED WITH THE INVESTIGATION OF THE EFFECTS OF CARBON MONOXIDE ON DRIVING

I, ____ have been informed of the
(name)

dangers associated with carbon monoxide (headache, nausea, possible phlebitis from blood sampling), and automobile driving by the staff and associated of Dr. C. E. Billings. I understand that the purpose of this research is to determine the effects of carbon monoxide exposure on driving performance. I also understand that drivers on the streets and highways have been found to have COHb levels greater than 30% and that smokers can readily obtain a COHb level of 16% or greater. I have also been informed that there are no detectable physiological effects of carbon monoxide below the level of 20% COHb, and that there are no damaging effects below a 30% COHb level.

I therefore consent to allow Dr. Billings and his associates to administer carbon monoxide to me in amounts that will result in COHb levels up to 20% on the condition that there will be a licensed medical doctor available at all times during the experiments, and that my COHb level will not exceed 20% at any time.

Signed ____________________________

Witnessed by: ____________________________

____
Investigator

Subjects RF Project 3332

Date: ______________

1. Name: ______________________________

2. Address: ____________________________

____

3. Telephone: _________________

4. Age: ______ 5. Date of birth: __________ 6. SS# ______________

7. Next of kin: __________________________

Address: ____________________________

____

Phone: ______________

8. Married: ________________ 9. No. children: _______________

10. Military Service: __________ 11. Branch: __________________

12. Number of years: __________ 13. Rank: ____________________

14. Present status: ____

15. Do you smoke? __________ 16. Have you smoked in last 6 months? ___

17. Have you ever been employed by The Ohio State University in any position prior to this interview? _____________________________________

18. If the answer to the above question is yes, what department did you work in?

____

19. Why do you want to be a part of this study? ________________________

____

20. Have you ever spent any length of time away from your home? _________

____

21. Have you ever been confined to a hospital or had a serious health problem?

______________________ If yes, give explanation: ________________

____

22. Major and minor academic interests: ______________________________

____

HABIT INVENTORY

Do you smoke?

Cigarettes
Pipe
Cigars

Age you started to smoke.

Age you last quit smoking.

Was it difficult to stop?

Number of smokes per day?

What is your maximum weight?

Your present weight?

How many meals eaten daily?

Time of day meals eaten (a.m., p.m.)

Breakfast
Lunch
Supper

Quantity of food taken at each mean (small, medium, large)

Breakfast
Lunch
Supper

Do you snack during daytime or night?

How much?

Do any foods make you sick?

List

Number of glasses of water daily

Does chlorinated, fluoridated, or chlorinated and fluoridated drinking water make you sick?

Number of glasses of milk daily

Number of cups of coffee daily

Number of cups (glasses) of tea daily

Alcohol usage

Kind
Amount
Frequency

Other beverages

Kind
Amount
Frequency

Sleep

Number of hours per night
Time of retiring
Time of arising
Difficulty with sleeping?
Do you take naps?
When?

Bowel and Bladder

Number of bowel movements a day(s)
Number of urinations during day
Number of urinations during night

Exercise

Frequency of exercise
Kind of exercise (mild, moderate, strenuous, exhausting)
Describe
What length of time do you exercise?
What time of day do you exercise?

Drugs

Drugs currently being used (list - e.g., aspirin)

Frequency of use.

Is drug controlled by a physician or yourself?

List physician's name and address:

Hobbies

List hobbies

How much time are you involved with hobbies?

Reading

Books (list type)

Newspapers (names)

Magazines (names)

Time spent reading daily

Television and Radio

Time viewing TV daily

Time listening to radio daily

Describe what type TV and radio programs you enjoy (e.g., music, sports, comedy, etc.)

THIS FORM IS STRICTLY CONFIDENTIAL. INFORMATION HEREIN WILL BE USED ONLY FOR PURPOSES OF THIS STUDY.

Date________

HEALTH QUESTIONNAIRE

Print Your Name____________________ Your Home Address____________________

How Old Are You?______ Circle If You Are . . Single, Married, Widowed, Separated, Divorced.

Circle the Highest Year You Reached In School | 1 2 3 4 5 6 7 8 | (Elementary School) | 1 2 3 4 | (High) | 1 2 3 4 | (College) What Is Your Occupation?________________

Directions: This questionnaire is for ***MEN ONLY.***
If you can answer YES to the question asked, put a circle around the (Yes)
If you have to answer NO to the question asked, put a circle around the (No)
Answer all questions. If you are not sure, guess.

A

1. Do you need glasses to read? Yes No
2. Do you need glasses to see things at a distance? Yes No
3. Has your eyesight often blacked out completely? Yes No
4. Do your eyes continually blink or water? Yes No
5. Do you often have bad pains in your eyes? Yes No
6. Are your eyes often red or inflamed? Yes No
7. Are you hard of hearing? Yes No
8. Have you ever had a bad running ear? Yes No
9. Do you have constant noises in your ears? Yes No

B

10. Do you have to clear your throat frequently? Yes No
11. Do you often feel a choking lump in your throat? Yes No
12. Are you often troubled with bad spells of sneezing? Yes No
13. Is your nose continually stuffed up? Yes No
14. Do you suffer from a constantly running nose? Yes No
15. Have you at times had bad nose bleeds? Yes No
16. Do you often catch severe colds? Yes No
17. Do you frequently suffer from heavy chest colds? Yes No
18. When you catch a cold, do you always have to go to bed? Yes No
19. Do frequent colds keep you miserable all winter? Yes No
20. Do you get hay fever? Yes No
21. Do you suffer from asthma? Yes No
22. Are you troubled by constant coughing? Yes No
23. Have you ever coughed up blood? Yes No
24. Do you sometimes have severe soaking sweats at night? Yes No
25. Have you ever had a chronic chest condition? Yes No
26. Have you ever had T.B. (Tuberculosis)? Yes No
27. Did you ever live with anyone who had T.B.? Yes No

C

28. Has a doctor ever said your blood pressure was too *high?* Yes No
29. Has a doctor ever said your blood pressure was too *low?* Yes No
30. Do you have pains in the heart or chest? Yes No
31. Are you often bothered by thumping of the heart? Yes No
32. Does your heart often race like mad? Yes No
33. Do you often have difficulty in breathing? Yes No
34. Do you get out of breath long before anyone else? Yes No
35. Do you sometimes get out of breath just sitting still? Yes No
36. Are your ankles often badly swollen? Yes No
37. Do cold hands or feet trouble you even in hot weather? Yes No
38. Do you suffer from frequent cramps in your legs? Yes No
39. Has a doctor ever said you had heart trouble? Yes No
40. Does heart trouble run in your family? Yes No

OPEN TO NEXT PAGE

D

41. Have you lost more than half your teeth? Yes No
42. Are you troubled by bleeding gums? Yes No
43. Have you often had severe toothaches? Yes No
44. Is your tongue usually badly coated? Yes No
45. Is your appetite always poor? Yes No
46. Do you usually eat sweets or other food between meals? Yes No
47. Do you always gulp your food in a hurry? Yes No
48. Do you often suffer from an upset stomach? Yes No
49. Do you usually feel bloated after eating? Yes No
50. Do you usually belch a lot after eating? Yes No
51. Are you often sick to your stomach? Yes No
52. Do you suffer from indigestion? Yes No
53. Do severe pains in the stomach often double you up? Yes No
54. Do you suffer from constant stomach trouble? Yes No
55. Does stomach trouble run in your family? Yes No
56. Has a doctor ever said you had stomach ulcers? Yes No
57. Do you suffer from frequent loose bowel movements? Yes No
58. Have you ever had severe bloody diarrhea? Yes No
59. Were you ever troubled with intestinal worms? Yes No
60. Do you constantly suffer from bad constipation? Yes No
61. Have you ever had piles (rectal hemorrhoids)? Yes No
62. Have you ever had jaundice (yellow eyes and skin)? Yes No
63. Have you ever had serious liver or gall bladder trouble? Yes No

E

64. Are your joints often painfully swollen? Yes No
65. Do your muscles and joints constantly feel stiff? Yes No
66. Do you usually have severe pains in the arms or legs? Yes No
67. Are you crippled with severe rheumatism (arthritis)? Yes No
68. Does rheumatism (arthritis) run in your family? Yes No
69. Do weak or painful feet make your life miserable? Yes No
70. Do pains in the back make it hard for you to keep up with your work? Yes No
71. Are you troubled with a serious bodily disability or deformity? Yes No

F

72. Is your skin very sensitive or tender? Yes No
73. Do cuts in your skin usually stay open a long time? Yes No
74. Does your face often get badly flushed? Yes No
75. Do you sweat a great deal even in cold weather? Yes No
76. Are you often bothered by severe itching? Yes No
77. Does your skin often break out in a rash? Yes No
78. Are you often troubled with boils? Yes No

G

79. Do you suffer badly from frequent severe headaches? Yes No
80. Does pressure or pain in the head often make life miserable? Yes No
81. Are headaches common in your family? Yes No
82. Do you have hot or cold spells? Yes No
83. Do you often have spells of severe dizziness? Yes No
84. Do you frequently feel faint? Yes No
85. Have you fainted more than twice in your life? Yes No
86. Do you have constant numbness or tingling in any part of your body? Yes No
87. Was any part of your body ever paralyzed? Yes No
88. Were you ever knocked unconscious? Yes No
89. Have you at times had a twitching of the face, head or shoulders? Yes No
90. Did you ever have a fit or convulsion (epilepsy)? Yes No
91. Has anyone in your family ever had fits or convulsions (epilepsy)? Yes No
92. Do you bite your nails badly? Yes No
93. Are you troubled by stuttering or stammering? Yes No
94. Are you a sleep walker? Yes No
95. Are you a bed wetter? Yes No
96. Were you a bed wetter between the ages of 8 and 14? Yes No

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H

97. Have you ever had anything seriously wrong with your genitals (privates)? Yes No

98. Are your genitals often painful or sore? Yes No

99. Have you ever had treatment for your genitals? Yes No

100. Has a doctor ever said you had a hernia (rupture)? Yes No

101. Have you ever passed blood while urinating (passing water)? Yes No

102. Do you have trouble starting your stream when urinating? Yes No

103. Do you have to get up every night and urinate? Yes No

104. During the day, do you usually have to urinate frequently? Yes No

105. Do you often have severe burning pain when you urinate? Yes No

106. Do you sometimes lose control of your bladder? Yes No

107. Has a doctor ever said you had kidney or bladder disease? Yes No

I

108. Do you often get spells of complete exhaustion or fatigue? Yes No

109. Does working tire you out completely? Yes No

110. Do you usually get up tired and exhausted in the morning? Yes No

111. Does every little effort wear you out? Yes No

112. Are you constantly too tired and exhausted even to eat? Yes No

113 Do you suffer from severe nervous exhaustion? Yes No

114 Does nervous exhaustion run in your family? Yes No

J

115 Are you frequently ill? Yes No

116. Are you frequently confined to bed by illness? Yes No

117 Are you always in poor health? Yes No

118. Are you considered a sickly person? Yes No

119. Do you come from a sickly family? Yes No

120. Do severe pains and aches make it impossible for you to do your work? Yes No

121. Do you wear yourself out worrying about your health? Yes No

122. Are you always ill and unhappy? Yes No

123. Are you constantly made miserable by poor health? Yes No

K

124. Did you ever have scarlet fever? Yes No

125. As a child, did you have rheumatic fever, growing pains or twitching of the limbs? Yes No

126. Did you ever have malaria? Yes No

127. Were you ever treated for severe anemia (thin blood)? Yes No

128. Were you ever treated for "bad blood" (venereal disease)? Yes No

129. Do you have diabetes (sugar disease)? Yes No

130. Did a doctor ever say you had a goiter (in your neck)? Yes No

131. Did a doctor ever treat you for tumor or cancer? Yes No

132. Do you suffer from any chronic disease? Yes No

133. Are you definitely *under* weight? Yes No

134. Are you definitely *over* weight? Yes No

135. Did a doctor ever say you had varicose veins (swollen veins) in your legs? Yes No

136. Did you ever have a serious operation? Yes No

137. Did you ever have a serious injury? Yes No

138. Do you often have small accidents or injuries? Yes No

L

139. Do you usually have great difficulty in falling asleep or staying asleep? Yes No

140 Do you find it impossible to take a regular rest period each day? Yes No

141 Do you find it impossible to take regular daily exercise? Yes No

142. Do you smoke more than 20 cigarettes a day? Yes No

143. Do you drink more than six cups of coffee or tea a day? Yes No

144. Do you usually take two or more alcoholic drinks a day? Yes No

TURN TO NEXT PAGE

M

145. Do you sweat or tremble a lot during examinations or questioning? Yes No

146. Do you get nervous and shaky when approached by a superior? Yes No

147. Does your work fall to pieces when the boss or a superior is watching you? Yes No

148. Does your thinking get completely mixed up when you have to do things quickly? Yes No

149. Must you do things very slowly in order to do them without mistakes? Yes No

150. Do you always get directions and orders wrong? Yes No

151. Do strange people or places make you afraid? Yes No

152. Are you scared to be alone when there are no friends near you? Yes No

153. Is it always hard for you to make up your mind? Yes No

154. Do you wish you always had someone at your side to advise you? Yes No

155. Are you considered a clumsy person? Yes No

156. Does it bother you to eat anywhere except in your own home? Yes No

N

157. Do you feel alone and sad at a party? Yes No

158. Do you usually feel unhappy and depressed? Yes No

159. Do you often cry? Yes No

160. Are you always miserable and blue? Yes No

161. Does life look entirely hopeless? Yes No

162. Do you often wish you were dead and away from it all? Yes No

O

163. Does worrying continually get you down? Yes No

164. Does worrying run in your family? Yes No

165. Does every little thing get on your nerves and wear you out? Yes No

166. Are you considered a nervous person? Yes No

167. D[illegible] nerv[illegible] in your family? Yes No

168. Did you ever have a nervous breakdown? Yes No

169. Did anyone in your family ever have a nervous breakdown? Yes No

170. Were you ever a patient in a *mental* hospital (for your nerves)? Yes No

171. Was anyone in your family ever a patient in a *mental* hospital (for their nerves)? Yes No

P

172. Are you extremely shy or sensitive? Yes No

173. Do you come from a shy or sensitive family? Yes No

174. Are your feelings easily hurt? Yes No

175. Does criticism always upset you? Yes No

176. Are you considered a touchy person? Yes No

177. Do people usually misunderstand you? Yes No

Q

178. Do you have to be on your guard even with friends? Yes No

179. Do you always do things on sudden impulse? Yes No

180. Are you easily upset or irritated? Yes No

181. Do you go to pieces if you don't constantly control yourself? Yes No

182. Do little annoyances get on your nerves and make you angry? Yes No

183. Does it make you angry to have anyone tell you what to do? Yes No

184. Do people often annoy and irritate you? Yes No

185. Do you flare up in anger if you can't have what you want right away? Yes No

186. Do you often get into a violent rage? Yes No

R

187. Do you often shake or tremble? Yes No

188. Are you constantly keyed up and jittery? Yes No

189. Do sudden noises make you jump or shake badly? Yes No

190. Do you tremble or feel weak whenever someone shouts at you? Yes No

191. Do you become scared at sudden movements or noises at night? Yes No

192. Are you often awakened out of your sleep by frightening dreams? Yes No

193. Do frightening thoughts keep coming back in your mind? Yes No

194. Do you often become suddenly scared for no good reason? Yes No

195. Do you often break out in a cold sweat? Yes No

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