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# Effects of CO on Vigilance Performance

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE / Public Health Service
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EFFECTS OF CO ON VIGILANCE PERFORMANCE

# EFFECTS OF LOW LEVEL CARBON MONOXIDE ON DIVIDED ATTENTION, PITCH DISCRIMINATION, AND THE AUDITORY EVOKED POTENTIAL

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ABSTRACT

The purpose of this study was to investigate certain behavioral and neurological aspects of low level exposure to carbon monoxide (CO). Thirty volunteer subjects were exposed for four hr in a double-blind study to either 5 parts per million (ppm), 35 ppm, or 70 ppm of CO. Three behavioral measures of performance were used: (1) a compensatory tracking task to measure eye-hand coordination; (2) a visual-peripheral monitoring task to measure light intensity discrimination; and (3) an auditory monitoring task to measure tone discrimination. Neurological assessment consisted of an analysis of the components of the auditory evoked response (AER). In order to load or stress performance, and potentially reveal subtle but functional deficits, two automated testing procedures were used. First, the tracking task was paired with the peripheral monitoring task, which allowed an analysis of divided attention by providing a dual-task arrangement; task difficulty was varied by including two tracking frequencies and two peripheral light levels. Second, the auditory task was paired with EEG monitoring, which allowed an analysis of evoked responses to critical and noncritical stimuli. The accompanying response time data were used to assess the capacity to process auditory information. Breath samples were collected every 30 min for CO determination and blood samples were collected before and after the exposure period for carboxyhemoglobin (COHb) assay. COHb levels of 1, 3, and 5% were obtained at the end of the fourth hr of exposure for CO exposures of 5, 35, and 70 ppm, respectively.

Principal findings were:

(1) A significant eye-hand coordination impairment of 30 percent occurred during the fourth hr of exposure at 70 ppm CO when 5% COHb was approached, as compared to performance at 5 and 35 ppm. The impairment was manifested during the dual-task procedure and under the difficult task condition of high frequency tracking. However, accurate eye-hand coordination was maintained throughout the 70 ppm exposure with a less demanding course to track (slow cursor frequency).

(2) Response times of subjects to the peripheral light intensity changes exposed at 70 ppm during the dual-task procedure increased during the third and fourth hrs at a significantly faster rate than in control subjects or those exposed at 35 ppm. From a baseline of 775 msec after the first hr, the increase by the end of the fourth hr averaged 7 msec for controls and 70 msec for the high CO group.

(3) Tracking accuracy and percentage of peripheral light detections were significantly reduced by the low level of peripheral light brightness, but brightness did not interact with the level of CO or the duration of exposure.

(4) Analysis of performance data from the auditory monitoring task indicated that response times, number of misses, false alarms, and percentage of correct detections for both critical and noncritical stimuli were not significantly affected by the CO-exposure conditions.

(5) The averaged auditory evoked potential (AEP) of the subjects indicated a significant difference in the ratio of the

dominant negative peak ($N_1$) to the dominant positive peak ($P_1$) for auditory stimuli judged significant by the subjects. The rate of increase of the $P_1/N_1$ ratio increased over the four-hr exposure for both the 35 and 70 ppm CO conditions as compared to the 0 ppm condition.

By using sensitive laboratory tests that measured human behavioral performance under test conditions of controlled difficulty, statistically significant decrements in performance were noted at COHb levels of 5%, which is the NIOSH-recommended exposure limit. The significance of these findings as they relate to safe job performance by workers in CO-laden atmospheres remains to be determined.

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# INTRODUCTION

Carbon monoxide (CO) once into the blood stream binds to the hemoglobin of the red blood cells and becomes carboxyhemoglobin (COHb). Due to the greater affinity that hemoglobin has to CO than to oxygen, a principal effect of CO exposure is to reduce the oxygen-carrying capacity of the blood. Since the brain requires approximately 20% of the basal oxygen of the entire body, it is an organ sensitive to oxygen deficiency. Without an adequate supply of oxygen, central nervous system (CNS) activity is depressed.

The effect of CO-induced hypoxia on sedentary human activity has been the subject of numerous studies over the years. The results of the studies having health and safety implications for workers have been summarized in a criteria document prepared by the National Institute for Occupational Safety and Health (NIOSH) (Note 1). At CO concentrations producing COHb levels of 15% or less, the behavioral findings have been equivocal, while the cardiovascular and neurological effects have been somewhat more compelling in establishing a recommended standard. Some of the difficulties with the behavioral research on CO are due in part to the complexity of behavioral assessment techniques and their related statistical designs. Also, comparisons among studies have also been hampered by the lack of equivalent CO concentrations and accurate COHb measurements.

Sensory and Behavioral Effects: A Review

Visual thresholds received much of the early attention in CO studies due to interest in possible CO effects on aviator performance. McFarland, Roughton, Halperin, and Niven (1944) found that the visual threshold increased as COHb levels increased. At 5% COHb the threshold increase was 12%. Lilienthal and Fugitt (1945) with similar levels of COHb found a decrease in critical flicker fusion at an altitude of 1524 m. With a variety of psychological tests, Bender, Gathert, Malorny, and Sebbesse (1971) reported significant reductions in manual dexterity, visual perception, and ability to learn and perform certain intellectual tasks with COHb levels of 7.2%.

Using a 90-min exposure period, Beard and Grandstaff (Note 2) found decrements in both a vigilance and a velocity estimating task at COHb levels of 2.5%. In contrast, COHb levels of up to 6% did not influence tests of problem solving (involving short term memory), digit span, arithmetic computation, or spatial perception.

At an average COHb level of 6.6%, Horvath, Dahms, and O'Hanlon (1971) found a significant decrement in signal detection. Their subjects responded to light pulses which appeared brighter than the typical series, while in Beard's vigilance task similar results were found when the subjects were asked to respond to a light stimulus judged to be different in duration from the regularly occurring series of lights.

Wright, Randell, and Shephard (1973), using a driving simulator, tested 50 individuals, both urban and rural, with smoker and nonsmoker histories. For the CO-exposed group, COHb levels were experimentally increased on the average of 3.4% to produce a peak level of about 6.0% COHb. Using non-parametric analyses, a significant deficit in the CO-exposed group was found compared to the control in what they termed "careful driving" skills. In a NIOSH field study, the effects of CO from auto emissions on toll-booth collectors were evaluated by a battery of performance tests including time estimation, complex arithmetic, reaction time, visual perception, eye-hand coordination, and task time sharing. Statistically significant correlations between CO exposure, eye-hand coordination, and simultaneous task performance were found (Johnson, Cohen, Struble, Setzer, Anger, and Gutnik, 1974).

In an extensive research program conducted by Weir and Rockwell (Note 3), using 24 tasks under COHb levels ranging from 0.5% to 20%, a consistent pattern of performance changes with increasing COHb levels was observed. The magnitudes and directions of performance changes appeared to be highly dependent on the particular task and protocols employed. The largest effects were seen at the early stages of information processing: visual and psychomotor control. A main finding was that laboratory dual-tasks exhibited performance differences at lower COHb levels than more simple tasks. They reasoned that simple tasks are often over-learned, and that subjects could compensate enough to negate possible CO effects.

In contrast to the above findings, Stewart, Peterson, Baretta, Bachand, Hosko, and Herrmann (1970) were unable to find behavioral effects in sedentary males over an eight-hr period with COHb levels reaching 11% to 13%. A battery of simple tests was used: Crawford collar, pin and screw test, hand and foot reaction time in a driving simulator, Flanagan coordination test, orthorator visual test, audiogram, time estimation, and steadiness.

O'Donnell, Chikos, and Theodore (1971) also failed to find performance effects at 5.9% and 12.7% COHb. Mental arithmetic tests, time estimation, critical flicker fusion, tracking, and monitoring tests were used. The tracking-monitoring task was a complex activity requiring the subject to center a needle on a dial for one min while simultaneously monitoring three other dials located above the tracking dial. Eight times a min a monitor dial would deviate off center and require adjustment. Tracking was scored in time off-target, while response time was recorded for the monitoring dials. In a high work load variation of this task, subjects were also required to monitor the number of times three lights flashed on during the trial. The frequency of light flashing was not recorded. The addition of the flashing light produced a greater decrement in performance than all of the CO given. No information about practice time or number of performance trials was provided.

McFarland (1973) exposed subjects to 700 parts per million (ppm) CO to produce COHb levels of 6%, 11%, and 17%. Using each subject as his own control, tests on driving-related laboratory tasks, and actual on-the-road measures were taken. COHb levels of 6%, 11%, and 17% produced no effect on actual driving ability, but with a laboratory dual-task arrangement a deleterious CO effect was apparent during the learning period or during unfamiliar situations. Response blocking was also found. At the 11 and 17% COHb levels, peripheral vision and stimulus detection were slightly impaired.

Brain-Wave Effects: A Review

The toxic effects of acute and chronic exposure to carbon monoxide (CO) on the central nervous system (CNS) have been reviewed elsewhere (Goldsmith & Landaw, 1968). The general finding from this review is that COHb levels below 20% do not disturb CNS function as measured by electroencephalograms, sensory evoked brain potentials, and brain tissue histopathology. The more recent work of Hosko (1970) concerning CO effects on evoked brain potentials also supports the above finding. The visual evoked response (VER) was examined in Hosko's study by means of a strobe flash with a duration of 3 microsec. Since VER amplitude may be affected by varying levels of attention, Hosko requested his subjects to clap their hands five times slowly and forcibly before each VER run in order to ensure that they were alert. Carbon monoxide exposures resulting in COHb saturation greater than 20% resulted in an increase in the amplitude of the 2-3-4 wave complex, and a marked negative-going shift in the 5b and 5c segments of the VER. Since the late components of the VER are known to be sensitive to drugs of various types, the conclusion was that the negative shift of the VER produced by CO exposure could have been associated with general CNS depression, or represent a specific pharmacological action of CO.

Groll-Knapp, Wagner, Hauck, and Haider (1972) investigated the effects of two-hr exposures of 50, 100, and 150 ppm, which were estimated by them to be equivalent to 3%, 5.4% and 7.6% COHb, on auditory vigilance and slow-wave brain potentials. The slow-wave brain potentials are called anticipation waves (also called contingent negative-variation potentials), since they arise as a consequence of anticipation of the stimulus. The three CO exposures caused more auditory stimuli to be missed. In addition, a decrease in the overall amplitude of the anticipation potentials was found.

The current interest in evoked responses (ER) as an indicator of CNS functioning has paralleled the technological advances in small computers which enable investigators to sum and average evoked responses rapidly and efficiently to provide quantifiable data. The computerized ERs are believed to represent activity initiated by sense organs, cortical, and subcortical brain areas. In a recent review of the area, Beck (1975) found that a number of investigators reported that attending, learning, and other mental processes may be reflected in the size and wave form of the ER.

During inattention the late components of the response have been reported to diminish. Investigating the effects of selective attention on VERs, Harter and Salmon (1972) found a reliable enhancement of a surface negative wave, which peaked at about 220 msec, and a surface positive wave at about 315 msec when the stimulus was attended. Picton and Hillyard (1974) requested subjects to direct their attention towards an auditory stimuli to detect an occasional faint signal. A significant increase occurred in the amplitude of the two late waves: $N_1$ at 83 msec, and $P_2$ at 161 msec, and a large $P_3$ component appeared at about 450 msec in response to the detected signals. The current view is that the $P_3$ wave is enhanced only when stimulus information is being actively processed, and is uniquely associated with the occurrence of a signal and its correct detection.

## PURPOSE

The first purpose of the current investigation was to determine if the level of human attention as measured by performance under a dual-task condition would be reduced by CO levels producing 5% COHb or less. The NIOSH (note 1) recommended standard for CO sets a maximum COHb level at 5%, which can be produced by a 35 ppm exposure over an eight-hr-workday. Impaired performance at CO concentrations yielding less than 5% COHb, combined with the results of previous work, might lead to reconsideration of the current recommended exposure level.

The dual-task arrangement consisted of eye-hand tracking as the central task, and brightness-monitoring as the peripheral task. Variations of this dual-task arrangement have been used frequently in applied research. A main reason is that such conditions simulate basic work activity typically involving an operator engaged in continuous manual control while simultaneously monitoring task-related, peripheral-visual information (Wiener, 1975; Putz and Rothe, 1974; Hockey, 1970a, 1970b). Success in finding low-level CO effects with dual-tasks, however, has been mixed (O'Donnell et al., 1971; Weir and Rockwell, Note 3).

The second purpose of our study was to incorporate some of the methodological refinements that emerged from earlier CO research. Specific attention was given to minimizing the arousing aspects of the testing situation by eliminating direct subject-experimenter interaction with the use of a computer interface. Putz (1975), using a monitoring task similar to that used in this study, documented the potential arousal value of an experimenter's presence. To keep motivation level constant, one hour of training was provided with moderate levels of task difficulty and interest. Task length was extended to four hr. Instead of using a battery of tests involving diversity and novelty, two tasks were employed in a repeated manner. The dual-task design served to load the behavioral system and reduce spare compensatory capacity that could mask subtle, but functional deficits. Finally, to minimize the extent of individual differences found in many sensory-motor tasks, a simple control-display ratio was designed.

A third and last purpose was to examine the auditory evoked response (AER) under conditions of low-level CO exposure and during a complex auditory discrimination task requiring attention and active information processing. The task of pitch discrimination was chosen. Thurlow (1965) found that pitch perception, particularly for the higher frequencies, depended on the arousal state of the subject. Loss of sleep tended to lower the perceived pitch of sounds while administration of an excitatory drug has a counteracting effect. Certain interneuronal inhibitory circuits, which are regulated by the reticular activating system according to Bremer (1961), were postulated by Thurlow to account for the effect of arousal on perceived pitch.

Hypotheses: Dual Task

In this study each of three groups received one of three levels of CO. The group receiving the lowest level (normal-ambient level) served as the control group. Each subject also performed under two levels of tracking frequency and under two levels of peripheral brightness over a four-hr consecutive exposure period. Performance was assessed in terms of speed and accuracy of peripheral signal detection and tracking accuracy.

The hypotheses concerned with the effects of CO on attention are related to the capacity model of attention presented by Kahneman (1973). One aspect of the theory is that a person's limited attention or capacity varies with level of arousal; when arousal drops, capacity drops. Changes in task allocation also occur with changes in arousal. The data from Weisz and McElroy (Note 4) indicated that the change in allocation of attention would be away from the peripheral task, while maintaining the central tracking task. They found that tasks which possess the greatest uncertainty, such as brightness monitoring, suffered more than a continuous and relatively predictable activity such as tracking, when arousal is increased by speed stress, and/or the spare capacity has been exhausted. Similar support for an impairment of peripheral monitoring under dual-task conditions was found by Moskowitz and Sharma (1974) using alcohol to decrease arousal.

There were three main hypotheses for the dual task component of the study:

1. Attention or arousal level would be reduced by inhalation of CO. This assumption was based on evidence that CO reduces CNS activity, and that CNS activity correlates with arousal level. With an imposed peak blood saturation of 5% COHb or less, the reduction in arousal level would be small.
2. Carbon monoxide would produce poorer performance under the high frequency tracking condition, and the dim peripheral-light condition than under the easier low frequency tracking and bright peripheral light test conditions. The premise is that the reduction in arousal with low CO levels would be more apparent when subjects are faced with information processing demands that tax their performance near its capacity, which is more likely in a dual-task with difficult test conditions.

3. Peripheral monitoring performance would deteriorate more readily than tracking, which would remain relatively stable. Furthermore, when arousal is low, selectivity is low, and irrelevant stimuli are accepted uncritically (Easterbrook, 1959). This would lead to an increase in misses and false alarms in the monitoring task used here.

In short, the first hypothesis was developed to provide information concerning the nature and direction of the potential effect. The second hypothesis described the task conditions under which the effect was likely to occur, and the third hypothesis indicated in which task the effect was likely to appear.

<u>Hypotheses: Auditory Discrimination Task and Evoked Response</u>

The nature of the research relating variations in arousal level to changes in the ER, and to pitch discrimination is at best rather tenuous. Nevertheless, two hypotheses were suggested:

1. A task that depends on attention or information processing such as pitch perception would be affected by the level of CO. This is based primarily on the fact that CO affects the activity of the CNS and reticular activating system.
2. Evoked responses produced by pitches defined as signals by the subject will show larger latencies and lower amplitudes under CO-exposure producing 5% COHb than under the control or lower COHb levels. A similar finding was

expected with the AER underlying the nonsignal pitches except that the effect would be smaller.

The task for the subject was to attend to the serial presentation of three tones of 1.0 sec duration each. When the tone defined as the signal occurred, the subject responded by pressing a button. Simultaneously the subjects' EEGs were recorded for subsequent computerized analysis of the AER.

## METHODS

### Subjects

Twenty males and ten females between the ages of 18-26 participated in the study. The subjects responded to an advertisement placed in the University of Cincinnati student newspaper. The advertisement indicated that subjects were wanted for a psychology experiment and that nonsmokers in good health with normal vision were eligible. Subjects were paid $5 per hr for approximately 6.0 hr of participation, and one hr for a physical examination. Each subject participated once in a single session serving either as a control, or under one of the two levels of CO.

In response to a student's telephone inquiry the experimenter described in some detail the nature of the study. If continued interest was expressed after learning of the exposure conditions involving low level concentrations of CO, a complete physical examination was scheduled. The physicals were performed by a private physician skilled in cardiology at the Cincinnati General Hospital. Since it is known CO is a cardiovascular stressor, expertise in cardiology was deemed essential. In order to obtain the 30 individuals needed for the study, 38 examinations were given by the cardiologist. The remaining 8 individuals not included in the study fell into one of the following categories: no-show (2), medical problems (2), extras (2), and participants used to check-out the test conditions and instrumentation (2). Upon the positive recommendation by the physician, and the notification of the laboratory's standby-physician, the subjects' medical history and examination results, including the electrocardiogram tracings, were transferred to the research laboratory for review by the experimenter and for reference during the experiment. All procedures were in accordance with the American Psychological Association's ethical principles (Note 5), and were approved by the NIOSH Human Subjects Review Board.

Exposure Procedures

Two subjects were exposed simultaneously, but independently, on the same day. In all but one case the two subjects were acquainted prior to their participation in the study. Male-male, female-female and male-female subject pairings occurred in approximately equal number across the experimental conditions. For each subject a 6.0-hr continuous block of time was scheduled beginning at approximately 10:00 a.m. Since the experiment ran through the noon hour, a common snack which consisted of a hamburger, potato chips, and noncaffeinated soft drink was provided.

Upon their arrival the subjects read and signed a consent form which described all experimental activities including the probability of being exposed to CO. Both the principal investigator and subjects were blind as to the exposure conditions. Two additional investigators were knowledgeable about the condition, but had limited contact with the subjects. In order to discourage social interaction, and to enhance the medical monitoring, continuous auditory surveillance was maintained.

Prior to the beginning of the study, breath and blood samples were taken in order to determine pre-exposure CO and COHb levels. The subjects exited from the chamber on an hourly schedule to give a breath sample. The 20-sec breath holding technique described by Jones, Ellicott, Cadigan, and Gaensler (1958) was used to obtain alveolar breath samples. The subjects were instructed to hold their breath for 20 sec, release one-fourth of the inhaled air into the room, and then exhale the remaining air into a closed plastic bag. This was repeated at the end of every hr for a total of five samples. Each sample was immediately analyzed for CO content by an Ecolyzer (Energetic Sciences, Model 2400). Blood samples were taken both prior to and after the last exposure hr. Sterile needle-type lances were used, with the blood being collected in capillary tubes for later COHb analysis. A spectrophotometer (Beckman, Model 25) was used to obtain COHb values through use of the method of Commins and Lawther (1965).

The subjects' exposure gas was administered from a pressurized cylinder of 100% CO which flowed through a Matheson Valve (Model 8-356). The gas was passed first through a desiccant ($CaSO_4$) and then into the inlet port of the exposure chamber (Webber Environment Chamber) where it was recirculated in a closed system using laminar flow. The air flow provided a slight negative pressure within the chamber. The chamber was designed for complete temperature-humidity control, and was adequate to house two subjects and the necessary testing equipment (2.13 x 1.8 x 2.13M). Temperature averaged 22.7°C with relative humidity set at 50%. A large window in the door provided two-way visibility. A view of the interior of the chamber with subject and performance equipment can be seen in Figure 1.

Two Ecolyzers were used to monitor chamber CO levels. One unit was located within the chamber, but out of sight of both the subjects' and principal investigator's view. However, the display was visible via closed circuit TV to the two investigators responsible for the monitoring and administration of the gas. The second Ecolyzer, which was located in an adjoining enclosure, sampledexposure room air through a port. All CO equipment was calibrated daily prior to subject testing. Chamber CO readings were recorded every 30 min to an accuracy of 1 ppm. In addition, a continuous record of the CO concentration was displayed on one channel of a 12 channel recorder (Grass, Model 78B),

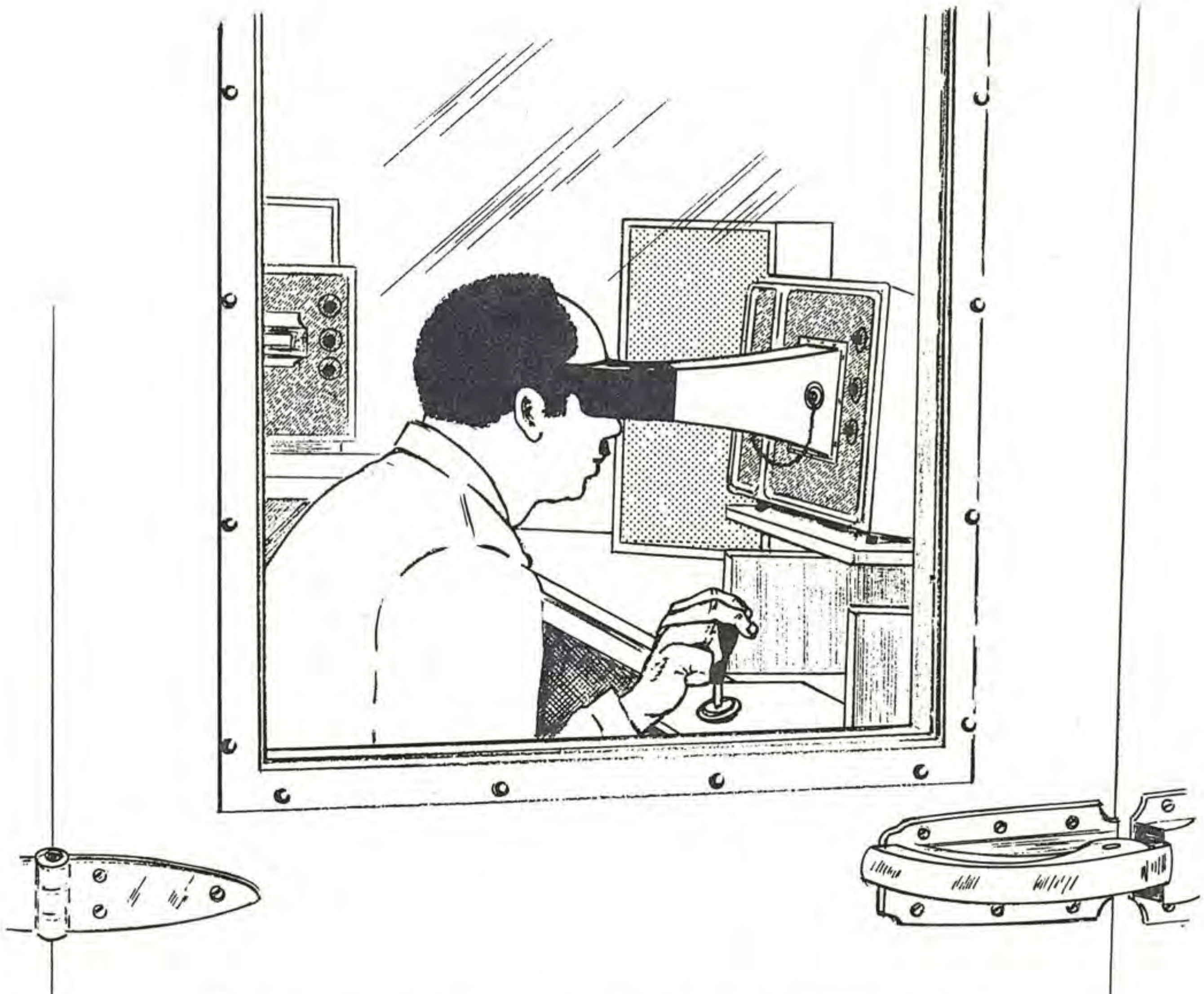

Figure 1.  Subject seated in chamber with head against viewing hood performing the dual-task.

along with the accompanying behavioral and neurological activity. For medical purposes a single lead electrocardiogram (EKG) was continuously monitored.

At the end of the four-hr exposure period each subject remained in the laboratory for approximately 50 min for the final blood-breath samples. A debriefing was provided which included the disclosure of the exposure condition and appropriate precautions concerning the level of subsequent physical exertion.

Tracking Task

Vertical compensatory tracking was the central activity in the dual-task arrangement. Two subjects were seated in the exposure chamber facing their own cathode ray tube (CRT) (Digital Equipment Corporation, Model VR14). Attached to the face of each CRT was a viewing hood extending outward from the CRT surface about 28 cm. At a designated tone each subject would lean slightly forward and place his or her face against the hood, which can be seen in Figure 1. The hood provided a visual field subtending about $52^{o}$ in both the horizontal and vertical plane. In the center of the visual field on the CRT face, a small white ring was located. The ring was designated the stationary target and had an inside diameter of 4 mm, and outside diameter of 1.2 cm. At the beginning of every trial a small white spot, subtending about $0.3^{o}$ of visual angle, was centered in the target ring and called the cursor beam. After one sec the beam began to oscillate vertically in response to a semirandom, sinusoidal forcing function generated by a computer program which was run on a PDP 12 (Digital Equipment Corporation). Five half-wave tables varying in amplitude and frequency were randomly combined in a manner to ensure that every wave function appeared equally under all conditions. The maximum amplitude subtended $48^{o}$ of visual angle, while the minimum was $24^{o}$ of visual angle. The frequency of the half-waves was varied to produce the two levels of tracking difficulty used in the study: 4 cycles/min (low frequency), and 7 cycles/min (high frequency). In addition to this computer function, all task stimuli, feedback, response measurement, and timing were automated by the laboratory computer. Since no existing software of this exact nature was available, a special program (MTAP6) was written by the senior author in assembly language.

Each of the two subjects was provided with a sensitive DC hand control (Measurement Systems, Model 435), which was mounted directly in front of their respective displays. The subject was able to manipulate the position of the cursor by applying pressure on the control in a forward or backward direction. The control-display calibration was linear with a 10-gr pressure producing a visual angle displacement of the cursor by $0.1^{o}$ with an aided time constant of zero. For every $0.1^{o}$ of visual-angle displacement from the center target-ring, the tracking error-score increased by five. Therefore, a score of 50 was registered when the cursor was displaced by $1^{o}$ of visual angle from the center of the target ring. One degree represents 0.5 cm of absolute deviation between the cursor and central target on the CRT. This control/display relationship produced a very sensitive tracking task, which was capable of responding to some of the more pronounced tremor of the hand.

The task for the subject consisted of exerting manual compensatory pressure on the control stick to align the cursor with the central target ring in order to negate the action of the forcing function on the cursor. The DC signal from the control stick was digitized by the computer's analog/digital converter, subtracted from the forcing function value, scored for absolute deviation, then reconverted and displayed on the appropriate CRT. At the end of each 55-sec trial, the mean absolute-deviation score (error score) for that trial was displayed on the CRT for the subject's feedback. The smaller the score, the better was the eye-hand coordination under the trial condition.

Monitoring Task

For the peripheral brightness task, two indicator lights (Dialco 801-1030) about 1 cm in diameter were mounted facing the interior on each side of the CRT viewing hood. Red lights were chosen since that hue has minimal effect on the dark adaptation process. With reference to the subject's line of sight each light was located about $25^{o}$ to the left and right of the central target ring, and displaced inward 2.0 cm from the face of the CRT. The viewing hood display area was illuminated by a continuous dim green light (0.2152 lux), which matched the CRT phosphorous, and served to reduce the contrast effects. Every 2.25 sec either the left or the right lamps were illuminated for 1.5 sec, and extinguished for 0.75 sec. On the average 8 of the 22 on-off sequences were signal events in a 55-sec trial period. A lamp illumination at a higher intensity was defined as the signal to which the subject was instructed to respond by pressing a button held in the left hand. Subjects were not to respond to the more frequent light presentations at the lower illumination level, which were nonsignal events. Both the occurrence of the signal, and the choice of left or right lamps were randomly determined by a subroutine (Decus 5-25) in the main computer program. If a lamp was illuminated at the higher signal intensity, and the subject responded by pressing the button within 1.5 sec, this was scored as a hit. The response time (RT) was accumulated, and the subject was provided feedback in the form of a 0.5 sec tone burst. No feedback was provided for false alarms, or misses which were also recorded.

Four levels of illumination were used to produce the two peripheral light conditions labeled bright and dim, and their accompanying signal and nonsignal intensities. The bright-nonsignal intensity averaged 0.3767 lux, while the bright-signal intensity averaged 1.5069 lux. In the dim condition, the nonsignal intensity averaged 0.0430 lux, while the dim signal level averaged 0.1722 lux. Brightness values of the stimuli were determined with a photometer in foot candles, and converted to the SI equivalent in illumination (United Detector Technology, Model 40 x). Readings were taken in a totally dark room with the photometer placed 6.5 cm from the lamp assembly. For both the bright and dim conditions the contrast ratio between the signal and nonsignal intensities was four, while there was a factor of 8.75 separating the bright from the dim intensity levels. With an alert and trained subject the bright-signal was detected in 96% of the pre-exposure trials, while the dim-signal was detected in 87% of the pre-exposure trials. No signal was presented during the first 10 sec of every two-trial block in order to allow the subject to make a judgment regarding the trial block condition (bright or dim) and to become accustomed to the lower intensity.

Auditory Task

For 15 min every hr the subjects performed a pitch discrimination task which involved monitoring three tones of equal loudness. The middle frequency tone of 1000 Hz, 80 dB(A), was designated as the signal, while a 2000 Hz, 78 dB(A) sinusoid served as the non-signal, high tone, and a 400 Hz, 87 dB(A) sinusoid served as the non-signal, low tone (80 phons). Each tone was generated by one of three audio oscillators (Wavetek, Model 30). On a given presentation one of the three tones was gated through an audio amplifier (Fisher, x-100) into a high fidelity speaker (Advent, Model-Smaller). Each tone was monitored by the subject to determine if it was the signal tone. If the tone was judged to be the signal, a response was made by pushing a hand-held button. No response was required to a non-signal tone. In addition to the subject's response time, misses, false alarms and hits were accumulated for analysis. No feedback was provided.

Every 2.25 sec either the high or the low tone was presented for 1.5 sec, and then extinguished for 0.75 sec. On the average

8 of the 22 on-off sequences were signal events in a 55-sec trial period. Both the occurrence of the signal, and the choice of high or low tone were randomly determined by a subroutine (Decus 5-25) in the main computer program. In addition to this computer function, all response accumulation and task timing were automated through use of computer program MTAP6.

Auditory Evoked Potential

After the training period, and prior to the four-hr exposure, one disc electrode and two ear electrode clips (Grass, E4S, E34G) were applied to the vertex of the scalp, and to the ears, respectively. The sites were prepared by wiping the surface with alcohol and rubbing in a generous amount of electrode cream (Grass, type EC2). The electrodes were embedded in the cream, which served as an electrolyte and an adhesive. Moist cotton balls were fixed to the site to cover the electrode cream to prevent drying. The electrodes were attached to a 2-m cable attached to a Grass 87B polygraph with an EEG preamp (7P511) located outside the exposure chamber.

A continuous visual record of the EEG on the oscillograph was maintained throughout the course of the exposure to ensure the reliability of the electrode connections. After amplification by the EEG preamp, the signal was recorded on 1" magnetic tape by a Honeywell FM tape recorder (Model 7600) at 1 7/8 ips for subsequent off-line analysis. A 1/2 amp Low Frequency setting of 1.0 KHz and 1/2 amp High Frequency of 10 KHz was used in the amplification stage.

At the completion of the exposure phase of the study, the EEG's were played back via the FM tape recorder into the analog/digital converter of the PDP 12 computer for analysis by the program AVUPT08 (Decus 12-107, A.M. Halliday). The program looks for a trigger-pulse associated with a stimulus event and initiates an averaging sweep. During the exposure phase, a pulse was generated coincident with both signal and non-signal tone events which was recorded on one channel of the magnetic tape. In each of the four-hr exposure periods, about 75 signal tones and about 200 non-signal tones (high or low tones) were presented to each subject. Since 70 AER were used by the program to generate averaged ER, one averaged ER was produced for the signal-tone stimulus each hr per subject. For the non-signal stimulus event the first 70 events of the occurrence of the high tone was chosen to provide a non-signal AER. The result was that two averaged AER were produced per subject per hr for all three exposure conditions.

The output of AVUPT08 consisted of a plot of the averaged AER, and a double precision digital record of the AER which were stored on a Linc tape of unit 1 of the computer's magnetic tape system. After conversion from double precision to single precision, the data were analyzed by the program AEPPT, which was written by the second author in order to quantify the major components of the averaged AER. The Fortran program calls the digitized, averaged AER from the Linc tape, and computes the latencies of the first major negative ($N_1$) and positive ($P_1$) peaks, amplitude of N1, P1, the ratio of P1/N1, and the RMS value of the AER. Lastly, the areas under the positive and negative portions of the AER can be computed, along with the correlation coefficient between consecutive averaged AER pairs.

### Design

Thirty subjects were randomly exposed to one of three levels of CO, forming three exposure groups of ten subjects each. The ambient CO level in the laboratory area was about 5 ppm, which produced about 1% COHb; this served as the control exposure. In order to achieve the desired treatment levels of 3% and 5% COHb, after a four-hr exposure period, chamber CO levels of 35 and 70 ppm were chosen according to the prediction of Peterson's (1970) equation. Although both experimental exposure levels are considered relatively low, the label of low-CO was applied to the group where 3% COHb was desired, and high-CO to the group where 5% COHb was desired.

Within each hr of a test session were two time periods each consisting of a set of eight trials. Within each time period of eight trials, four trials were run under conditions of high tracking frequency, and four under conditions of low tracking frequency. Nested within each level of tracking frequency were two levels of peripheral light brightness: bright and dim. Two-50 sec trials were run at each brightness level. Refer to Appendix Ib for a schematic of the experimental design. Both the tracking frequency, and peripheral brightness factors were counterbalanced in an A-B, B-A sequence. The design involved one group factor and five or six repeated measures, depending on the particular analysis (Winer, 1962, Ch.7).

Three different rest periods were provided during each hr. After each 50-sec trial the subject had a 10-sec pause, and at the end of two consecutive one-min trials, an additional two-min pause was provided. This sequence continued for 16 trials accounting for 32 min; the remaining 28 min in each hr were divided equally between a 14-min auditory discrimination-evoked potential task, which occurred immediately after the 32-min dual-task activity, and before the main rest period of 14 min. This sequence of events was repeated in each of the four exposure hr. Since two subjects were exposed at the same time, the performance trials alternated with the two-min rest pause by having one subject rest, while the other performed. This alternation continued for eight two-trial sequences or 32 min.

During the first hr prior to the four-hr exposure training to a common criterion was employed. Training data were obtained on each of the two tasks performed separately and in conjunction. All subjects were instructed to perform both tasks equally to the best of their ability. No priorities were established or references made to a primary or secondary task.*

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*See Appendix I for the temporal sequence of study events.

## RESULTS

### Carbon Monoxide Levels

In the control condition the chamber CO level averaged 4.4 ppm over the four hr with a standard deviation ($\sigma$) of 0.5 ppm. In the two treatment conditions--labeled high-CO and low-CO--the desired chamber CO levels were obtained within the first 30 min of exposure, and maintained for the four-hr period. For the low-CO level 35 ppm was desired, while an average of 35.7 ppm was actually recorded (0.2$\sigma$). The target for the high-CO exposure was 70 ppm. The actual recorded level averaged 74.1 (1.3$\sigma$).

Figure 2 shows the result of the breath samples taken at the onset and after each exposure hr for three groups. For both the high-CO and low-CO groups the concentration of CO in expired air increased fairly rapidly in the first hr with a slow leveling off in the subsequent hr. The data confirmed the expectation that a 70 ppm exposure (high-CO) with a low ventilation rate would produce about a 35 ppm body burden level after four hr. This is indicated by the top curve in Figure 2, which shows 36 ppm after four hr and 31 ppm after three hr. The middle curve (low-CO) leveled off at around 20 ppm, while the control group produced an average breath level of 7.8 ppm-about 2.8 ppm above the chamber level. This increment was probably due to the buildup of CO in the closed chamber each hr prior to the subjects' exit for the breath sample. Carbon dioxide measurements

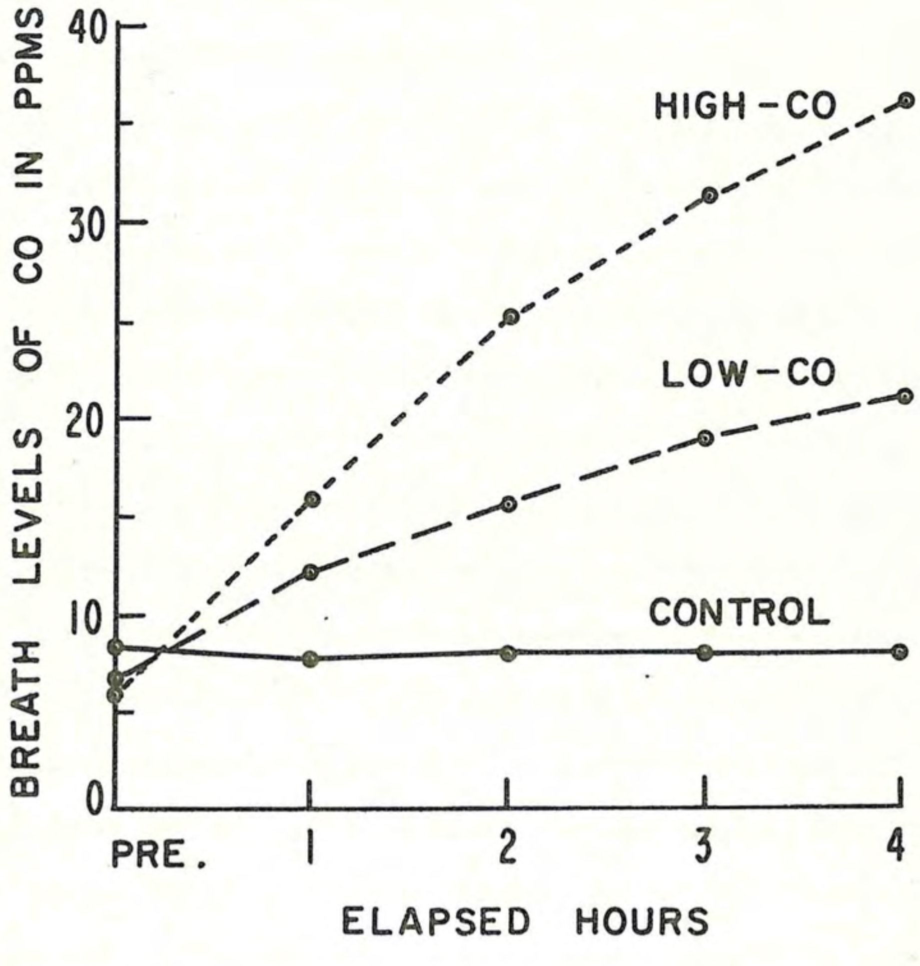


Figure 2. Comparison of CO uptake for control group, low-CO group, and high-CO group expressed in ppms. Breath samples were taken at each of five one hr intervals.

taken every 30 min on two exposure days indicated that no buildup of $CO_2$ occurred during the course of the four-hr exposure.

Carboxyhemoglobin (COHb) levels were determined for each subject from the two blood samples taken before and after exposure. For the control group, 1% COHb was obtained in both sample periods. The low-CO exposure group had a 1.5% COHb level (0.27$\sigma$) during the pre-exposure period, and 3.03% (0.71$\sigma$) at post-exposure. In the high-CO group a 1.3% COHb (0.39$\sigma$) was found before exposure and 5.1% (0.57$\sigma$) after exposure. The COHb values in the latter group equal the maximum acceptable limits (5%) recommended by the National Institute for Occupational Safety and Health in the 1972 criteria document (Note 1).

The overall correlation between breath and blood samples was very high ($\underline{r}$ = 0.92) and, the slope of the regression line was 1.3 with an intercept of 3.4. However, when the samples were broken down according to groups, and further into pre-and post-sample periods, the correlations between breath and blood samples were not as strong. For example, the high-CO group in the post-exposure period produced a correlation coefficient of 0.51, which was not significant. On the other hand a significant correlation was found in the post-exposure period in the low-CO group. In general, this suggested that the correlations between blood and breath samples of CO were good, but that variances did exist, and were more evident in certain subset correlations.

Behavioral Training Data

Since it was desired that all three groups be at or near the same proficiency on the performance tasks prior to the exposure, a trials-to-criterion index was used to achieve comparable training levels. From previous work in this area (Smith & Putz, 1970), in addition to the pilot work, it was established that two successive trials with a criterion score of 16 represented about a 90% learning level when a tracking task at comparable levels of difficulty was the only activity. A score of 16 represents about $1.5^{\circ}$ of deviation of the cursor from the target with respect to the subject's line of sight. The mean number of 50-sec trials needed to reach or exceed the criterion for the control group was 5.2, for the low-CO group 4.7, and 4.8 for the high-CO exposure. An analysis of variance (ANOVA) indicated that there was no significant difference in the number of trials needed to reach criterion on the tracking task for the three groups, $\underline{F}$ (2, 27) = 0.36, $\underline{p} > .01$.

The criterion for performance on the single task of monitoring was set at two consecutive trials with one or fewer misses with an average response time (RT) of less than 750 msec for the bright level of peripheral intensity. The average trials-to-criterion for the control group was 6.0, for the low-CO group 6.2, and 5.8 for the high-CO group. No significant difference among groups was found, $\underline{F}$ (2, 27) = 0.09, $\underline{p} > .01$.

After comparable levels of task proficiency had been achieved with the single tasks for the three groups, the next consideration was to determine if the individual task performances deteriorated under simultaneous conditions. Six additional trials were given during the last stage of the training period with the two single tasks combined into a dual-task arrangement. Using the low level of tracking frequency and the bright peripheral light intensity for the task variables, the scores on the last two trials of dual-task training were compared with the scores on the last two trials from the single task training period. The scores for the single task were at or near the criterion level of 16. With the tracking task measure of error, single versus dual-task performances were not significantly different, $\underline{F}$ (1, 27) = 0.24, $\underline{p} > .01$. The mean for the single task was 16.8 and 17.1 for the dual task.

On the peripheral task using RT as the measure, there was a significant difference between single and dual task performance, $\underline{F}$ (1, 27) = 58, $\underline{P} < .01$. For the single task the mean RT was 755 msec, while an average RT of 813 msec was recorded for the dual-task. A similar significance was found for hits or percentage of correct detections, $\underline{F}$ (1, 27) = 201, $\underline{p} < .01$. An average percent detection of 94% was found for the single arrangement and 81% for the dual-task. These findings indicated that performance on the peripheral light task deteriorated in comparison with single task activity when performed in conjunction with the tracking task.

There were no differences among the three groups at the completion of the training phase of the dual-task arrangement. The average tracking error for the control group during dual-task training was 16.7, while scores of 17.5 and 16.8 were produced by the low-CO and high-CO groups respectively, $F$ (2,27) = 0.52, $p$ > .01. Peripheral RTs for dual-task training averaged 824 msec for the control group, 829 msec for the low-CO group, and 826 msec for the high-CO group. Again, no significant differences were found among the three groups for the peripheral component of the dual-task, $F$ (2,27) = 0.28, $p$ >.01. With the same task the percentage of hits was 79, 79, and 83 for the control, low-CO, and high-CO groups, respectively, $F$ (2,27) = 4.0, $p$ >.01.

Since the above training data indicated that the groups were not significantly differentiated prior to the CO treatment, it was concluded that no sampling error was present. The observation that peripheral-monitoring under dual-task conditions was more difficult than performance on the same task performed alone suggested that the dual-task had exhausted the subjects' spare capacity for information processing, or dividing attention, and therefore was an appropriate procedure for studying divided attention.

## Performance Exposure Data*

Dual Task Tracking: Figure 3 summarizes the main findings with regard to the tracking component of the dual-task arrangement. The relationships among three variables are shown: tracking frequency, exposure time, and amount of exposure. This three-way interaction

*Performance means for all statistically significant data are found in Appendices II and III.

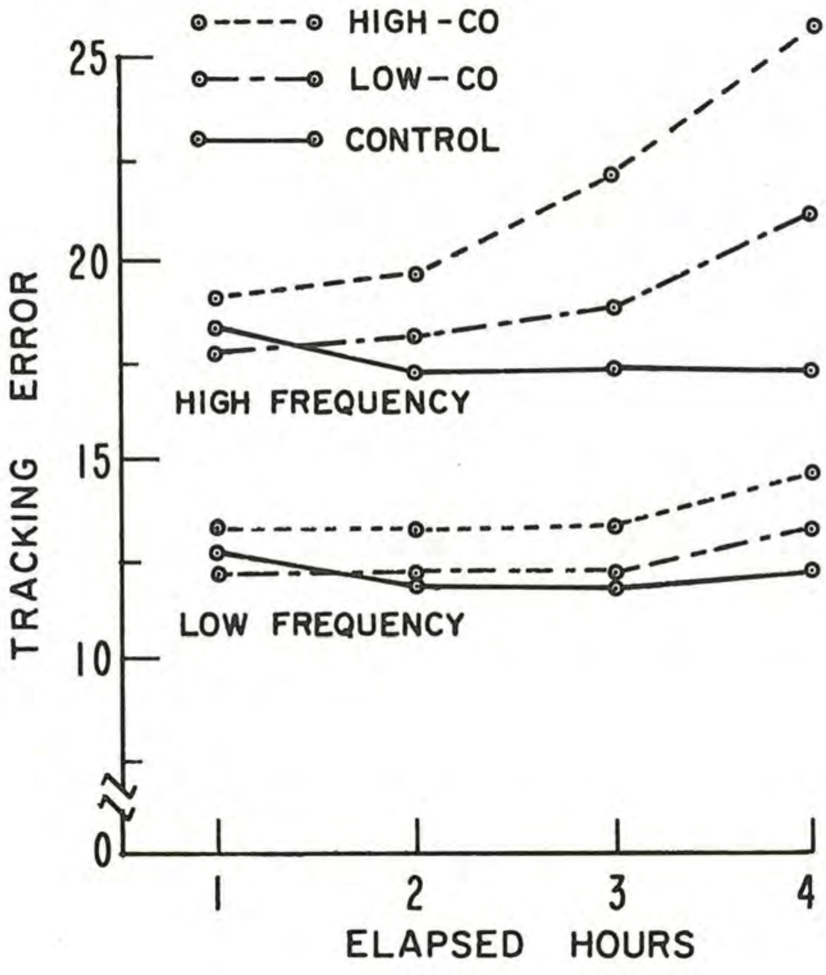


Figure 3. Tracking error for the three exposure groups plotted as a function of elapsed time, and task difficulty. Task difficulty was defined according to the frequency of the forcing function: high and low. Data were taken under dual-task conditions.

was significant in the ANOVA at the 1% level, $F$ (6, 81) = 5.7. An examination of the curves in Figure 3 suggests that CO had its greatest influence on tracking error at the high frequency or more difficult tracking level during the third and fourth exposure hr. Subsequent tests of the simple interaction effects and simple simple main effects confirmed this observation. Specifically, at the high frequency level the interaction between treatment and exposure time was significant, $F$ (6, 81) = 14.5, $p < .01$, while no significance was found at the low frequency level, $F$ (6, 81) = 1.26, $p > .01$. A simple simple main effects test was run in order to determine in which exposure hr(s) the above significant interaction appeared. The results indicated that only in exposure hr four, after 180 min of exposure, were there significant differences among the three groups, $F$ (2, 27) = 14.7, $p < .01$. In exposure hr three, two, and one no significance was found at the 1% level. With 2, and 27 df, their respective $F$ values were 4.0, 1.2 and 0.49.

Tracking in the dual-task at the high frequency level during exposure hr four produced a control mean of 17.6, a low-CO mean of 21.2 and a high-CO mean of 25.7. Using Dunnett's (1955) test for comparisons involving a control group, a critical value of 3.9 was computed for a test at the 1% level. A significant difference was only found between the high-CO and the control groups. With a less conservative Newman-Keuls range test (Newman, 1939; Keuls, 1952) significant differences were found at the 1% level for all three means. The position here is that Dunnett's test, and the accompanying result is the more appropriate.

To examine potential within-task variation a comparison was made on tracking accuracy between the two 16-min segments. In addition, the variable of peripheral light brightness was analyzed in the overall ANOVA. Peripheral light brightness produced a significant main effect with a tracking error mean of 15.9 for the bright condition and 16.4 for the dim condition, $\underline{F}$ (1,27) = 19.5, $\underline{p}$ < .01. No significant difference was found between the two 16-min tracking segments $\underline{F}$ (1,27) = 2.6, $\underline{p}$ > .10. In addition, neither variable produced any significant higher interactions. In summary, the tracking component of the dual-task deteriorated significantly in response to the high-CO exposure, during the fourth hr, and under the more difficult tracking condition. The peripheral task - light brightness - had a general influence on all the conditions analyzed in the tracking task.

Peripheral Monitoring: Figure 4 shows RT data from the peripheral component of the dual-task arrangement. The graph suggests that RT performances on the task increased at different rates as a function of the CO exposure level. This effect was also manifested in the ANOVA, which produced a significant interaction between CO level and exposure time, $\underline{F}$ (6, 81) = 2.74, $\underline{p}$ < .05. To determine in which group(s) the significant change occurred, simple main effects tests

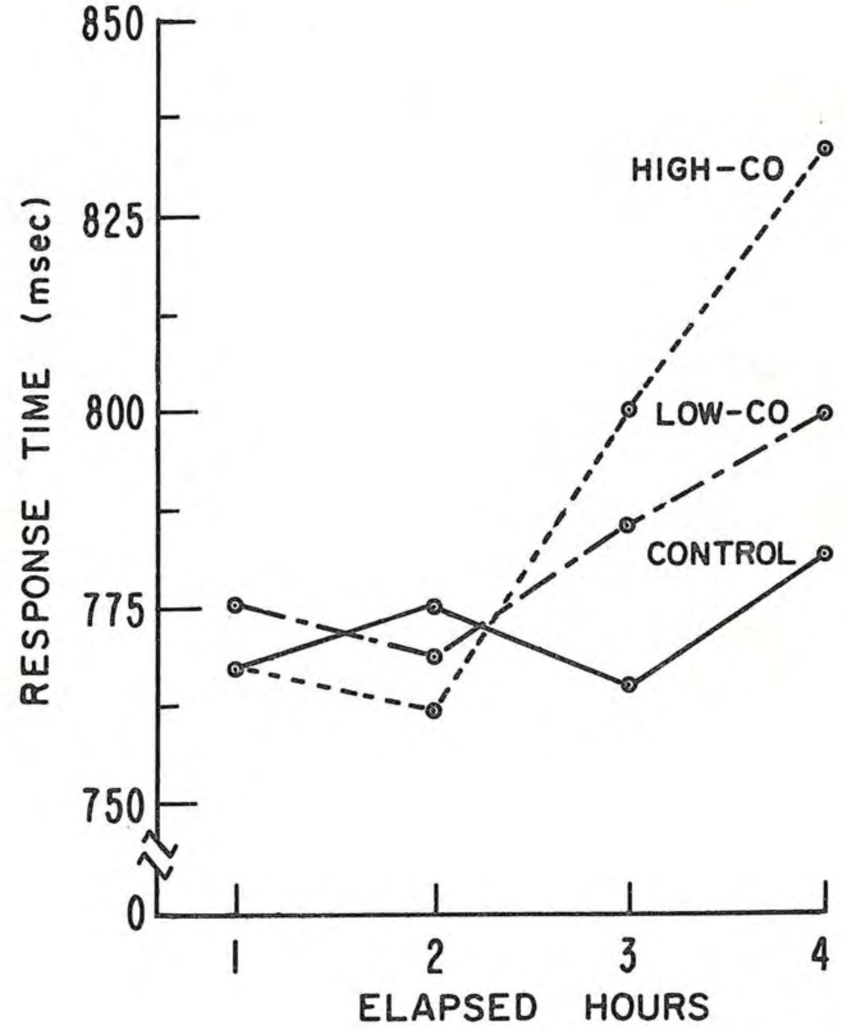


Figure 4. Peripheral light, response time expressed as a function of exposure time and CO concentration. Data were taken under dual-task conditions.

were run for each treatment group over the four exposure hr. The control and the low-CO groups produced F values of 0.81 and 1.6, respectively, with 3 and 27 df, which eliminated them as the source of significant variance. The high-CO group produced a significant simple main effect, $F$ (2, 27) = 12.7, $p > .01$. In other words, performance deteriorated (RTs increased) more rapidly under the high-CO exposure group than under the low-CO exposure and control groups over the four exposure hrs. The deterioration appeared to occur most rapidly with an increase in RT of 70 msec over the baseline of 775 between the second hr of exposure and the fourth hr in the high-CO group compared to an increase of 6 msec for the same periods in the control. No significant difference appeared in the subsequent range test for three groups (Newman-Keuls) between hr one and hr two. However, a significant difference ($p > .01$) appeared between hr two and three, and hr three and four of the high-CO group. The critical values were 12.4, 14.2 and 15.3 with 27 df for each successive step among the comparisons. Finally, a simple main effect test failed to confirm the expectation involving a possible significant difference among the three exposure groups at hr four, $F$ (2, 27) = 1.29, $p > .01$. In short, the variation among the groups at hr four was statistically nonsignificant in comparison to the significant deterioration in performance experienced by the high-CO group over the last two exposure hrs.

With RT as a measure of the peripheral task component, brightness was again significant as a main effect, $F$ (1, 27) = 486, $p < .01$.

A main concern was to determine if brightness, like tracking frequency, would serve to differentiate performance under various levels of CO exposure. Unfortunately, the answer was not as clear as it was for the tracking variable of frequency. The CO exposure x exposure length x brightness interaction was not significant, $F$ (6, 81) = 0.2, $p > .05$, but a significant two-way interaction between CO exposure and brightness was obtained, $F$ (2, 27) = 3.6, $p < .05$. The RTs obtained under the dim condition of the brightness factor were 859, 887, and 909 msec, corresponding to the control, low-CO, and high-CO groups, respectively. Simple main effects tests run on the above scores indicated no significance among the three groups at either the dim or bright level. With 2 and 27 df, the $F$ values were 1.3, and 0.7, $p > .05$, respectively. As expected, the major influence of the brightness variable was within each group, and across the two brightness levels. Brightness produced a significant difference in the control group with mean RTs of 684 and 859 msec for the dim and bright conditions respectively, $F$ (1, 9) = 77, $p < .01$. With the low-CO group the means were 676 msec bright, and 887 msec dim, $F$ (1, 9) = 319, $p < .01$. The same trend was continued with the high-CO with means of 671 for bright and 908 for dim, $F$ (1, 9) = 213, $p < .01$. The obvious result is that RT was influenced by stimulus intensity, but this provides little information concerning the effects of CO on attention.

In addition to RTs, hits, misses, and false alarms were also collected for the peripheral monitoring component of the dual-task. The results of the ANOVAs on the three remaining measures of performance followed a similar trend with the brightness variable dominating. Hits, or percentage of correct detections were enhanced by the brightness of the peripheral lights with 95% correct detections under the bright level, and 82% correct detections across all conditions under the dim level which was significant at the 1% level, $F\ (1, 27) = 33$, $p < .01$. The same effect was seen in the analysis for the number of misses and false alarms. In all cases no significant CO-related effects were found. Response time in the present study was clearly a more sensitive indicator of peripheral monitoring performance than the more discrete indices of hits, misses, and false alarms, commonly used in signal detection analyses.

Auditory Monitoring

An analysis of variance (ANOVA) was performed on the percentage of correct detections occurring in each of the four 12-min auditory monitoring segments. The mean percentages of correct detections were 80%, 78% and 80% for the control, low-CO and high-CO groups, respectively, $F\ (2, 27) = 0.2$, $p > .05$. No relationship was found between CO level and exposure time with percentage of correct detections as a measure. As the COHb levels increased over the four hrs, detections were not affected, $F\ (6, 81) = 1.87$, $p > .05$. Both misses and false alarms were also nonsignificant across time and over the three CO exposure levels. The mean response time for correct detection of the signal tone for the control group was 609 msec, 651 for the low-CO group, and 680 for the high-CO group. No significant differences were found within the ANOVA, $F\ (2, 27) = 0.4$, $p > .05$. The results of a log transformation produced no change in the F value. The CO exposure x time (elapsed hr) also failed to produce a significant effect with RT as the measure, $F\ (6, 81) = 1.88$, $p > .05$. In short, this task was insensitive to low-level CO effects.

Auditory Evoked Potential Data

The averaged auditory evoked potentials were primarily biphasic and were characterized by the occurrence of a dominant negative peak occurring at approximately 70 msec ($N_1$), followed by a positive peak at approximately 130 msec ($P_1$). These latencies were unaffected by the significance associated to the auditory stimulus by the subjects, and analysis of the AER latency data showed no association with CO exposure for either significant or nonsignificant stimuli.

Analysis of the RMS value of the total AER showed no association with CO exposure. However, examination of the ratio of the amplitudes of $P_1$ to $N_1$ for significant stimuli suggested an association with CO exposure. A ratio measure of the two aforementioned AER peaks was used in preference to absolute amplitude values in an attempt to reduce the effect of electrode preparation and other intra-subject influences. The results of plotting mean $P_1/N_1$ amplitude ratio for significant stimuli are given in Figure 5. Examination of Figure 5 suggests that CO exposure exerted an effect on this ratio of amplitudes. Analysis of the slopes of regression lines fitted to the three

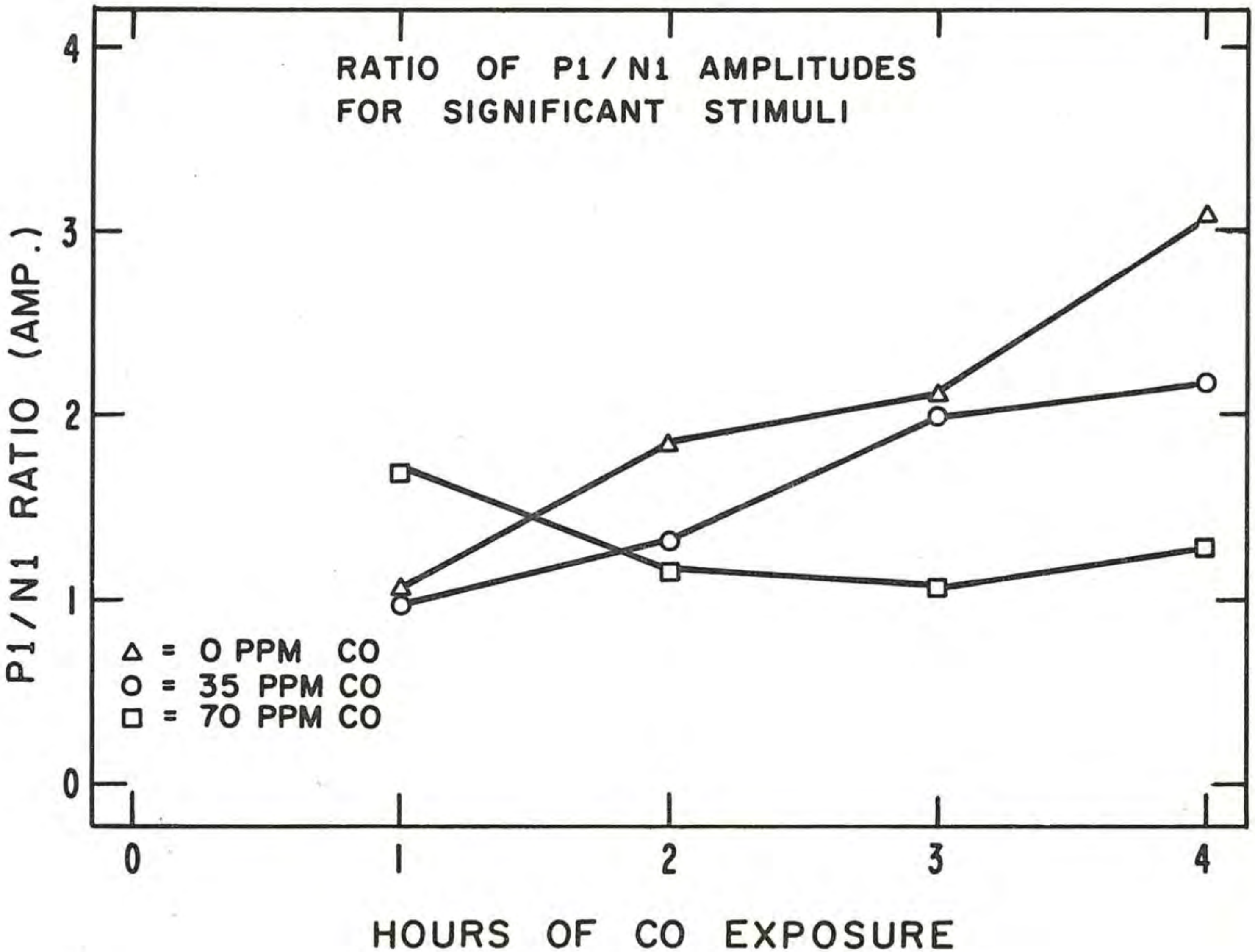


Figure 5. Ratio of $P_1/N_1$ amplitudes for averaged auditory evoked potentials for significant stimuli as a function of time and CO exposure.

curves shown in Figure 5 showed both slopes for the two CO conditions were significantly different from the slope of the regression line for the control data. For the 35 ppm CO exposure data the slope was 0.43, whereas the slope for the control data was -0.13; $t = 8.97$, $df = 2$, $p < 0.05$. The comparable values for the 70 ppm CO data were $m = 0.64$; $t = 8.39$, $df = 2$, $p < 0.05$. Examination of the AEP amplitude data indicated that the increase in the ratio of $P_1/N_1$ amplitudes resulted from an increase in AEP component $P_1$, rather than a decrease in $N_1$. Similar observation concerning AEP amplitudes generated in response to nonsignificant stimuli were not noted, which indicated CO-induced changes in auditory evoked potentials were confined to those stimuli of significance to the subject.

## DISCUSSION

The results supported the first two dual-task hypotheses: (1) carbon monoxide levels producing 5% COHb decreased arousal or alertness as measured by performance on the dual-task, when compared to performance with CO levels of 1%, and 3% COHb; (2) the deteriorating effect of CO was evident only under conditions of high frequency tracking as opposed to the low frequency condition. The task variable of peripheral light brightness had a general impact on both tracking accuracy and peripheral monitoring accuracy, but brightness did not interact with CO exposure level and/or duration.

Evidence for the third hypothesis, predicting deterioration in peripheral monitoring, while maintaining stable tracking performance, was inconclusive. Peripheral response times for the high-CO group increased at a significantly faster rate than for the low-CO and control groups after the first hour of exposure, but detection accuracy was unaffected, as well as the number of misses or false alarms. Contrary to the expectation, tracking accuracy did not remain stable, but deteriorated in the fourth hr of high frequency tracking when COHb reached 5%.

The validity of these findings were predicated upon the empirical confirmation that the desired COHb levels were obtained for each group. In addition, appropriate data from the pre-exposure or training phase were necessary to support the underlying experimental and theoretical contentions. Specifically, performance for the three groups on the two tasks both singly and in combination were not significantly different prior to the exposure periods. During the same pre-exposure phase it was also shown that dual-task performance required divided attention, since monitoring when paired with tracking produced fewer correct detections than when performed separately (a procedure described by Keele, 1973).

The exposure data on the slowed RTs during peripheral monitoring loosely parallels the findings of Horvath et al. (1971), and the vigilance data of Beard and Grandstaff (Note 2). Horvath used a single task, and requested the subjects to identify signal and nonsignal lights which were also defined according to their brightness levels, while Beard's task involved monitoring light pulses for changes in duration. As in the present study, the subjects lost vigilance more rapidly than normal as their average COHb level approached 5%.

In both the Horvath and Beard study, percentage of signal identification was used as the measure, rather than RT, which was not analyzed. The general conclusion from the three studies is that low level CO exposure enhances the normal vigilance decrement.

The finding related to the vigilance decrement is also in agreement with the predictions of the capacity model of attention presented by Kahneman (1973). When the arousal level of the subjects dropped, their capacity to time-share dropped. The change in the subjects' capacity was not manifested in a discrete all-or-none manner of perceiving since the percentage of detections and misses were not significantly changed, but rather in their rate of responding which decreased. They became more hesitant and demanded more time (msec) to make their decisions, as if the data were cueing up to be handled when central information processing capacity was available.

Within the tracking component, however, the subjects' accuracy was dependent on their speed of corrective action. When a high speed of responding was demanded by the high frequency target motion, their accuracy decreased. The decrease in the subjects' arousal did not in this task make them less selective, as Easterbrook (1959) hypothesized, but it made them slower, which in a time-paced task can ultimately lead to errors as seen in the condition involving high frequency tracking.

Two conditions of peripheral light brightness were used in the present study to determine if CO concentrations and brightness would interact. McFarland et al. (1944) found visual threshold increased, using a classical psychophysical procedure, with COHb levels as low as 5%. With the monitoring task technique in the present arrangement, the variable of brightness produced a significant level of interference on both tasks when performed simultaneously, but it did not interact with CO concentration and duration. The strong effect that brightness had in influencing all dual-task performance scores suggested that the levels chosen for dim and bright were too extreme, and that perhaps more subtle variations of light brightness would have allowed an interaction with the treatment rather than potentially washing the effect out.

The only task variable in the present study other than time to interact with CO concentration was the frequency of the tracking component of the dual-task, which produced a deterioration in tracking accuracy. In Weir and Rockwell's (Note 3) dual-task arrangement, a pursuit tracking task was paired with a complex memory retrieval task. They found with a COHb level of 20% that a tracking time-lag was particularly evident in the tracking condition featuring high frequency target motion. However, performance on the memory retrieval task was not affected by any of the CO conditions. With COHb levels below 20%, no significant differences or interactions between task complexity and COHb level were found, but a large number of individual differences were evident. Their memory retrieval task was similar to the Sternberg (1967) paradigm used in short-term memory research. Performance is typically more a function of motivation and amount of practice in the memory task than with tasks involving pure sensory discrimination. Spare capacity and individual differences are generally less of a factor in the discrimination procedures where the physical levels of a stimuli are set at or near each subject's threshold level, which precludes the subject from overcompensating through increased motivation.

The duration of the test period appears to be a critical factor which may account for some of the differences between the findings of the present study, and those of O'Donnell et al. (1971), and Stewart et al. (1970). Wilkinson (1969), in a review article on the effects of environmental stressors upon performance, maintained that the length of the working period was one of the most important factors to consider in deciding whether a stress will impair performance or not. In a study on the behavioral effects of partial sleep, he concluded that had the performance test been a brief 10 to 15-min procedure given only once during the day, he would not have found any effect. According to Wilkinson, the subjects would have been able to sustain concentration and normal performance levels for that relatively short period, if they knew no more was to be required of them. The full day's work is by far the more vulnerable performance setting, but unfortunately it is the more difficult one to implement, which is what tempts researchers to predict on the basis of a short and easily administered test or battery of tests.

The AER data suggest a CO-induced disruption of amplitudes of auditory evoked potentials recorded in response to stimuli of significance to the subjects. Due to the variability of the AER data as a consequence of other large inter-subject differences, this observation should be considered as tentative. Evoked potential amplitude changes were also found by Hosko (1970) for visual stimuli, but the COHb level had to exceed 20 percent. However, the visual stimuli used by Hosko were presented as neutral stimuli, i.e., the subjects were not required to discriminate the stimuli. Our data would suggest that the extra mental effort required for discrimination increases the susceptibility of disruption of sensory evoked potentials by CO.

## Conclusion

The deterioration of tracking accuracy in the fourth hour under a high frequency tracking condition, and the slower RTs found with the peripheral monitoring of the dual-task support the view that low level CO (around 5% COHb) interacts with task difficulty and duration to accelerate the loss of vigilance, and adversely affects the efficiency of difficult task performances, such as tracking. The conclusion based on evidence from the neurological component of the study -- the auditory-evoked responses -- suggests that CO at levels producing 5% COHb can significantly influence the level of brain potentials of exposed individuals who are engaged in extended and repetitious decision-making activity. These findings suggest that sensitive and provocative laboratory tests can reveal subtle functional deficits at 5% COHb, which is the current NIOSH recommendation for the maximum acceptable blood level of CO for the industrial population. The significance of these findings to safe job performance by workers remains to be determined.

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## APPENDIX Ia

## TEMPORAL SEQUENCE OF EVENTS IN CO STUDY*

| | |
|---|---|
| 10:00 | Participants Arrive at Laboratory |
| 10:15 | Read and Signed Consent Forms |
| 10:30 | Blood and Breath Sample Collected (1) |
| 10:35 | Enter Chamber for Pre-Exposure Training |
| 11:35 | Training Completed |
| | Exit from Chamber for Application of Electrodes for EEG and EKG |
| 11:45 | Enter Chamber for Exposure |
| | Dual-Task Testing I Begins |
| 12:15 | Auditory Task Testing I Begins |
| 12:30 | Lunch; Breath Sample Collected (2) |
| 12:45 | Dual-Task Testing II |
| 1:15 | Auditory Task II |
| 1:30 | Rest and Breath Sample Collected (3) |
| 1:45 | Dual-Task Testing III |
| 2:15 | Auditory Task III |
| 2:30 | Rest and Breath Sample Collected (4) |
| 2:45 | Dual-Task Testing IV |
| 3:15 | Auditory Task IV |
| 3:30 | Exposure Completed |
| | Blood and Breath Sample Collected (5) |
| 4:00 | Debriefing |
| 4:15 | Participants leave |

*Approximate times-rounded to the nearest 5-min period.

Appendix Ib
Schmematic of Experimental Design (CO Study)

<table>
<tr><td rowspan="5" colspan="3"></td><td colspan="12">$H_1$</td><td>$H_2 . . H_4$</td></tr>
<tr><td colspan="8">$P_1$</td><td colspan="2">$P_2$</td><td rowspan="4">Auditory Test</td><td rowspan="4">Rest</td><td rowspan="4"></td></tr>
<tr><td colspan="4">$F_1$</td><td colspan="4">$F_2$</td><td></td><td></td></tr>
<tr><td colspan="2">$I_1$</td><td colspan="2">$I_2$</td><td colspan="2">$I_1$</td><td colspan="2">$I_2$</td><td></td><td></td></tr>
<tr><td>$T_1$</td><td>$T_2$</td><td>$T_1$</td><td>$T_2$</td><td>$T_1$</td><td>$T_2$</td><td>$T_1$</td><td>$T_2$</td><td></td><td></td></tr>
<tr><td>I</td><td>Control<br>0-5 ppm</td><td>$S_1$<br>.<br>.<br>.<br>$S_{10}$</td><td colspan="8">$X_n$ . . .</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>II</td><td>Low<br>CO<br>35 ppm</td><td>$S_{11}$<br>.<br>.<br>.<br>$S_{20}$</td><td colspan="8"></td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>III</td><td>High<br>CO<br>70 ppm</td><td>$S_{21}$<br>.<br>.<br>.<br>$S_{30}$</td><td colspan="8"></td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
</table>

Key:

- H = hours of exposure (4)
- P = periods (2)
- F = frequency of forcing function of tracking task (high and low)
- I = intensity of peripheral lights (bright and dim)
- T = trials (2)
- $X_n$ = raw data

## APPENDIX II

Coding scheme: S = Subject number (three groups of 10 subjects, 1-10)
T (treatment exposure) = 1 = Control (0-5 ppm)
= 2 = Low CO ( 35 ppm)
= 3 = High CO ( 70 ppm)
F (frequency/task difficulty) = 1 = Low frequency
= 2 = High frequency
H (hours elapsed during exposure) = 1 = End of first hour
= 2 = End of second hour
= 3 = End of third hour
= 4 = End of fourth hour

### TRACKING MEANS UNDER DUAL-TASK CONDITIONS*

T = 1, S = 1

| H | F = 1 | F = 2 |
|---|---|---|
| 1 | 8.75000 | 15.25000 |
| 2 | 8.62500 | 14.37500 |
| 3 | 7.62500 | 14.12500 |
| 4 | 7.50000 | 14.25000 |

T = 1, S = 2

| H | F = 1 | F = 2 |
|---|---|---|
| 1 | 9.00000 | 14.50000 |
| 2 | 7.50000 | 13.62500 |
| 3 | 8.25000 | 13.25000 |
| 4 | 9.12500 | 13.62500 |

T = 1, S = 3

| H | F = 1 | F = 2 |
|---|---|---|
| 1 | 13.37500 | 21.62500 |
| 2 | 14.12500 | 21.62500 |
| 3 | 14.87500 | 21.00000 |
| 4 | 15.25000 | 19.12500 |

T = 1, S = 4

| H | F = 1 | F = 2 |
|---|---|---|
| 1 | 15.00000 | 21.12500 |
| 2 | 15.12500 | 20.62500 |
| 3 | 15.75000 | 23.12500 |
| 4 | 14.25000 | 20.00000 |

T = 1, S = 5

| H | F = 1 | F = 2 |
|---|---|---|
| 1 | 14.00000 | 17.00000 |
| 2 | 14.12500 | 15.62500 |
| 3 | 14.12500 | 16.12500 |
| 4 | 14.37500 | 17.87500 |

T = 1, S = 6

| H | F = 1 | F = 2 |
|---|---|---|
| 1 | 12.62500 | 17.62500 |
| 2 | 12.62500 | 17.87500 |
| 3 | 11.62500 | 16.75000 |
| 4 | 11.50000 | 16.62500 |

T = 1, S = 7

| H | F = 1 | F = 2 |
|---|---|---|
| 1 | 16.25000 | 20.25000 |
| 2 | 14.75000 | 20.37500 |
| 3 | 15.12500 | 22.50000 |
| 4 | 15.62500 | 22.62500 |

T = 1, S = 8

| H | F = 1 | F = 2 |
|---|---|---|
| 1 | 12.75000 | 17.12500 |
| 2 | 10.62500 | 14.62500 |
| 3 | 10.12500 | 14.87500 |
| 4 | 12.25000 | 15.12500 |

T = 1, S = 9

| H | F = 1 | F = 2 |
|---|---|---|
| 1 | 10.87500 | 16.87500 |
| 2 | 9.25000 | 16.00000 |
| 3 | 10.00000 | 15.87500 |
| 4 | 10.12500 | 16.37500 |

T = 1, S = 10

| H | F = 1 | F = 2 |
|---|---|---|
| 1 | 15.00000 | 21.37500 |
| 2 | 11.37500 | 21.75000 |
| 3 | 11.37500 | 19.62500 |
| 4 | 11.50000 | 19.87500 |

*The smaller the number the greater the tracking accuracy. See the methods section of the report for the absolute calibration value of numbers.

b

| T = 2 | S = 1 | |
| --- | --- | --- |
| F = | 1 | 2 |
| H = 1 | 9.37500 | 14.37500 |
| 2 | 10.63500 | 16.12500 |
| 3 | 9.00000 | 17.00000 |
| 4 | 14.00000 | 20.75000 |

| T = 2 | S = 2 | |
| --- | --- | --- |
| F = | 1 | 2 |
| H = 1 | 10.37500 | 16.50000 |
| 2 | 11.12500 | 17.50000 |
| 3 | 9.50000 | 16.25000 |
| 4 | 14.75000 | 21.12500 |

| T = 2 | S = 3 | |
| --- | --- | --- |
| F = | 1 | 2 |
| H = 1 | 10.62500 | 17.75000 |
| 2 | 9.00000 | 18.75000 |
| 3 | 9,75000 | 22.25000 |
| 4 | 8.37500 | 22.50000 |

| T = 2 | S = 4 | |
| --- | --- | --- |
| F = | 1 | 2 |
| H = 1 | 10.25000 | 14.75000 |
| 2 | 7.0000 | 14.50000 |
| 3 | 6.62500 | 16.00000 |
| 4 | 6.62500 | 17.12500 |

| T = 2 | S = 5 | |
| --- | --- | --- |
| F = | 1 | 2 |
| H = 1 | 13.37500 | 17.75000 |
| 2 | 13.62500 | 19.00000 |
| 3 | 14.00000 | 17.87500 |
| 4 | 16.12500 | 22.62500 |

| T = 2 | S = 6 | |
| --- | --- | --- |
| F = | 1 | 2 |
| H = 1 | 9.25000 | 14.50000 |
| 2 | 9.12500 | 14.62500 |
| 3 | 8.12500 | 13.87500 |
| 4 | 8.62500 | 13.00000 |

| T = 2 | S = 7 | |
| --- | --- | --- |
| F = | 1 | 2 |
| H = 1 | 12.75000 | 15.00000 |
| 2 | 14.75000 | 16.25000 |
| 3 | 14.62500 | 16.12500 |
| 4 | 14.50000 | 19.37500 |

| T = 2 | S = 8 | |
| --- | --- | --- |
| F = | 1 | 2 |
| H = 1 | 13.75000 | 21.12500 |
| 2 | 14.25000 | 21.50000 |
| 3 | 15.12500 | 21.12500 |
| 4 | 17.12500 | 23.50000 |

| T = 2 | S = 9 | |
| --- | --- | --- |
| F = | 1 | 2 |
| H = 1 | 14.50000 | 20.87500 |
| 2 | 12.62500 | 19.12500 |
| 3 | 12.50000 | 20.37500 |
| 4 | 16.00000 | 24.50000 |

| T = 2 | S = 10 | |
| --- | --- | --- |
| F = | 1 | 2 |
| H = 1 | 19.25000 | 26.50000 |
| 2 | 21.50000 | 24.12500 |
| 3 | 21.12500 | 27.25000 |
| 4 | 17.75000 | 27.62500 |

| T = 3 | S = 1 | |
|---|---|---|
| F = | 1 | 2 |
| H = 1 | 12.62500 | 18.62500 |
| 2 | 11.62500 | 15.87500 |
| 3 | 11.75000 | 23.75000 |
| 4 | 12.62500 | 25.12500 |

| T = 3 | S = 2 | |
|---|---|---|
| F = | 1 | 2 |
| H = 1 | 9.75000 | 16.25000 |
| 2 | 10.00000 | 15.75000 |
| 3 | 9.62500 | 15.75000 |
| 4 | 13.62500 | 18.00000 |

| T = 3 | S = 3 | |
|---|---|---|
| F = | 1 | 2 |
| H = 1 | 13.25000 | 20.50000 |
| 2 | 14.00000 | 20.25000 |
| 3 | 14.25000 | 21.50000 |
| 4 | 15.12500 | 25.37500 |

| T = 3 | S = 4 | |
|---|---|---|
| F = | 1 | 2 |
| H = 1 | 12.37500 | 18.12500 |
| 2 | 14.37500 | 20.25000 |
| 3 | 13.37500 | 20.50000 |
| 4 | 17.62500 | 24.87500 |

| T = 3 | S = 5 | |
|---|---|---|
| F = | 1 | 2 |
| H = 1 | 15.12500 | 20.00000 |
| 2 | 14.87500 | 19.75000 |
| 3 | 13.87500 | 27.87500 |
| 4 | 14.87500 | 28.25000 |

| T = 3 | S = 6 | |
|---|---|---|
| F = | 1 | 2 |
| H = 1 | 15.62500 | 19.25000 |
| 2 | 16.50000 | 21.87500 |
| 3 | 16.75000 | 19.87500 |
| 4 | 16.87500 | 25.62500 |

| T = 3 | S = 7 | |
|---|---|---|
| F = | 1 | 2 |
| H = 1 | 13.37500 | 16.75000 |
| 2 | 13.37500 | 16.87500 |
| 3 | 13.50000 | 21.12500 |
| 4 | 13.37500 | 27.00000 |

| T = 3 | S = 8 | |
|---|---|---|
| F = | 1 | 2 |
| H = 1 | 12.87500 | 19.75000 |
| 2 | 13.25000 | 21.00000 |
| 3 | 12.75000 | 22.75000 |
| 4 | 17.25000 | 28.00000 |

| T = 3 | S = 9 | |
|---|---|---|
| F = | 1 | 2 |
| H = 1 | 13.37500 | 20.25000 |
| 2 | 11.75000 | 21.25000 |
| 3 | 14.37500 | 23.75000 |
| 4 | 12.50000 | 26.12500 |

| T = 3 | S = 10 | |
|---|---|---|
| F = | 1 | 2 |
| H = 1 | 15.37500 | 22.12500 |
| 2 | 17.25000 | 23.50000 |
| 3 | 13.37500 | 25.50000 |
| 4 | 13.87500 | 28.62500 |

Coding Scheme:

S = Subject number (Three groups of 10 Subjects, 1-10)

T = Treatment Exposures:

T = 1 = Control (0-5 ppm)

T = 2 = Low CO (35 ppm)

T = 3 = High CO (70 ppm)

H = Hour - Elapsed Time During Exposures

H = 1 = End of 1st hour

H = 2 = End of 2nd hour

H = 3 = End of 3rd hour

H = 4 = End of 4th hour

Peripheral Light Response Time Means*
Under Dual-Task Conditions

T = 1

| H = | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| S = 1 | 751.00000 | 731.12500 | 741.25000 | 754.12500 |
| 2 | 767.25000 | 762.75000 | 781.62500 | 786.12500 |
| 3 | 722.37500 | 726.50000 | 722.12500 | 723.37500 |
| 4 | 817.25000 | 853.25000 | 818.87500 | 865.00000 |
| 5 | 688.25000 | 681.12500 | 637.12500 | 667.37500 |
| 6 | 775.62500 | 720.50000 | 746.50000 | 761.00000 |
| 7 | 717.75000 | 748.50000 | 742.25000 | 746.87500 |
| 8 | 762.00000 | 771.37500 | 763.37500 | 760.62500 |
| 9 | 800.75000 | 817.87500 | 852.00000 | 914.87500 |
| 10 | 870.25000 | 939.25000 | 836.12500 | 832.87500 |

T = 2

| H = | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| S = 1 | 761.50000 | 702.62500 | 779.75000 | 767.62500 |
| 2 | 756.25000 | 721.25000 | 703.62500 | 814.00000 |
| 3 | 798.37500 | 792.75000 | 801.75000 | 762.37500 |
| 4 | 841.62500 | 855.12500 | 806.75000 | 838.50000 |
| 5 | 755.37500 | 755.00000 | 781.12500 | 817.00000 |
| 6 | 647.00000 | 644.37500 | 674.50000 | 671.75000 |
| 7 | 785.00000 | 729.37500 | 752.62500 | 753.50000 |
| 8 | 811.00000 | 837.75000 | 833.12500 | 866.37500 |
| 9 | 809.00000 | 743.12500 | 850.00000 | 804.37500 |
| 10 | 790.12500 | 908.25000 | 871.62500 | 897.87500 |

T = 3

| H = | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| S = 1 | 712.87500 | 716.12500 | 776.37500 | 790.00000 |
| 2 | 725.12500 | 777.62500 | 748.75000 | 792.37500 |
| 3 | 693.37500 | 736.37500 | 727.00000 | 749.37500 |
| 4 | 784.00000 | 780.00000 | 840.12500 | 843.50000 |
| 5 | 739.12500 | 704.87500 | 727.12500 | 783.37500 |
| 6 | 685.87500 | 687.62500 | 681.12500 | 775.00000 |
| 7 | 943.12500 | 844.00000 | 935.37500 | 965.00000 |
| 8 | 760.00000 | 769.12500 | 816.87500 | 786.75000 |
| 9 | 882.12500 | 822.50000 | 888.87500 | 979.12500 |
| 10 | 745.12500 | 787.25000 | 850.00000 | 860.25000 |

*Data in msec



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