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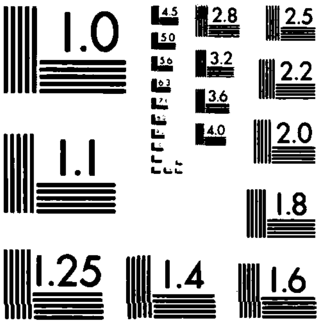

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EFFECTS OF LOW LEVEL CARBON MONOXIDE (CO) ON TRACKING AND MONITORING. AN ATTEMPT TO REPLICATE THE FINDINGS OF PUTZ ET AL. (1976)

PROTOCOL 2, FINAL REPORT

Vernon A. Benignus[1], Keith E. Muller [2], Curtis N. Barton[3] and James D. Prah[1]

JANUARY 1985

Supported by

U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Fort Detrick, Frederick, MD 21701-5012

Project Order 1812

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The present study was an attempt to replicate the experiment and findings of Putz et al. (1976). In the Putz et al. study it was shown that 5 percent COHb resulting from four hours of exposure to 70 ppm CO produced decrements in tracking and monitoring behavior in healthy young men. Intensive effort was made to assure that the Putz et al. procedure and equipment were duplicated. Certain procedural changes were introduced out of necessity or due to lack of exact information.

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ABSTRACT (continued)

The results of the present study using 22 healthy men did not show a statistically significant effect of CO exposure to 100 ppm for four hours on either tracking or monitoring. The criterion for experimentwise significance was $\alpha = 0.05$ which was divided equally between the two kinds of performance so that for each overall significance test, $\alpha = 0.025$. The The planned analysis was based on (a) reanalysis and power analysis of Putz's original data and (b) pilot data from our laboratory. For tracking, the test of CO effects of interest (the CO x hour interaction) had $p = 0.035$. For monitoring the appropriate test of CO x hour effect yielded $p > 0.39$.

In the present study (a) observed trends were in the same direction as those of Putz _et al_. (b) results approached statistical significance criterion and (c) several inadvertent methodological changes from Putz _et al_. apparently occurred. Due to these considerations and the findings of Putz _et al_. (1976) and Putz (1979), it may be tentatively concluded that (a) tracking may be sensitive to impairment by CO exposure (b) monitoring does not appear to be affected by CO exposure and (c) important variables in research on the effects of CO exposure on tracking appear to be the level of subject training and the task difficulty. It is important to note that this publication does not claim that the results of Putz _et al_. have been replicated. Much, however, was learned from this study in terms of the stability of tracking behavior for further quantitative CO research planning.

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EXECUTIVE SUMMARY

Carbon Monoxide (CO) is the byproduct of incomplete combustion. As such it occurs in many environments ranging from outdoor air to industrial and military. The neural and behavioral effects of CO exposure are poorly understood but have been reported to affect the variables measured in this study: hand-eye coordination (in the form of compensatory tracking) and visual monitoring of peripheral events.

This is the final report of a protocol designed to replicate the finding of Putz _et al_. (1976) who have published much of the original work in this area. The objective was to help determine if tracking and perhaps monitoring are reliably affected by CO exposures in other, unrelated experiments and laboratories than those of Putz _et al_. If so, then those behavioral dependent variables could be used in further dose response studies of CO effects.

Twenty-two healthy young men were exposed to either 100 ppm CO or to ambient air for four hours while they were tested on a tracking and monitoring task. Tracking consisted of attempting to keep a spot on a cathode ray tube (CRT) centered by manipulating a pressure sensitive joystick. Monitoring was tested by having subjects detect the occurrence of an unusually bright flash of light in a string of regularly flashing red lights. Tracking and monitoring were performed simultaneously.

The results of the present study did not show a statistically significant effect of CO exposure to 100 ppm for four hours on either tracking or monitoring. The criterion for experimentwise significance was $\alpha =$ 0.05, divided equally between the two kinds of performance so that for each overall significance test, $\alpha = 0.025$. The planned analysis was based on (a) reanalysis and power analysis of Putz's original data and (b) pilot data from our own laboratory. For tracking, the test of CO effects (the CO x hour interaction) had $p = 0.035$. For monitoring the test of CO x hour effect yielded $p > 0.39$.

In the present study (a) observed trends were in the same direction as those of Putz *et al*. (b) the results approached statistical significance criterion and (c) several inadvertent methodological changes from Putz *et al*. apparently occurred. Due to these considerations and the findings of Putz *et al*. (1976) and Putz (1979), it may be tentatively concluded that (a) tracking may be sensitive to impairment by CO exposure (b) monitoring does not appear to be affected by CO exposure and (c) important variables in research on the effects of CO exposure on tracking appear to be the level of subject training and the task difficulty. It is important to note that this publication does not claim that the results of Putz *et al*. have been replicated. Much, however, was learned from this study in terms of the stability of tracking behavior for further quantitative CO research planning.

Conclusions. From the above discussion and in consideration of findings by Putz *et al*. (1976) and Putz 1979, the following conclusions seem appropriate.

(a) tracking may be sensitive to impairment by CO exposure.

(b) monitoring may not be affected by CO exposure.

(c) important variables in research on the effects of CO exposure on tracking appear to be the level of subject training and the task difficulty.

LIST OF FIGURES

LIST OF TABLES

TABLE OF ABBREVIATIONS

CNS	central nervous system
COHb	carboxyhemoglobin, a measure of the level of carbon monoxide in the blood
CRT	cathode ray tube, a video screen
dB	decibel, a measure of sound intensity
FF	forcing function. A signal or voltage which drives the CRT spot away from the target
Hz	cycles per second, a measure of frequency
MANOVA	multivariate analysis of variance, a statistical analysis technique
n	number of subjects
p	probability
ppm	parts per million, used to express the level of CO in the air

GLOSSARY

a priori	An experimental hypothesis made before conducting the experiment
A-weight	The weighting of a sound by a frequency weighting network which approximates human loudness of sounds of different frequency compositions
Bonferroni Correction	A statistical technique employed to adjust the calculated p values for the number of statistical tests conducted to arrive at a more accurate estimate. This reduces the probability of committing a type I error for the experiment as a whole (Kirk, 1968)
double blind	An experimental strategy in which neither the subject nor the experimenter in contact with the subject is aware of the exposure condition. This strategy is used of minimize experimenter and subject bias
evoked potential	Electrical activity in the central nervous system occasioned by a sensory stimulus
forcing function (FF)	A time varying voltage used to drive a spot on a CRT
joystick	A lever similar to that used on video games or in remote control system to manipulate some event
post hoc	Here refers to analyses which do not satisfy criteria of a-priori hypotheses
power	Chances of (correctly) detecting a true effect
pseudorandom	Random except for certain constraints, e.g. no strings of repeated numbers longer than some fixed number
SAS	A statistical analysis package
single blind	An experimental paradigm in which the experimenter but not the subject is aware of the experimental condition
threshold	In psychophysics the arbitrarily defined point on the physical continuum above which perception of a stimulus is regarded as reliably occurring, frequently defined as > 50% detection.
type I error	In hypothesis testing, falsely rejecting the null hypothesis and concluding that a significant difference was due to the experimental manipulation

INTRODUCTION

Experiments on the effects of carbon monoxide (CO) on neural and behavioral variables in man have frequently not been replicable (Benignus et al., 1983; Laties and Merigan, 1979). Such nonreplicability could be due to (a) low level exposures which are near threshold for effects (b) unreliable performance of human subjects on the tasks chosen for study (c) changes in procedure in replication studies with respect to the original studies (d) lack of double blind design or (e) type I errors which are reported, in contrast to nonsignificant findings which are typically not reported (Rosenthal, 1979).

Putz et al. (1976, 1979), a possible exception to the above, performed studies of the effects of CO upon (a) tracking (b) monitoring and (c) auditory evoked potentials. The tracking task involved keeping a moving spot centered on a CRT by manipulating a joystick. The monitoring task was performed simultaneously with tracking and consisted of detecting bright flashes of light interspersed among a series of dimmer flashes. The subject's task was to detect the bright flashes. The auditory evoked potential task consisted of listening to a series of tones presented serially and pressing a button when a target tone was 1 KHz. Nontarget tones were either higher or lower in frequency.

Subjects were exposed to either 70 ppm CO, 35 ppm CO or room air for 4 hours. In one study an independent group of subjects served at each exposure level (Putz et al., 1976). In the other study each subject served in all exposure levels (Putz et al., 1979). The 70 ppm group reached about 5 percent COHb at the end of the 4 hour exposure.

In both studies the 70 ppm group showed statistically significant decrements in tracking accuracy. The amount of decrement increased as a function of time of exposure. Latency of detection on the light flash task also was significantly increased by 70 ppm CO exposure in a time-on-task related fashion. No effect of 35 ppm CO exposure was observed. The evoked potential was not affected by any CO level, at any time.

The studies discussed above have a high credibility. They constitute a study which was independently replicated, although by the same investigator. This pair of studies appears to be the only neurobehavioral work in the extant literature which can boast this quality. The behaviors which were affected have high face validity as measures of important nonlaboratory tasks in which humans engage, such as driving and machine operation.

A replication of the above studies is urgently needed because if an independent laboratory can show similar results then the results will have more credibility in the scientific community. These results are among the lowest CO exposure levels reported to have produced neurobehavioral decrements in healthy young subjects. For these reasons a replication should be undertaken.

The present study was undertaken to attempt to replicate the findings of Putz et al. (1976), since this report gives more methodological detail and since raw data are published there. Much effort was expended in exactly replicating procedure and equipment.

METHOD

EXPERIMENTAL DESIGN

A complete list of raw data was published by Putz et al. (1976). These data were reanalyzed by the present investigators and the results verified those of Putz et al. Analyses were also performed to determine the power (Muller and Peterson, 1984) of the significance tests used by Putz et al. The p-values were smaller and the estimated powers were greater when only 0 and 70 ppm groups were used. For the same number of subjects (per exposure level), $\alpha = 0.05$, assuming the same size of effect and the same variance as Putz et al., the CO x TIME effect would be tested with power approaching 1.0, if only room air and 70 ppm groups were used. The same test for the light monitoring behaviors would have a power of 0.72. Thus for a total of 20 subjects, using room air and 70 ppm CO exposure, the probability of nonreplication was considered to be very small provided that the findings are reliable.

It was planned, therefore, to test two groups of subjects, control and CO exposed, using approximately 10 subjects per group according to the Putz et al. paradigm and experimental design. It was decided to collect data from only the tracking and monitoring tasks since the auditory evoked potential results were nonsignificant. Subjects were, however, tested in the tone judgement (evoked potential) task since the performance of the task may have influenced performance on other tasks.

SUBJECTS

Subjects were 24 healthy males. One subject was eliminated from the exposed and one from the control group because they failed to perform the yrs (SD = ± 2.83, range = 19-31 yrs). Subjects were paid $5.00 per hour to participate. All subjects had been given examinations by a physician and had made normal scores ± 1 S.D. on the Minneapolis Multiphasic Personality Inventory.

TASKS

Tracking Task. The tracking task consisted of keeping a moving spot centered on a cathode ray tube (CRT) by manipulation of a pressure sensitive, nonmoving joystick. The CRT was a 20.3 x 25.4 cm (8" x 10") green phosphor oscilloscope with the 25.4 cm dimension on the vertical axis. The oscilloscope was equipped with a viewing hood and joystick mount as shown in Figure 1. During task performance the subject was seated on an adjustable chair in front of the viewing hood. The screen was viewed by the subject by positioning his head in the rubber viewing port, thus fixing the position and distance from eye to screen.

The view of the screen as seen by the subject is shown schematically in Figure 2. In the center of the screen was a circular fixed target consisting of a white ring, glued to the CRT screen. The inside (clear) circle of the target ring had a diameter of 4 mm and the outer target diameter had a diameter of 12 mm. A spot on the CRT moved up and down (vertically only) as driven by a forcing function (FF) generated by a microcomputer. The subject's task was to keep the spot centered in the stationary target. The subject exerted control over spot position by pushing forward or backward on the joystick.

The FF in this task consisted of half sinusoids of one of four amplitudes and either positive (up) or negative polarity. Zero FF left the spot centered in the target ring. Polarity and amplitude of the FF were independently and pseudorandomly selected for each half cycle. The amplitudes which were used produced ± 12.7, ± 6.35, ± 4.763 and ± 3.175 cm of deflection. There were two speeds of the FF, 4 sec/half cycle and 8 sec/half cycle (the "fast" and "slow" speeds). The fast and slow FFs were alternately presented in blocks of trials during the testing as will be discussed later.

The joystick was a Measurement Systems PN 436 pressure sensitive control. The joystick did not move in response to pressure. The length of the joystick handle was about 12 cm overall with a wooden ball at the end of 4.5 cm diameter. The handle of the joystick was mounted on a wooden platform below the CRT. It was calibrated such that full scale consisted of a push or pull of 2.4 Kg (5.3 lbs) for ± 12.7 cm deflection. Error scores for tracking were expressed in mean absolute deviation in cm of the spot from the target (averaged over time).

Monitoring Task. The monitoring task consisted of monitoring the brightness of two red lights on either side of the CRT as shown in Figure 2. One or the other of these lights was on for 1.5 sec and both were then off for .74 sec. The on/off periods were repeated continuously for the duration of the tracking task. Left and right lights were selected pseudorandomly.

Within any block of trials, the light level to which the red lights were illuminated was either "dim" or "bright". The subject was required to press a hand-held switch when a bright light level occurred on either left or right light. On alternate blocks the overall level of illumination was switched between two levels. During the overall bright condition the nonsignal intensity was .38 lux and the signal intensity was 1.5 lux. During the overall dim condition the nonsignal intensity was .04 lux and the signal intensity was .17 lux. Intensity was measured by placing a photometer sensor 6.5 cm in front of the lights. Signals and non signals were pseudorandomly interspersed. Among 25 light stimuli 9 were signals.

Auditory Task. A third task was performed by subjects in an alternating fashion with the tracking/monitoring task. This (auditory) task was the same as the one used by Putz et al. to elicit evoked potentials. In the present study the task was performed by the subjects and electrodes were attached to vertex and linked mastoids but no data were actually collected. The only rationale for including this task was that it might affect performance of the other tasks.

The auditory task consisted of judging tones sounded over a loudspeaker. Each tone had a duration of 1.5 sec and a loudness of approximately 80 dbA (SPL). The time between tones was .75 sec. The three tone frequencies were 400 Hz, 1000 Hz and 2000 Hz. The subject's task was to press a handswitch only when the 1 KHz tone signal was sounded.

Hood lighting. Figure 3 shows a schematic drawing of the inside of the viewing hood. A diffused green light was used to illuminate the screen so as to reduce contrast effects. The intensity of the light was adjusted to .22 lux when the photometer sensor was located 6.5 CM from the CRT. In order to avoid glare from reflected light, the light source was vertically polarized while a horizontal polarizing filter was placed over the viewing port.

Reversal Test. After all of the replication data was collected and just after the last tracking/monitoring task, another tracking/monitoring task was substituted. This last task was included for exploratory work only (Muller *et al.* 1984). The results were not to be included in the first study's *a priori* hypotheses. The reversal test might become a part of a formal experiment later, however, should the exploratory results prove useful.

This last exploratory task was the same as the other tracking/monitoring tasks except that the responses which were required were reversed. Pushing on the joystick moved the spot downward rather than upward. The monitoring target signals were made dim rather than bright. The subject was instructed as to what was to be expected via intercom, just before the reversal task was to begin. This corresponds to the reversal learning paradigm, performance of which is frequently impaired by injury or drugs.

PROCEDURE

The schedule of events for a typical day in this experiment is shown in Table 1. This was the same schedule and same times of day as used by Putz *et al.* (1976). Once informed consent and training was completed, the schedule followed an hourly cycle of performance.

Figure 4 shows the schedule of events within each hour of performance testing. The tracking/monitoring task was performed first for 32 min. Immediately following, the subject performed the auditory task for 14 min. This performance was followed by a rest period of 11 min, during which the subject was permitted to read, after which the subject briefly exited from the chamber to have an end-tidal alveolar air sample collected. The cycle then repeated itself during the subsequent hour. Again, this was exactly the procedure used by Putz *et al.* (1976).

The temporal order of events within tracking/monitoring task was quite complex as shown in Figure 5. Performance was divided into 56 sec trials. Two trials form a block and there were 8 blocks in the 32 min performance period. Blocks were separated by 118 sec. pauses. Trials were separated from each other (within blocks) by a 10 sec pause.

Monitoring behavior alternated in a blockwise fashion between the overall bright and dim conditions. Tracking FF speed alternated between fast and slow on a two-block cycle. Thus, each block had a bright or dim (monitoring) condition and a fast or slow (tracking) condition. Within a 32 min performance period, each combination of conditions occurred twice.

Differences from Putz et al. Despite major efforts to make this replication exact, several differences from Putz et al. were found to be necessary or extremely convenient. The differences are summarized in Table 2.

The two forcing functions used by Putz, et al. had speeds of 7 cycles/min and 4 cycles/min for fast and slow conditions. Presumably this means that the fast function had a speed of 4.28 sec. per half cycle (8.57 sec per cycle). This would have necessitated stopping the FF during a nonzero crossing since each trial was only 50 sec long. Putz was unable to shed any light on this problem (personal communication). The only speed which was close to the Putz et al. FF and still resulted in an integer number of cycles was a 4 sec per half cycle FF which went through 14 half cycles in 56 sec. A slow FF which also came out in integer half cycles was 8 sec per half cycle, which completed 7 half cycles in 56 sec. Thus the trial was made 56 sec long (rather than 50 sec) and the fast and slow FFs were 4 and 8 sec/half cycle (instead of 4.28 and 7.5 sec/half cycle). The interblock pause was adjusted to 108 sec (rather than 120 sec) to keep task length constant. These are relatively minor changes.

The CRT size used by Putz et al. was 25.4 cm square (10" x 10"). The screen available for the present study was 24.5 cm high by 20.3 cm wide (8" x 10"). Since no horizontal spot movement was used, the stimulus lights were mounted so as to have the same horizontal visual angle from center as those used by Putz et al. A different hood design (square vs. long tapered) was also used. Since the visual effect was the same, this should not matter.

The CRT hood shown in Figure 1 was illuminated to an intensity of .22 lux, measured at 6.5 cm from the screen. Putz et al. did not specify the distance of the photometer sensor but in the same paragraph specified the distance for measurement of the signal light intensity. It was assumed it was the same distance for the CRT screen. Putz was unable to resolve the problem (personal communication).

Putz et al. stated that in 22 light stimuli, 8 were signals. They also stated that lights on/off cycles were 2.25 sec long (1.5 sec on/.75 sec off). Thus 22 stimuli would take 48.5 sec. In order to provide stimuli for the 56 sec trial length, stimuli in the present study were 1.5 sec long but the off time was .74 sec. In this case, 25 stimuli exactly occupied the 56 sec. trial. Of the 25 stimuli, 9 were signals. The proportion of signals was therefore .36 whereas in Putz et al. it was .364. These are, again, probably trivial differences.

A major difference between the present study and that of Putz et al. was that they tested two subjects at a time on two tracking/monitoring devices in the same chamber. In the present study, only one subject was studied at a time in a visually and acoustically isolated chamber. In the Putz et al. study, the two subjects were tested alternately, one during the 120 sec rest time of the other. The possible social contact between subjects, even without transmission of information about performance, could have affected baseline values. It is not reasonable to assume that results should be differentially affected for CO and air exposed subjects, however. The reasons for testing only one subject at a time are (a) resource limitations in terms of computer speed/time (b) logistic complications in terms of technician time per experiment, thus increasing possible confusion related errors and (c) the general principle that for vigilance-like tasks, isolated subjects show clearer and earlier decrements. If the baseline performance of the subjects in the present report should not differ from those of Putz _et al_., it would be additionally reasonable to suppose that the social effect was not important for these tasks.

Random event scheduling was apparently done with random number generators by Putz _et al_. in their online control program. Certain highly desirable distribution characteristics do not usually obtain in such programs, _e.g_. exactly equal number of signals per trial, exactly balanced amplitudes in the FF, absence of runs of specifiable length, local stationarity, _etc_. For these reasons, random events were scheduled by exhaustively sampling from finite populations of playing cards and then entering these fixed schedules into the controlling computer program. All event schedules were checked for distribution similarity, short run lengths and balanced first order conditional probability distributions. The schedules for FF amplitudes and polarity and for the monitoring events repeated after eight two-min blocks of performance. Considering the number of events, the length of the trials and the pauses between, it is very doubtful that the subjects could detect a pattern.

As discussed in the introduction, Putz et al. exposed their subjects to 70 ppm CO. Subjects were exposed to 100 ppm CO in the present study.

Counterbalanced Orders. Figure 5 implies that four possible combinations of FF speed and monitoring brightness exist, depending on which pair the subject is given first. In order to eliminate possible difficulty order differences due to starting combinations, the starting speeds and brightness were pseudorandomly selected for each subject. Since complete counterbalancing would require 12 subjects per group, this strategy was not possible. The same number of each starting combination were used in CO exposed as in air exposed groups.

Double Blind Design. This study was entirely double blind. CO level was determined by a computer stored pseudorandom schedule. No one knew *a priori* what that day's subject was to be exposed to unless they looked at the computer code, which was cumbersome to read. Everyone who had any contact with the subject was strictly enjoined not to attempt to break the blind. CO level was monitored by one of the senior investigators who had no contact with the subject after the study began. Thus that senior investigator remained blind until after his last subject contact.

Statistics. Two dependent variables were analyzed: (a) mean absolute deviation for the tracking task and (b) response time for the peripheral light task. Univariate repeated measures analysis (Kirk, 1968) was used for both. Each analysis is detailed below.

For the tracking task variable, a CO by Difficulty by Hour factorial design (2 x 2 x 4) was used. CO is a "between" factor and the other two are "within" factors. Levels were 0 and 100 ppm CO, low and high frequency for difficulty, and 1st, 2nd, 3rd, 4th hour.

For the peripheral light task, CO and Hour (2 x 4) were the factors, with levels as above. A factorial model was tested, again with CO "between" and Hour "within".

For both analyses, stepdown tests (Kirk, 1968) were to be done as separate tests for each hour. If the three-way interaction were involved in tracking, second level stepdowns were to be CO within difficulty. Three differences exist with Putz' analyses: (a) the dropping of the 35 ppm CO level (b) the use of a Geisser-Greenhouse correction for F tests and (c) a Bonferroni correction to test each overall test at $\alpha = 0.025 = 0.05/2$. Stepdowns, if needed, were to be tested at $\alpha = 0.025/k$, with k = number of stepdowns within the family. These choices were made after using Putz's data for exploratory analysis.

COHb. Blood was drawn, as shown in Table 1, before and after exposure. At each drawing, two three-ml vacutainers were used. COHb values were measured in triplicate immediately after blood was drawn for each set of samples by use of an Instrumentation Laboratories model 282 CO oximeter. Triplicate values were averaged to provide a final pre and post COHb value. Alveolar air samples were not analyzed because of the need to keep the number of dependent variables in this study at a minmum. Comparison of blood and air values would have constituted additional hypothesis tests and therefore required further division of α. This would have reduced the power of the hypothesis tests and thus required more subjects in the study.

RESULTS

COHb.

Table 3 shows the results of the COHb analyses. These were well within expected limits.

TRACKING (CONFIRMATORY).

The results of the significance tests for tracking behavior are shown in Table 4. No CO related test was significant by the Bonferroni adjusted criterion of $\alpha = 0.025$. The CO x Hour interaction, which was significant in the study by Putz *et al.* (1976) had a value of $p = 0.035$ in this study. Figure 6 shows the mean tracking errors for the fast FF for both the data reported by Putz *et al.* and the data collected in the present study over the four hours of behavior and exposure. Figure 7 shows the corresponding data for the slow FF. In both figures it is seen that data from the present study tend to follow in the same direction of those of Putz *et al.*, *i.e.* the CO exposed group made a higher mean tracking error than the control group. This difference was statistically significant for the data from Putz *et al.* but not for data from the present study. The mean squared error (MSE) for the tracking data for the test of CO x Hr interaction from Putz *et al.* was 1.5 whereas for the present study the same MSE was 4.6.

MONITORING (CONFIRMATORY).

Table 5 shows the significance tests for the peripheral light montoring task. Here, no test was even close to statistically significant. Figure 8 shows the mean reaction times over the four hours of performance and exposure for both the data of Putz *et al.* and the data from the present study. For the data from Putz *et al.*, MSE was 775 and for the present study MSE=1423.

REVERSAL (EXPLORATORY).

Exploratory analyses showed that the reversal behavior was extremely non-Gaussian in its distribution. For exploratory purposes the mean tracking scores and mean reaction times in the CO and control groups were tested using the Wilcoxon Rank-Sum Test. There were no significant differences between control and CO groups on tracking, $Z = -1.02$, $p > 0.31$ or on reaction time, $Z = 0.60$, $p > 0.55$. Table 6 shows the mean scores during reversal training.

In order to explore the question of performance improvement (learning) a plot was made of the tracking score over the eight two-min reversal blocks (Figure 9) and of the reaction times for the same blocks (Figure 10).

DISCUSSION

TRACKING (CONFIRMATORY).

Figures 6 and 7 demonstrate that at the start of the experiment, the subjects from the present study performed with nearly identical level of error to the subjects of Putz et al. (1976). This was true for both fast and slow FFs. Especially for the fast FF, the CO exposed group from Putz et al. increased their mean error of tracking more than for the subjects in the present study. This results in a greater divergence between groups for Putz et al. than for the present study. By the end of the four-hour exposure period the between group difference for the fast FF in the Putz et al. data was approximately three times as great as for the data from the present study.

Inspection of the control group values in Figures 6 and 7 reveals that subjects in the present study improved the mean level of performance over the four hour period by a greater amount than did the subjects of Putz et al. This fact, together with the higher MSE for present study, suggests that subjects in the present experiment were not as well trained as those of Putz et al.

If it is the case that subjects for the present study were not trained as well as those of Putz et al., then it is also implied that the tracking task for the present study was in some way easier than that of Putz et al. If their subjects were better trained but performed on a par with more poorly trained subjects, then their task must have been harder to perform. It is not clear from the parameters of the task that any difference should exist, however. The above comments ignore the possibility that all of the differences in results could be explained by the fact that a different pool of subjects was used in the two studies.

The possible reasons for the nonsignificant finding in this study (relative to that of Putz) are multifold. The task for the present study might have been slightly easier while the subjects might have been more poorly trained. The MSE for the present study was larger while the CO exposed and control groups diverged less. A Bonferroni corrected α criterion was used and the degrees of freedom were Geisser-Greenhouse corrected in the present study while the Putz *et al*. study used no such corrections. The present study would have yielded $p = 0.0274$ without correction. The power in the Putz study approached 1.00, however, even with corrections when the original data was reanalyzed in the planning stage of the present study. The increased variability and the reduced effect size jointly reduced the power from that which was expected. It is presumed that the small effects size reflects subject or task differences while the large error variance reflects less well trained subjects.

Monitoring (CONFIRMATORY)

Figure 8 reveals that the mean reaction times for the data from the present studies were substantially lower than for the data from Putz *et al*. This implies, again, that the task in the present study was easier for some unknown reason. Task parameters were carefully measured. Minor differences do not provide a clue to the reasons for the different level of difficulty.

REVERSAL (EXPLORATORY)

The reversal task was included as a possible measure of the effect of CO on learning (relearning). It appears that most of the improvement in tracking occurs during the first two-min block of performance after which little systematic change occurs. Even after eight blocks of reversal practice the level of performance in neither group was as good as it had been during the regular performance (compare Figure 9 to Figure 6).

The non Gaussian distribution of the reversal data resulted from what appeared to be behavioral lapses of individual subjects from the learned reversal to the previous polarity of responding. This is conjecture because the time functions of the tracking lever response was not recorded and so could not be inspected. The hypothesis of lapses to the previous polarity of responding seems justified by the occasional but nonsystematic occurrance of large scores.

It would seem from inspection of Figure 9 that the CO group performed consistently worse than the control. High variability and small differences, however, prevented the difference from becoming significant. While the CO group consistently performed more poorly during reversal (as it also did during previous regular performance) there was a much less clear difference in the rate at which performance improved. This might have been due to the brief improvement during block 1 and the general lack of further learning.

The reaction times during reversal were unsystematic (see Figure 10) and continued to be much higher than in the previous performance (compare Figures 10 and 8). The only conclusion one can draw from this observation is that the monitoring task was poorly relearned.

GENERAL CONCLUSIONS.

Tracking. One of the major objectives of this work was to determine whether compensatory tracking was sensitive to CO effects. It appears, despite the nonsignificant effects observed, that the confidence in this measure has increased, if the task can be properly designed. Due to the higher variance, smaller mean differences, and methodological differences from the research and data published by Putz _et al_. (1976) the a priori hypothesis tested in the present study was not significant. The mean trends for tracking scores were apparently in the expected direction. While none of the above considerations, or all of them collectively, can be used to claim that the results of Putz _et al_. have been replicated, the findings of Putz _et al_. (1976) and Putz (1979) combined with these results to suggest that tracking is sensitive to degradation by CO exposure.

Monitoring. Much of what has been said about tracking can also be said about monitoring. With respect to Putz _et al_. the trends in this study were in the same direction but not significant. There were more extreme deviations from the data of Putz _et al_. in the present study, compared to tracking _e.g._ the task was much easier in the present study. It was also true that in the data reported by Putz _et al_. the CO effects upon reaction time were weaker than the CO effects upon tracking.

Reversal. The reversal was apparently so disruptive as to have prevented complete relearning in the time allowed. The evidence for this statement is that (a) not much relearning was demonstrated in either task except on the first block of trials (b) the variance was high and the distribution skewed by apparent frequent behavioral lapses and (c) the performance never recovered to prereversal levels. If reversal learning is to become a useful measure of CO effect in this context, either a longer relearning period will have to be used or some way of reducing the difficulty will have to be devised.

Conclusions. From the above discussion and in consideration of findings by Putz et al. (1976) and Putz (1979), the following conclusions seem appropriate.

(a) tracking may be sensitive to impairment by CO exposure

(b) monitoring may not be affected by CO exposure

(c) important variables in research on the effects of CO exposure on tracking appear to be the level of subject training and the task difficulty.

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TABLE 1. Daily Schedule of Events

Time	Event	Cum. Time
10:00 AM	Prescreened subject arrives.	0
10:15	Sign consent forms	15 min.
10:30	Blood and breath samples collected	30 min.
10:35	Enter chamber for training*	35 min.
11:35	Training completed - apply electrodes	1:35 min.
11:45	Begin tracking/vigilance task	1:45
12:17	Begin evoked potential (tone) task	2:17
12:31	Begin rest - lunch - breath sample	2:31
12:45	Begin 2nd hour	2:45
1:45	Begin 3rd hour	3:45
2:45	Begin 4th hour	4:45
3:45	Exit chamber - blood sample - debrief	5:45
4:00	Subject leaves	6:00

*Training hour is typical of regular test hour except that verbal feedback is used.

TABLE 2. DIFFERENCES* BETWEEN PRESENT STUDY AND THAT OF PUTZ ET AL. (1976)

Parameter	Value in Present Study	Value in Putz et al.
Fast FF speed	4 sec/half cycle	4.28 sec/half cycle
Slow FF	8 " " "	7.5 " " "
Trial length	56 sec.	50 sec.
Interblock	108 sec.	120 sec.
CRT screen size	25.4 cm. vert., 20.3 horiz.	25.4 cm square
Hood illumination	.22 lux at 6.5 cm	unclear
Monitoring stimulus ISI	.74 sec.	.75 sec.
No. of monitoring stimuli per trial	25	22
Monitoring signal/nonsignal ratio	.36	.364
Number of subjects per chamber	1	2
Window in chamber	No	Yes
Randomization of events	fixed schedules	computer controlled
CO level **	100 ppm	70 ppm

*Rationale for these differences is discussed in text.

**100 ppm exposure was inadvertantly selected in the present study. A 30 ppm difference is unlikely to affect results and should if anything increase effects of CO.

TABLE 3. MEAN, SD AND RANGE OF COHb, IN PERCENT, FOR EXPOSED AND CONTROL GROUPS, BEFORE AND AFTER EXPOSURE TO 100 PPM CO FOR FOUR HOURS

	Before Exposure Period	After Exposure Period
Control Group	SD =± 0.39 M = 1.42 range = 0.9 - 2.32	SD=± 0.24 M = 1.22 range = 0.87 - 1.55
Exposed Group	SD =±0.18 M = 1.36 range = 1.07 - 1.57	SD=± 0.49 M = 8.24 range = 7.57 - 9.03

TABLE 4. SIGNIFICANCE TESTS ($\alpha = 0.025$) FOR TRACKING BEHAVIOR USING GIESER-GREENHOUSE ADJUSTED DEGREES OF FREEDOM

Effect	F*	P**	df_1, df_D***
CO	0.66	0.43	1,20
Speed (of tracking stimulus)	346.56	0.0	1,20
Hour	0.79	0.49	2.6, 51.3
CO x Speed	0.96	0.34	1,20
CO x Hour	3.27	0.035	2.6, 51.3
Speed x Hour	1.75	0.18	2.4, 47.8
CO x Speed x Hour	0.39	0.72	2.4, 47.8

*F = Computed value of significance test (Fisher's F)

**p = Probability value represented by the particular value of F

***df_1 and df_D are the degrees of freedom for the hypothesis and for the for error term, respectively, in the F test tables.

TABLE 5. SIGNIFICANCE TESTS ($\alpha = 0.025$) FOR MONITORING TASK USING GIESSER-GREENHOUSE CORRECTED DEGREES OF FREEDOM.

Effect	F*	P*	df_N, df_D*
CO	0.29	0.60	1,20
Hour	1.11	0.34	1.9, 38.5
CO x Hour	0.96	0.39	1.9, 38.5

* See TABLE 4 for explanations

TABLE 6. MEANS OF TRACKING ERROR IN CM AND OF REACTION TIME IN MS FOR CO EXPOSED (100 PPM FOR FOUR HOURS) AND CONTROL GROUPS DURING REVERSAL LEARNING (EXPLORATORY ANALYSIS), ± 1 SD.

	CONTROL		CO EXPOSED	
TRACKING	1.10	± 0.28	1.45	± 0.73
REACTION TIME	865.4	± 169.1	849.2	± 107.2

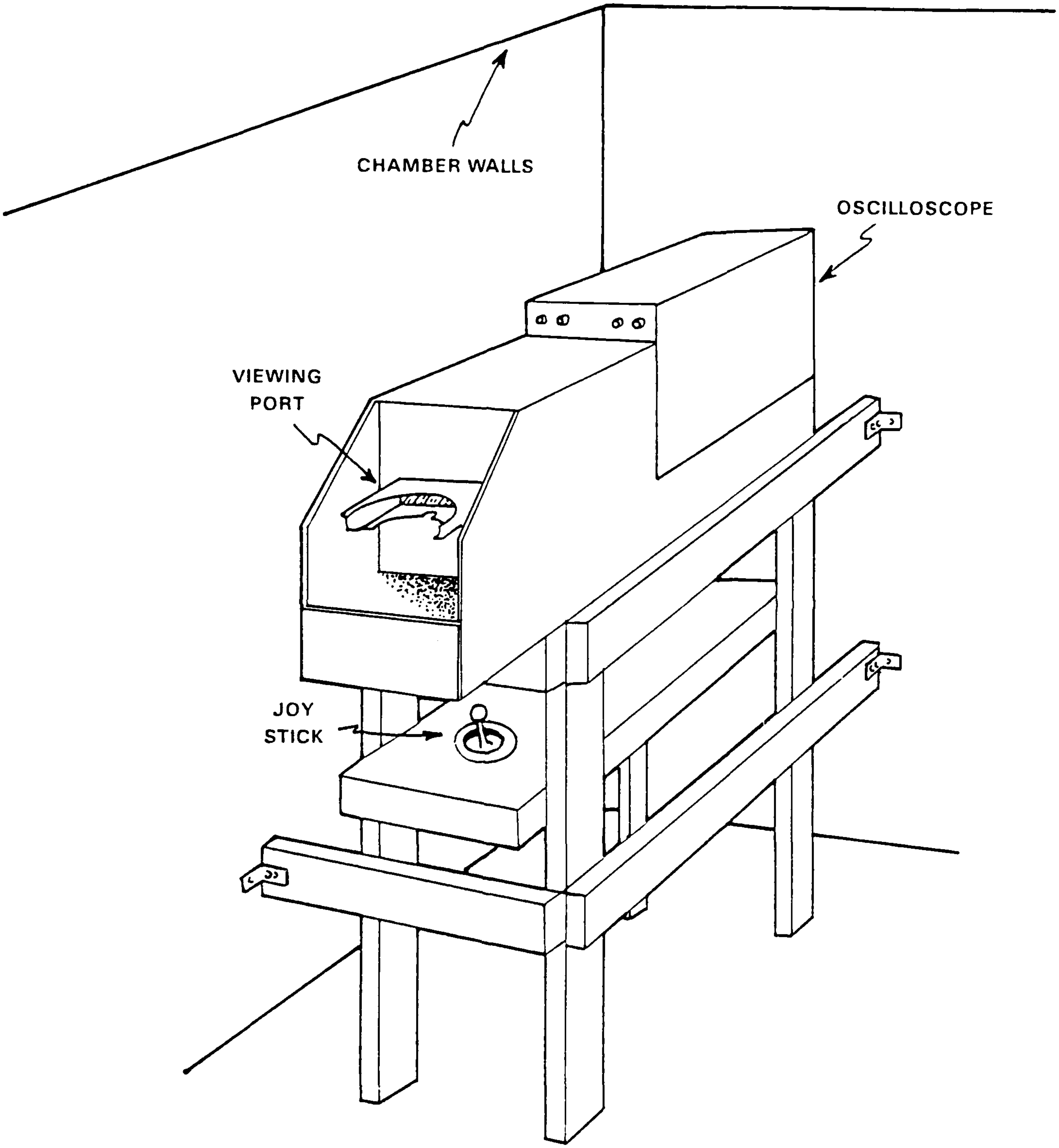

Figure 1. Sketch of tracking / monitoring apparatus.

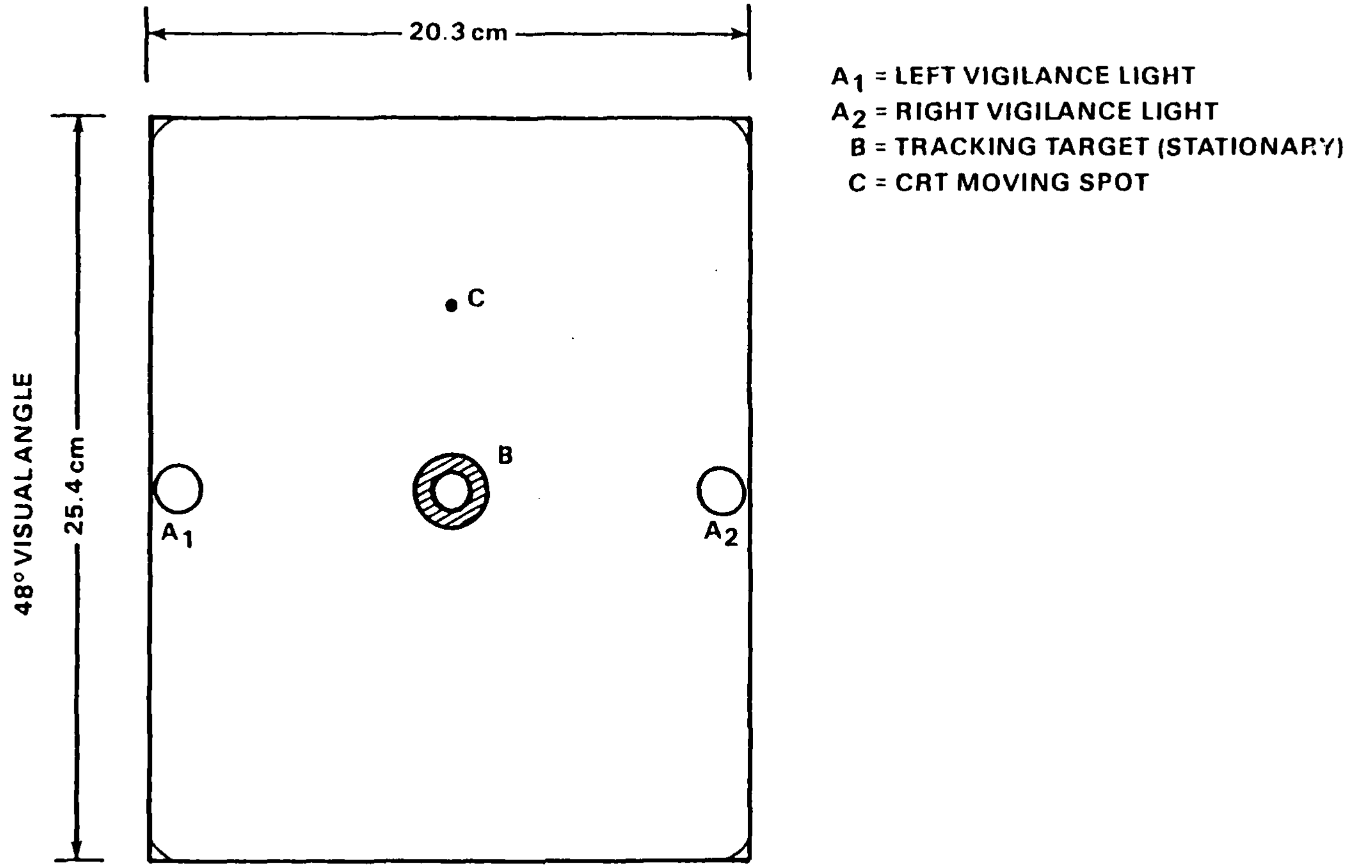

Figure 2. Sketch of CRT screen and monitoring lights as seen by the subject through the viewing port.

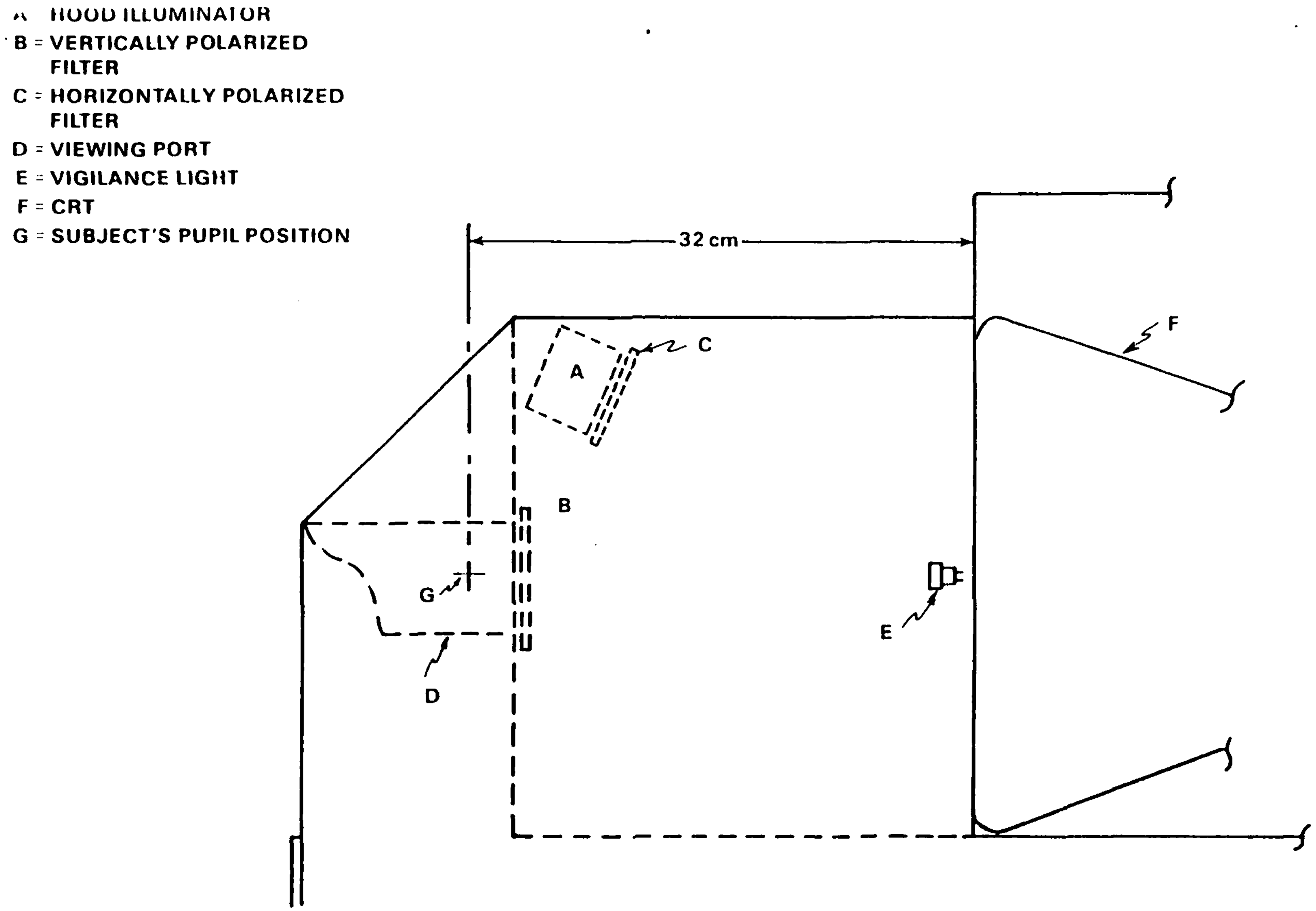

Figure 3. Sketch of the inside of the viewing hood.

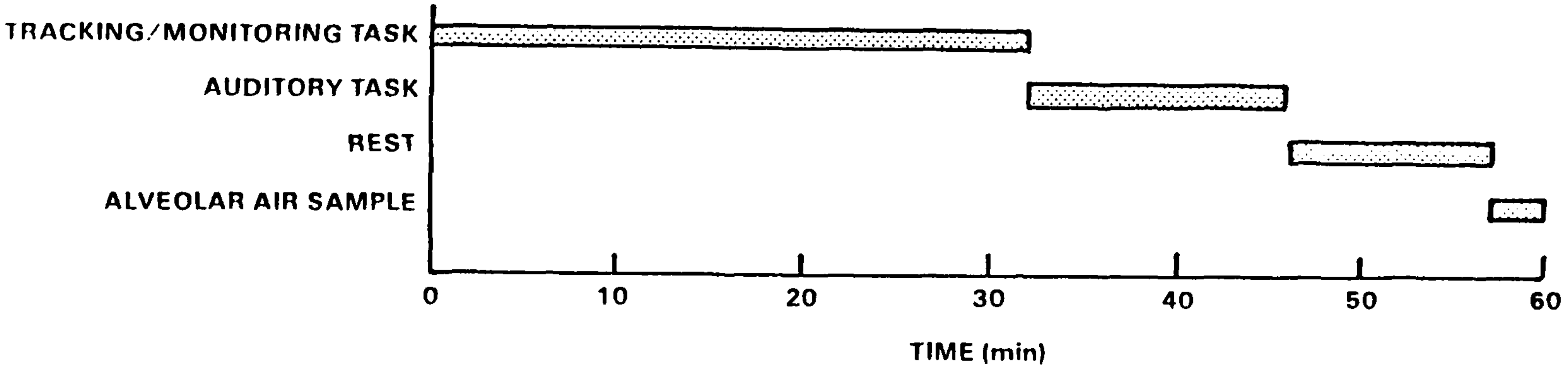

Figure 4. Temporal order of events during each hour of the experiment and during training.

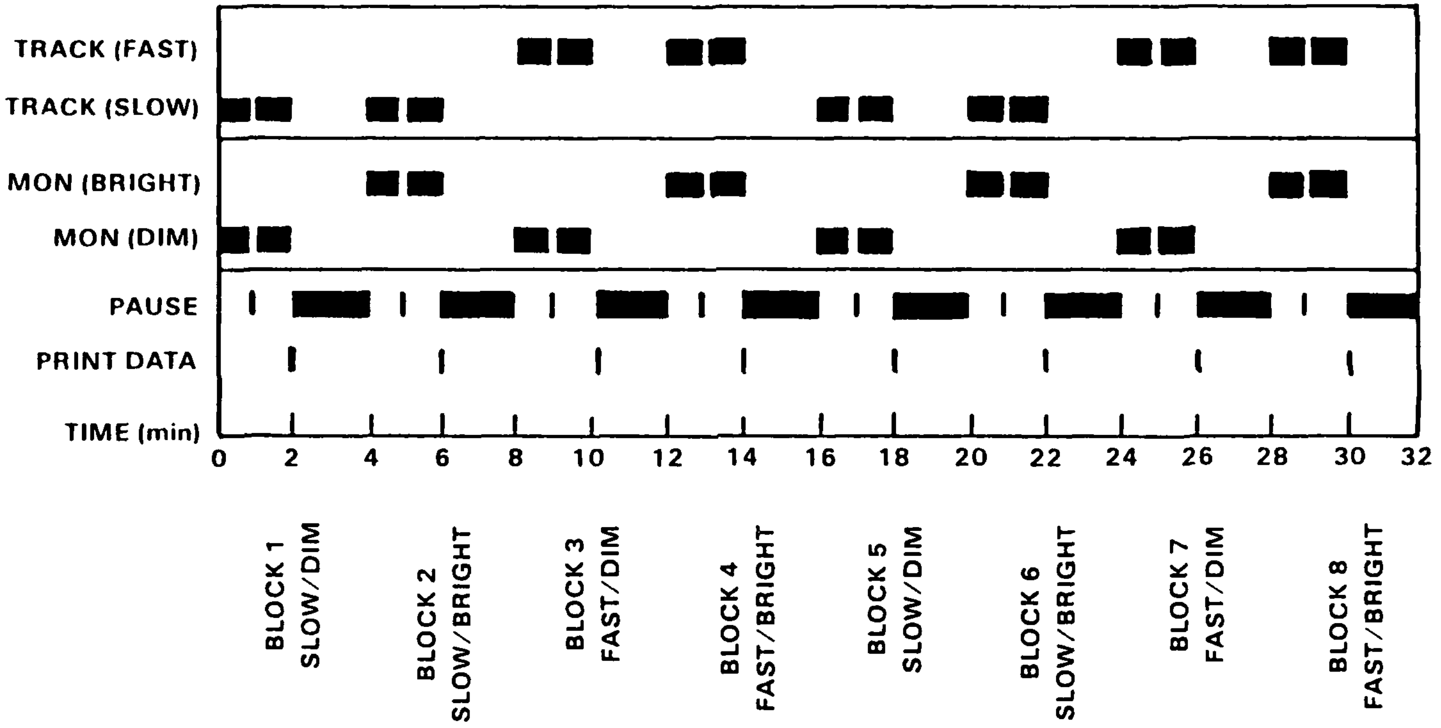

Figure 5. Temporal order of events during tracking/monitoring task. Four schedules exist depending upon the particular combinations of tracking speed and vigilance brightness which are selected for the first trial. Pause durations: Short = 10 sec., Long = 118 sec. Trial length = 56 sec. Printout occurs after every two trials. Fast forcing function = 4 sec./half wave, slow forcing function = 8 sec./half wave.

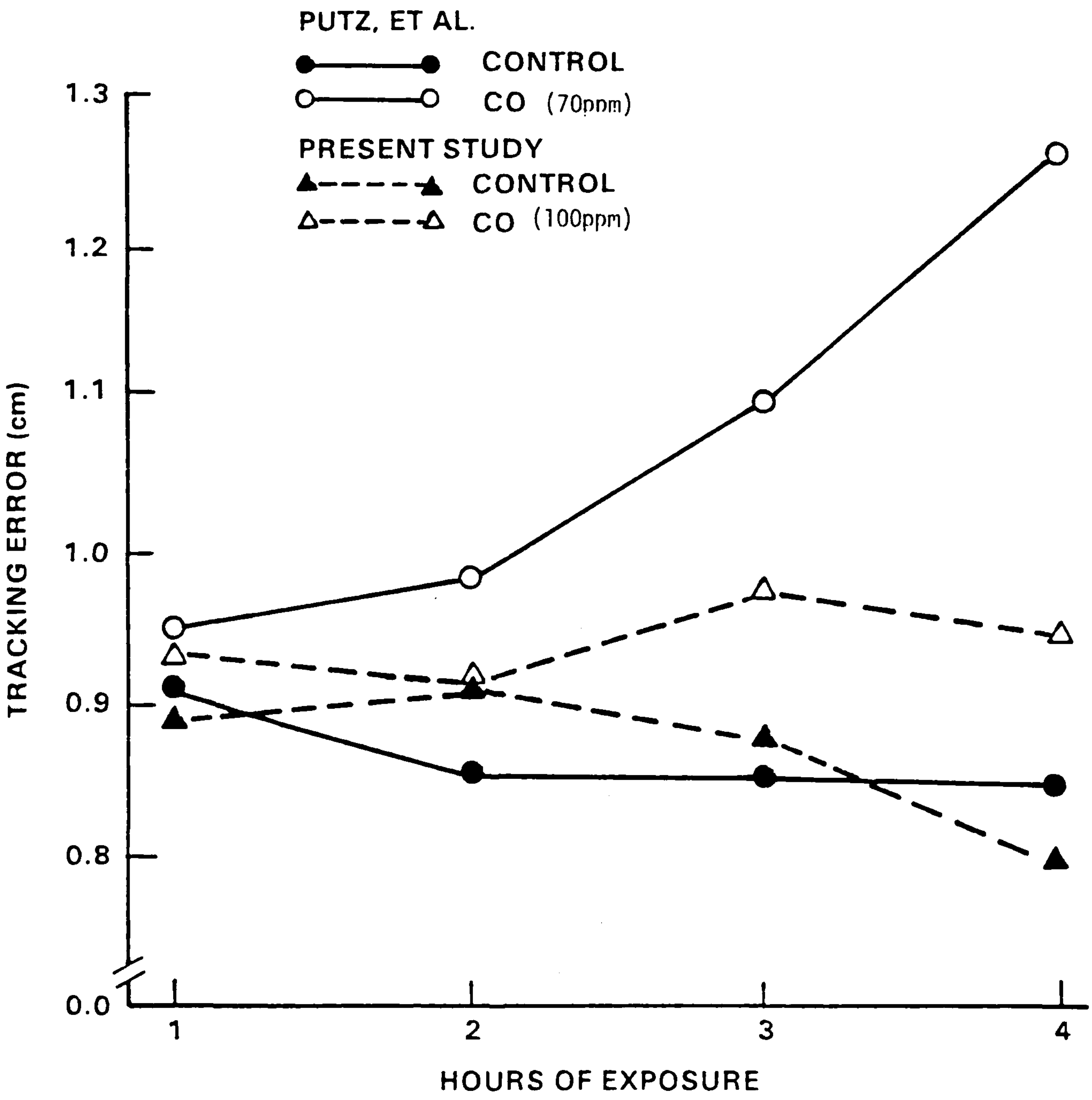

Figure 6. Performance of tracking task, fast FF, for data from prestent study and from Putz et al. (1976). Tracking error is mean absolute deviation of spot from center screen in cm.

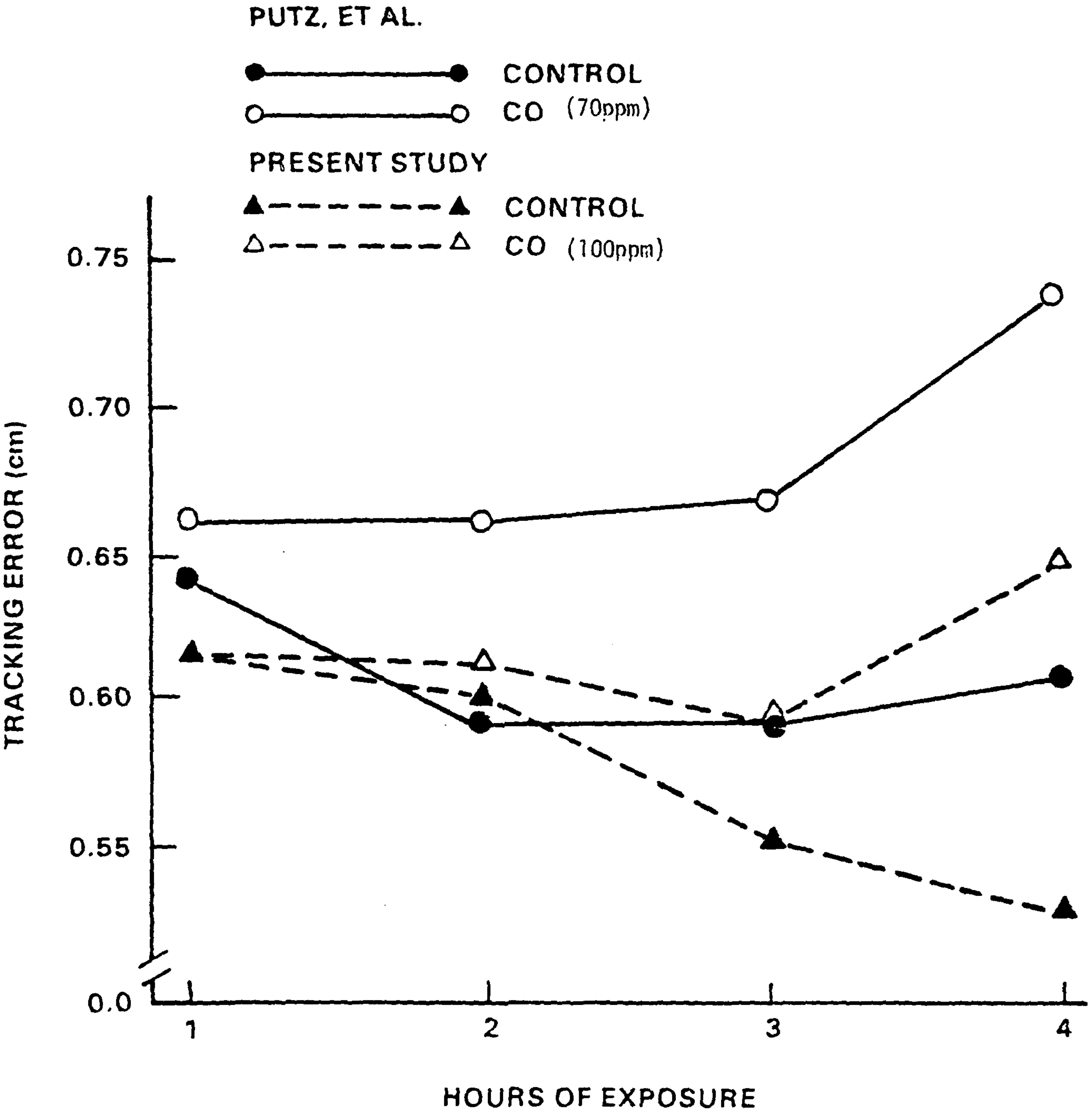

Figure 7. Performance of tracking task, slow FF, for data from present study and from Putz et al. (1976). Tracking error is mean absolute deviation of spot from center screen in cm.

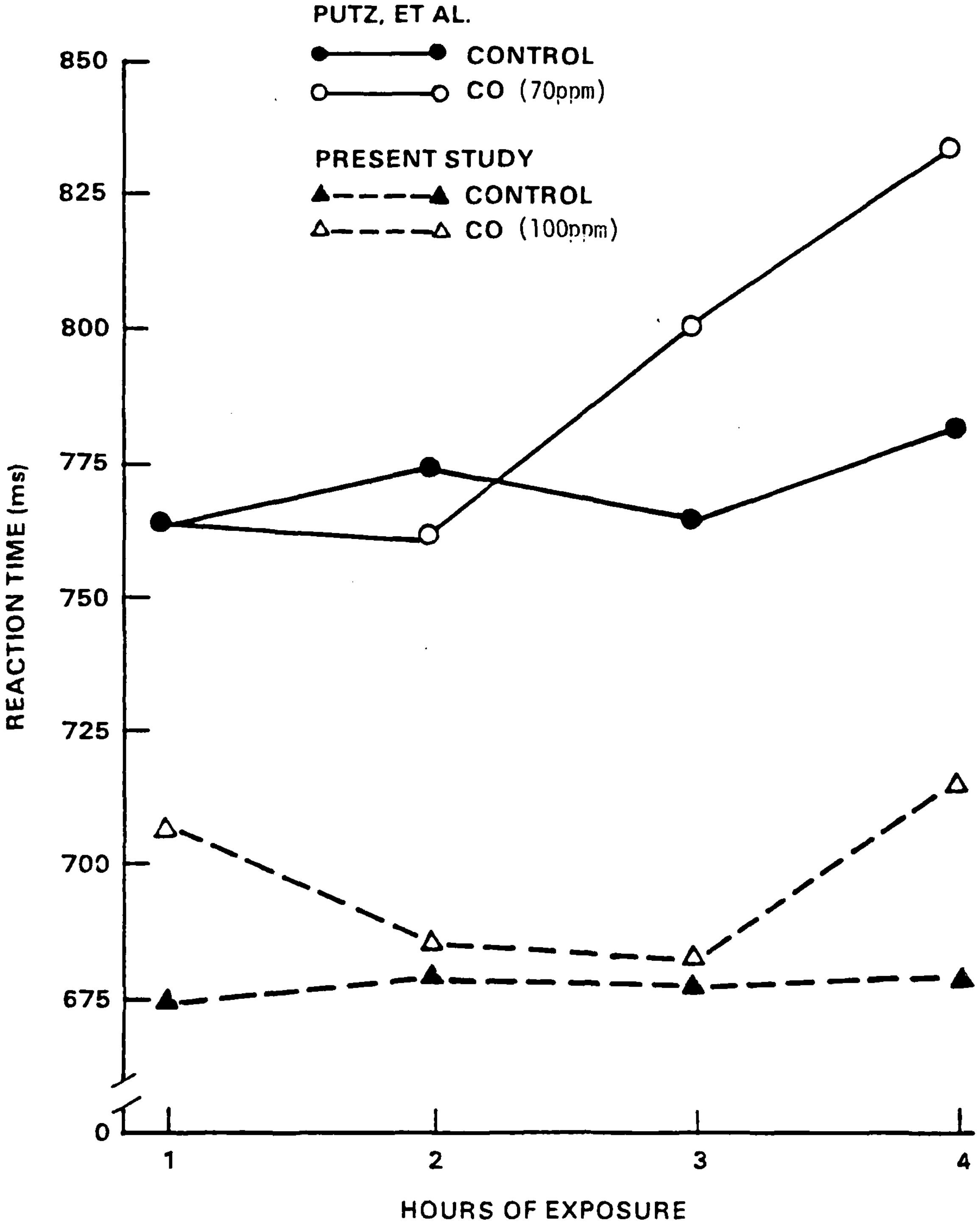

Figure 8. Performance of monitoring task for data from present study and from Putz *et al.* (1976).

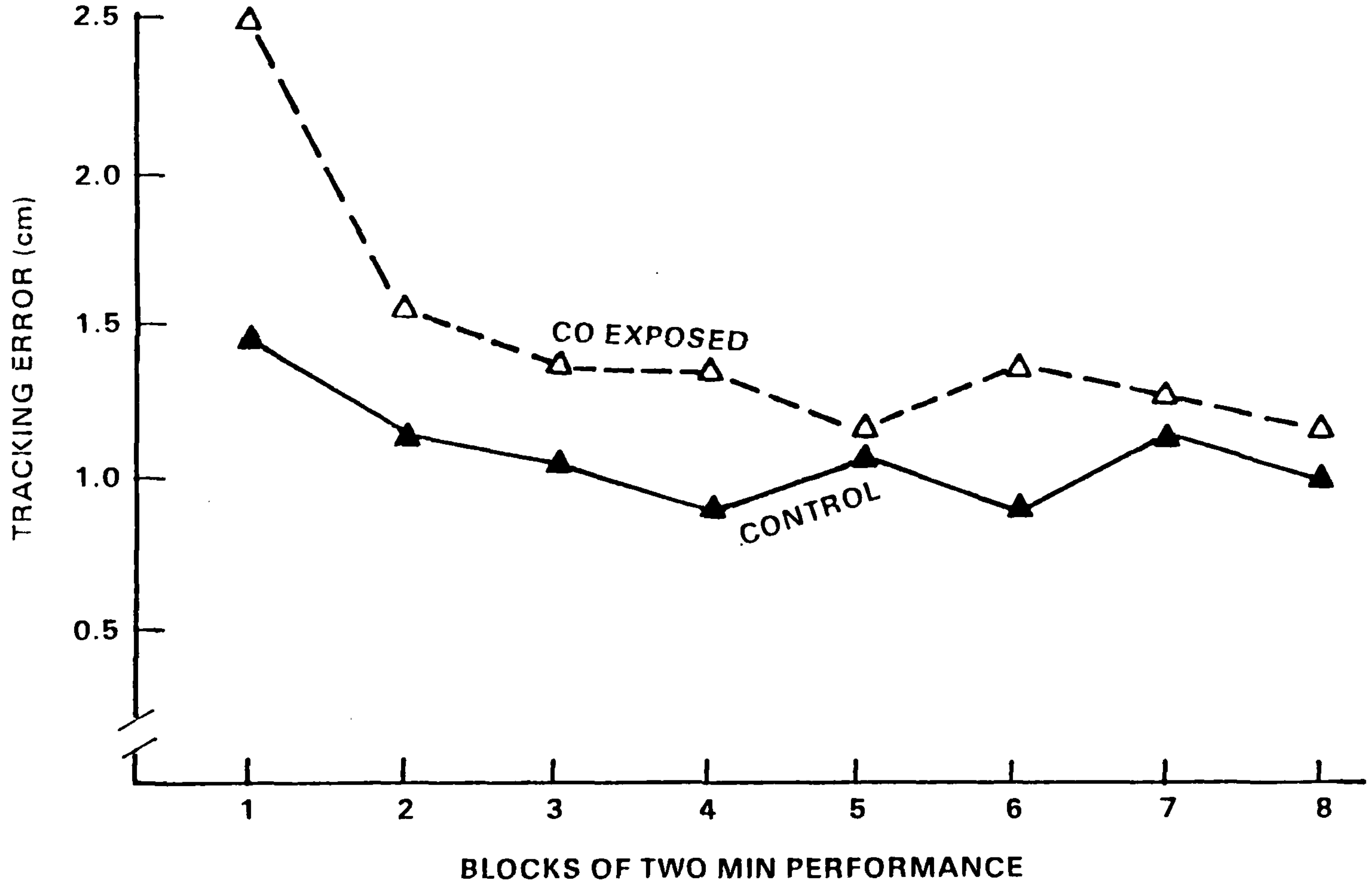

Figure 9. Performance on the tracking task during reversal. Tracking error is mean absolute deviation of spot from center screen in cm.

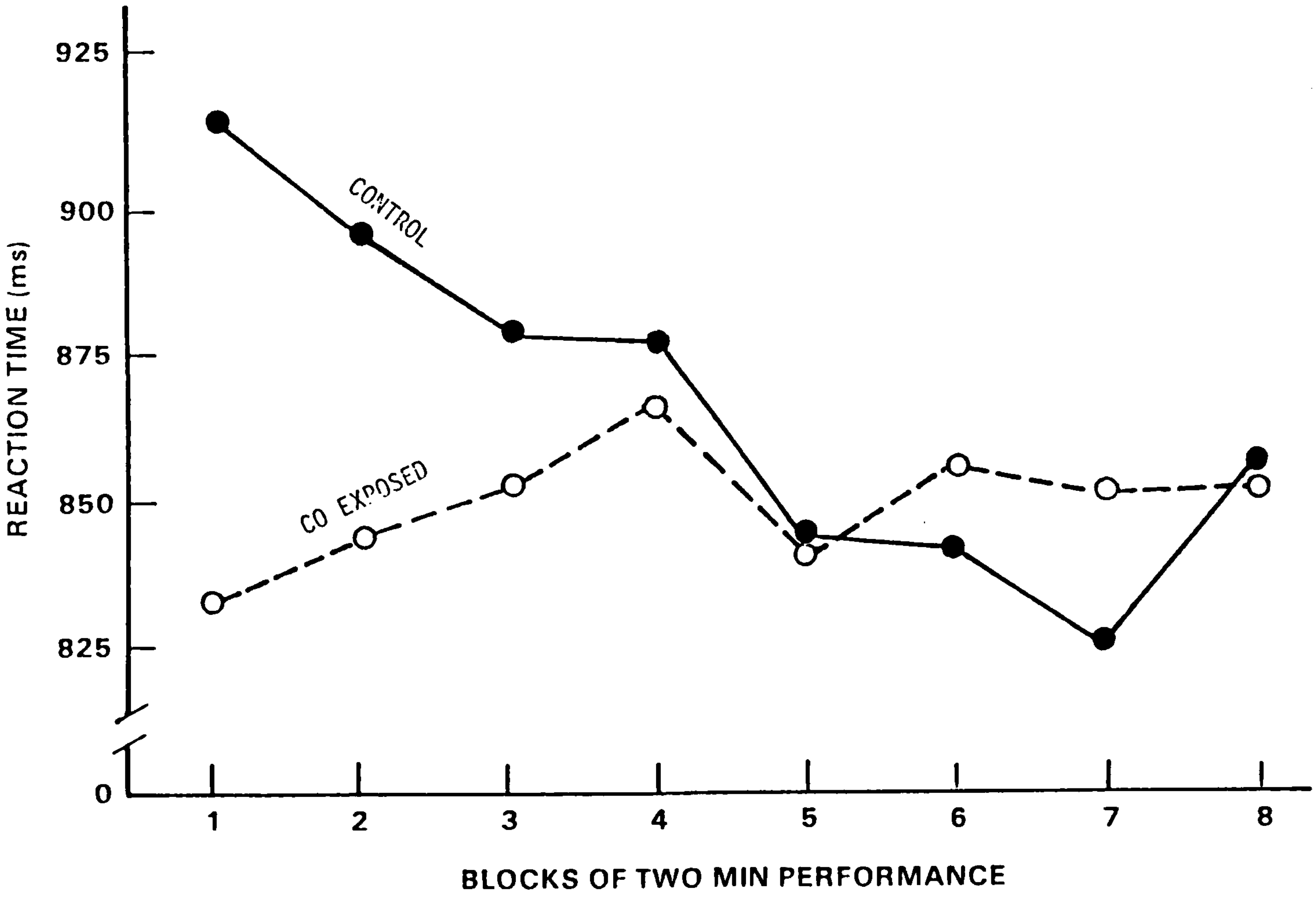

Figure 10. Performance on the monitoring task during reversal.

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