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Carbon Monoxide: Dosimetry in Occupational Exposures in Denver, Colorado

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ABSTRACT. The occupational carbon monoxide (CO) exposure of Denver traffic control personnel was evaluated during 8-hr workshifts using three parameters: (1) 98, 8-hr time-weighted average breathing zone air samples (personal dosimetry); (2) before- and after-workshift CO breath samples; and (3) 8-hr moving average, ambient CO levels during the fall and winter months. Different shifts and work experiences were taken into consideration. The data revealed greater CO exposure in subjects working on the street than controls working inside downtown buildings with respect to breath CO concentration and breathing zone air samples. The CO concentrations in the after-workshift breath samples were closely associated with the 8-hr time-weighted average CO levels. The greatest source of CO to the sample population was cigarette smoking, followed by occupational-related sources, and finally, the ambient background CO levels.

WORKERS IN OCCUPATIONS which involve extensive time spent on city streets (e.g., traffic policemen) are exposed to carbon monoxide (CO) emissions from high densities of automobile traffic. Carbon monoxide is inspired directly from the polluted urban environment and quickly absorbed into the blood. A wide range of adverse health effects caused by CO's hypoxic action on oxygen-sensitive organs (e.g., brain and heart) have been attributed to low level CO exposure. Numerous studies have quantitated the CO concentrations in the urban atmosphere; none of these studies, however, have attempted to measure an integrated occupational CO exposure experienced during an 8-hr shift in an occupation closely associated with urban traffic.

Previous studies on occupational groups exposed to high-density emissions from automobile traffic have critically examined only one element of this complex exposure —carboxyhemoglobin (COHb). Chovin[1] investigated COHb levels of traffic policemen working 5-hr shifts in Paris. Smith[2] examined CO exposure in four occupations that involved extensive time spent driving on city streets in Calgary, Alberta. The study involved taking "end-expired" breath samples to estimate COHb, and intermittent spot sampling of CO in the workplace environment. Jones et al.[3] reported COHb levels of taxi drivers working different shifts in London, England.

The present investigation measured the fluctuating, chronic CO exposure experienced by traffic control personnel in Denver, Colorado—a city whose air quality has been rated exceptionally poor by the Environmental Protection Agency (EPA). The traffic control workers' CO exposures were quantitated during 8-hr workday shifts, accounting for those parameters listed above, which offer a nearly complete picture of this complex occupational exposure.

METHODS AND MATERIALS

Study population. Members of the Denver Police Department Traffic Operations Bureau were periodically monitored for occupational CO exposure from September 1978 through January 1979. Four subjects were monitored on each sampling day, and a total of 98 samples was collected during this study period. The Traffic Control Bureau (TCB) regulates motor vehicle traffic on all streets and highways within the Denver city limits. This regulation includes enforcement of parking regulations, direction of traffic at special events, and responding to all traffic problems. A wide variety of both young and old, male and female, and smokers and nonsmokers were included, who worked different jobs, shifts, locations, and transportation modes. The controls were police department employees who worked at the traffic bureau, but stayed in the office during working hours. Other controls selected were employees at the air pollution office of the Colorado State Health Department.

The study population consisted of a stratified random sampling (based on shift and job classification) of volunteers. At the start of the shift being studied, each volunteer—both subject or control—was asked to wear a CO dosimeter attached conveniently to an article of clothing (e.g., belt or pocket). Breath samples were then taken, and questionnaires and consent forms were distributed to the four individuals being monitored. At the end of the work shift, the dosimeters were collected from each subject and another breath sample collected along with the questionnaires and consent forms.

As a result of the great impact that smoking has on COHb levels, all subjects were questioned about their smoking habits, and this information was carefully recorded. The number of cigarettes smoked by the subjects during the 8-hr shift was also recorded.

Personal air samples (dosimetry). Carbon monoxide sampling was carried out using four General Electric CO dosimeters which made possible the monitoring of three subjects and one control each day sampling was conducted. These self-contained sampling devices included a low-flow sampling pump, a solid polymer electrolyte CO sensor, and a rechargeable Ni/Cd battery pack. The system also featured a support console used for visual display of dosimeter readings during calibration and read-out of accumulated dosage (Fig. 1). At the end of a sampling period the dosimeter was attached to the support console unit, which visually displayed the accumulated dosage record stored in the dosimeter. The support console also served as an instantaneous read-out display for both dosimeter calibration and spot sampling. Initially the four dosimeters were calibrated with 0 ppm CO gas and 60 ppm CO "span gas" before and after each daily run. After the first 2 months of use, the dosimeters exhib-

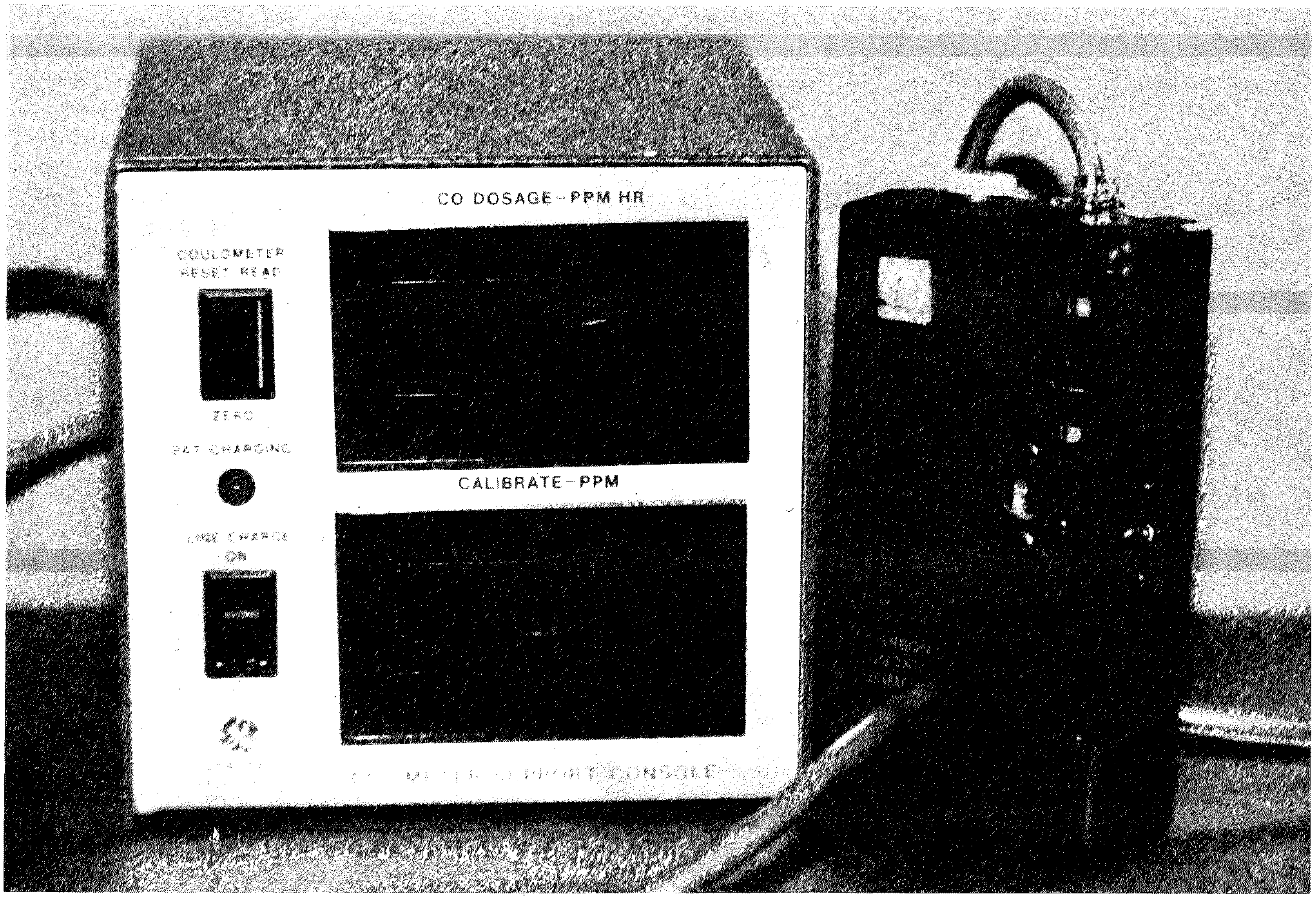

Fig. 1. Personal CO dosimeter and support console.

ited little span or zero drift; thereafter only one dosimeter was recalibrated after a sampling run.

The accuracy of the dosimeters was checked against one of the Colorado Health Department's nondispersed infrared analyzer (NDIR) at the continuous air monitoring program (CAMP) station in downtown Denver. The dosimeters were attached to the station's ambient air intake and a 6-hr dosimeter sample was taken and compared to that measured by the NDIR analyzer. When the percent error of three readings was averaged for each dosimeter, three dosimeters were found to be within 10% of the expected value, while the fourth dosimeter was within 12%. The manufacturer states the accuracy of the dosimeter should be within 10% during an 8-hr sampling period. The precision of the four dosimeters was very good, but the fourth was consistently lower by 3 to 4 ppm during the sampling period. All four dosimeters yielded reliable data under the field conditions of this study.

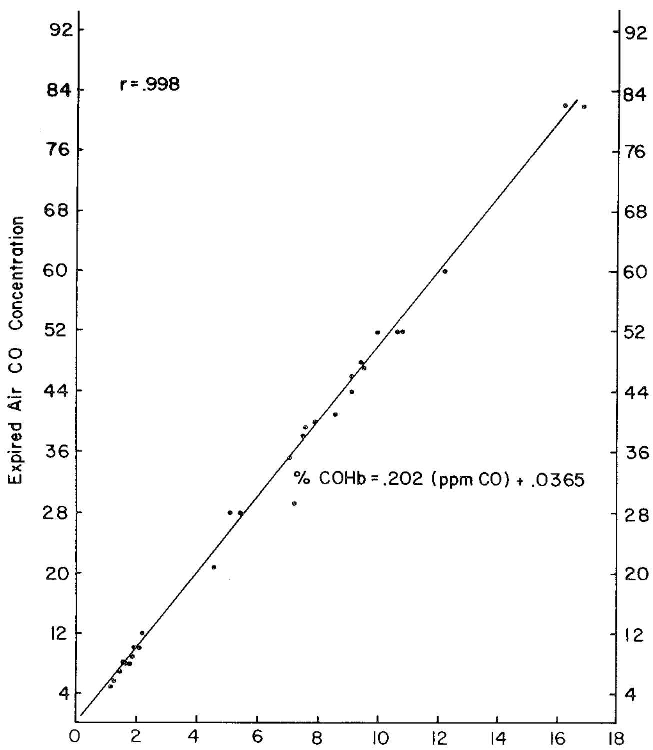

Fig. 2. Linear regression line correlating CO levels in the expired air (ppm) and CO levels in the blood (% COHb) from data collected in Denver, Colorado by Stewart.[6]

Biological samples (breath). The breath samples were collected in heavy-duty polyvinyl bags which are capable of containing a CO sample for 1 wk without loss of sample.[4] Breath samples were taken before and after each workshift. The 20-sec "end-expired breath" method of Jones et al.[5] was utilized, and the CO content of the breath samples was analyzed with a recently calibrated CO dosimeter.

In December 1978, Stewart[6] sampled CO in the breath of blood donors and compared it to COHb in blood of the respective donors in Denver, Colorado. Carboxyhemaglobin was measured with a model 282 CO-Oximeter and breath samples were analyzed with a series 2000 Ecolyzer. A blood-breath curve (Fig. 2) for Denver's altitude of 1,610 m was then developed from this data to convert Denver's police breath samples from ppm CO to percent COHb. The regression equation of the line was:

$$\% \text{ COHb} = 0.202 \text{ (ppm expired CO)} + 0.0365.$$

RESULTS AND DISCUSSION

The complete exposure data, separated into five work groups and a control group, is shown in Table 1. Various statistical methods of analysis were employed to facilitate meaningful interpretation of the data. Initially, frequency distributions were analyzed to obtain a description of the experimental population characteristics. Variables such as age, sex, smoking habits, quantitation of controls and subjects working different shifts and sampling periods, etc. were ordered into various measures of central tendency. Analysis of variance (AOV) tests were then performed to determine what significant differences existed between specified data sets. Finally, the strength of linear relationships was established by the Pearson's product moment correlation. The correlation coefficients and significance of the relationships between dosimeter readings, ambient air concentrations, before and after breath concentrations, and change in breath concentrations during an 8-hr period were calculated. Regression equations were developed for any statistically significant correlations.

Dosimeter readings. The dosimeter reading could be thought of as the total interval CO exposure, which was a combination of both occupational CO exposure and ambient CO exposure. The occupational CO exposure was exemplified by personnel writing traffic tickets in the exhaust plume of an idling car, cold morning vehicle warm-up in the police station parking garage, and working in close proximity to slow-moving, high-density automobile traffic for extended periods of time.

Dosimeter readings by job type indicate that variations in CO exposure relate directly to the amount of time spent working among heavy vehicle traffic. The "highway" section and "meter people" were in close contact with high-density auto traffic during most of their work shifts. The "special enforcement" section spent little time involved with traffic and demonstrated the lowest CO dosimeter readings.

Table 2 displays the results of the two-way analysis of variance on selected parameters and shows that exposed subjects had statistically significant higher CO exposures than controls based on the dosimeter readings ($P = .001$). This illustrates the great impact of occupational CO exposure in regards to the amount of CO inspired. Figure 3 illustrates the ranges and measures of central tendency for the dosimeter readings for smokers and nonsmokers. The nonsmoking controls had five high dosimeter readings (average 18.7 ppm CO/hr). It is speculated that this was due to CO leakage into the police department office from the downstairs parking garage, which occurred during very cold mornings when the garage doors were kept closed and vehicles were warmed-up before work. If these five dosimeter readings were eliminated, the average dosimeter reading would have been 6.4 ppm CO/hr. This average would have been very similar to the lower smoking control dosimeter readings.

Table 1.—Complete Carbon Monoxide Data on the Five Sampled Work Sections and Control Group

Work Section	N	Dosimeter*	*Before*† ppm CO	*Before*† % COHb	*After*‡ ppm CO	*After*‡ % COHb	*Change*§ ppm CO	*Change*§ % COHb	Ambient//
Nonsmokers									
Traffic teams	4	19.25	13.3	2.72	13.8	2.82	0.5	0.14	10.5
Highway	6	27.25	8.5	1.75	20.2	4.17	11.7	2.40	6.9
Enforcement	4	16.00	9.3	1.90	14.5	2.97	5.3	1.10	8.9
Special enforcement	6	11.00	6.0	1.25	7.6	1.57	2.0	0.44	3.5
Meter people	29	21.75	10.3	2.12	15.4	3.15	5.1	1.07	6.3
Controls	16	10.50	10.4	2.14	9.3	1.92	−1.3	−0.30	6.8
(Controls – 5 "high" values)	(11)	(6.40)	(7.5)	(1.56)	(5.8)	(1.20)	(−1.8)	(−0.36)	(6.9)
TOTAL	65								
Smokers									
Traffic teams	4	20.88	66.0	13.36	82.7	16.74	16.8	3.43	4.7
Highway	4	28.00	47.0	9.53	67.0	13.57	20.3	4.14	6.9
Enforcement	8	16.75	37.0	7.51	47.6	9.65	10.4	2.14	6.3
Special enforcement	2	13.25	41.5	8.42	41.0	8.32	−0.5	−0.14	3.3
Meter people	8	33.88	32.2	6.54	47.4	9.61	15.1	3.09	6.3
Controls	7	7.13	40.3	8.18	43.9	8.90	3.7	0.78	5.9
TOTAL	33								

*ppm CO per hr.
†Before work breath sample in ppm CO and estimated % COHb.
‡After work breath sample in ppm CO and estimated % COHb.
§Average difference between before and after in ppm CO and estimated % COHb.
//Eight-hr running average in ppm per hr.

Table 2.—Analysis of Variance of Ambient, Dosimeter, Change, and After by Subject and Control, Shift, Period, Smoker and Nonsmoker

		F	Significance
Dosimeter			
By:	Subject and control	30.70	.001
	Shift*	0.79	.378
	Period†	2.88	.095
	Smoker and nonsmoker	0.43	.513
Ambient			
By:	Subject and control	0.01	.922
	Shift	17.70	.001
	Period	27.30	.001
	Smoker and nonsmoker	3.90	.052
Change in breath			
By:	Subject and control	10.5	.002
	Shift	0.69	.409
	Period	1.13	.292
	Smoker and nonsmoker	13.19	.001
After breath			
By:	Subject and control	7.399	.008
	Shift	4.056	.047
	Period	1.177	.281
	Smoker and nonsmoker	161.927	.001

NOTES: *Dosimeter:* Personal breathing zone sampling for CO, with an integration of the CO dose over the entire workshift (8-hr time-weighted average). *Ambient:* Stationary site sampling for CO, 8-hr moving average. *Change in breath:* After shift breath CO level minus the before-shift breath CO level. *After breath:* Personal measurement of CO in the workers' expired breath after the workshift.
*Shift = day and evening.
†Period = fall and winter.

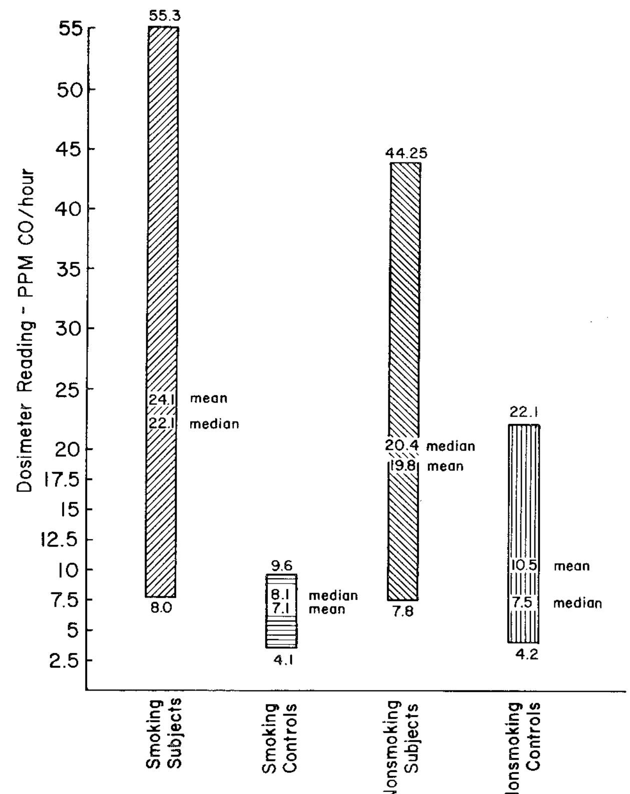

Fig. 3. Average maximum, minimum, mean, and median CO dosimeter readings for the subjects and controls.

The high ranges of the subject dosimeter readings exceeded the NIOSH recommended CO standard of 35 ppm. The smoking subjects even exceeded the OSHA standard of 50 ppm for an 8-hr time-weighted average (TWA). However, when the average of all dosimeter readings was computed, both groups were well within the occupational standards. There was a slight, but not statistically significant, increase in the dosimeter readings during the P.M. shift and during the winter months, which confirmed the slight impact high ambient CO levels had on personal CO exposures. The differences observed in the dosimeter readings for the two shifts monitored and the seasons of the year were not statistically significant. When the dosimeter readings of smokers and nonsmokers were compared, there were no significant differences in exposure based on breathing zone samples.

Ambient carbon monoxide levels. Exposure to ambient CO levels, as monitored at fixed sites, comprise a small portion of the total occupational exposure. Because the ambient levels are measured at fixed monitoring sites, they are only a very rough estimation of personal CO exposures. The levels of ambient CO on any given day are influenced by randomly occurring meteorological factors; therefore, the differences in ambient CO exposure in the five work sections are mainly a result of daily random sampling schedules.

Figure 4 shows the average daily dosimeter readings for subjects, controls, and the ambient CO concentrations from September through January. Also shown is the great difference between the low ambient CO levels and the actual occupational exposures experienced by workers. It is apparent, therefore, that the ambient CO levels measured by the fixed monitoring sites did not provide an accurate estimation of the CO exposure of those workers in the downtown city streets. The ambient CO levels do seem to follow control dosimeter values, which could indicate that the ambient CO levels are representative of the CO exposure of those persons working in street-level downtown office buildings.

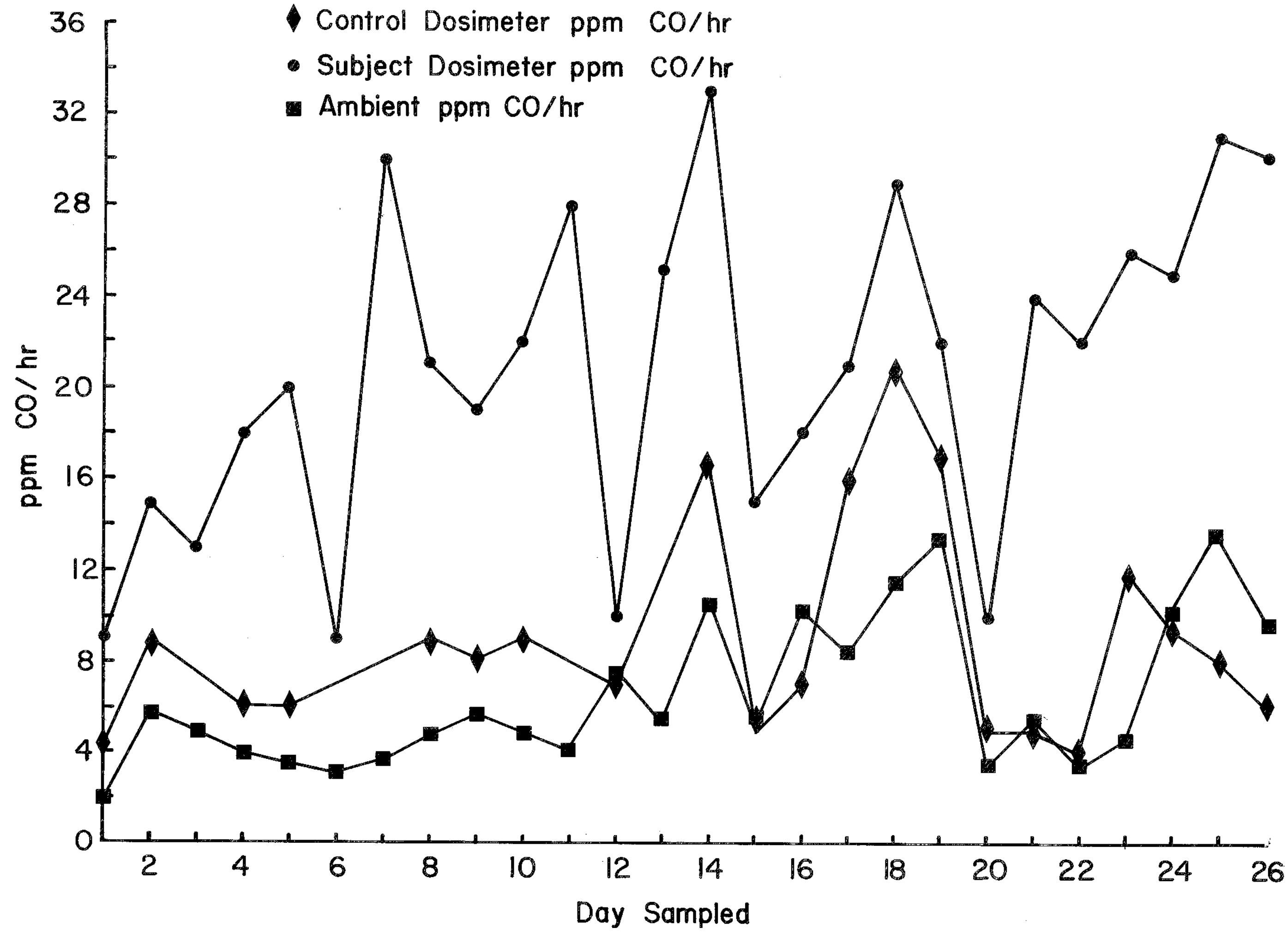

Fig. 4. Average daily dosimeter readings for the subjects and controls compared to the ambient CO concentrations.

The significant difference in ambient CO levels between the A.M. and P.M. shift was principally a result of greater rushhour traffic volumes during the evening rushhours and the accumulation of CO during the day (Table 2). The greater ambient CO concentrations during the winter months than the fall months were due to meterological conditions. As would be expected, the ambient CO levels show no significant differences for exposures between subjects and controls, or smokers and nonsmokers.

Breath carbon monoxide levels. The after-work expired breath samples represent COHb levels in equilibrium with the occupational environment. Carboxyhemoglobin levels in the blood continually shift to approach equilibrium with the fluctuating CO levels. The body absorbs CO when the levels are high, and excretes it when the environmental levels are low. The effect is mediated by the half-life of CO, which is 3 to 4 hr. Therefore, after-shift COHb levels tend to reflect the body's ability to approach this equilibrium with the constantly fluctuating CO levels. An example of this concept is represented by a nonsmoking subject whose before-work breath concentration was 22 ppm and after-work breath concentration was 14 ppm, or a net decrease of 8 ppm. The dosimeter reading was 15.5 ppm CO/hr. This individual's COHb level fell because the occupational CO exposure could not sustain his before-shift COHb level. The subject stated that his wife was a heavy smoker, and this may have been the reason for his high before-shift COHb level. In general, the "smokers" in this study could smoke freely during the various types of duty.

The "end-expired breath" CO levels for smokers and nonsmokers are presented in Figure 5, which display the average before-shift breath levels and the resulting average after-shift breath samples. The estimated percent COHb was computed from the equation developed from Stewart's blood-breath data (Fig. 2). It should be noted that the nonsmoking controls had a net decrease in COHb during the 8-hr shift. All nonsmokers began work with comparable COHb levels, which indicates that there was little COHb carried over from the preceding day. While there were three instances in which nonsmokers' after-workshift COHb levels exceeded the NIOSH recommended limit of 5.0% COHb, the average after-workshift level of 3.04% COHb did not represent a recognized unhealthful CO exposure.

The smokers' COHb levels were approximately 4 times higher than the nonsmokers. The smoking subjects' before-work COHb levels were slightly higher than the smoking controls, which could have been due to some carryover from the preceding day. Since the subjects' after-work COHb levels were so high, they may not have completely eliminated their COHb burden before beginning work the next day.

The change in breath CO concentration is calculated by subtracting the before-shift breath CO level from the after-shift level to estimate the total CO dose received during the 8-hr shift. The changes in CO breath concentrations for subjects and controls are shown in Figure 6. The increase in nonsmoking subjects was due principally to personal CO exposures and ambient CO exposures. The smoking controls' increased COHb levels were due primarily to smoking during the 8-hr shift. The smoking subjects were exposed to three sources of CO which appear to be additive. The ambient CO exposure was the least significant source, while the personal CO exposure appeared to be equal to that experienced by nonsmokers. Finally, cigarette smoking was the greatest source of CO exposure to the smoking subjects, overshadowing all other sources.

The analysis of variance of "change" in COHb levels during the 8-hr shift and after-shift COHb levels showed similar results; for both "change" and "after" there were significant differences between subjects and controls, and smokers and nonsmokers (Table 2). Occupational CO exposures had a significant effect on the COHb levels of the subjects compared to the controls. Obviously, smoking had a significant impact on the COHb levels of smokers compared to nonsmokers. There were no significant differences

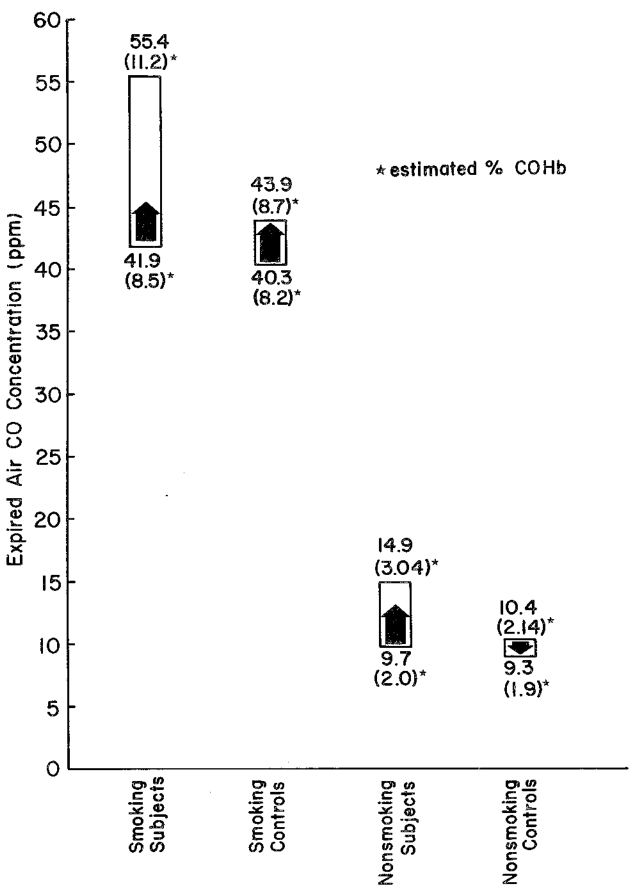

Fig. 5. Average before- and after-workshift CO breath concentrations for the subjects and controls.

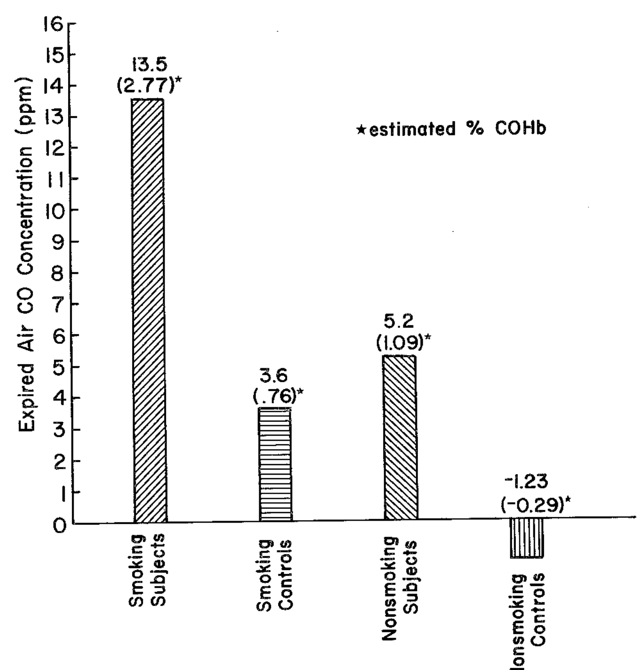

Fig. 6. Change in CO concentrations in the breath samples during the 8-hr workshift for subjects and controls.

Table 3.—Correlation Coefficients and Significance between Measured Data for Smoking and Nonsmoking Subjects

	Smokers	Nonsmokers
1. Dosimeter vs. After	.1829 .186	.8228 .001
2. Dosimeter vs. Change	.4947 .005	.6431 .001
3. Before vs. After	.8171 .001	.3091 .016
4. Before vs. Ambient	−.1483 .235	.3631 .005
5. Dosimeter vs. Before	−.1292 .265	.2177 .066
6. Dosimeter vs. Ambient	.2119 .149	.3990 .002
7. Before vs. Change	.0409 .421	−.4051 .002
8. After vs. Ambient	.0139 .473	.3018 .019
9. After vs. Change	.6094 .001	.7443 .001
10. Ambient vs. Change	.2280 .131	.0381 .399

NOTES: *Dosimeter:* Personal breathing zone sampling for CO, with an integration of the CO dose over the entire workshift (8-hr time-weighted average). *Ambient:* Stationary site sampling for CO, 8-hr moving average. *Before* (breath): Personal measurement of CO in the workers' expired breath before the workshift. *After* (breath): Personal measurement of CO in the workers' expired breath after the workshift. *Change* (in breath): After-shift breath CO level minus the before-shift breath CO level.

in COHb levels between shift or season, which again emphasized the weak influence of significant changes in ambient CO concentration on COHb levels.

Correlation coefficients and significance. Table 3 shows the correlation coefficients and significance between measured data for smoking and nonsmoking subjects. The correlations for the smokers' COHb were influenced by the variation caused by cigarette smoking. The nonsmokers' correlations showed many significant relationships. The relationship between the dosimeter and after-shift breath samples ($r = .82$) points out that the dosimeter readings were a good indication of the COHb levels at the end of the workshift. The dosimeter vs. change relationship also indicated a significant correlation ($r = .64$) between dosimeter readings and total CO dose experienced during the 8-hr shift. The before-shift vs. after-shift relationship showed that the change in nonsmokers' COHb levels during the 8-hr shift was not very significant. The ambient CO levels appear to be related to the breath samples before occupational CO exposure, as shown by the significant ($P = .005$) relationship between the before-shift breath samples and the ambient CO levels.

Throughout the statistical analysis of the data, a close association was noted between the dosimeter readings and the COHb levels. The COHb levels for individuals are a result of the biological integration of the occupational CO exposure experienced. Therefore, it appeared that the CO dosimeter readings could be used as an index of CO exposure in an occupational setting.

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