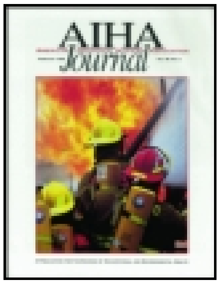

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Welding Helmet Airborne Fume Concentrations Compared to Personal Breathing Zone Sampling

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Metal fume concentrations inside the welding helmet and in the personal breathing zone in 23 experimental welding exposures were studied to explore whether welding helmet use substantially attenuates exposure to airborne metal fume. Observations produced a mean ratio of inside to outside metal fume concentrations of 0.9 ± S.D. 0.2 with a highly variable effect. Iron fume concentration was inversely correlated with this ratio, representing greater helmet-associated attenuation with heavier exposure ($r = -0.70$, $p < 0.001$). In contrast to previous reports, these data suggest that welding helmet use provides marginal and highly variable reductions in fume exposure and cannot substitute for standard respiratory protection.

The National Institute for Occupational Safety and Health (NIOSH) recommends that worker exposure to inhalational hazards related to welding processes be minimized.[1] Engineering controls generally are preferred for controlling airborne contaminants released from welding processes. Personal protective equipment, including respirators, also can be an important part of worker protection. Despite these recommendations welders are frequently unprotected by engineering controls or the use of appropriate personal respiratory protective equipment.

The welding helmet would offer some degree of respiratory protection were the level of metal fumes inside meaningfully lower than that in the breathing zone outside the helmet. It is generally accepted that some attenuation of fume exposure occurs with welding helmet use.[2] This has called into question the adequacy of industrial hygiene monitoring outside the welding helmet. Nonetheless, data are limited on which this assumption of helmet-attributable exposure attenuation is based. As part of a larger study designed to examine the pulmonary health effects of welding fumes on workers, the authors measured the concentrations of zinc and iron fumes both inside and outside the welding helmet by personal breathing zone monitoring to address this question.

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METHODS

Study Population

Twenty welders, men and women, were recruited by advertisements and through local metal trade unions as part of a larger controlled exposure investigation studying welding fume inhalation and metal fume fever.[3-4] Persons were excluded from the study who had welded on galvanized steel within the two weeks prior to being studied. The study protocol was approved by the University of California San Francisco Committee on Human Research. The mean subject age was 32 ± 9 years (range 20 to 47 years). Of the 20 participants, 15 (75%) were men. Years of welding experience ranged from 1 to 22 years (median, 8 years).

Exposure Conditions

Welding fume challenges took place in a 14.6 m^3 (506 ft^3) environmental exposure chamber with controlled humidity and temperature. Chamber airflow was measured by a Balometer (Alnor Instrument Co., Skokie, Ill.) to be 150 f^3/min, yielding a calculated 18 air exchanges per hour. The subjects used standard work practices, wearing welding helmets as personal protective equipment. All welding helmets were of standard design meeting American National Standards Institute (ANSI) Z87.1-1979 criteria. No specific respiratory protective equipment was worn by the welders. They carried out routine electric arc (stick) welding on galvanized mild steel with a standard cellulose-covered carbon steel (cadmium-free) electrode (E6011). The subjects' welding times ranged from 10 to 30 minutes. Sixteen welded continuously. Three of these subjects welded on two separate occasions and therefore contributed two observations each to the study. Four other subjects welded during a portion of their time in the

TABLE I. Data for 23 Experimental Electric Arc Welding Exposures

Exposure Variables	*Results*
Duration of welding in minutes, median (range)	20 (10 to 30)
Welding rods used per minute welding, mean ± SD	0.6 ± 0.14
Fume concentrations[A] inside welding helmet, mg/m^3	
Iron, mean ± SD (range)	27 ± 15 (5 to 65)
Zinc, mean ± SD (range)	93 ± 67 (0.1 to 332)
Fume concentrations[A] outside welding helmet, mg/m^3	
Iron, mean ± SD (range)	32 ± 24 (4 to 117)
Zinc, mean ± SD (range)	93 ± 67 (0.1 to 359)
Difference in concentrations[A] outside-inside, mg/m^3	
Iron, mean ± SD (range)	6 ± 16 (−10 to 71)
Zinc, mean ± SD (range)	17 ± 40 (−11 to 169)
Ratio concentrations, inside:outside helmet	
Iron, mean ± SD (median)	0.9 ± 0.2 (0.96)
lowest quartile (n = 6) range	0.40 to 0.83
highest quartile (n = 6) range	1.03 to 1.30
Zinc, mean ± SD (median)	0.9 ± 0.2 (0.97)
lowest quartile (n = 6) range	0.42 to 0.87
highest quartile (n = 6) range	1.01 to 1.12

[A] All sampling data expressed for elemental metal concentrations

chamber. During the nonwelding periods, these four welders wore their helmets in a routine "up" position. All of the other welders had their helmets in the up position only while changing rods.

Exposure Sampling

Air samples were collected on mixed cellulose ester filters (MCE) with personal sampling pumps according to NIOSH Sampling and Analytical Method 7300 at flow rates of 1.5 to 2.0 L/min.[5] The filters used to collect samples inside the helmet were attached inside the welding helmet in the vicinity of the welder's mouth. The American Welding Society standard F1. 1-76, "Method for Sampling Airborne Particulate Generated by Welding and Allied Processes," specifies that air samples should be taken within the helmet 50 mm to the left or right of the welder's mouth.[6] This sampling method is approved by ANSI.

The outside samples were collected in the breathing zone at the shoulder near the lower edge of the helmet in the lapel area. Filters were sampled simultaneously, closed-face, each with separate pumps. Samples were collected for the entire exposure time, which ranged from 15 to 30 minutes. They were analyzed for metal fumes by inductively coupled argon plasma atomic emission spectroscopy at an American Industrial Hygiene Association-accredited laboratory (AcuLab Environmental services, Petaluma, Ca.). All sampling data were quantified and reported as elemental metal concentrations in milligrams per cubic meter (mg/m^3).

Because the study protocol was designed to investigate metal fume fever, the level of exposure was intended to be above the exposure limits recommended to prevent acute symptoms. The American Conference of Governmental Industrial Hygienists (ACGIH) recommends an eight-hour, time-weighted average (TWA) threshold limit value (TLV®) of 5 mg/m^3 and a 15-minute short-term exposure limit (STEL) of 10 mg/m^3 for zinc oxide fume.[7] This is in concordance with the Occupational Safety and Health Administration permissible exposure limit (PEL) and STEL for zinc oxide fume.[8] The TLV for iron oxide fume is also 5 mg/m^3.[7]

Statistical Methods

Twenty-three exposure measurements were obtained on these twenty subjects. Three subjects were exposed on two separate occasions. Exposure variables measured included the iron and zinc concentrations outside and inside the welding helmet. The authors analyzed the exposure data for the elemental forms of the metals in which they were analytically quantified.[5] It should be remembered, however, that exposure standards for zinc and for iron are promulgated as concentrations of the corresponding metal oxides. The authors also analyzed additional exposure variables including duration of welding (minutes), length of time in the exposure chamber (minutes), and number of welding rods used.

From these measurements were calculated the ratio of zinc and iron concentrations inside to outside the helmet, the amount of time the welding helmet was in the up position (exposure time minus welding time), and the rate at which rods were used (number of rods divided by continuous welding time). The authors also calculated the rate of use of the welding rod as a measure of welding efficiency.

The authors correlated the level of exposure outside the helmet with the ratio of the inside-to-outside exposure concentration using the Pearson product-moment correlation in a standard statistical package.[9] To take into account the possible effect of noncontinuous welding on the observed relationship between the outside helmet concentration and the ratio of inside:outside the helmet concentrations, the authors re-estimated the correlation excluding the three noncontinuous welding exposures. To take into account the possible effect of an outlying heavy exposure (117 mg/m^3) on the observed relationship between the outside helmet concentration and the inside:outside ratio, they again re-estimated the correlation excluding that observation. As a further test of the possible effect of the wide range of observed values on the estimated correlation, the nonparametric Spearman rank correlation between the outside helmet concentration and the inside:outside ratio also were calculated.[9] Air sampling exposure measurements were correlated with other variables that might affect exposure level, such as welding time, exposure time, rate of rod use, amount of time the helmet was in the up position, and prior welding experience (in years).

RESULTS

Exposure Data

The concentrations of iron and zinc inside the welding helmet did not differ greatly from those outside the helmet (Table

TABLE II. Outside to Inside Welding Helmet Fume Sampling Data

Welding Challenge	*Iron Outside Helmet mg/m³*	*Fume Ratio Inside:Outside*	*Zinc Outside Helmet mg/m³*	*Fume Ratio Inside:Outside*
1	4.2	1.14	0.1	1.00
2	5.0	1.14	27.4	1.18
3	9.3	1.01	47.3	1.01
4	13.2	1.00	39.4	0.97
5	14.0	1.07	84.0	1.07
6	14.7	1.02	57.6	1.00
7	16.5	0.96	70.5	0.98
8	18.2	1.03	79.8	1.02
9	18.3	0.97	81.1	0.95
10	21.4	1.01	86.1	1.01
11	24.4	0.96	72.2	1.00
12	30.2	0.79	58.5	0.79
13	31.2	0.83	179.0	0.95
14	33.1	1.30	100.0	1.11
15	35.0	0.91	59.0	0.90
16	40.0	0.84	76.7	0.87
17	42.3	0.89	85.4	0.90
18	43.8	0.78	209.0	0.82
19	44.9	0.63	203.0	0.68
20	50.1	0.48	166.0	0.49
21	55.6	0.88	359.0	0.92
22	59.8	1.09	107.0	1.10
23	117.0	0.40	291.0	0.42

I). As a measure of attenuation the authors analyzed the difference between concentration outside and inside the welding helmet (outside concentration − concentration inside helmet). For 10 of 23 iron exposures (44%), inside helmet exposure levels were greater than those measured by personal breathing zone monitoring at the shoulder. For zinc, 8 of 23 exposures (35%) demonstrated a greater concentration inside than outside the welding helmet.

As another measure of attenuation the authors analyzed the ratio of inside:outside concentrations. For iron, the mean ratio of inside:outside concentration was 0.9; the median value was 0.96. Six exposures (the lowest quartile) were associated with a ratio of 0.83 or less (Table I). Among the four exposures where the helmet was in the up position for a longer period, the median inside:outside ratio was 0.9. The pattern for zinc was similar.

Because helmet-associated attenuation of fume concentration was highly variable, the authors wished to assess the correlation of exposure variables with the ratio of inside:outside fume concentrations. With increasing outside concentration for either iron or zinc there was a decreasing ratio of inside:outside concentrations, representing greater proportional attenuation. The data for all 23 exposures demonstrating this relationship are presented in Table II. The correlation between outside exposure and helmet attenuation was statistically significant for both iron ($r = -0.70$, $p < 0.001$) and zinc ($r = -0.56$, $p = 0.006$). The relationship for iron is presented visually in Figure 1. There was no statistical correlation between attenuation and welding time, experience, or rod-use rate.

The authors recalculated the correlation excluding the four subjects who did not weld continuously during the entire exposure period and therefore had their helmets in the up position for a greater amount of time. Among the 19 remaining exposures, the inside:outside ratio correlations with the outside-the-helmet concentrations of iron ($r = -0.68$, $p = 0.001$) and zinc ($r = -0.47$, $p = 0.04$) were not substantially changed. The correlation was again re-estimated, excluding the welding challenge with the heaviest exposure as shown in Table II. For iron the correlation was -0.52 ($p = 0.012$), while for zinc it was -0.40 ($p = 0.057$). When reanalyzed nonparametrically with the Spearman rank correlation using all 23 observations, the inside:outside fume ratio continued to demonstrate a statistically significant decline with increasing outside concentration ($r = -0.64$, $p = 0.001$), while the zinc fume correlation was again less strong ($r = 0.40$, $p = 0.06$).

DISCUSSION

Goller reported that concentrations of metal fumes in a platform gas-shielded welding operation demonstrated a mean value 1.4 times higher when measured at the shoulder than in the welding helmet, or the equivalent to an inside:outside ratio of 0.7 (ratio range 0.4 to 1.4).[10] In that study inside helmet levels of airborne iron oxide fumes ranged from 1.8 to 19.0 mg/m³ with sampling times ranging from 4.2 to 7.5 hours. Several earlier studies also observed varying degrees of welding helmet-associated exposure attenuation. One of these studies also found an inside:outside helmet ratio of approximately 0.7; two other studies observed somewhat higher and lower ratios.[11–13]

An experimental exposure model, employing a welding dummy, where fume concentrations were higher and in a range more comparable to that shown in the current study (mean iron concentrations > 80 mg/m³ for stick welding) found levels outside the welding helmet more than 20 times the concentration inside, yielding an inside:outside ratio of less than 0.05.[14] However, in that study the dummy was designed to inhale ambient air and exhale clean (nonexposed) air, the helmet had a cup-type chin, and sampling took place during arc time only; important differences as compared to these exposures.

A lesser degree of helmet-associated fume attenuation was observed than in most of these studies. Moreover, the reduction

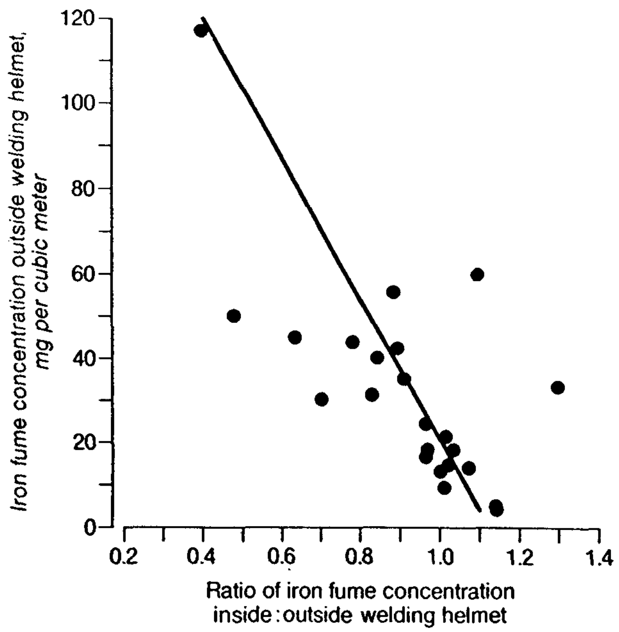

FIGURE 1. Correlation ($r = -0.7$; $p < 0.001$) between the airborne concentration of iron fume assessed by personal breathing zone monitoring at the shoulder and the ratio of the concentration within the welding helmet to the outside shoulder value (n = 23 pairs of samples). Concentration expressed as that of the elemental metal.

that was observed was largely accounted for by the highest exposures. The authors cannot account for the inverse relationship observed, manifest as greater fume attenuation with higher concentration exposures. Possible explanations could include aerodynamic effects or mechanical factors such as body position. For example, under conditions of very heavy exposure, fume aggregation could modify aerodynamics such that the welding helmet offers a more efficient barrier. Conversely, body position may be potentially associated with less shoulder proximity to the welding arc at a time when the head position provides poorer helmet attenuation. However, the relationship between absolute concentration and helmet attenuation did not appear to be explained by welding efficiency, total welding duration, or time with the helmet in the up position.

It is important to note that this exposure model may not reproduce field conditions, where air exchanges per minute may be less or more and where welding may be more intermittent. Nonetheless, the data suggest that welding helmet use provides unreliable and ineffective attenuation of exposure. At lower exposure levels there is virtually no difference between fume concentrations sampled inside and outside the welding helmet.

CONCLUSIONS

These findings suggest that in acute heavy-exposure situations, welding helmet attenuation of metal fume exposures is highly variable and frequently negligible. The welding helmet may provide some exposure reduction in situations of very concentrated metal fume exposure. Data from this study indicate that in situations of low to moderate exposure, environmental sampling based on outside-the-helmet, personal breathing zone monitoring may in fact be fairly representative of the actual dose to the worker.

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