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Fertility among Danish male welders

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BONDE JP, HANSEN KS, LEVINE RJ. Fertility among Danish male welders. *Scand J Work Environ Health* 1990;16:315–22. Welding may be detrimental to the male reproductive system. Fertility was examined in a Danish cohort of 3702 male metalworkers over a follow-up of 47 674 person-years. Occupational histories were gathered by postal questionnaires. Information on births was obtained by record linkage to the Danish Central Population Register. Among persons who had ever worked as welders, the probability of having a child was slightly reduced the year after a year of welding exposure, even after control for differences in age, birth cohort, paternal parity, birth of a child in the preceding five years, smoking, and consumption of alcoholic beverages (odds ratio 0.89, 95 % confidence interval 0.83–0.97). The reduction in fertility was associated with the welding of mild steel, but not with the welding of stainless steel. These findings are consistent with results of previous studies of time to conception and semen quality in welders.

Key terms: birth rate, mild steel, occupational hazard, reproduction, stainless steel, welding.

In recent years several Danish studies have suggested that welding may have deleterious effects on the male reproductive system, causing reduced semen quality and delayed conception. Two hospital-based case-referent studies of infertile couples found an increased risk of reduced semen quality in welders (1, 2). A cross-sectional study of metalworkers revealed an exposure-response relationship between welding fume exposure and semen quality in mild steel welders (3). Semen quality was observed to decrease with increasing exposure to welding fumes. Preliminary results of a study of stainless steel welders did not, however, indicate reduced semen quality (4). Two studies with different methodological approaches have reported associations between paternal welding exposure and delayed conception (2, 5).

Because of the extensive worldwide application of welding technology, often resulting in occupational exposures which far exceed recommended occupational exposure limits (6), additional studies are needed to verify suggested effects on the male reproductive system and to estimate their magnitude. We examined the relationship between fertility and welding exposure in a cohort of Danish male metalworkers.

Subjects and methods

Source population

Subjects for this fertility study were selected from a cohort of 10 059 male production workers employed at Danish stainless steel or mild steel manufacturing companies for a minimum of one year within the period April 1964 through December 1984. The cohort was created for a study of welders' health with special emphasis on cancer risk (unpublished report "A Cohort Study of Welders' Health — With Special Reference to Cancer Occurrence: Background and Design" by KS Hansen).

The cohort members were enrolled at 74 companies employing about 60 % of all Danish stainless steel welders and at five large mild steel companies. [Stainless steel is an alloy of iron, nickel, and chromium, occasionally containing cobalt, vanadium, manganese, and molybdenum. Mild steel is an alloy of iron, carbon, and silicon, occasionally containing molybdenum or manganese (6).] With the objective of minimizing the incompleteness of registration of the cohort members, the cohort was created in two phases with the use of two independent data sources. In phase 1 index companies were asked to establish a roster of men who had ever been employed as production workers. In phase 2 additional index company workers were identified from records of the Danish Pension Fund and the Danish Central Population Registry. Data on job titles and departments of potential cohort members were obtained at each of the index companies by means of standard interviews with managers, foremen, and long-term workers. Only subjects employed as mild steel welders, stainless steel welders, stainless steel grinders, or nonwelding/grinding production workers (eg, turners, fitters, warehousemen, but not apprentices or craftsmen) were admitted into the cohort. The

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nonwelders selected as cohort members had to be employed in departments which included welders. During the autumn of 1986 the cohort members were mailed a questionnaire on lifetime occupational exposures, smoking, and drinking habits. Nonrespondents were contacted by mail twice more and asked for their cooperation. Information on the few decedents was obtained in an interview with the spouse, next of kin, and/or fellow workers. Responses were received for 85 % of the cohort members.

Study population

Fertility was examined within a subset of the source population, consisting of the 3702 cohort members born in 1945 or subsequently. Births of children were monitored from January 1968 through December 1986 and were included in the analysis if cohort members had attained 21 years of age by the child's birth year.

Live-born children

Information on the births of the subjects' live-born children was obtained by record linkage to the Danish Central Population Register. The cohort members were identified in the Register by their official personal identification number, a 10-digit number unique to each individual. The following data on these children were collected from the records of the subjects: birth date, birthplace (country of birth available only for children born in 1973 and subsequent years), and a verification code indicating a biological parent-child relationship.

The Central Population Register was established on 1 April 1968. It contains cross-references between parents and their children. During the period through 1978 a cross-reference did not necessarily imply a biological relationship, but merely a shared residence. Cross-references were deleted if the children moved away from home, had children themselves, or, in cases of divorce, if the child and parent were separated by custody arrangements.

Entries into the Register changed in 1979. The parent-child cross-reference became permanent, regardless of marital status at childbirth, subsequent divorce, or any other event with the exception of adoption. Prior register information was corrected to reestablish references that had been deleted. Reliability of the father-child relationship could be assessed by means of the verification code. During the period 1968–1986, the 3702 subjects of our study had fathered 4620 children. For 99.4 % of these children the parent-child relationship could be verified.

When a child is adopted, the biological parent-child cross-reference is cancelled. A new reference is made to the adopting parents. Although, compared to the number of births, the frequency of adoptions is low (about 2.6 % of children born during 1968–1986) (7), this source of misclassification could bias the assess-

ment of fertility. While 47 % of adopted children are the biological children of the spouse of the adopting parent and are unlikely to reflect infertility in the adopting parent, the rest are more likely to be adopted by infertile parents.

About 75 % of Danish children born in foreign countries are not biologically related to either parent (adopted by both parents). Of the 3778 children born to the subjects of our study in 1973 and later years when country of birth was included in the register data, 54 had been born outside Denmark. The father-child relationship was judged to be adoptional if the child's surname had changed soon after immigration or if the child had been born illegitimately without verified sponsorship and had not immigrated to Denmark at the same time as one or both parents. These criteria were fulfilled for 28 of the 54 children, who were thereupon used for computing paternal parity, but not fertility. On the assumption that the rate of adoption in the study population was comparable to the national rate, it can be estimated that approximately 45 % of the adoptions of children biologically unrelated to both parents were identified.

Occupational exposure

Information on welding mild steel, welding stainless steel, and grinding stainless steel was obtained from separate series of questions in the questionnaire. For each activity the workers were asked to record their first and last years worked and the number of years that the particular type of work had been performed in each of the following three periods: 1960–1969, 1970–1979, and 1980–1986. In the present study all years within the interval spanning first and last years worked were considered exposed years, conferring risk on the likelihood of occurrence of births during the following year. A person-year of observation was designated at risk from exposure in the preceding year (figure 1) in order to allow for effects on any stage of spermatogenesis and epididymal transport (three months) and for the period of gestation (nine months). The interval spanning first and last years worked is a useful approximation of the actual years exposed since the number of years contained in the interval exceeded the sum of exposed years between 1960 and 1986 by only 10–16 %. The total number of person-years exposed to mild steel welding, stainless steel welding, and stainless steel grinding was 29 060, 16 252, and 890, respectively, if the interval spanning first and last years worked is used and 25 036, 14 530, and 812, respectively, if the sum of the exposed years 1960–1986 is used.

Exposure to nickel and hexavalent chromium in stainless steel welding depends substantially on the welding methods employed. Manual metal-arc welding confers much greater exposure to these metals than does the tungsten inert-gas method (6). The respondents were asked to note the welding methods used in

each of the three periods covered by the investigation. A year was considered exposed to manual metal-arc welding if it fell within a period in which manual metal-arc welding had been used. An arbitrary exposure score for stainless steel welding was constructed: 0 = unexposed; 1 = stainless steel welding, tungsten inert-gas method; 2 = stainless steel welding, manual metal-arc method. Scores thus defined constituted the basis for a dose-response evaluation of fertility at risk from stainless steel welding.

The distribution of the subjects and person-years of follow-up in this study is given in table 1 by categories of exposure. Only mild steel welding had been performed during a substantial portion (34 %) and only stainless steel welding in a small portion (14 %) of the experience of the stainless steel welders (22 805 years at risk).

The proportion of person-years of follow-up at risk from exposure varied considerably between persons. The percentage of persons with less than 25, 50, and 75 % of their years at risk during the follow-up was 14, 27, and 39 %, respectively, among ever welders; and 30, 47, and 60 % among persons who had ever welded mild steel, but had never welded stainless steel.

Smoking and alcoholic beverage consumption

Information on first and last year of smoking was obtained in the questionnaire. All intervening years were

considered exposed to smoking. Those cohort members whose current and previous consumption of alcoholic beverages exceeded 10 beers, 5 glasses of wine, or 5 drinks of liquor per week comprised the high-consumption group. They were considered "highly exposed" to alcoholic beverages during their person-years. The other subjects were classified as "lowly exposed" during their person-years.

Analysis and statistical methods

The occurrence of birth in a year was analyzed by logistic regression conditional on exposure to welding during the preceding year and on several potential confounding factors. The unit of observation was an entire calendar person-year in the age range 21–41 years and within the period 1968–1986. The dependent variable was occurrence or absence of birth (excluding births of recognized adopted children) during the person-year.

Each person-year was identified with the worker's birth cohort, age, parity (0, 1, 2, ≥ 3), smoking habit (yes/no), consumption of alcoholic beverages (high/low), and occupational exposure status during the preceding year. Paternal parity was the parity attained by the start of the year of observation, and it took into account children born before 1968 and also adopted children. For each person-year variables specific to exposure category (stainless steel welding, mild steel

Figure 1. Relationship of welding exposure to fertility risk. A person-year corresponds to a calendar year (January 1–December 31). An entire person-year was designated as exposed even if welding had been undertaken only during a part of the year. The questionnaire data did not allow for a more-detailed categorization.

Table 1. Subjects and person-years of follow-up.

	Stainless ^a steel welders	Mild ^b steel welders	Nonwelders		Total
			Grinders	Others	
Birth cohort					
1945—1949	786	315	51	161	1313
1950—1954	579	214	44	147	984
1955—1959	500	164	37	129	830
1960—1964	418	81	24	52	575
Total	2283	774	156	489	3702
Person-years of follow-up					
Not at risk, before exposure	2396	1412	613	6209	10630
At risk from exposure	22805	5719	831	—	29355
Not at risk, after exposure	3699	3460	530	—	7689
Total	28900	10591	1974	6209	47674

^a Ever welding stainless steel, regardless of welding mild steel.

^b Ever welding mild steel, never welding stainless steel.

welding, stainless steel grinding) were designated and used to indicate the number of previous exposed years and the number of years elapsed since last exposure.

In the strict sense, paternal parity is the number of children fathered. In computing parity for this study, however, where parity was used as a determinant of the likelihood of having children, adopted children were included. Parity levels were increased by two in the case of twins. Registrations prior to 1968 may have been incomplete, and only 62 % of these 192 father-child relationships had been verified. Nevertheless, the degree of inaccuracy in paternal parity caused by chil-

dren born prior to 1968 is expected to be small and is unlikely to correlate with welding exposure.

To minimize the dependence of outcomes among person-years belonging to the same individual, three dichotomous lag variables were constructed as proposed by Starr et al (8). These variables indicated whether a birth had occurred during the preceding year (lag 1), two or three years earlier (lag 2,3) or in the fourth or fifth years prior to the year of observation (lag 4,5). Birth cohort (calendar year of birth minus 1900) and age entered the logistic regression model as continuous variables. The probability of birth was not

Table 2. Determinants of fertility in years at risk and those not at risk from exposure. (SD = standard deviation)

	Age		Year of birth ^a		Parity ^b		Lag 1 (%)	Lag 2,3 (%)	Lag 4,5 (%)	Smoking (%)	High alcohol consump- tion (%)	
	Mean	SD	Mean	SD	Mean	SD						
Welders												
At risk	28.1	5.1	50.5	4.7	0.80	0.96	8.7	16.1	13.7	66.9	9.7	
Not at risk	29.1	5.5	50.1	4.5	0.95	1.02	8.8	16.7	15.5	67.7	7.5	
Grinders												
At risk	28.6	4.8	51.1	4.5	0.92	1.00	9.1	17.9	16.3	74.1	3.7	
Not at risk	28.1	5.1	50.7	4.5	0.76	0.97	8.2	15.3	13.5	61.9	5.6	
Other metalworkers												
Not at risk	28.2	5.0	50.7	4.5	0.72	0.95	7.8	14.6	12.8	60.5	5.2	

^a Year of birth is expressed as calendar year minus 1900.

^b Parity ≥ 3 has been computed as parity 3.

Table 3. Birthrates and risk from welding exposure among 3057 male welders: stratification by paternal parity and age. (95 % CI = 95 % confidence interval)

Age (years)	At risk from exposure		Not at risk from exposure		Relative risk	95 % CI
	Births /1000 years	Number of person-years	Births /1000 years	Number of person-years		
<i>Parity 0</i>						
21—24	67.4	7034	77.6	2423	0.87	0.74—1.02
25—29	118.7	5155	134.9	1586	0.88	0.76—1.02
30—34	84.1	1902	76.7	639	1.09	0.81—1.49
35—39	28.9	726	36.8	326	0.79	0.39—1.58
40—41	0.0	90	2.1	47	.	.
<i>Parity 1</i>						
21—24	144.0	1000	171.3	356	0.84	0.64—1.11
25—29	189.1	2665	178.0	1000	1.06	0.91—1.24
30—34	160.0	1688	179.8	684	0.89	0.73—1.08
35—39	62.7	622	78.0	282	0.80	0.49—1.06
40—41	14.7	68	58.8	34	0.25	0.02—2.66
<i>Parity 2</i>						
21—24	36.1	166	47.1	85	0.77	0.44—2.65
25—29	58.9	1527	82.8	495	0.71	0.50—1.06
30—34	42.9	2471	49.7	1107	0.86	0.63—1.19
35—39	16.8	1611	18.7	857	0.90	0.49—1.01
40—41	0.5	212	0.7	142	0.67	0.04—10.62
<i>Parity ≥ 3</i>						
21—24	500.0	6	0.0	5	.	.
25—29	3.9	230	5.1	79	0.77	0.25—2.44
30—34	27.7	650	41.5	313	0.67	0.33—1.34
35—39	32.7	612	18.9	423	1.73	0.77—3.88
40—41	11.2	89	11.9	84	0.94	0.06—14.85
Overall ^a	.	.	.	.	0.91	0.85—0.98

^a Mantel-Haenszel chi-square test for homogeneity of the relative risk: $\chi^2 = 18.37$, $df = 19$, $P = 0.54$.

a monotonic function of age, but was greatest between ages 25 and 29 years of age. For this reason a squared age term was included in the logistic regression model. The distribution of potential confounding factors by exposure categories is given in table 2.

Estimates of the logistic regression coefficients and standard errors (STDERR) were calculated with the use of the SAS Logist procedure (9). All the terms were included regardless of the level of significance or the magnitude of the coefficients; however, no interaction terms were used. The regression coefficient (BETA) provides a measure of the direction and magnitude of change in the dependent variable as the independent variable of interest changes from one level to the next. The odds ratio (OR), an approximation of relative risk, was calculated from the regression coefficient with standard methods. The 95 % confidence interval (95 % CI) of the OR was obtained as follows:

$$95\% \text{ CI} = \text{EXP} [\text{BETA} \pm (1.96 \times \text{STDERR})].$$

Age- and parity-specific birthrates in person-years at risk and not at risk from exposure were also computed. The relative risk of exposure in each age-parity stratum, the overall adjusted relative risk, and the respective 95 % confidence interval were computed with the use of Cochran-Mantel-Haenszel statistics (10). In order to examine the age-specific dependence of nulliparity on years of welding exposure and on years elapsed since last welding exposure, tests for trend in $2 \times n$ contingency tables were performed within each age stratum. Significance was assessed by the Mantel-Haenszel chi-square statistic (10).

Results

Among the men who had ever welded, the probability of having a child in years not at risk from exposure was significantly greater than that of metalworkers

who had never welded, even after adjustment for age, birth cohort, paternal parity, children born in the previous five years (lag variables), smoking, and alcoholic beverage consumption (OR 1.27, 95 % CI 1.14–1.43, $P < 0.0001$). Comparison of the fertility of ever welders with that of never welders, therefore, is inappropriate. Consequently, we restricted the analysis to internal comparisons of ever welders and compared years that were at risk from exposure with years that were not. Since fertility was identical during not-at-risk years before and after the period with welding exposure (OR 1.01, 95 % CI 0.86–1.20), these two components of not-at-risk years were combined in all further analyses of ever welders.

Parity- and age-specific birth rates for the years at risk and those not at risk from welding exposure are presented in table 3. In 16 of the 20 parity-age strata a decreased rate of births was observed during at-risk years, although individually none of the rates was significantly decreased. The overall adjusted relative risk indicated a 9 % reduction in fertility with exposure. While this reduction was significant, the computed confidence intervals may have been too narrow owing to the lack of independence of person-years belonging to the same individual.

The possible deficiency was addressed by the logistic regression model in which interindividual interdependence of person-years was diminished by inclusion of the lag variables. The model also controlled for birth cohort, age, parity, smoking, and alcoholic beverage consumption, each of which was a significant predictor of fertility (table 4). The probability of birth in years at risk from exposure was found to be significantly reduced by an amount similar to that of the stratified analysis (OR 0.89, 95 % CI 0.83–0.97, $P = 0.005$).

We investigated the separate effects of welding mild or stainless steel by restricting the analysis to subjects who had welded only one type of steel. In both groups

Table 4. Logistic regression analysis of fertility among all the welders, the mild steel welders who never welded stainless steel, and the stainless steel welders who never welded mild steel. (β = logistic regression coefficient, SE = standard error of β , 95 % CI = 95 % confidence interval)

Term	Welders (person-years = 39 491)		Mild steel welders (person-years = 10 591)		Stainless steel welders (person-years = 1766)	
	β	SE	β	SE	β	SE
Parity	-0.48***	0.04	-0.52***	0.07	-0.40**	0.19
Age	1.02***	0.06	0.86***	0.10	1.13***	0.28
Age · age	-0.02***	0.00	-0.02***	0.00	-0.02***	0.01
Birth cohort	-0.04***	0.00	-0.03***	0.01	-0.04	0.02
Lag 1	-0.79***	0.10	-0.88***	0.19	-1.40***	0.55
Lag 2,3	0.81***	0.06	0.87***	0.11	0.74***	0.27
Lag 4,5	0.59***	0.07	0.56***	0.12	0.27	0.32
Smoking	0.09**	0.04	0.10	0.07	-0.07	0.18
High alcohol consumption	-0.20**	0.07	-0.13	0.13	-0.77	0.47
Welding risk	-0.11***	0.04	-0.15* ^b	0.07	-0.02 ^c	0.17

^a Odds ratio = e^{β} = 0.89 [95 % CI 0.83–0.97], $P = 0.005$.

^b Odds ratio = e^{β} = 0.86 [95 % CI 0.76–0.99], $P = 0.03$.

^c Odds ratio = e^{β} = 0.98 [95 % CI 0.70–1.37], $P = 0.89$.

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

of welders, after control for confounding factors, fertility did not differ between the not-at-risk years before and after welding (OR 0.99, 95 % CI 0.76–1.30; OR = 0.96, 95 % CI 0.28–3.72, respectively). Both components of years without risk from exposure were, therefore, combined for the analysis. Whereas mild steel welders experienced a significantly reduced likelihood of having a child during years at risk from welding (OR 0.86, 95 % CI 0.76–0.99, $P = 0.03$), stainless steel welders did not (OR 0.98, 95 % CI 0.70–1.37). (See table 4.) When we incorporated the differences in the exposure levels experienced by the stainless steel welders into the regression model by distinguishing between manual metal-arc and tungsten inert-gas welding, the workers' fertility still did not decrease during at-risk years (OR 1.05, 95 % CI 0.84–1.31).

Since the number of stainless steel welders who had never welded mild steel was limited, an analysis was performed for all men who had welded stainless steel, regardless of their mild steel experience. Years at risk from mild steel welding only were excluded. No difference in fertility was noted between the not-at-risk years before and after welding (OR 0.96, 95 % CI 0.74–1.24), nor was fertility decreased during years at risk from exposure (OR 0.95, 95 % CI 0.86–1.17). Including exposure levels for stainless steel welding in the regression model did not change the result. No decrease in fertility was observed for at-risk years (OR 0.95, 95 % CI 0.90–1.01).

Among never welders, stainless steel grinders comprise a group with a well-defined exposure that is not considered toxic to the reproductive system. The fertility of the stainless steel grinders was similar during years with and without exposure risk (OR 1.00, 95 % CI 0.74–1.36). Although in not-at-risk years the fertility of the grinders did not differ significantly from that of the mild steel welders (OR 0.94, 95 % CI 0.78–1.14), during at-risk years the fertility of mild steel welders was significantly lower (OR 0.82, 95 % CI 0.71–0.96, $P = 0.01$).

To establish an exposure-response relationship between fertility and welding exposure, two approaches were taken. First a logistic regression analysis was performed restricted to years at risk from exposure. The duration of exposure (number of years exposed) did not correlate with fertility among all welders or mild steel welders, whether or not a squared duration term was included to allow for a possible nonlinear relationship. The analysis tests the significance of differences in fertility associated with a one-year change in exposure duration. Another approach for detecting an exposure-response relationship is to examine the association of the age-specific prevalence of childlessness (parity 0) with broader categories of exposure duration (<5, 6–10, >10 years). However, consistent increases in the age-specific proportion of ever welders at parity 0 were not found with increasing durations of welding exposure. No trend was observed towards

increasing fertility with increasing years elapsed since last welding exposure.

Discussion

This study was undertaken to test the hypothesis that welding is toxic to the male reproductive system and decreases fertility. The fertility of welders was compared during years at risk and those not at risk from welding exposure. Fertility was found to be slightly, but significantly reduced during years at risk from welding, an effect attributed to welding mild, but not stainless, steel. The fact that the fertility of welders and stainless steel grinders differed only during years at risk from exposure is consistent with the internal analysis of welders. While the decrement in fertility with welding was small (OR 0.9, 95 % CI 0.8–1.0), its magnitude was consistent with that of effects reported in studies of conception delay [inverse OR 0.8, 95 % CI 0.6–1.0 (2); and 0.5, 95 % CI 0.3–1.0 (5)] and reduced semen quality [inverse OR 0.5, 95 % CI 0.3–0.8 (1)]. It should be noted, however, that a small relative risk may more easily result from uncontrolled confounding. No trend in fertility was observed with duration of welding exposure or with time elapsed since last exposure, but perhaps the effects of welding exposure were not cumulative.

Data on welders and grinders were obtained and analyzed in the same manner. Neither the process of data collection, therefore, nor an artifact of analytical design is likely to explain the reduced fertility observed during years at risk from welding. Information bias can be excluded altogether. Data on occupational exposure had been collected prior to the planning of the fertility study, and births of children were obtained independently from the Central Population Registry.

Fertility is strongly associated with age and declines rapidly after the age of 30 years. An unbalanced distribution of age with respect to the exposed and unexposed years cannot explain the fertility reduction observed during the years of welding. On the average the men were slightly younger during the years when they did welding work than when they did not (28.1 versus 29.1 years) (table 2). Furthermore, the logistic regression model seemed to adjust adequately for an unbalanced age distribution since adjusted fertility in the not-at-risk years before and after exposure was similar in all the groups studied.

Inaccuracies in the assignment of children born alive and in the timing of exposure in relation to births would result in misclassification bias and a consequent underestimation of risk. About 10–16 % of the at-risk years might have been classified as not-at-risk if it had been possible to obtain more precise information on occupational exposure. Although not all of the adopted children were identified, the frequency of adoption was so small that this source of error is of little importance.

In developed countries where most pregnancies are planned, studies of the effect of occupational exposures on fertility may be especially susceptible to confounding. Three approaches were taken to address this problem. First of all, the source population was restricted to metalworkers who were believed to be comparable with regard to educational, socioeconomic, and geographic factors. Second, the analysis was performed with a number of covariates which at least partially accounted for volitional factors. Third, internal comparisons were made of the fertility of welders during years at risk and those not at risk from exposure. The first two approaches were insufficient to control confounding, as evidenced by the rather marked difference in adjusted fertility between the ever welders during not-at-risk years and never welding metal workers (OR 1.3, 95 % CI 1.1–1.4, $P < 0.0001$).

Probably the most important means with which confounding was controlled was the analysis of within-group variation in fertility during years at risk and those not at risk from exposure. A number of determinants of fertility for which information was not obtained in this study can be expected to remain stable for persons across changes in exposure status. Such factors include age at marriage, frequency of separation and divorce, attitude towards family size, contraceptive practice (including induced abortion and sterilization), sexual behavior, and prevalence of urogenital disease.

Because of a greatly skewed distribution of the proportion of exposed years among the ever welders, however, the within-group risk estimate associated with welding may not have derived solely from the within-person variation. Some individuals, for example, may have contributed much more reproductive experience during years at risk from exposure than during their not-at-risk years; and for others the reverse might be true. The distribution of the proportion of exposed years among the mild steel welders, on the other hand, was not skewed. (Forty-seven percent of the welders had less than 50 % of their years exposed.) On the average mild steel welders contributed equal numbers of person-years to the exposed and unexposed categories. Yet they experienced reduced fertility during their at-risk years, as did ever welders. Although one cannot exclude bias due to variation in fertility between subpopulations of welders who contributed different proportions of exposed and unexposed person-years, this finding makes such bias less likely.

Welding stainless steel is considered more hazardous than welding mild steel due to the greater content of hexavalent chromium and nickel in stainless steel welding fumes (6). Both metals are absorbed by the lungs and distributed to other organs, including the testes (11). However, in earlier studies, whenever a distinction was made between mild steel and stainless steel welding, the most substantial effects were found among mild steel welders (2, 3). A cross-sectional study of stainless steel welders did not reveal a reduction in

semen quality, even among those who used the manual metal arc method and were thought to be the most exposed (4).

Manganese may occur in substantial amounts in both mild and stainless steel welding fumes (6). Limited data from laboratory animals suggest that manganese is toxic to spermatogenesis (12); moreover, a study of men exposed to manganese dust reported decreased fertility with exposure (13). Perhaps the difference between mild steel and stainless steel welding noted in our study can be attributed to greater exposure to manganese among mild steel welders. However, welding exposure is complex (6); and other chemical and physical agents, including heat, (14) may be of relevance.

While results of the few investigations of welding and male reproductive capacity have generally been consistent, additional efforts are needed before a clear picture will emerge. The small magnitude of risk could have resulted from confounding. The differences between mild steel and stainless steel welding in this study and the lack of a demonstrable dose-response relationship remain to be explained. The absence of laboratory animal studies of the effects of welding fumes on male reproduction is a deficiency which should be remedied as soon as possible.

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