

Original Article

Pregnancy Outcome in Women Exposed to Metal Fume in Welding: A Canadian Cohort Study

Jean-Michel Galarnau^{1,2,◉}, Jeremy Beach^{1,◉} and Nicola Cherry^{1,*,◉}

¹Division of Preventive Medicine, University of Alberta, Edmonton, Canada; ²Faculty of Kinesiology, Sports Injury Prevention Research Centre, University of Calgary, Calgary, Canada

*Author to whom correspondence should be addressed. Tel: +1-780-492-7851; e-mail: ncherry@ualberta.ca

Submitted 14 January 2022; revised 25 March 2022; editorial decision 26 March 2022; revised version accepted 31 March 2022.

Abstract

Objectives: Welding is a physically demanding job that entails exposure to metal fume and particles. There is little information on the effect of welding exposures on the outcome of a pregnancy conceived during a period when a woman was employed as a welder.

Methods: Women welders recruited to the Workers Health in Apprenticeship Trades—Metal and Electrical (WHAT-ME) study were followed-up every 6 months for up to 5 years (January 2011–August 2018), and every pregnancy recorded. At the first 6-month follow-up, a detailed questionnaire was completed for the most recent day in welding, and this information was collected again at each follow-up and also from questionnaires completed during pregnancy. The date of conception was estimated for each pregnancy and the job at that date identified. Exposures to ergonomic factors, work schedule and perceptions of noise, heat and cold were extracted for the job at conception. Exposures to metals (aluminum, chromium, manganese, and nickel) and particles in welding fume were estimated from previously validated exposure algorithms reflecting the welding process, base metal and consumables of the job at the conception date. The effects of exposures were estimated in multilevel multivariable models allowing for confounding.

Results: There were 242 pregnancies conceived by a welder working in her trade, 87 were before the first follow-up, 3 were after first follow-up but detailed information was not collected, 22 of those potentially included in the assessment group were in-trade but not welding leaving 122 pregnancies in 90 welders for analysis. Of these 91 resulted in a live birth and 31 in a fetal loss (27 miscarriages and 4 stillbirths). Mean birth weight for live births was 3365 g and gestation 39.4 weeks. Final models showed that risk of fetal loss increased with manipulating heavy objects [odds ratio (OR) = 5.13, 95% confidence interval (CI) 2.04–12.92], whole-body vibration (OR = 5.86, 95% CI 1.81–18.92), a higher rating for noise exposure intensity (OR = 1.52, 95% CI 1.24–1.85), and decreased with use of local exhaust ventilation (OR = 0.20, 95% CI 0.03–1.18). Gestation decreased with perceived heat intensity ($\beta = -0.15$, 95% CI -0.29 to -0.02) and number of previous pregnancies ($\beta = -0.35$, 95% CI -0.65 to -0.05). Birth weight was lower in those reporting whole-body vibration ($\beta = -596$ g, 95% CI -924 to -267) and increased with the welder's body mass index ($\beta = 36$ g, 95% CI 12–61). Estimates of

What's important about this paper

Women, and the fetus if they become pregnant, may face poorly documented hazards as they move into work traditionally carried out by men. Welding tasks entail heavy physical and ergonomic demands, together with exposure to metals and particles in welding fume. There have been few studies of such working conditions on the fetus. This study shows that exposures in welding may result in fetal loss and shorter gestation, with manipulating heavy loads, whole-body vibration, and perceived intensity of noise and heat exposure being more important than welding fume in determining pregnancy outcome. Ergonomic interventions to reduce workplace hazards would improve conditions for pregnant welders.

exposure to metals and particles were unrelated to gestation or birth weight. In a bivariate analysis, allowing for the same welder reporting >1 pregnancy, estimated airborne aluminum exposure (and to a lesser degree exposure to nickel and particles) was related to greater risk of fetal loss (OR = 1.52, 95% CI 1.04–2.24) but neither aluminum nor the other estimated elements of welding fume added to the final model.

Conclusions: In this group of women actively engaged in welding during the time surrounding conception, the outcome of pregnancy was strongly related to work exposures, particularly vibration (reported in grinding tasks), manipulation of heavy objects, and perceived intensity of noise and heat. The study was unable to show an independent effect of exposure to metal fume constituents.

Keywords: ergonomic exposures; metal fume; pregnancy; welding; WHAT-ME

Introduction

The WHAT-ME study (Women's Health in Apprenticeship Trades—Metal and Electrical) was set up to examine the effects of working as a welder on the outcome of pregnancy (Cherry *et al.*, 2018). The possible risk of welding in pregnancy was identified as a priority by the Canadian Standards Association (CSA) Technical Committee on safety in welding (W117.2) and later supported by analysis of data from Finland, in which 68 women who reported, postdelivery, that she had been exposed to welding fume or metal dust/fumes had a greater than expected risk of delivering a low birth weight infant (Quansah and Jaakkola, 2009). More recent work from Sweden was consistent with the suggestion of a risk of low birth weight and also of prematurity (Norlén *et al.*, 2019). The risk of fetal loss (miscarriage or stillbirth) was reported for women in Montreal, Canada (McDonald *et al.*, 1988a). Multiple hazards to the fetus may be in play. Work in the welding trade carries risk of exposure to potentially fetotoxic metals (Galarneau, 2021), including nickel and chromium (McDermott *et al.*, 2015), manganese (Tsai *et al.*, 2015; Xia *et al.*, 2016), and aluminum (Domingo, 1995; Sakr *et al.*, 2010). Olgun *et al.* (2020) have shown welding fume to be toxic to placental trophoblast cells. Particles, in welding found in fume or released during

grinding, have been implicated in low birth weight and prematurity in population studies (Bekkar *et al.*, 2020; Yuan *et al.*, 2020). There are also substantial ergonomic demands, from the welding itself, grinding tasks, the manipulation of heavy components and the body postures needed to reach parts to be welded, as well as environmental factors such as heat and noise (Cherry *et al.*, 2022). Recent systematic reviews and meta-analyses have supported the role of heavy physical work in poor pregnancy outcomes, with increased risk of spontaneous abortion and preterm birth with lifting of heavy loads (Cai *et al.*, 2020; Croteau, 2020). In Western Canada, much of the demand for welders has been in the extraction industries, with exposure to harsh conditions, including long working schedules implicated elsewhere in adverse pregnancy outcomes, with a dose–response found between hours worked and preterm delivery (Cai *et al.*, 2019).

The aim of the present report was to assess the effect of inhaled metals and particles in welding fume on pregnancy outcome in the subgroup of women welders who reported that their tasks in the job held at the time of conception included welding and for whom estimates of exposure to metals in welding fume could be made. While other, ergonomic, exposures were again considered (Cherry *et al.*, 2022), this paper addresses

primarily the effects of welding fume in the subgroup for which this could be estimated.

Methods

Preliminary work included the development and validation of a self-report questionnaire to accurately reflect welding tasks (Cherry, 2011). Women entering apprenticeships in welding trades (welding, boiler-making, steam fitting, and pipefitting) were identified by apprenticeship boards (or equivalent) across Canada (Cherry *et al.*, 2018). Baseline information was collected when a consent form, indicating a willingness to join the study, was received by the research team. Women were subsequently contacted at 6-month intervals for up to 5 years. The baseline questionnaire collected demographic information, a job history, use of tobacco and alcohol, and details of all pregnancies and births. At each 6-month follow-up, use of tobacco and alcohol was brought up to date, all jobs since the last contact were recorded and detailed trade-specific questionnaires completed about tasks and activities on the most recent day on which they were welding (Supplementary Material A, available at *Annals of Work Exposures and Health* online).

Women were asked to notify the research team as soon as they became pregnant, by phoning a toll-free line, by email or by sending back a 'pregnancy card', a distinctive prefranked postcard distributed at recruitment and at intervals during the study. A postpregnancy questionnaire was completed after the due date, to collect information on pregnancy outcomes. Every follow-up questionnaire also asked about pregnancies since the last contact, and a 'wrap-up' questionnaire included an additional question on miscarriages.

Pregnancy outcomes of interest, reported by the participant, were fetal loss (spontaneous abortion or stillbirth) at any gestation, and, for live births, gestation in weeks along with birth weight (g). Ectopic pregnancies and pregnancies ending in an elective abortion were omitted. For those living in Alberta, linkage was made (with consent) to the perinatal register and administrative health database from which dates of physician-consulted miscarriages and deliveries, gestation, birth weight, and status (live birth) were retrieved and used to supplement estimates of gravidity (miscarriage) or to clarify missing or ambiguous reports of gestation or birth weight. When a woman reported a pregnancy, she was asked to complete two questionnaires (usually in the first and third trimester) and a further one postpregnancy. Conception date was estimated for each pregnancy, from the date of the last menstrual period where reported on a pregnancy questionnaire, or from

gestation. Where no gestation data were available for a miscarriage, this was assumed to be at 8 weeks (the median length for those with such data). The estimated date of conception was linked to the employment record to determine occupation and exposures close to the time of conception.

For those working in welding at conception, and whose pregnancy was ongoing at the recruitment questionnaire or later, we considered ergonomic demands (hours manipulating heavy objects, standing, crouching, working above shoulder height, driving, work with tools or equipment causing hand/arm or whole-body vibration), ratings (from 1 to 10) of intensity in the noisiest, hottest, and coldest part of the job, work schedules (hours of work, maximum days worked without a rest day, number of consecutive nights worked after midnight), and factors influencing respiratory exposure [percentage of time using a respirator, working with general mechanical ventilation, local exhaust ventilation (LEV), outdoors, in a confined space]. The questions used had been validated during preliminary work (Cherry, 2011). They were focused on the most recent day of welding before the periodic (or pregnancy) questionnaire was completed. Derivation of these estimates is outlined in Supplementary Material B (available at *Annals of Work Exposures and Health* online). For women in a job that entailed welding at the time of conception (postrecruitment), we also estimated exposures to particles, aluminum, chromium, manganese, and nickel using task-exposure estimates derived from the literature, calibrated by measurements from laboratory-based welding tasks (Galarneau, 2021) and validated against urinary metal concentrations in this population (Cherry *et al.*, 2022). A summary of the development and validation of these estimates is given as Supplementary Material C (available at *Annals of Work Exposures and Health* online).

Potential confounders considered were age, number of previous pregnancies, number of previous live births, a history of previous fetal loss, number of cigarettes/day, number of alcoholic drinks/week, and body mass index (BMI). These were determined for each woman at the estimated date of each conception.

Statistical methods

The effects of exposures on pregnancy outcome were estimated in multilevel models with robust standard errors, allowing for 'clustering' (more than one conception for each woman) and adjusting for confounders at conception. Logistic regression models were fitted when examining factors related to fetal loss and linear mixed regression models for gestation and birth

weight considered as continuous variables. Exposures to particles and metals were log transformed and entered as continuous variables, as were all confounders except history of a previous fetal loss, which was entered as a binary variable. Where ergonomic exposures were considered as categorical variables, they were initially grouped into approximate tertiles, using the closest whole unit as the breakpoint, and the highest tertile of exposure compared with those with lower exposure. They were then collapsed to binary factors for analysis. Where less than a third had been exposed, the binary (any/none) grouping was used throughout. Factors (exposures or potential confounders) were considered for the final models if they reached $P < 0.10$ in bivariate analyses with the outcome of interest, and were retained in the final model if, on a Wald test, their removal changed the model with $P < 0.05$. A multi-level, multivariable model with robust variances was developed for each outcome from confounding and ergonomic factors relating to that outcome. The additional explanatory power of each metal/particle exposure estimate to the final model was examined by a Wald test of the model with and without the addition. To investigate the possible mitigating effects of LEV and respiratory protective equipment (RPE) on the relation of metals and particulates to pregnancy outcome, terms were added to the final model to contrast the effects of each metal/total particulates in those with and without reported use of LEV or RPE. The difference in effects was tested using the postestimation command *lincom* in Stata 17.0. This is described more fully in [Supplementary Material D](#) (available at *Annals of Work Exposures and Health* online).

Results

The first recruitment questionnaire was completed on 8 January 2011 and the last on 24 September 2017. Follow-up continued until 27 August 2018. The cohort included 447 women who had entered the welding trade. Women welders were recruited from all Canadian provinces, the Yukon and North West Territories but with the majority 69.8% (312/447) from Alberta. Women were followed for up to 5 years, with those in welding completing a mean of 7.0 (range 1–16) questionnaires. Of the 447 women welders, 295 (70.0%) reported at least 1 pregnancy since leaving high school: 29 high school pregnancies contributed to gravidity but were not considered further. The average number of pregnancies in these gravid women was 2.3 (range 1–9) resulting in a total of 680 pregnancies ([Fig. 1](#)). Of these, 121 ended in an elective abortion, 8 were terminated as ectopic

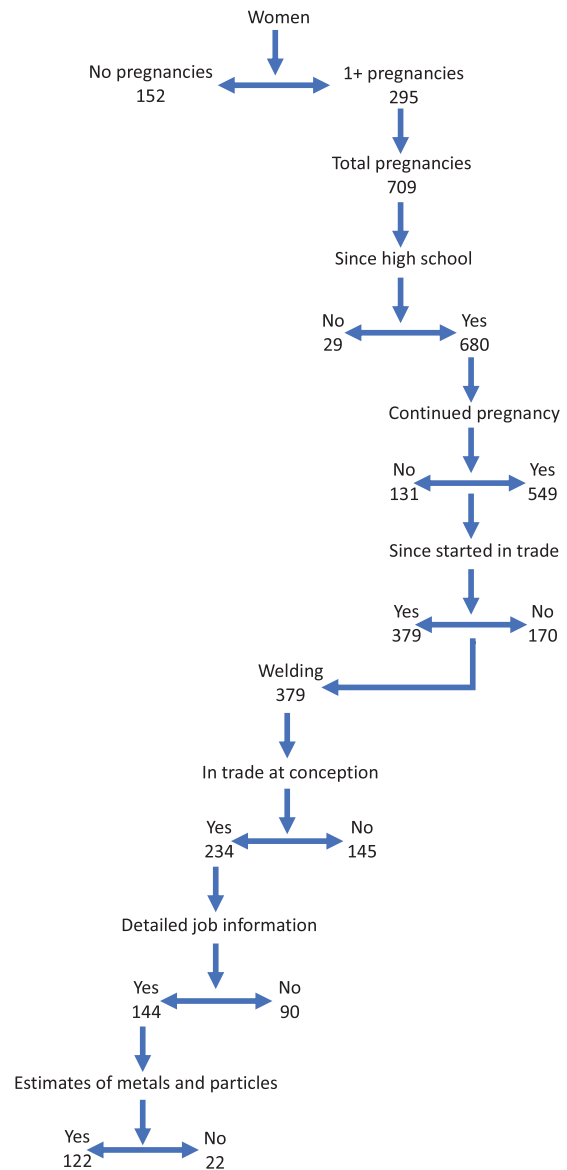


Figure 1. Flow chart of pregnancies in welders.

pregnancies, and the outcome of 2 pregnancies was unknown. Many of the 549 pregnancies with known outcome, not electively terminated, were before the woman started in her trade ($N = 170$) and many more ($N = 145$) were conceived during periods when she was either not in paid employment or working outside her trade. Among the 234 pregnancies in welders in their trade at conception, detailed information on ergonomic factors was available for 144. Estimates of exposure to welding fume (and its metal constituents) at conception were made for 122 pregnancies.

Demographic features at recruitment of the 158 women welders with 234 pregnancies (excluding terminations) conceived during a period working in welding are shown in the top panel of Table 1: the lower panel considers characteristics of pregnancies by assessment of exposure. Pregnancies that were in-trade, but not assessed for welding fume, were largely those where the conception was before recruitment to the study ($N = 87$) and as such the women were older and began training as a welder earlier. Three pregnancies were after recruitment but, in error, detailed information was not collected. A further 22 of those potentially included in the assessment group were

working in-trade but not welding, leaving 122 pregnancies in 90 welders for analysis. The pregnancies assessed for welding fume were similar to those not assessed on other dimensions, including a previous fetal loss, number of previous pregnancies and amounts of smoking and drinking. Those assessed had marginally longer gestation but very similar birth weight to those not assessed. Fewer women continued work in the third trimester in the assessment subsample, but this was not asked specifically for in-trade pregnancies completed before recruitment and time taken away from the job during pregnancy may not have been well recorded in this group.

Table 1. Characteristics of women and pregnancies conceived in the welding trade by inclusion in exposure estimates substudy.

Women	Welding fume exposures assessed						ρ
	Yes		No		All		
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	
Finished high school	76	84.4	53	77.9	129	81.6	0.308
Ever smoker	50	55.6	46	67.6	96	60.8	0.141
Ever drinker	81	90.0	62	91.2	143	90.5	0.803
	Mean	SD	Mean	SD	Mean	SD	
Age at recruitment	26.2	4.4	31.8	7.6	28.6	6.6	<0.001
Year started training	2009	3.5	2005	6.8	2007	5.4	<0.001
<i>N</i>	90		68		158		
Pregnancies	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	ρ
Outcome							
Live birth	91	74.6	70	62.5	161	68.8	0.030
Still birth	4	3.3	1	0.9	5	2.1	
Miscarriage	27	22.1	41	36.6	68	29.1	
Previous fetal loss	27	22.1	30	26.8	57	24.4	0.448
	Mean	SD	Mean	SD	Mean	SD	
Age at conception	27.6	4.5	29.0	5.8	28.3	5.2	0.034
BMI	24.7	4.1	26.4	4.0	25.5	4.1	0.002
Cigarettes/day	2.7	5.7	4.1	6.8	3.3	6.3	0.114
Alcohol/week	3.2	5.4	3.0	5.4	3.1	5.4	0.971
Previous pregnancies	1.1	1.2	1.1	1.3	1.1	1.3	0.982
Hours welding/week	31.9	17.7	23.9	21.9	28.1	20.2	0.002
<i>N</i>	122		112		234		
Live births	Mean	SD	Mean	SD	Mean	SD	
Gestation(weeks)	39.4	1.6	38.7	3.0	39.1	2.4	0.090
Birth weight (g)	3365.4	453.0	3345.1	699.6	3356.5	571.5	0.828
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	
Worked beyond the second trimester	51	62.2	51	76.1	102	68.5	0.050
<i>N</i>	87 ^a		67 ^a		154 ^a		

^aBirth weight and gestation were missing for four assessed and three not assessed pregnancies.

Date stopped work during pregnancy was missing for eight assessed and three not assessed pregnancies.

The relation of potential confounders to birth outcomes in the assessment substudy is shown in Table 2. None of the factors considered was related to the risk of fetal loss in this sub group. A shorter gestation was seen with a greater number of previous pregnancies and a slightly increased gestation with a greater number of alcoholic drinks and with continuing work into the third trimester. Birth weight increased with age and BMI and was marginally less in those with a history of an earlier fetal loss. Age, BMI, the number of previous pregnancies, and a previous fetal loss were retained as potential confounders for the analysis of the effects of metal, particulate, and ergonomic exposures on pregnancy outcome.

The bivariate relation of each ergonomic exposure of interest to fetal loss, gestation, and birth weight is shown in Table 3, which includes only factors showing some relation ($P < 0.10$) to one of the three outcomes considered. All three outcomes are seen to be related to whole-body vibration, with fetal loss and gestation also related to hand arm vibration greater than an hour a day and to hours of heavy physical work greater than 1.5 h. Ratings of intensity of noise and heat were related to risk of fetal loss, and a greater rating of the heat intensity involved in the job was associated with shorter gestation. Risk of fetal loss also increased in those working more than 10 h day⁻¹ and decreased if LEV was used. Gestation was shorter in those working more than 8 days without a rest day or crouching for 2 h or more.

Table 4 gives the relation of estimated exposure to metals and particles to birth outcome. Exposure to aluminum, and to a lesser extent nickel and particles, was greater in those whose pregnancy ended in fetal loss. No relation was seen with gestation or birth weight,

shown here dichotomized as close as possible to the median. Those in the group with shorter gestation had higher estimates on each estimated exposure, but none approached significance. With birth weight any tendency was toward higher exposures in the group with higher birth weight, but differences were minimal.

The relation of ergonomic, metal, and particulate exposure to birth outcomes, with adjustment for clustering of pregnancies within women, is shown in Table 5. For fetal loss, time manipulating heavy objects, whole body and hand arm vibration, noise and heat, working 10 or more hours a day, and use of LEV were retained for inclusion in the multivariate model. Heat was the only work factor retained for gestation, and only whole-body vibration for birth weight. Log aluminum, nickel, and total particulates were also related to fetal loss with $P < 0.10$. Factors (other than metals and particles) that remained with $P < 0.10$ after adjustment for clustering were then entered, together with confounders from Table 2, to create the final model for each outcome (Table 6). For fetal loss the final model (before metals and particulates) retained manipulating heavy loads, whole-body vibration, and rating of noise intensity, together with a protective effect of LEV (with a Wald test for removal $P = 0.032$). None of the potential confounders added to the final model for fetal loss. Heat intensity rating was retained for gestation, together with the number of previous pregnancies. For birth weight, whole-body vibration, and BMI were retained. The final column of Table 6 shows how the inclusion of the 'best' exposure estimate for metals and particles added to the final model: all remaining metals/particles contributed less than the one shown. None of the estimated metal/particles exposures added ($P < 0.10$) to the model without the factor. The

Table 2. Relation of potential confounders to pregnancy outcome in the assessment subgroup, adjusting for clustering in pregnancies within participants.

	Fetal loss			Gestation (weeks)			Birth weight (g)		
	OR	95% CI	ρ	β	95% CI	ρ	β	95% CI	ρ
Maternal age	1.04	0.90 to 1.20	0.591	0.02	-0.07 to 0.11	0.683	24.92	-0.05 to 49.88	0.050
BMI	0.96	0.86 to 1.08	0.526	-0.01	-0.10 to 0.08	0.847	34.23	9.02 to 59.45	0.008
Number of pregnancies	1.09	0.73 to 1.63	0.660	-0.37	-0.69 to -0.05	0.024	-31.50	-125.11 to 62.11	0.510
Past fetal loss	1.71	0.39 to 7.41	0.473	-0.95	-2.22 to 0.32	0.143	-247.16	-516.66 to 21.34	0.071
Number of cigarettes/day	1.00	0.90 to 1.12	0.942	-0.05	-0.12 to 0.03	0.209	-3.48	-28.76 to 21.79	0.787
Number of drinks/week	0.96	0.87 to 1.05	0.362	0.04	-0.00 to 0.09	0.075	-0.54	-14.06 to 12.99	0.938
Worked into third trimester	—	—	—	0.65	0.07 to 1.23	0.028	11.19	-195.88 to 218.27	0.916
N									
Pregnancies		122			87			87	
Participants		90			75			75	

Table 3. Relation of ergonomic demands to pregnancy outcome in the assessment subgroup without adjustment for clustering.

	Fetal loss				Gestation (weeks)				Birth weight (g)			
	<i>n</i>	<i>N</i>	%	ρ	Mean	SD	<i>N</i>	ρ	Mean	SD	<i>N</i>	ρ
Manipulating heavy objects												
<1.5 h	15	90	16.7	< 0.001	39.6	1.4	73	0.041	3393	408	73	0.186
≥1.5 h	16	32	50.0		38.6	2.6	14		3218	640	14	
Whole-body vibration												
None	25	112	22.3	0.017	39.5	1.6	83	0.040	3394	436	83	0.008
Any	6	10	60.0		37.8	2.5	4		2781	465	4	
Hand arm vibration												
≤1 h	13	73	17.6	0.021	39.6	1.5	59	0.096	3392	447	59	0.437
>1 h	18	49	36.7		39.0	1.9	25		3310	468	28	
Hours of work/day												
<10	12	69	17.4	0.023	39.4	1.6	55	0.841	3357	483	55	0.825
≥10	19	53	35.8		39.4	1.8	32		3380	402	32	
Maximum days without a rest day												
≤8	17	82	20.7	0.121	39.6	1.5	62	0.066	3360	422	62	0.868
>8	14	40	35.0		38.9	1.9	25		3378	531	25	
Kneeling or crouching												
<2 h day ⁻¹	21	85	24.7	0.823	39.6	1.5	60	0.077	3356	417	60	0.769
≥2 h day ⁻¹	10	37	27.0		38.9	1.9	27		3387	532	27	
Work with LEV												
None	29	99	29.3	0.060	39.3	1.5	67	0.625	3358	428	67	0.775
Any	2	23	8.7		39.6	2.0	20		3391	540	20	
Noise-level rating												
≤7	47	9	16.1	0.033	39.7	1.6	43	0.040	3403	433	43	0.236
>7	40	21	34.4		39.0	1.7	40		3288	420	40	
Heat-level rating												
≤4	46	11	19.3	0.143	39.8	1.3	43	0.009	3388	444	43	0.386
>4	41	19	31.7		38.9	1.9	40		3304	434	40	
Overall	31	122	25.4	—	39.4	1.6	87	—	3365	453	87	—

closest was log aluminum that predicted an increase in fetal loss with an odds ratio of 1.19 (95% confidence interval 0.80–1.76). Comparison of effect in those with and without LEV or RPE did not show modification of the effects of metals and particulates on pregnancy outcome, after adjustment for other exposures. For LEV (but not RPE) the effects on fetal loss approached conventional ($P < 0.05$) levels of statistical significance and were consistent with lower risk in those using LEV ([Supplementary material D](#), available at *Annals of Work Exposures and Health* online).

Discussion

The objective of the analysis reported here was to determine whether, for welders carrying out welding tasks in their job at conception, estimated exposures to

aluminum, chromium, manganese, nickel, or total particulates were associated with the outcome of the pregnancy. No significant effect was seen, having allowed for ergonomic exposures and confounders. There was some suggestion of an increase in risk of fetal loss with higher metal/particulate exposures, particularly to aluminum but, with the sample size available, the risk was compatible with no effect. There was also a somewhat higher risk of fetal loss with metal/particulate exposure in those who did not use LEV compared with those reporting its use, but this did not reach conventional levels of statistical significance. As before ([Cherry et al., 2022](#)) whole-body vibration was related to fetal loss in welders, with manipulating heavy objects and perceived noise intensity also being factors in the subgroup with detailed exposure data reported here. The present analysis also showed that perceived heat intensity was related to

Table 4. Mean log estimates of exposure to metals and particles by pregnancy outcome without adjustment for clustering of pregnancies within participants.

	N	Aluminum			Chromium			Manganese			Nickel			Particles		
		Mean	SD	P*	Mean	SD	P*	Mean	SD	P*	Mean	SD	P*	Mean	SD	P*
Fetal loss																
No	91	6.07	1.51	0.041	4.47	1.43	0.266	8.53	1.40	0.151	5.16	1.23	0.087	10.74	1.24	0.099
Yes	31	6.67	1.01		4.78	0.90		8.92	0.94		5.57	0.79		11.14	0.78	
Overall	122	6.22	1.42		4.55	1.32		8.63	1.30		5.26	1.14		10.84	1.15	
Gestation (weeks)																
≤39	47	6.22	1.44	0.293	4.54	1.30	0.569	8.69	1.22	0.255	5.31	1.18	0.209	10.86	1.13	0.344
>39	40	5.88	1.61		4.36	1.59		8.34	1.56		4.97	1.30		10.60	1.37	
Overall	87	6.04	1.53		4.45	1.36		8.30	1.42		5.13	1.24		10.72	1.26	
Birth weight (g)																
≤3330	44	6.06	1.57	0.862	4.35	1.36	0.550	8.38	1.41	0.418	5.09	1.28	0.746	10.60	1.32	0.374
>3330	43	6.01	1.51		4.54	1.56		8.62	1.42		5.17	1.23		10.84	1.19	
Overall	87	6.04	1.53		4.45	1.46		8.50	1.41		5.13	1.24		10.72	1.26	

*From analysis of variance of the log-transformed data.

Table 5. Bivariate analysis of exposures and outcomes, adjusting for clustering of pregnancies.

Exposure	Fetal loss			Gestation (weeks)			Birth weight (g)		
	OR	95% CI	ρ	β	95% CI	ρ	β	95% CI	ρ
Manipulating heavy weights									
≥1.5 h	5.0	2.14 to 11.69	< 0.001	-0.95	-2.24 to 0.34	0.149	-201.8	-533.7 to 130.1	0.233
Whole-body vibration									
Any	5.52	1.30 to 23.44	0.020	-1.48	-3.56 to 0.61	0.165	-522.3	-980.3 to 64.4	0.025
Hand arm vibration									
>1 h	2.83	1.08 to 7.39	0.034	-0.55	-1.27 to 0.20	0.152	-103.7	-292.9 to 85.4	0.282
Hours of work/day									
≥10 h	2.81	1.02 to 7.77	0.046	0.35	-0.59 to 1.30	0.463	19.4	-155.5 to 194.4	0.828
Maximum days without a rest day									
>8	1.99	0.69 to 5.69	0.201	-0.41	-1.42 to 0.61	0.431	24.0	-180.9 to 229.0	0.818
Kneeling or crouching									
≥2 h	1.28	0.38 to 4.29	0.687	-0.52	-1.23 to 0.18	0.145	21.9	-212.5 to 256.4	0.855
LEV									
Any	0.21	0.04 to 1.19	0.078	0.21	-0.52 to 0.95	0.571	1.1	-254.3 to 256.5	0.993
Noise-level rating	1.37	1.01 to 1.86	0.042	-0.09	-0.23 to 0.05	0.190	0.00	-0.05 to 0.05	0.931
Heat-level rating	1.21	1.01 to 1.46	0.042	-0.16	-0.30 to -0.02	0.021	-0.00	-0.04 to 0.03	0.797
Exposure: aluminum	1.52	1.04 to 2.24	0.032	-0.03	-0.23 to 0.17	0.742	10.6	-43.9 to 65.0	0.703
Exposure: chromium	1.22	0.88 to 1.71	0.237	-0.08	-0.25 to 0.09	0.367	30.7	-40.9 to 102.2	0.401
Exposure: manganese	1.35	0.93 to 1.96	0.115	0.03	-0.40 to 0.46	0.900	49.2	-23.5 to 121.8	0.185
Exposure: nickel	1.51	0.96 to 2.37	0.078	-0.12	-0.36 to 0.13	0.344	45.2	-40.6 to 131.0	0.302
Exposure: particles	1.49	0.95 to 2.33	0.082	0.08	-0.63 to 0.78	0.832	45.3	-25.1 to 115.6	0.208
N									
Pregnancies			122			87			87
Participants			90			75			75

Table 6. Final models for pregnancy outcomes with adjustment for clustering of pregnancies.

	All factors			Final model			Final model + 'best' metal		
	OR	95% CI	ρ	OR	95% CI	ρ	OR	95% CI	ρ
Fetal loss									
Manipulating heavy objects									
≥1.5 h	3.69	1.19 to 11.45	0.024	5.13	2.04 to 12.92	<0.001	4.95	1.92 to 12.80	0.001
Whole-body vibration: any	7.96	1.86 to 34.09	0.005	5.86	1.81 to 18.92	0.003	5.40	1.71 to 17.03	0.004
Hand arm vibration									
>1 h	2.30	0.82 to 6.44	0.122						
Work hours ≥10	1.14	0.38 to 3.38	0.818	—			—		
LEV									
Any	0.16	0.03 to 0.71	0.016	0.20	0.03 to 1.18	0.076	0.21	0.04 to 1.14	0.070
Noise rating	1.48	1.11 to 1.96	0.008	1.52	1.24 to 1.85	<0.001	1.48	1.21 to 1.82	<0.001
Heat rating	0.96	0.78 to 1.18	0.692						
Aluminum exposure	1.18	0.79 to 1.77	0.419	—			1.19	0.80 to 1.76	0.390
N									
Pregnancies		122			122			122	
Participants		90			90			90	
	β	95% CI	ρ	β	95% CI	ρ	β	95% CI	ρ
Gestation									
Number of previous pregnancies	-0.33	-0.62 to -0.04	0.026	-0.35	-0.65 to -0.05	0.023	-0.34	-0.695 to -0.04	0.027
Number of drinks/week	0.02	-0.03 to 0.07	0.371	—			—		
Heat rating	-0.15	-0.29 to -0.02	0.027	-0.15	-0.29 to -0.02	0.023	-0.15	-0.28 to -0.02	0.026
Chromium exposure	—			—			-0.04	-0.21 to 0.13	0.656
N									
Pregnancies		87			87			87	
Participants		75			75			75	
Birth weight									
Age	20.8	-3.0 to 44.6	0.087	—			—		
BMI	37.1	13.2 to 61.1	0.002	36.3	12.0 to 60.6	0.003	36.9	14.5 to 59.3	0.001
Past fetal loss: any	-197.9	-410.1 to 14.4	0.068	—			—		
Whole-body vibration: any	-487.0	-811.0 to -163.0	0.003	-595.5	-924.3 to -266.7	<0.001	-604.5	-907.1 to -301.9	<0.001
Manganese exposure	—			—			50.9	-14.4 to 1116.1	0.126
N									
Pregnancies		87			87			87	
Participants		75			75			75	

shorter gestation and whole-body vibration to reduced birth weight.

There are limited published data against which to compare these results, particularly those for fetal loss. McDonald *et al.* (1988a) considered effects of work in the metal working trades (among other occupations) and found vibration and noise to be related to

miscarriage and stillbirth. Systematic reviews support a role for heavy or frequent occupational lifting (Cai *et al.*, 2020; Croteau, 2020)) on miscarriage, as found here. There are a greater number of studies of effects on gestation, prematurity, and birth weight. Two studies, using community-based data from Finland (Quansah and Jaakkola, 2009) and Sweden (Norlén *et al.*, 2019) both

found evidence of an increased risk of preterm delivery and low birth weight in welders, supporting earlier suggestions (Farrow *et al.*, 1998; Li *et al.*, 2010) that women who welded might be at increased risk of these outcomes. No study (other than that of Olgun *et al.* (2020) with placental trophoblast cells) has considered the metal content of welding fume on pregnancy outcome. There have been several studies suggesting occupational noise exposure may result in low birth weight and prematurity (not seen in this population) (McDonald *et al.*, 1988b; Ristovska *et al.*, 2014; Selander *et al.*, 2019). High temperatures have been found to relate to early delivery (Auger *et al.*, 2014; Bekkar *et al.*, 2020; Ilango *et al.*, 2020) in the general population, giving credibility to the result reported here, but this has been less well studied in occupational settings.

The strong association of poor pregnancy outcomes with whole-body vibration is based, in this analysis, on only 10 pregnancies with such exposure, 6 of which resulted in fetal loss and 4 with lower birth weight and shorter gestation. Whole-body vibration, assigned by a job exposure matrix, has recently been reported, from Sweden, to relate to preterm birth but not low birth weight (Skröder *et al.*, 2020), with similar findings, using self-report of vibration exposure, in Nigeria (Omokhodion *et al.*, 2010) and Canada (Croteau *et al.*, 2007). In the present study, vibration, both whole body and hand arm, arose mainly from using grinding tools, and avoidance of such tasks would seem a reasonable precaution for pregnant welders.

Strengths of the study include the repeated measures, prospective design, in which information about job demands around the time of conception was collected before the outcome of the pregnancy was known. Where this did not happen as planned, this was also a weakness: miscarriages and even term births might be discovered after the event and, if information was collected postevent, the possibility of reporting bias cannot be excluded. The design did, however, give confidence that very few pregnancies were missed completely and the quality of the information on numbers, dates, and outcome of pregnancies is likely to be higher than in studies using a retrospective design. A further strength was the homogeneity of the sample, with little adjustment needed for confounders. Factors, such as noise intensity, not related to fetal loss in the broader group of women in the welding trade (Cherry *et al.*, 2022), were found to be of importance in this group in which welding was the prime activity.

Limitations of the study include the relatively small number of pregnancies (not electively terminated) in women who conceived during a period of work in the welding trade. Although great efforts were made to

assemble pregnancies with detailed job information, the final numbers were not sufficient to detect small risks or those associated with rare exposures. Equally, with only four stillbirths in the assessment substudy, it was not possible to carry out a separate analysis for these, which have been considered together with miscarriages as a fetal loss. Further the research design did not allow collection of data on very early fetal loss, prior to pregnancy testing, and did not seek to establish whether miscarriage resulted from fetal abnormality. The participants may not have been representative of all Canadian apprentices, although the high proportion from Alberta reflects national statistics for welders. Moreover, welding in Alberta is a 'registered' trade, permitting identification of all welding apprentices, which was not the case in all jurisdictions.

A further limitation was that estimated airborne exposures were only to welding fume. Particles released during grinding, for example, will have added to exposure and may have been inhaled. The lack of any clear relationship of estimated metal or particulate exposure to pregnancy outcome may be simply an issue of power, but there is no suggestion of any detrimental effect on birth weight, and nothing consistent for gestation. Although the majority of these welders continued working into the third trimester, no detrimental effect of continued work on pregnancy outcome was seen for those whose pregnancy ended with a live birth. Earlier work (Galarneau *et al.*, 2022) showed a clear relationship between urinary aluminum and chromium and the exposure estimates used here, suggesting that, for these metals at least, the estimates were a valid measure of exposure. Effects of such exposures were less tenuous for fetal loss than for the outcome of term (or close to term) pregnancies. This might, in part, reflect the strategy for estimating exposures. These were based on the most recent day at work at around the time of conception, when effects of metal exposure might be expected to be most apparent. The study was not well designed to examine the differential effects of exposures by trimester. Information was collected about work tasks, normally twice during pregnancy, but it was of variable quality and a single exposure estimate (at conception) was used for all outcomes. Insofar as women were able to modify their work demands, use of this estimate would result in exposure misclassification in the later months of pregnancy and this may have contributed to the absence of an observed effect of exposures on these outcomes.

Although the mechanisms of damage are not always well understood (Cai *et al.*, 2019, 2020; Croteau, 2020), the developing fetus and placenta are likely to have changing vulnerabilities to work exposures as the pregnancy advances. Studies of medication, infection,

and ionizing radiation during pregnancy show that teratogens, probably including environmental chemicals, have effects particularly in the first trimester. This may result in miscarriage or be evident at birth if the fetus survives. There is little information on how physical exposures cause miscarriage or preterm births, although reduced capacity for heat regulation has been suggested as a contributory factor (Basu *et al.*, 2010). Few occupational studies have been able to identify critical periods for exposures during pregnancy. Croteau *et al.* (2007) were able to compare rates of preterm delivery in those withdrawn from work during pregnancy with those who remained in employment and suggested that effects of job demands (including whole-body vibration) continued for exposures beyond 24 weeks of pregnancy. In a population-based study, Yuan *et al.* (2020) were able to show the effects of particulates on birth weight and preterm birth were largely from exposures during the third trimester. While there is considerable uncertainty about mechanisms, it is likely that, as in this study, exposures identified will differ by endpoint.

Despite considerable efforts to assess exposures to metals and particles (Galarneau, 2021) we have not been able to demonstrate marked effects on fetal loss or any effect on gestation or birth weight of the calculated exposure estimates for metals and particles. There was little prior reason to expect a relation of aluminum to fetal loss. Two, underpowered, epidemiological studies concluded there was no evidence of effect on pregnancy outcome (Golding *et al.*, 1991; Sakr *et al.*, 2010) and a comprehensive review of laboratory studies does not suggest effects on the fetus (Domingo, 1995). We did find a protective effect of LEV for fetal loss, which would be consistent with some element of welding fume being fetotoxic, but might also reflect other features of the task or workplace, with such ventilation being less practical for welding outside a static workshop.

We do not conclude from this study that the welding environment is safe for the fetus should a welder become pregnant, but rather that it is ergonomic factors that present the greatest risk, and the most urgent need for intervention.

Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

Funding

The study was funded by the Canadian Institutes of Health Research (FRN 130236), the OHS Futures program of the

Government of Alberta, the Canadian Standards Association, and WorkSafeBC.

Ethical approval

The project was reviewed by the Health Ethics Review Board of the University of Alberta (Pro00017851). All participants gave written informed consent.

Conflict of interest

None of the authors declared any conflict of interest.

Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

References

- Auger N, Naimi AI, Smargiassi A *et al.* (2014) Extreme heat and risk of early delivery among preterm and term pregnancies. *Epidemiology*; 25: 344–50.
- Basu R, Malig B, Ostro B. (2010) High ambient temperature and the risk of preterm delivery. *Am J Epidemiol*; 172: 1108–17.
- Bekkar B, Pacheco S, Basu R *et al.* (2020) Association of air pollution and heat exposure with preterm birth, low birth weight, and stillbirth in the US: a systematic review. *JAMA Netw Open*; 3: e208243.
- Cai C, Vandermeer B, Khurana R *et al.* (2019) The impact of occupational shift work and working hours during pregnancy on health outcomes: a systematic review and meta-analysis. *Am J Obstet Gynecol*; 221: 563–76.
- Cai C, Vandermeer B, Khurana R *et al.* (2020) The impact of occupational activities during pregnancy on pregnancy outcomes: a systematic review and meta-analysis. *Am J Obstet Gynecol*; 222: 224–38.
- Cherry N. (2011) Females welding and the unborn child. WorkSafeBC; 2011. Available at <https://www.worksafebc.com/en/resources/about-us/research/womens-health-in-apprenticeship-trades>. Accessed 13 January 2022.
- Cherry N, Arrandale V, Beach J *et al.* (2018) Health and work in women and men in the welding and electrical trades: how do they differ? *Ann Work Expo Health*; 62: 393–403.
- Cherry N, Beach J, Galarneau JM. (2022). Ergonomic demands and fetal loss in women in welding and electrical trades: a Canadian cohort study. *Am J Ind Med*; 65: 371–81.
- Croteau A. (2020) Occupational lifting and adverse pregnancy outcome: a systematic review and meta-analysis. *Occup Environ Med*; 77: 496–505.
- Croteau A, Marcoux S, Brisson C. (2007) Work activity in pregnancy, preventive measures, and the risk of preterm delivery. *Am J Epidemiol*; 166: 951–65.
- Domingo JL. (1995) Reproductive and developmental toxicity of aluminum: a review. *Neurotoxicol Teratol*; 17: 515–21.

- Farrow A, Shea KM, Little RE; the ALSPAC study team. (1998) Birth weight of term infants and maternal occupation in a prospective cohort of pregnant women. *Occup Environ Med*; 55: 18–23.
- Galarneau JM. (2021) Construction and calibration of an exposure matrix for the welding trades. *Ann Work Expo Health*. Epub ahead of print. PMID: 34453157.
- Galarneau JM, Beach J, Cherry N. (2022) Urinary metals as a marker of exposure in men and women in the welding and electrical trades: a Canadian cohort study. *Ann Work Expo Health*; 66: 178–91.
- Golding J, Rowland A, Greenwood R *et al.* (1991) Aluminium sulphate in water in north Cornwall and outcome of pregnancy. *BMJ*; 302: 1175–7.
- Ilango SD, Weaver M, Sheridan P *et al.* (2020) Extreme heat episodes and risk of preterm birth in California, 2005–2013. *Environ Int*; 137: 105541.
- Li X, Sundquist J, Kane K *et al.* (2010) Parental occupation and preterm births: a nationwide epidemiological study in Sweden. *Paediatr Perinat Epidemiol*; 24: 555–63.
- McDermott S, Salzberg DC, Anderson AP *et al.* (2015) Systematic review of chromium and nickel exposure during pregnancy and impact on child outcomes. *J Toxicol Environ Health A*; 78: 1348–68.
- McDonald AD, McDonald JC, Armstrong B *et al.* (1988a) Fetal death and work in pregnancy. *Br J Ind Med*; 45: 148–57.
- McDonald AD, McDonald JC, Armstrong B *et al.* (1988b) Prematurity and work in pregnancy. *Br J Ind Med*; 45: 56–62.
- Norlén F, Gustavsson P, Wiebert P *et al.* (2019) Occupational exposure to inorganic particles during pregnancy and birth outcomes: a nationwide cohort study in Sweden. *BMJ Open*; 9: e023879.
- Olgun N, Morris A, Bowers L *et al.* (2020) Mild steel and stainless steel welding fumes elicit pro-inflammatory and pro-oxidant effects in first trimester trophoblast cells. *Am J Reprod Immunol*; 83: e13221.
- Omokhodion FO, Onadeko MO, Roberts OA *et al.* (2010) Paid work, domestic work, and other determinants of pregnancy outcome in Ibadan, southwest Nigeria. *Int J Gynaecol Obstet*; 111: 165–70.
- Quansah R, Jaakkola J. (2009) Paternal and maternal exposure to welding fumes and metal dusts or fumes and adverse pregnancy outcomes. *Int Arch Occup Environ Health*; 82: 529–37.
- Ristovska G, Laszlo HE, Hansell AL. (2014) Reproductive outcomes associated with noise exposure—a systematic review of the literature. *Int J Environ Res Public Health*; 11: 7931–52.
- Sakr C, Taiwo O, Galusha D *et al.* (2010) Reproductive outcomes among male and female workers at an aluminum smelter. *Am Coll Occup Environ Med*; 52: 137–43.
- Selander J, Rylander L, Albin M *et al.* (2019) Full-time exposure to occupational noise during pregnancy was associated with reduced birth weight in a nationwide cohort study of Swedish women. *Sci Total Environ*; 651: 1137–43.
- Skröder H, Pettersson H, Norlén F *et al.* (2020) Occupational exposure to whole body vibrations and birth outcomes—a nationwide cohort study of Swedish women. *Sci Total Environ*; 751: 141476. Epub ahead of print.
- Tsai M, Liao K, Chang C *et al.* (2015) The critical fetal stage for maternal manganese exposure. *Environ Res J*; 137: 215–21.
- Xia W, Zhou Y, Zheng T *et al.* (2016) Maternal urinary manganese and risk of low birth weight: a case-control study. *BMC Public Health*; 16: 142.
- Yuan L, Zhang Y, Wang W *et al.*; Shanghai Birth Cohort Study. (2020) Critical windows for maternal fine particulate matter exposure and adverse birth outcomes: the Shanghai birth cohort study. *Chemosphere*; 240: 124904.