Final Report
Project Title: Control of Welding Fume in Shipbuilding Confined Spaces
Principal Investigator: Dr. Noah Seixas
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Abstract

Ship construction and repair can require welding in enclosed and confined spaces, leading to high fume exposures for welders. The temporary ventilation of these spaces is often inadequate; it is an extremely challenging task made more difficult by a lack of specific training and barriers such as personal habits, equipment availability, and workplace norms. Observation and air monitoring indicated that welding fume could be controlled more effectively by improving certain aspects of ventilation design, such as raising exhaust ducts and avoiding situations where the airflow does not affect the areas of highest fume concentration. Ventilation recommendations specific to the control of welding fume in these spaces were developed. They emphasized ventilation of the entire workspace because local exhaust ventilation is difficult to use effectively in many shipbuilding situations. The recommendations were made into a graphical training program and presented to 131 welders at two shipyards in Washington State. A survey, completed by participants before and after training, was used to assess the effectiveness of the training. The survey did not indicate that the training was effective in improving the welders' knowledge or behavior regarding ventilation. Further, while controlled tests of the recommendations supported their effectiveness, real-world shipyard tests did not show that they reduced welders' personal exposure. The results reflect the difficulty in effecting behavioral change with a relatively-limited one-time training. The failure of the ventilation adjustments to reduce personal exposure in real-world situations are an important reminder, to both shipyard workers and researchers, of the difficulty in applying valid basic theories to more complex situations.

Background

Shipyard welders can be exposed to high concentrations of welding fume because they often weld in enclosed or confined spaces in which fume can accumulate. Portable ventilation equipment is typically used to remove the welding fume and provide clean air, but it often fails to keep the fume concentration at an acceptable level. The spaces can be complex in shape, exacerbating the difficulty of removing fume. Some are so small that the welder must crawl or lie down to work. Observations of ventilation effectiveness suggest that fume could be better controlled by more careful configuration of the blowers and ducts that comprise the temporary ventilation system.

From 2010 to 2013, the University of Washington Department of Environmental and Occupational Health Sciences conducted a behavioral intervention study that addressed this issue. The study created and tested the effectiveness of a training program aimed at improving shipyard welders' use of ventilation. The following sections will describe the creation, presentation, evaluation, and potential application of that training in shipyard welding practice. The study was conducted at shipyards in the Puget Sound area of Washington State. Participants

were structural welders employed by the shipyards. Each took part in a one-time training session of approximately one hour. Some participated in personal air monitoring for fume exposures. All activities were approved by the Institutional Review Board of the University of Washington.

Several significant impediments to completion of the original study design were encountered, necessitating a revised design to accomplish the primary aims of the study. While welding in confined spaces is a common shipyard activity, we spent several months at three yards trying to identify individuals who would be welding consistently. Identifying welding activity on a single day was remarkably difficult, while identification of welders who would be welding repeatedly and consistently over a sufficient period to allow for pre-intervention, post-intervention, and intervention participation proved impossible. In addition, two of the three yards that had consented to participate did primarily ship repair and renovation work, making the work even more intermittent; identifying welders with consistent work at these facilities proved impossible. Eventually, an additional yard with new ship construction activity was identified and agreed to participate, giving us two large yards for the study.

Revised design

As a result of these difficulties, a revised study design was developed that would still allow for the development and testing of ventilation design concepts for confined space welding, development of a training program incorporating these concepts, training a group of shipyard welders, and testing changes in behavior and knowledge of ventilation use subsequent to training. The specific elements of the revised study were:

- Assessing use and barriers to use of ventilation among shipyard welders
- Development of confined space ventilation concepts in an experimental setting
- Testing of ventilation training concepts in real-world application
- Observation of shipyard ventilation use and testing of exposure levels
- Development of a ventilation training for shipyard welders
- Delivery of training to shipyard welders and evaluation of training

Assessing use and barriers to use of ventilation among shipyard welders

Effective ventilation use is hindered both by a lack of knowledge of ventilation concepts and by a failure to apply that knowledge. Configuring ventilation can be cumbersome and time-consuming, particularly in the small and hard-to-reach spaces that characterize many shipbuilding tasks. The training program would need to address personal and social factors that affect the decision of whether to expend the time and energy required to apply ventilation skills effectively. In this respect, the program was framed by a modified version of the Revised Health Promotion Model, which seeks to explain health-related decisions by accounting for factors such as perceptions of the decision's benefits and interpersonal influences. To investigate these factors, we conducted focus group discussions with welders at participating shipyards. Groups of six to 10 welders were guided through a discussion of the "behavior-specific cognitions" in the model, as they apply to ventilating enclosed and confined spaces for welding (Figure 1).

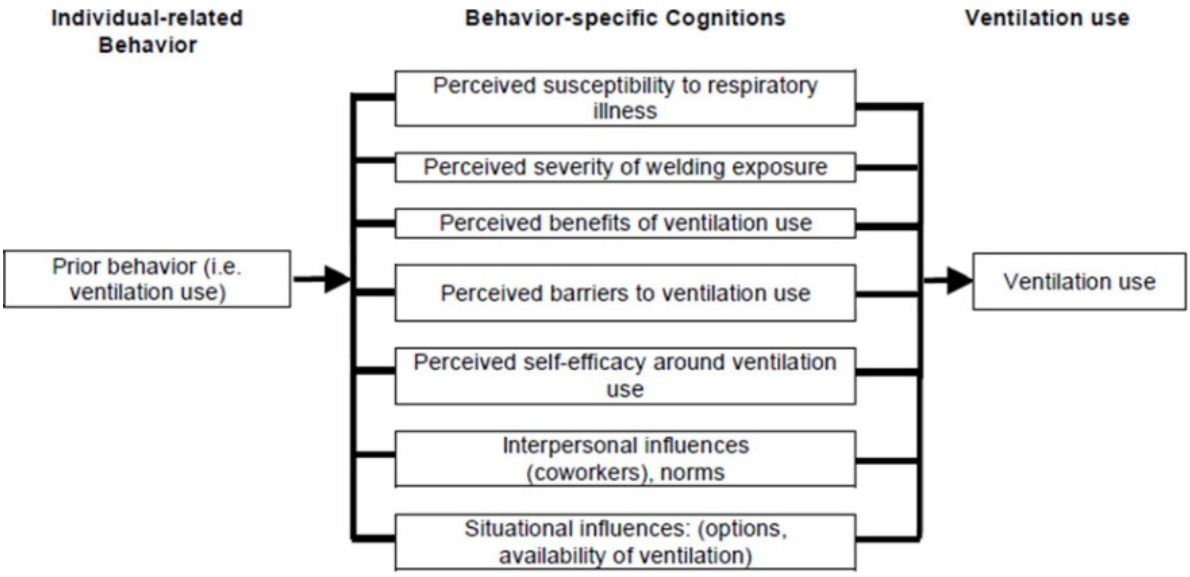


Figure 1. An adaptation of the Revised Health Promotion Model was used to guide the creation of the training.

Focus-group discussions made it clear that welding fume exposure was a concern to many of the participants. Responses also highlighted some of the obvious problems with temporary shipyard ventilation; comments included, “My welds are short. I don’t always bother.” and, “It’s hard to want to constantly move the vent around,” referring to the inherent difficulty in using local exhaust ventilation for a task that must continuously move along a seam, as many shipbuilding welding tasks do. Others expressed concern about the disruption of shielding gas by the ventilation, which can reduce the quality of the weld. While some welders described getting advice about ventilation configuration from Shipyard Competent Persons, others reported only very general ventilation training. As one participant said, “I guess it’s almost intuition – how we set up our vent.”

Development of confined space ventilation concepts in an experimental setting

Hypothesized improvements to ventilation problems, developed after several weeks of observations in shipyards, were tested in a controlled setting. Tests were done in a room with multiple wall and ceiling openings, which allowed for different ventilation configurations. The configurations were tested systematically while a welder generated a consistent amount of fume. Direct-reading particulate monitors were placed at three locations in the vault – on the welder’s lapel, in the exhaust duct or outlet, and at a constant location in the middle of the room, to investigate the effect of the ventilation parameters on personal exposure, fume removal, and the general room concentration.

The controlled tests supported several key points:

- Higher placement of exhaust ducts is typically more effective.
- Positioning equipment to remove fume from the highest concentration area should be a priority.
- A cross-draft across the welder's breathing zone can reduce personal exposure.
- Mixing can be useful, particularly when working alone in a space.
- Ventilation equipment should be configured to avoid short-circuiting (where the airflow does not affect the areas of high fume concentration).
- The amount of air moved by a blower decreases dramatically with bends in the duct and with increasing duct length.

Testing of ventilation training concepts in real-world application

These key ventilation concepts were then tested in real-world shipyard situations. Researchers monitored changes in welders' personal fume exposure and in area fume concentration after making one of the recommended improvements to the worker's ventilation configuration. The change in personal breathing zone and area concentrations after ventilation adjustments are summarized in Table 1. Adjustments that had appeared effective in the controlled tests did not reduce personal breathing zone concentrations, and only the introduction of an exhaust duct at the top of the space produced a statistically-significant reduction in fume concentration in the room. Mixing the air in the space appeared to reduce both breathing-zone and area concentrations, though the changes were not statistically significant.

Table 1. Paired differences in geometric mean concentration after ventilation adjustment (mg/m^3)

	Personal Breathing Zone			Area		
	n	mean (sd) unadjusted	p-value, two-sided	n	mean (sd) unadjusted	p-value, two-sided
High	18	-0.5 (5.44)	0.697	17	-3.4 (5.6)	0.025
Low	7	-5.2 (9.6)	0.205	6	-11.6 (21.2)	0.239
Near	5	-1.2 (1.8)	0.139	5	-2.4 (2.8)	0.127
Far	6	-0.6 (5.1)	0.791	5	-1.3 (1.8)	0.184
Crossdraft	4	1.7 (1.6)	0.128	3	0.1 (1.4)	0.952
Mixing	5	-4.9 (6.9)	0.192	2	-4.2 (6.2)	0.514

Observation of shipyard ventilation use and testing of exposure levels

Extensive monitoring of personal fume exposures and ventilation use, without researcher adjustments, was conducted in the two main study shipyards. Researchers documented characteristics of ventilation, the workspace, and the work performed. Measured fume concentrations, stratified by space and ventilation characteristics, are shown in tables 2 and 3, respectively. Multivariable regression found that of these characteristics, only the type of welding, the proximity of the welder's head to the plume, and mixing of the space were associated with fume exposure. Both being farther from the plume and mixing the air were associated with a reduction in exposure. Relative location of the exhaust duct to the weld, either horizontally or vertically, had little effect on breathing zone concentration.

Table 2. Personal breathing zone concentrations (mg/m^3) and space characteristics

	All Observations			Shipyard A			Shipyard B		
	n	GM	(GSD)	n	GM	(GSD)	n	GM	(GSD)
All samples	65	2.40	(4.2)	48	1.86	(3.9)	17	4.90	(4.1)
Welding Method									
SMAW	5	0.75	(4.5)	5	0.75	(4.5)	0	-	(-)
FCAW (Dual Shield)	49	3.18	(3.6)	32	2.53	(3.2)	17	4.90	(4.1)
FCAW (Inner Shield)	5	3.67	(4.9)	5	3.67	(4.9)	0	-	(-)
Oxyacetylene	6	0.44	(2.9)	6	0.44	(2.9)	0	-	(-)
Proximity of Welder's Head to Fume									
In	12	3.98	(1.9)	9	3.60	(1.7)	3	5.39	(2.8)
Near	30	3.42	(4.3)	19	2.50	(4.0)	11	5.89	(4.5)
Away	23	1.16	(4.3)	20	1.05	(4.2)	3	2.27	(5.3)
Space Volume									
< 28 m^3	45	2.47	(4.6)	29	1.73	(4.3)	16	4.74	(4.3)
28 m^3 - 56 m^3	18	2.39	(3.7)	17	2.22	(3.7)	1	8.28	(-)
> 56 m^3	2	1.23	(2.3)	2	1.23	(2.3)	0	-	(-)

Table 3. Personal breathing zone concentrations (mg/m^3) and ventilation characteristics

	All Observations			Shipyard A			Shipyard B		
	n	GM	(GSD)	n	GM	(GSD)	n	GM	(GSD)
All samples	65	2.40	(4.2)	48	1.86	(3.9)	17	4.90	(4.1)
Ventilation Used									
No	19	2.31	(4.4)	19	2.31	(4.4)	0	-	(-)
Yes	46	2.43	(4.2)	29	1.61	(3.7)	17	4.90	(4.1)
Air Changes Per Minute									
< 1	34	2.35	(4.4)	29	2.05	(4.1)	5	5.26	(6.6)
1-2	12	1.76	(3.5)	10	1.58	(3.8)	2	2.96	(2.2)
2-3	2	2.39	(1.2)	2	2.39	(1.2)	0	-	(-)
> 3	17	3.11	(4.8)	7	1.48	(5.3)	10	5.23	(3.9)
Mixing Used									
No	42	2.67	(4.9)	34	2.04	(4.4)	8	8.26	(5.1)
Yes	23	1.97	(3.1)	14	1.48	(3.0)	9	3.08	(3.0)
Dead space									
No	31	2.37	(3.8)	21	1.84	(3.8)	10	4.02	(3.5)
Yes	34	2.42	(4.7)	27	1.88	(4.2)	7	6.50	(5.4)
Crossdraft Used									
No	55	2.65	(4.5)	42	1.97	(4.1)	13	6.94	(3.9)
Yes	10	1.38	(2.6)	6	1.25	(2.7)	4	1.58	(2.7)
Exhaust Proximity									
Local	2	1.08	(47.1)	2	0.61	(7.2)	0	-	(-)
Regional	6	2.09	(1.9)	6	1.53	(3.7)	0	-	(-)
General	19	1.57	(3.5)	18	1.55	(3.7)	1	2.04	(-)
Relative Exhaust Height									
Below	6	1.53	(3.7)	6	1.74	(3.5)	0	-	(-)
Even	7	1.50	(5.4)	6	1.43	(6.3)	1	2.04	(-)
Above	14	1.74	(3.5)	14	1.53	(3.7)	0	-	(-)

Development of one-hour ventilation training for shipyard welders

Despite the fact that ventilation recommendations were not proven in real-world situations, we felt confident that the basic concepts were valid and that careful, concerted, application of the adjustments could improve ventilation. Thus, the behavioral and ventilation concepts were developed into a graphical training program for use by a skilled trainer. A graphic designer was employed to create visuals that would effectively and simply convey the ventilation concepts. Below is an outline of the training program. A full version can be found in the appendix.

Discussion of risks of fume exposure and benefits of ventilation

- hazardous components of welding fume
- health effects
    - short-term
    - long-term
- exposure limits, employee and employer rights and responsibilities
- barriers to ventilation
    - equipment
    - set up
    - weld quality
    - space constraints
- benefits of ventilation
    - reduces risk of health effects
    - improves visibility
    - improves comfort

Information about how ventilation works

- box model
    - number of welders/type of welding (generation rate)
    - space size (volume)
    - airflow (ventilation rate)
- number of blowers needed
- duct effects
    - pushing and pulling have different reach
    - length of duct
    - bends in duct
- cross-draft
- short-circuiting
- working near others

In addition, a short pamphlet covering key concepts of the training was created. It was provided to participants in a sturdy, waterproof, format that was intended to be kept in toolboxes and used as a reminder of key considerations when setting up ventilation. The pamphlet is also included in the appendix.

Delivery of training to shipyard welders and evaluation of training

The training was presented in classroom-style sessions of approximately one hour by an industrial hygienist with extensive experience with the ventilation of confined spaces for welding. Each subject participated in one session. The instructor presented the training program slideshow and facilitated a discussion with each group of participants about ventilation concepts and ventilation behaviors. 131 participants completed the training in a total of eight separate training sessions, which took place during paid work time.

The primary tool used to evaluate the training's effectiveness was a survey completed by participants up to a week prior to participation in the training and again within three weeks following the training. In cases where a language barrier made the survey difficult, coworkers assisted the subjects in interpreting the questions. Due in part to worker turnover, post-training surveys were completed by 73 of the 131 participants. Comparison of pre-training and post-training survey responses indicated little change in worker skills, attitudes, or behavior in regard to ventilation. Table 4 summarizes the results of section 2, which focused on attitudes toward ventilation. See the appendix for a full report of the survey results.

Table 4. Post-training improvement (positive indicates a change toward the desired answer) in mean response on agree/disagree scale with a range of 4 units.

	n	Post-training improvement in mean response	standard error	P-value
Ventilation is worthwhile for short jobs.	71	0.11	0.13	0.39
Setting up ventilation is too much work.	70	0.17	0.14	0.22
Ventilation equipment is available when I need it.	70	0.14	0.14	0.33
Setting up ventilation takes too much time.	69	0.00	0.13	1.00
I know what kind of ventilation will work best.	70	0.17	0.10	0.10
I know how to set up ventilation equipment.	71	0.10	0.83	0.24
Good ventilation can reduce my exposure to smoke.	71	-0.01	0.08	0.87
Good ventilation will increase comfort and visibility.	71	-0.28	0.09	0.74
Good ventilation reduces exposure for those around me.	71	-0.03	0.07	0.69
I'm given enough time to set up ventilation.	71	0.11	0.11	0.31
I'm given enough help to set up ventilation.	71	0.11	0.09	0.23
My employer requires me to use ventilation in a confined space.	71	0.11	0.09	0.25
The ventilation equipment is in good working order.	71	0.18	0.09	0.05
My supervisor encourages me to use a respirator.	70	0.01	0.08	0.85
My employer requires a respirator when welding in a confined space.	71	0.09	0.11	0.37

Survey responses did indicate that there were some differences between the shipyards in the project, particularly in the workers' perceptions of the importance their employer places on ventilation. McNemar's chi-squared tests of change in response found no statistically-significant changes to questions in section three, regarding fume movement and ventilation.

Summary

While adding ventilation to shipyard welding workspaces is likely necessary, we saw no evidence that it had a direct impact on localized breathing zone concentrations or area concentrations near the ceiling. Extensive air monitoring and ventilation assessments in shipyards confirmed that welders are exposed to high levels of fume in enclosed and confined spaces and that their exposure can be reduced by improving the configuration of the ventilation. However, we were unable to validate our own ventilation recommendations in real shipyard practice. This may be a result of the difficulty of applying simple adjustments to complex and unique work spaces. Perhaps, armed with a better knowledge of ventilation basics, workers will be able to better predict the movement and accumulation of fume and apply multiple basic concepts together to control it. It may also indicate that general ventilation is simply not the most effective strategy for the ventilation of shipbuilding spaces for welding tasks. Perhaps the control of such a large amount of fume in a small space may require local exhaust ventilation, in which case better means of rigging the exhaust equipment and keeping it close to the plume as the weld moves will need to be developed.

The apparent lack of effect of the training program likely indicates the inadequacy of a single training session in this setting. The training materials developed for the project present valid basic ventilation concepts that would certainly be useful in many shipbuilding situations. Shipyard health and safety personnel may be able to use the training material to greater effect with more-frequent and prolonged opportunities to work with shipyard welders on their application.

Products

Papers:

> Confined space ventilation by shipyard welders: Observed use and effectiveness. Jane Pouzou, Chris Warner, Rick Neitzel, Gerry Croteau, Michael Yost, Noah Seixas. Under Revision.

Students supported and resulting products:

> Jeffrey Walls
>
> Walls, Jeffrey Robert. Characterization of Work Practices and Ventilation Techniques in Shipyard Confined Space Welding. Thesis (Master's) - University of Washington, 2012. http://hdl.handle.net/1773/21931
>
> Lea Duffin
>
> Duffin, Lea. Validation of Training Concepts for Effective Ventilation Control for Welding Fumes in Confined Spaces. Thesis (Master's) - University of Washington, 2013. http://hdl.handle.net/1773/23401
>
> Jane Pouzou
> (paper listed above)

Appendices

Training materials

Ventilation pamphlet

Survey

Further survey analysis

Slides from training program for the ventilation of enclosed and confined spaces in shipyard welding

VENTILATION IN SHIPYARD WELDING

DEPARTMENT OF ENVIRONMENTAL & OCCUPATIONAL HEALTH SCIENCES
SCHOOL OF PUBLIC HEALTH
UNIVERSITY OF WASHINGTON

GOALS OF PRESENTATION

- Discuss risks of welding fume exposure and benefits of ventilation.
- Provide information about how ventilation works to help you solve smoke problems when welding

WELDING SMOKE EXPOSURES

Hazardous Components

WELDING SMOKE EXPOSURES

Hazardous Components

SHORT-TERM HEALTH EFFECTS

Shortness of breath

Cough

Headache

Nausea

Metal Fume Fever

LONG-TERM HEALTH EFFECTS

Lung disease

Cancer risk

Nervous system problems

Increased risk of infection

EXPOSURE LIMITS

Washington state has limits on how much exposure you can have to various components of welding smoke.

Most exposures UW has measured in shipyard confined spaces are over these limits.

Workers exposed over these limits have to be protected by their employers.

GOALS OF VENTILATION

Remove the highest concentrations of smoke in the work area

Areas of concern

- Breathing zone
- Spaces where you and your coworkers may be exposed

OVERCOMING BARRIERS TO VENTILATION

- Getting equipment
- Set up
- Weld quality
- Space restraints

BENEFITS OF VENTILATION

- Reduces risk of health effects
- Improves visibility
- Improves comfort
- Can reduce smoke damage to ships
- May reduce need for respiratory protection
  - Maybe not for welder, but for nearby workers
  - Respirators may still be required

VENTILATION IN AN IDEAL WORLD

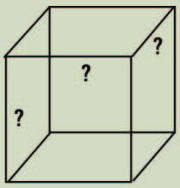
HOW MANY BLOWERS DO I NEED?

Rule of thumb

1 confined space blower moves about 750 cubic feet of air per minute

How much is 750 cubic feet?

About a 9 ft x 9 ft x 9 ft room
1 blower will "change" the air in this size room every minute



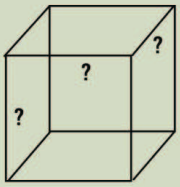
HOW MANY BLOWERS DO I NEED?

Number of blowers needed goes up quickly with space size

9 ft x 9 ft x 9 ft = 1 blower

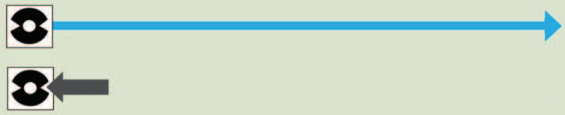
12 ft x 12 ft x 12 ft = 2 blowers

15 ft x 15 ft x 15 ft = 5 blowers

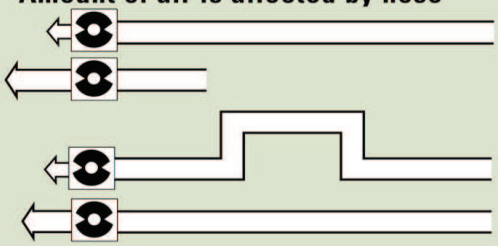


VENTILATION DETAILS

Blowing and sucking have a different "reach"



Amount of air is affected by hose



VENTILATION DETAILS

Amount of air is affected by bends in the duct...

1967 cfm

1704 cfm

1531 cfm

1423 cfm

VENTILATION DETAILS

and by the length of the duct...

No duct

2445 cfm

25' duct

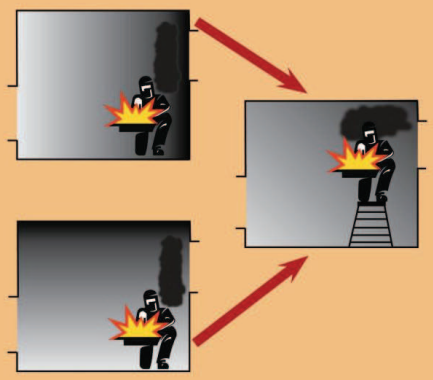
2238 cfm

50' duct

1917 cfm

BUT WHAT ABOUT THE REAL WORLD?

Smoke is highest nearest the source.



Smoke rises to the ceiling.

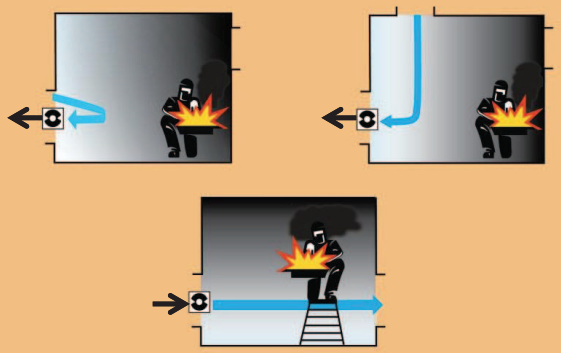
WHAT CAN YOU DO IN THE REAL WORLD?

Blow the smoke away from you (crossdraft)

Mix the smoke around the entire room

Avoid directing the smoke toward your breathing zone

SHORT CIRCUIT = BAD



How could you fix these problems?

BLOWING AIR

Blowing "fresh air" in may make smoke less concentrated.

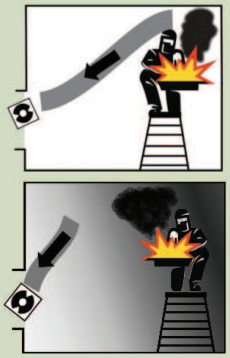
EXHAUSTING AIR

Local or regional exhausting captures the smoke

No exhaust | Regional exhaust | Local exhaust

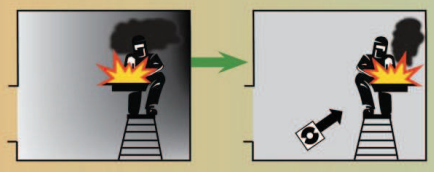
EXHAUSTING AIR

Remember: you can't pull air from very far.



WORKING NEAR OTHERS

Room mixing works well when you're alone



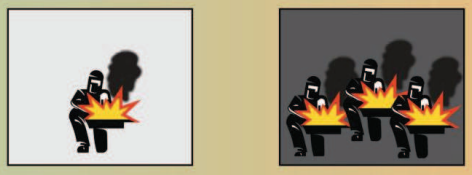
Mixing can increase exposure for others in room

VENTILATING SHORT JOBS: What do you need to consider?

- Length of time
- Amount of welding
- Size of space
- Mixing of space
- Number of people in space
- Use of respirators
- Welding process
- Base metal

REVIEW
Things to consider when selecting ventilation

How much welding is happening in the space?

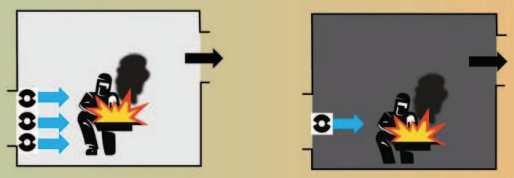


REVIEW
Things to consider when selecting ventilation

How big is the space?

REVIEW
Things to consider when selecting ventilation

How much "fresh air"?



REVIEW

MIXING
How can you spread the smoke around the place?

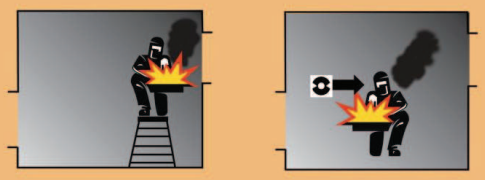
REVIEW

SMOKE

Where is the smoke going in the space?

Can you move it away from you?

Can you keep your head out of the smoke?



REVIEW

SHORT-CIRCUITING

Where is your "fresh air" supply in relation to your exhaust?

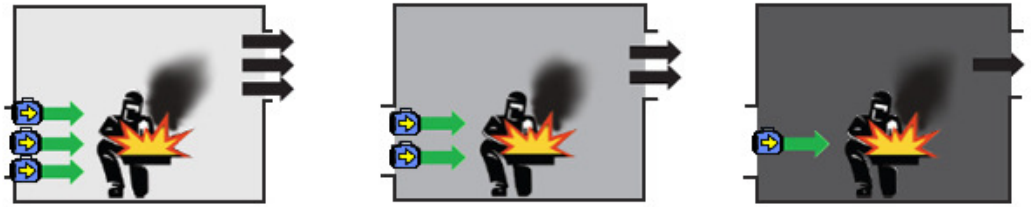
Pamphlet provided to training participants

What determines your welding smoke exposure:

1 Number and types of welding:

2 Room size:

3 Amount of air moved through the the space:



Benefits of ventilation

- Reduces risk of health effects
- Improves comfort
- Reduces smoke, improves visibility
- May reduce need for respirator

UNIVERSITY of WASHINGTON

For more information, visit http://blogs.uw.edu/uwseixas/

USING VENTILATION TO REDUCE WELDING SMOKE EXPOSURE

SCHOOL OF PUBLIC HEALTH
UNIVERSITY of WASHINGTON

How you can reduce your welding smoke exposure:

1 Exhaust the space:

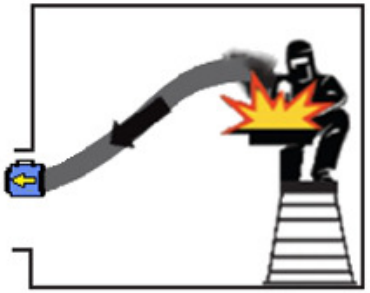
General Exhaust

effective in some situations

Regional Exhaust

more effective

Local Exhaust



most effective, but often impractical

2 Avoid short circuiting:

3 Mix the space:

Whole space

Cross draft

Respirators

You may still need a respirator during welding, even with ventilation.

Ventilation may eliminate the need for nearby workers to wear respirators.

Training-assessment survey

For office use only: Subject ID_____ Date_____

SECTION 1. WELDING SMOKE AND VENTILATION EQUIPMENT USE:

Please answer the following questions regarding your use of ventilation while welding in enclosed or confined spaces over the past two weeks.

1) In the past two weeks, on average, how many hours per day have you spent welding in enclosed or confined spaces?

- ☐ 0 hours
- ☐ 1-2 hours
- ☐ 3-4 hours
- ☐ 5-6 hours
- ☐ 7-8 hours
- ☐ Don't know

2) In the past two weeks, while welding in enclosed or confined spaces, how often did you use ventilation equipment?

- ☐ Never or almost never
- ☐ Less than half the time
- ☐ About half the time
- ☐ More than half the time
- ☐ Always or almost always
- ☐ Don't know
- ☐ Did not weld in enclosed or confined spaces

3) In the past two weeks, have you stopped or refused a welding assignment because a workspace was not adequately ventilated?

- ☐ Yes
- ☐ No
- ☐ Don't know
- ☐ Did not weld in enclosed or confined spaces

4) In the past two weeks, which of the following actions have you taken or requested while welding in enclosed or confined spaces? Check all that apply

- ☐ Changed the number of blowers ventilating the space
- ☐ Addressed kinks or excessive bending of ventilation ducting
- ☐ Moved an exhaust duct to the an area of high smoke
- ☐ Identified a "short-circuit" situation
- ☐ Fixed or improved a "short-circuit" situation
- ☐ Used a blower or fan to mix welding smoke around a space
- ☐ Used a blower or fan to push welding smoke away from my breathing zone
- ☐ None of the above

5) From Question 4, how many times on average did you perform any of the tasks over the past two weeks?

- ☐ Did not perform any of the actions
- ☐ Less than once per day
- ☐ Once per day
- ☐ Multiple times per day

6) In the past two weeks, while welding in enclosed or confined spaces, how often did you wear a respirator?

- ☐ Never or almost never
- ☐ Less than half the time
- ☐ About half the time
- ☐ More than half the time
- ☐ Always or almost always
- ☐ Don't know
- ☐ Did not weld in enclosed or confined spaces

Survey continues on following page

For office use only: Subject ID_____ Date_____

For questions 7 to 21 please mark your level of agreement using the following scale:	Strongly Disagree ↓	Disagree ↓	Not Sure ↓	Agree ↓	Strongly Agree ↓
7) It's worthwhile to set up ventilation for a short job (one that lasts less than 30 minutes).	1	2	3	4	5
8) It's too much work to set up ventilation equipment for any length of job.	1	2	3	4	5
9) Ventilation equipment is always available when I need it.	1	2	3	4	5
10) It takes too much time to set up ventilation equipment.	1	2	3	4	5
11) I have confidence in my ability to decide what kind of ventilation will work best in a space.	1	2	3	4	5
12) I have confidence in my ability to determine how to set up ventilation equipment in a space.	1	2	3	4	5
13) If I use ventilation equipment properly I can reduce the amount of welding smoke I'm exposed to.	1	2	3	4	5
14) Using ventilation properly will increase the comfort and visibility in a workspace.	1	2	3	4	5
15) If I use ventilation equipment properly it will reduce the welding smoke exposures of others working around me.	1	2	3	4	5
16) My employer encourages ventilation use by scheduling time for it to be set up before I start working.	1	2	3	4	5
17) My employer ensures that I can get the help and ventilation equipment I need in order to properly ventilate a space.	1	2	3	4	5
18) My employer has a policy that requires me to use ventilation equipment when I weld in confined spaces.	1	2	3	4	5
19) The ventilation equipment that my employer provides is in good working order.	1	2	3	4	5
20) My supervisor encourages me to use a respirator while welding.	1	2	3	4	5
21) My employer has a policy that requires me to use respirator when I weld in confined spaces.	1	2	3	4	5

Survey continues on following page

For office use only: Subject ID_____ Date_____

SECTION 2: KNOWLEDGE QUESTIONS

Please mark the answer you think is most correct for questions 22 to 31:

22) You may need to wear a respirator even if you use ventilation equipment while welding in a space.
- ☐ TRUE
- ☐ FALSE

23) When exhausting welding smoke, the length of the air duct does not matter.
- ☐ TRUE
- ☐ FALSE

24) Weld quality is <u>always</u> reduced if air is moving past you while you weld.
- ☐ TRUE
- ☐ FALSE

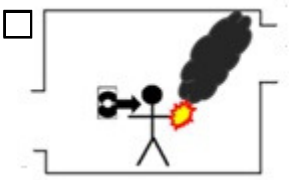
25) Welding smoke is heavy and tends to settle toward the floor of a space.
- ☐ TRUE
- ☐ FALSE

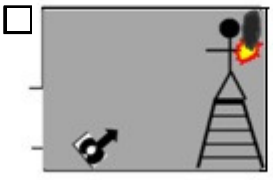
26) The number of ventilation blowers needed in a space is dependent on the number of people welding in the space.
- ☐ TRUE
- ☐ FALSE

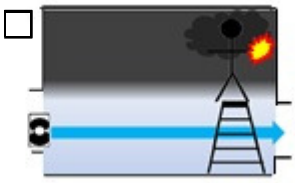
27) What do the guidelines suggest a single welder should use to ventilate a space of 9 ft x 9 ft x 9 ft?
- ☐ 0 blowers
- ☐ 1 blower
- ☐ 2 blowers
- ☐ As many blowers as possible

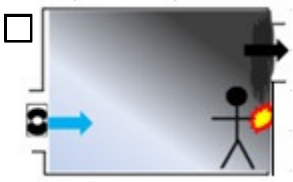
Picture Question:

28) Which of the images below shows short-circuiting?

☐ 

☐ 

☐ 

☐ 

29) Which type of exhaust ventilation is <u>both practical and effective?</u>
- ☐ Local - exhausting at the point of the weld
- ☐ Regional - exhausting from near the weld
- ☐ General - exhausting from the middle of the space

30) What advantage does blowing air into a space have over exhausting air from the space?
- ☐ You don't have to worry about where to aim a blower like you do an exhaust duct
- ☐ Blowing air doesn't reduce weld quality.
- ☐ Blowing air removes all smoke immediately.
- ☐ Blowing mixes the fume in addition to displacing air.

Survey continues on following page

For office use only: Subject ID_____ Date_____

SECTION 3: DEMOGRAPHIC INFORMATION

For Section 3, please tell us about yourself.

31) How old are you? _____years

32) What is your gender? ☐ Male ☐ Female

33) What is your job title at this shipyard?
- ☐ Welder
- ☐ Welder's Helper
- ☐ Ship Fitter
- ☐ Pipe Fitter
- ☐ Other (please list):

34) Are you a Shipyard Competent Person? ☐ Yes ☐ No

35) How long have you done welding at this shipyard? _____years _____months

36) How many years have you done welding in shipyards overall? _____years

37) Have you received the University of Washington ventilation training at this or any other shipyard before? ☐ Yes ☐ No

38) Have you ever had any formal training on use of ventilation equipment to reduce your exposure to welding fume? ☐ Yes ☐ No

a) If so, how long ago was the last training you received? _____years _____months

Please describe the training in a few words:_____

_____

39) How many years of education have you had? (high school = 12) _____years

40) What language do you speak most often at home?
- ☐ English
- ☐ Other

41) If you speak a language other than English at home, how comfortable are you speaking and understanding English?
- ☐ Very Comfortable
- ☐ Somewhat Comfortable
- ☐ Not at all Comfortable

Thank you for completing this survey!

Report of survey results

Training-assessment survey results

The survey was used to assess the effectiveness of the training program, which was presented to 131 subjects (table 1). Due to worker turnover and other difficulties, not all subjects completed post-training surveys. By necessity, the assessments below use only surveys from subjects who participated in the training and completed both surveys. This group comprised 73 welders, all of whom were male. While several female welders participated in the pre-training survey and the training program, none had complete data sets. The average age of participants was 43. Subjects had, on average, completed 12.8 years of education, where 12 years was defined as completion of high school. 31% reported having had previous formal training in ventilation set up. Of 73 subjects with complete data, 53 worked at "Shipyard 1" and 20 at "Shipyard 2" (table 2).

Table 1. surveys and trainings completed

	Shipyard 1	Shipyard 2	Total
Completed pre-training survey	138	24	162
Completed training	110	21	131
Completed training and both surveys	53	20	73

Table 2. Demographic characteristics of subjects who completed the training and both surveys:

	Shipyard 1	Shipyard 2	Total
Age (mean (sd))	46.0 (13.0)	36 (10.2)	43 (13.1)
Years of education (mean (sd))	12.8 (1.9)	11.8 (2.6)	12.8 (1.5)
Normally speak English at home	98%	63%	88%
Had previous formal training in ventilation	26%	44%	31%

In general, comparison of pre-training and post-training surveys indicated little change in response, though it did provide some useful insights into the use of ventilation in shipyard welding and a few indications that the training was effective. Of note in the responses to Section 1 is the large proportion of participants, 49 and 56% pre and post, respectively, reporting having not welded in an enclosed or confined space in the previous two weeks. This reflects the difficulty we encountered in identifying confined-space welding for monitoring.

Table 3. (Question 1) In the past two weeks, how many hours per day have you spent welding in enclosed or confined spaces?

	Shipyard 1				Shipyard 2				Total			
	pre		post		pre		post		pre		post	
	#	(%)	#	(%)	#	(%)	#	(%)	#	(%)	#	(%)
0-2 hours	6	(11)	6	(11)	1	(5)	1	(5)	7	(10)	7	(10)
3-4 hours	6	(11)	4	(8)	1	(5)	1	(5)	7	(10)	5	(7)
5-6 hours	5	(9)	3	(6)	2	(10)	3	(15)	7	(10)	6	(8)
7-8 hours	5	(9)	3	(6)	8	(40)	8	(40)	13	(18)	11	(15)
Don't know	1	(2)	2	(4)	2	(10)	1	(5)	3	(4)	3	(4)
Did not weld in an enclosed or confined space	30	(57)	35	(66)	6	(30)	6	(30)	36	(49)	41	(56)

Many people, despite having reported in question 1 (table 3) that they had not recently welded in enclosed or confined spaces, answered further questions as if they had. The following tables include responses from all subjects who answered the questions, and can be interpreted as if the question did not have the "In the past two weeks," preface. A large majority of participants reported using ventilation equipment “always or almost always” when welding in an enclosed or confined space (Table 4). Some reported having recently stopped or refused a welding assignment due to inadequate ventilation (Table 5), however this percentage did not change appreciably after training.

Table 4. (Question 2) In the past two weeks, while welding in enclosed or confined spaces, how often did you use ventilation equipment?

	Shipyard 1				Shipyard 2				Total			
	pre (n=33)		post (n=28)		pre (n=16)		post (n=16)		pre (n=49)		post (n=44)	
	#	(%)	#	(%)	#	(%)	#	(%)	#	(%)	#	(%)
Never or almost never	7	(21)	8	(29)	--	--	2	(14)	7	(14)	10	(23)
Less than half the time	1	(3)	--	--	--	--	--	--	1	(2)	--	--
About half the time	1	(3)	2	(7)	--	--	--	--	1	(2)	2	(5)
More than half the time	3	(9)	1	(4)	--	--	--	--	3	(6)	1	(2)
Always or almost always	21	(64)	17	(61)	14	(88)	14	(100)	35	(71)	31	(70)
Don't know	--	--	--	--	2	(13)	--	--	2	(4)	--	--

Table 5. (Question 3) In the past two weeks, have you stopped or refused a welding assignment because a workspace was not adequately ventilated?

	Shipyard 1				Shipyard 2				Total			
	pre (n=36)		post (n=31)		pre (n=17)		post (n=19)		pre (n=53)		post (n=50)	
	#	(%)	#	(%)	#	(%)	#	(%)	#	(%)	#	(%)
Yes	6	(17)	3	(10)	3	(18)	2	(11)	9	(17)	5	(10)
No	29	(81)	27	(87)	13	(76)	17	(89)	42	(79)	44	(88)
Don't know	1	(3)	1	(3)	1	(6)	--	--	2	(4)	1	(2)

Participants were asked to report which, if any, ventilation adjustments they had made or requested in the previous two weeks (Table 6). 51 and 70% of participants at Shipyards 1 and 2, respectively, reported having taken or requested one or more of the actions in the two weeks prior to the pre-training survey. 43 and 80% of participants at yards 1 and 2 reported having done so in the two weeks prior to the post-training survey. Among all participants, 56% reported having taken or requested one of these measures prior to the pre-training survey, compared to 53% post training.

Responses indicate that blowing smoke away from the breathing zone was the adjustment made or requested by the most subjects at both shipyards, and that the concept of ventilation short-circuiting was previously unknown to participants, particularly those at shipyard 2. Of subjects reporting having welded in an enclosed or confined space, most claimed to wear a respirator “more than half the time,” or “always or almost always” (table 7). The high degree of respirator use reported by subjects was corroborated by observations of welding in the shipyards.

Table 6. (Question 4) Which of the following actions have you taken or requested while welding in enclosed or confined spaces?

	Shipyard 1		Shipyard 2		Total	
	pre (n=38) %	post (n=31) %	pre (n=14) %	post (n=20) %	pre (n=52) %	post (n=51) %
Changed the number of blowers ventilating the space	37	32	43	25	38	29
Addressed kinks or excessive bending of ventilation ducting	29	29	21	35	27	31
Moved an exhaust duct to an area of high smoke	39	35	50	40	42	37
Identified a "short-circuit" situation	13	16	0	15	10	16
Fixed or improved a "short-circuit" situation	13	16	0	25	10	20
Used a blower or fan to mix welding smoke around a space	21	19	7	30	17	24
Used a blower or fan to push welding smoke away from my breathing zone	45	42	86	60	56	49
None of the above	26	26	0	20	19	24

Table 7. (Question 6) While welding in enclosed or confined spaces, how often did you wear a respirator?

	Shipyard 1				Shipyard 2				Total			
	pre (n=32)		post (n=25)		pre (n=16)		post (n=16)		pre (n=48)		post (n=41)	
	#	(%)	#	(%)	#	(%)	#	(%)	#	(%)	#	(%)
Never or almost never	6	(19)	6	(24)	--	--	--	--	6	(13)	6	(15)
Less than half the time	1	(3)	1	(4)	1	(6)	--	--	2	(4)	1	(2)
About half the time	2	(6)	1	(4)	--	--	--	--	2	(4)	1	(2)
More than half the time	3	(9)	2	(8)	--	--	1	(6)	3	(6)	3	(7)
Always or almost always	20	(63)	15	(60)	15	(94)	15	(94)	35	(73)	30	(73)

Responses to section two, which used Likert-scale items to assess attitudes and beliefs regarding ventilation are summarized in Tables 8 and 9. The items used a four-unit scale, ranging from 1 (strongly disagree) to 5 (strongly agree). Paired changes in response to the section two items were statistically-significant, at the 95% confidence level, in two cases. There was increased agreement with the statement, “I know what kind of ventilation will work best” after the training among welders at Shipyard 2. There was also increased agreement with the statement, “The ventilation equipment is in good working order” among all participants.

Table 8. (Questions 7-21) mean responses to Likert-scale items. (1 = strongly disagree, 5 = strongly agree)

	Shipyard 1 (n=53)		Shipyard 2 (n=20)		Total (n=73)	
	pre	post	pre	post	pre	post
7. Ventilation is worthwhile for short jobs.	4.02 (0.97)	4.21 (0.82)	4.25 (0.85)	4.10 (0.79)	4.08 (0.94)	4.18 (0.81)
8. Setting up ventilation is too much work.	1.68 (1.11)	1.64 (1.15)	1.80 (1.20)	1.30 (0.47)	1.71 (1.13)	1.55 (1.01)
9. Ventilation equipment is available when I need it.	3.53 (1.17)	3.51 (0.99)	3.70 (1.13)	4.16 (0.60)	3.58 (1.15)	3.68 (0.95)
10. Setting up ventilation takes too much time.	1.82 (1.03)	1.94 (0.81)	2.10 (1.07)	1.85 (1.04)	1.90 (1.04)	1.92 (0.87)
11. I know what kind of ventilation will work best.	4.08 (0.96)	4.23 (0.65)	4.10 (0.45)	4.30 (0.66)	4.08 (0.84)	4.25 (0.64)
12. I know how to set up ventilation equipment.	4.24 (0.68)	4.21 (0.69)	4.10 (0.45)	4.40 (0.50)	4.20 (0.62)	4.26 (0.65)
13. Good ventilation can reduce my exposure to smoke.	4.61 (0.53)	4.58 (0.60)	4.80 (0.41)	4.80 (0.41)	4.66 (0.51)	4.64 (0.56)
14. Good ventilation will increase comfort and visibility.	4.55 (0.7)	4.49 (0.64)	4.75 (0.44)	4.80 (0.41)	4.61 (0.64)	4.58 (0.60)
15. Good ventilation reduces exposure for those around me.	4.57 (0.5)	4.57 (0.50)	4.55 (0.69)	4.45 (0.69)	4.56 (0.55)	4.53 (0.55)
16. I'm given enough time to set up ventilation.	3.80 (1.04)	3.96 (0.83)	4.45 (0.6)	4.40 (0.60)	3.99 (0.98)	4.08 (0.80)
17. I'm given enough help to set up ventilation.	3.92 (0.96)	4.06 (0.79)	4.40 (0.60)	4.35 (0.67)	4.06 (0.89)	4.14 (0.77)
18. My employer requires me to use ventilation in a confined space.	4.08 (0.77)	4.19 (0.86)	4.60 (0.60)	4.70 (0.47)	4.23 (0.76)	4.33 (0.80)
19. The ventilation equipment is in good working order.	3.69 (1.03)	3.91 (0.84)	4.20 (0.62)	4.25 (0.72)	3.83 (0.96)	4.00 (0.82)
20. My supervisor encourages me to use a respirator.	4.14 (0.78)	4.19 (0.72)	4.75 (0.44)	4.60 (0.50)	4.31 (0.75)	4.31 (0.68)
21. My employer requires a respirator while welding in a confined space.	4.02 (0.91)	4.15 (0.82)	4.80 (0.41)	4.70 (0.47)	4.24 (0.87)	4.30 (0.78)

There were several statistically-significant differences between shipyards in mean responses. Pre-training mean responses to questions 16-21 were all significantly higher in shipyard 2 at the α=0.05 level. Post-training mean responses to questions 9, 14, 16, 18, 20, and 21 were all significantly higher at shipyard 2 at the same significance level. However, differences between post-training and pre-training responses among the same groups were essentially all not statistically-significant (Table 9).

Table 9. (Questions 7-21) post-training change in Likert-scale responses. Positive values indicate a change in the desired direction.

	Shipyard 1			Shipyard 2			Total		
	mean	SD	P	mean	SD	P	mean	SD	P
7. Ventilation is worthwhile for short jobs.	0.22	1.21	0.21	-0.15	0.75	0.38	0.11	1.10	0.39
8. Setting up ventilation is too much work.	0.04	1.05	0.79	0.50	1.36	0.12	0.17	1.15	0.22
9. Ventilation equipment is available when I need it.	0.02	1.17	0.91	0.47	1.26	0.12	0.14	1.21	0.33
10. Setting up ventilation takes too much time.	-0.10	1.14	0.53	0.25	0.97	0.26	0.00	1.10	1.00
11. I know what kind of ventilation will work best.	0.16	0.96	0.24	0.20	0.62	0.16	0.17	0.87	0.10
12. I know how to set up ventilation equipment.	0.02	0.73	0.85	0.30	0.57	**0.03**	0.10	0.70	0.24
13. Good ventilation can reduce my exposure to smoke.	-0.02	0.79	0.86	0.00	0.46	1.00	-0.01	0.71	0.87
14. Good ventilation will increase comfort and visibility.	-0.06	0.81	0.61	0.05	0.39	0.58	-0.03	0.72	0.74
15. Good ventilation reduces exposure for those around me.	0.00	0.57	1.00	-0.10	0.64	0.49	-0.03	0.58	0.67
16. I'm given enough time to set up ventilation.	0.18	0.97	0.14	-0.05	0.83	0.18	0.11	0.93	0.31
17. I'm given enough help to set up ventilation.	0.18	0.84	0.14	-0.05	0.60	0.72	0.11	0.78	0.23
18. My employer requires me to use ventilation in a confined space.	0.12	0.91	0.36	0.10	0.55	0.43	0.11	0.82	0.25
19. The ventilation equipment is in good working order.	0.24	0.86	0.06	0.05	0.51	0.67	0.18	0.78	**0.05**
20. My supervisor encourages me to use a respirator.	0.08	0.70	0.42	-0.15	0.59	0.27	0.01	0.67	0.86
21. My employer requires a respirator while welding in a confined space.	0.18	1.05	0.24	-0.10	0.45	0.33	0.10	0.93	0.37

Section three consisted of multiple-choice questions assessing ventilation knowledge. Question 22 was answered correctly by all participants on both pre- and post-training surveys. Responses to other questions were better-distributed across correct and incorrect answers. Two questions, numbers 26 and 27, showed statistically significant improvements in correct answers among all participants (Table 10). Question 26 was about fume generation rate, question 27 asked what type of equipment should be used for a given space size, both key considerations in ventilation configuration.

Table 10. (Questions 22-30) responses to knowledge questions. P-values are from McNemar's chi-squared tests of change in response.

	Shipyard 1				Shipyard 2				Total			
	% correct		change	p-value	% correct		change	p-value	% correct		change	p-value
	pre	post			pre	post			pre	post		
22. You may need to wear a respirator even if you use ventilation equipment while welding in a space.	100	100	0	1.00	100	100	0	1.00	100	100	0	1.00
23. When exhausting welding smoke, the length of the air duct does not matter.	92	83	-9	0.80	70	90	20	0.10	86	85	-1	0.80
24. Weld quality is <u>always</u> reduced if air is moving past you while you weld.	76	70	-6	0.29	79	68	-9	0.32	78	69	-9	0.16
25. Welding smoke is heavy and tends to settle toward the floor of the space.	77	79	2	0.81	58	65	7	0.71	72	75	3	0.68
26. The number of ventilation blowers needed in a space is dependent on the number of people welding in the space.	68	81	13	0.08	70	85	15	0.08	69	79	10	**0.05**
27. What do the guidelines suggest a single welder should use to ventilate a space of 9 ft. x 9 ft. x 9 ft.?	57	69	12	0.13	55	74	19	0.16	56	71	15	**0.04**
28. Which of the images shows short-circuiting?	24	22	-2	1.00	13	0	-13	0.16	22	18	-4	0.59
29. Which type of exhaust ventilation is <u>both practical and effective?</u>	26	33	7	0.25	26	37	11	0.74	25	34	9	0.26
30. What advantage does blowing air into a space have over exhausting air from the space?	63	55	-8	0.20	41	67	26	0.08	60	56	-4	0.64

Conclusions

Recruitment, training, and evaluation was very challenging in these two shipyards, and although we were able to train a total of about 131 welders, only 73 of these completed both pre and post training surveys and were available for analysis. Even among these, a substantial fraction reported not welding in the previous two weeks, or welding less than full time, further complicating the reporting of ventilation use.

Overall, most welders who reported welding activity did use ventilation in confined spaces, although use was more complete among Shipyard 2 welders. Indeed, in all cases where there was a significant difference between shipyards in responses to section 2, subjects from Shipyard 2 had more positive views of the ventilation practices in their workplace than subjects at Shipyard 1.

Ventilation of confined spaces for welding is difficult, as is effecting behavior change in others. In neither shipyard were we able to meaningfully improvement ventilation attitudes, knowledge, or behavior. However, the training materials created for this project may be used by shipyard health and safety personnel, and may prove effective if used in a more intensive and sustained manner.

Program Director/Principal Investigator (Last, First, Middle): Seixas, Noah, S.

Inclusion Enrollment Report

This report format should NOT be used for data collection from study participants.

Study Title: Control of Welding Fume in Shipbuilding Confined Spaces

Total Enrollment: 51 **Protocol Number:** 39450

Grant Number: R01OH009655

PART A. TOTAL ENROLLMENT REPORT: Number of Subjects Enrolled to Date (Cumulative) by Ethnicity and Race

Ethnic Category	Females	Males	Sex/Gender Unknown or Not Reported	Total
Hispanic or Latino	1	8	0	9 **
Not Hispanic or Latino	1	40	0	41
Unknown (individuals not reporting ethnicity)	0	1	0	1
Ethnic Category: Total of All Subjects*	2	49		51 *
Racial Categories				
American Indian/Alaska Native	0	0	0	
Asian	1	6	0	7
Native Hawaiian or Other Pacific Islander	0	0	0	
Black or African American	0	2	0	2
White	1	41	0	42
More Than One Race	0	0	0	
Unknown or Not Reported	0	0	0	
Racial Categories: Total of All Subjects*	2	49		51 *

PART B. HISPANIC ENROLLMENT REPORT: Number of Hispanics or Latinos Enrolled to Date (Cumulative)

Racial Categories	Females	Males	Sex/Gender Unknown or Not Reported	Total
American Indian or Alaska Native	0	0	0	
Asian	0	0	0	
Native Hawaiian or Other Pacific Islander	0	0	0	
Black or African American	0	0	0	
White	1	8	0	9
More Than One Race	0	0	0	
Unknown or Not Reported	0	0	0	
Racial Categories: Total of Hispanics or Latinos**	1	8		9 **

* These totals must agree.
** These totals must agree.

UNIVERSITY OF WASHINGTON

Office of Research
Office of Sponsored Programs

November 25, 2014

Mary Pat Shanahan
Grants Management Specialist
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Prevention Services Branch/Team 2
PO Box 18070
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Pittsburgh, PA 15236-0070

Ms. Shanahan:

Enclosed is the final progress report for Dr. Noah Seixas' grant 5R01OH009655 , titled "Control of Welding Fume in Shipbuilding Confined Spaces." This progress report covers the period 9/1/2010 to 8/31/2014.

Please add this report to the grant file. Thank you.

Sincerely,

Lynette Arias
Director, Office of Sponsored Programs
Assistant Vice Provost for Research

Please include reference #**A75729** on all correspondence related to this report.