# Asthma in Heavy and Highway Construction Workers Exposed to Silica

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## Abbreviations

| | |
|---|---|
| CAT | Central Artery/Tunnel construction project |
| CI | Confidence interval |
| HDPE | High-density polyethylene |
| OR | Odds ratio |
| OSHA | U.S. Occupational Safety and Health Administration |
| PEL | Permissible exposure limit |
| SCA | Symptoms consistent with asthma |

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In December, 2000 the federal Occupational Safety and Health Administration (OSHA) carried out a safety and health inspection on a contract site (CO9A4) on Boston's Central Artery/Tunnel (CAT) highway construction project. The inspection was conducted under a National Emphasis Program for silica and a Local Emphasis Program for the CAT. Work on the site involved construction of (1) two tunnels linking Boston's underground central artery to the Massachusetts Turnpike (I-90 West and I-90 East) and (2) an exit ramp connecting I-90 westbound to the central artery.

On November 1, 2, and 3, 2001, a health survey of more than 300 construction workers from the CO9A4 site was carried out by Occupational Health Initiatives and the New England Laborers Health & Safety Fund. The survey was done under the auspices of the Building & Construction Trades Council of the Metropolitan District and local unions representing the trades on the site. The focus of the survey was silica. No definite cases of silicosis were identified. However, review of the questionnaires completed by survey participants revealed what appeared to be a high number of positive responses to questions about wheeze and attacks of wheeze associated with shortness of breath. In some, but not all, cases there was a prior history of physician-diagnosed asthma. Only a few reported taking medication for asthma. These findings suggested a higher-than-expected prevalence of asthma (compared with the general population) among construction workers on the site, undiagnosed and untreated for the most part.

Based upon these findings, three hypotheses were generated:

1. There is an increased prevalence of asthma defined on the basis of physician diagnosis or symptoms among these heavy and highway construction workers.
2. For many of these workers, asthma is undiagnosed.
3. For many of those with physician-diagnosed asthma, control is not adequate.

The present study tests these hypotheses by statistical analysis of the data collected at the time of the survey, and examination and assessment of the results.

## Methods

All construction workers who had worked on the construction site during the time period June 1999 through December 2000 were invited to participate in a health survey held in November 2001 at the hall of Plumbers Union Local 12 in Boston, Mass. Trades included laborers, carpenters (including pile drivers), ironworkers, tunnel workers, operating engineers, and electricians.

### Workers' respiratory and smoking histories

Each worker's respiratory history was derived using the Epidemiology Standardization Project questionnaire (Ferris 1978). The focus of data analysis and the present report is asthma. Because the focus of the survey was silicosis, standardized questions for asthma epidemiology were not included on the questionnaire (*see* Venables and others 1993). Also analyzed but not reported here were chronic bronchitis and shortness of breath.

Based upon answers to questions about current symptoms of wheeze and prior history of asthma, participants were classified as having *symptoms consistent with asthma* (SCA) or physician-diagnosed asthma. A point system was developed to define SCA. Each of the following symptoms was given one point: wheeze with cold, wheeze occasionally apart from colds, wheeze most days or nights, two or more attacks of wheezing associated with shortness of breath. <u>If</u> a participant reported one or more attacks of wheeze associated with shortness of breath, one point was given also for a positive response to the question, "Have you ever required medicine or treatment for the(se) attack(s)?" Participants who received 3 or more of these 5 possible points were classified as SCA.

*Physician-diagnosed asthma* was determined on the basis of a "yes" response to the question, "Have you ever had asthma?" <u>and</u> "yes" to the question, "Was it confirmed by a doctor?" With a "yes" answer to the question, "Do you still have it?," a participant was included in a subcategory of current physician-diagnosed asthma. Both subcategories of physician-diagnosed asthma (those who don't and do still have it) were analyzed with regard to self-reported symptoms of asthma.

Participants were classified as *current smokers* if they reported "ever smoking cigarettes" and that they "now smoke cigarettes" (as of one month before the survey). *Former smokers* were those who reported "ever smoked" and "not smoking now." *Never smokers* were those who reported "no" to ever smoking cigarettes. Pack-years of cigarettes were calculated (for *ever smokers*) by multiplying total number of years of smoking by average number cigarettes per day over the entire time that they smoked, and dividing by 20 (number of cigarettes in a pack).

## Work histories

Principal work activities on the construction site studied were related to the construction of the two tunnels and the exit ramp.

The work history obtained from each questionnaire included present occupation/trade, union and local union number, usual occupation/job, years of work at usual occupation, and months of work on the CAT contract site of interest. Because of small numbers, pile drivers were grouped with carpenters; similarly, plumbers, millwrights, and nonunion engineers and managers were grouped with "other" for purposes of data analysis (with a group as small as "other," statistical results must be interpreted with caution). Included in the questionnaire were questions about work at three specific activities on the site: tunneling/mining, breaking through slurry walls, and chipping or hammering caisson overpour. The activities were selected because personal and area sampling on the site by OSHA and the responsible contractor showed elevated silica levels during each of these activities (silica is found in quartz, other rock, sand and masonry). This study assumed that total dust exposures would be high where silica levels were high, and thus included these three activities in the analyses. (Unlike tunneling and slurry wall breakthrough, most of the chipping or hammering of caisson overpour was done above ground.)

*Months of work on the site* was determined on the basis of start and stop dates and self-reported total months on the job. For those who had missing information for stop date and who did not report total number of months on the site, it was assumed they were still working on the site and the survey date was used to calculate total number of months. *Years at usual job* was determined on the basis of the response to the question, "Number of years employed in this occupation."

## Construction techniques

In order to better assess the results described below, additional information was sought about the construction work performed on this site. Sources of information included the CAT web site and consultation with OSHA personnel, trades working on the site, and the engineer responsible for a ground-freezing operation.

***Use of jacking boxes.*** The construction of the tunnels involved the use of "jacking boxes." A temporary concrete jacking box was built inside each of three concrete jacking pits dug along the path of I-90. The top of each pit was open. Each box was 80 feet wide and 40 feet high, with an open front end and two levels of four compartments each. Operators of heavy equipment and tunneling workers worked from inside the compartment at the open end of each box. The boxes were moved using cables that were along the bottom of each pit. At the front of each pit was a concrete slurry wall; beyond the slurry wall, the ground had been frozen (see below). Equipment was used to break through the slurry wall to create a tunnel through the earth.

***Ground freezing.*** Because the I-90 tunnel had to pass under a busy rail terminal, the soil had to be stabilized to avoid settling of the rail lines that were overhead. This was accomplished by ground freezing: A system of pipes was installed in the ground. The piping system was a series of four 4-inch-diameter carbon steel pipes with closed ends into which were dropped 1½ inch high-density polyethylene (HDPE) pipes with open ends. Brine was chilled to -23 degrees Centigrade in a refrigeration plant on site and circulated between the carbon steel and HDPE piping. Over time, the brine cooled the soil and eventually froze the ground outward from the pipes.

***Breaking through the slurry wall.*** The first step in actual tunnel construction was breaking through the concrete slurry wall at the head of the jacking pit. Operating engineers used a roadheader – with a rotary blade – to break through slurry wall and bore through the frozen ground behind it; a large bucket and crane removed and lifted soil to the surface. Any granite or rocks encountered in the soil were broken up by hoe rams. The roadheader and jacking equipment were electric; other heavy equipment, including forklifts, cranes, CAT loader, manlift, and bobcat were diesel powered. The jacked sections were 150 feet long for the ramp tunnel, 260 feet long for the I-90 westbound tunnel, and 560 feet long for the I-90 eastbound tunnel.

***Burning pipes.*** In order for a jacking box to be jacked forward, the pipes used for ground freezing had to be removed (the ground was still frozen). The removal was accomplished by burning the carbon steel pipes with a manganese rod using compressed oxygen at 5,000 degrees Fahrenheit. According to the engineer overseeing the ground- freezing operation, the brine and HDPE pipes were pulled out before the steel pipes were burned-in about 90% of the time; the rest were left in place.

## Statistical analysis

In the data analysis, logistic regression was used to model the relationship between dichotomous (yes, no) outcomes and work exposures. Principal outcomes of interest were SCA and physician-diagnosed asthma. To assess the relationships of outcomes to exposure variables while controlling for the possible confounding effects of the covariates, adjusted odds ratios (ORs) were calculated from models that included exposure variables and other covariates such as age, gender, and smoking. The unadjusted models were fit separately for each covariate. The number of observations in these models varied by the amount of missing data for the independent and the dependent (outcome) variables. The adjusted model includes only participants with complete data on all covariates. In computing odds ratios, laborers were chosen as the reference group because of the relatively low prevalence of asthma in that group. Electricians had a lower prevalence, but the total number of electricians was small (21 compared to 89 laborers).

The analysis assumed an alpha of 0.05 and calculated 95 percent confidence intervals (CIs). An overall p-value was also presented to allow an assessment of the importance of each covariate to the strength of the model, or of its predictive capability. For instance, in some cases, the 95% CI shows significant (meaning the CI does not include 1) differences between groups. However, the p-value may not be significant (<0.05), indicating that the covariate may not be a strong predictor of the outcome.

# Results

A total of 343 workers completed questionnaires, but data analysis was performed for 317 participants. The final count excluded 26 participants who reported working 30 days or less on the site or who had missing information on length of time worked on the site.

The average age for the whole group of 317 was 41 years (table 1). Most were male and Caucasian. About 29% were currently smoking.

Work histories showed a high correlation between present occupation/trade and usual job/occupation. More than half of the participants were laborers or carpenters (table 2).  Participants had been employed in their usual jobs for 14 years, on average, and had been working on the site an average of about 22 months. Of the group as a whole, 36% reported having done tunneling/mining, 45% breaking through slurry wall, and 51% chipping or hammering caisson overpour while on the project.

### Respiratory symptoms and physician-diagnosed asthma

The number of workers who reported physician-diagnosed asthma was far less than the number showing symptoms consistent with asthma (table 3). Prevalence of physician-diagnosed asthma and SCA varied by trade (table 4). Higher prevalence of physician-diagnosed asthma was observed among operating engineers, laborers, and carpenters at about 10%, 8%, and 7%, respectively. Carpenters, tunnel workers, and operating engineers were more likely to report SCA: about 35%, 34%, and 32%, respectively.

In the logistic regression analysis, physician diagnosis of asthma, breaking through slurry walls, and number of months on the site were all significantly associated with SCA (table 5).

Those with physician-diagnosed asthma were ten times more likely to report SCA as those without physician-diagnosed asthma. With regard to workplace activities, those who reported breaking through slurry walls were three times more likely to report SCA, compared with workers who didn't break through the walls. The breaking through was done primarily by operating engineers and tunnel workers, but carpenters were exposed as bystanders.

However, participants who worked 18 or more months on the site were <u>one-fourth</u> as likely to report SCA as those who worked less than 10 months. This finding is consistent with an earlier study of construction workers on the CAT project and suggests that workers who have respiratory symptoms tend to leave the construction project earlier than they would have otherwise (Oliver and others 2001).

Smoking status was a statistically significant predictor of SCA when other relevant factors were taken into account. Current smokers were more than twice as likely to report SCA, compared with former or never smokers. Present trade was not a significant predictor of SCA. However, there were some significant within-variable differences. All trades were more likely than laborers to report SCA; but for carpenters, the difference was significant at a greater than fourfold increase.

## Discussion

The statistical findings support hypotheses generated by responses to questions about wheeze and physician diagnosis of asthma at the time of this survey of silica-exposed workers involved in tunnel operations on the CAT construction project. The construction process was somewhat unusual in its use of jacking boxes and ground freezing.

In the present study, 6.6% of participants overall reported physician-diagnosed asthma. By comparison, data collected in Massachusetts in the 2000 Behavioral Risk Factor Surveillance System survey showed that 11.9% of 8,139 respondents answered "yes" to the question, "Have you ever been told by a doctor that you have asthma?" (MMWR 2001) This finding suggests that asthma is under-diagnosed in those who participated in this survey. Further, of the 21 in this survey in whom asthma was diagnosed, more than half reported SCA.

In contrast to the prevalence of physician-diagnosed asthma, about 25% of participants reported symptoms consistent with asthma, with a range of 19% in laborers and electricians to more than 30% in carpenters, tunnel workers, and operating engineers. About 23% of ironworkers reported SCA.

Slurry wall breakthrough emerged as a significant risk factor for SCA in the analysis, depending on trade. Participation in this work activity was associated with a sevenfold increase in risk for SCA in carpenters, an increase in risk that was statistically significant (OR 6.87, 95% CI 1.66-28.39).

Silica levels measured during slurry wall breakthrough were high. OSHA's recalculation of sampling data collected by the general contractor during the breaking through of slurry walls revealed that of 11 samples taken, six showed calculated silica levels of 130%, 135%, 200%, 220%, 305%, and 1170% of the OSHA permissible exposure limit (PEL). Area samples taken during slurry wall breakthrough showed silica levels 314% and 397% of the PEL. These data are consistent with high dust exposures during slurry wall breakthrough reported by workers on the site and are an indicator of high-level exposure to cement dust, as silica and cement dust are often fellow travelers. Silica has not been reported to cause asthma. However, Portland cement present in most cement manufactured in the United States has been reported to cause asthma ( Alvear-Galindo and others 1999; DeRaeve and others 1998). Portland cement contains hexavalent chromium, a known irritant and sensitizer to the airways and to the skin.

The tunneling operation involved other potential causes of asthma. These included diesel emissions and fumes/vapors from the burning of the steel and HDPE pipes. Diesel emissions are a known cause of asthma, most likely because of irritants in the particulate and the vapor phase (Rudell and others 1996; Wade and Newman 1993; Ulfvarson and others 1991). The level of risk associated with burning HDPE is unknown presently. Polyethylene itself has been reported to burn cleanly, but if polyvinylchloride is an additive – as in the case of HDPE – hydrochloric acid vapors may be generated (Sakata, Uddin, Koizumi, and Murata 1996). If this occurs, the risk for airway inflammation and asthma is high.

Carpenters were found to be at significantly increased risk for SCA compared to laborers. The carpenters were downwind of the jacking box during slurry wall breakthrough and followed along behind the jacking box as the tunnel was bored. These findings suggest bystander exposures that created an increase in risk for carpenters that was greater than for trades directly associated with the slurry wall breakthrough and the tunneling. Other as-yet-unidentified factors may be operative as well.

With regard to these exposures, it is important to remember that they occurred in relatively enclosed spaces. This was true for those working in the jacking box, such as operating engineers and tunnel workers, and for those working in the larger jacking pit, such as carpenters.

## Conclusions

The present study reveals that over 25% of a group of heavy and highway construction workers report symptoms consistent with asthma. Risk was related to type of work and trade. The prevalence of physician-diagnosed asthma was lower than that for the general adult population of Massachusetts, which suggests that asthma in these workers is going undetected. That 10 of 21 of the workers in this survey with physician-diagnosed asthma still report symptoms consistent with asthma suggests, as well, that asthma is not adequately treated.

The findings are consistent with the results of a previously reported study of airways disease in heavy and highway construction workers and point out the need for better understanding of causes of asthma in the construction industry. In addition, construction workers should be better educated with regard to signs and symptoms of asthma (Oliver and others 2001). Methods of reducing potentially harmful airborne exposures in the construction industry exist (Rappaport, Goldberg, Susi, and Herrick 2003). The methods, which include the use of water to suppress dust during drilling and cutting, should be used.

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**1. Demographics: participants' age, gender, race, and smoking status**

| | Number | % |
|---|---|---|
| **Age (in years)** | | |
| < 35 | 91 | 28.5 |
| 35-<40 | 71 | 22.5 |
| 40-<50 | 94 | 29.8 |
| 50+ | 57 | 18.0 |
| Missing information | 4 | 1.3 |
| *Mean (SD)=40.8 (9.6)* | | |
| *Range 19.9-66.8* | | |
| **Gender** | | |
| Male | 309 | 97.5 |
| Female | 7 | 2.2 |
| Missing information | 1 | 0.3 |
| **Race** | | |
| White | 265 | 83.6 |
| Black | 29 | 9.2 |
| Other | 14 | 4.4 |
| Missing information | 9 | 2.8 |
| **Smoking Status** | | |
| Current | 93 | 29.3 |
| Former | 63 | 19.9 |
| Never | 157 | 49.5 |
| Missing information | 4 | 1.3 |

*Note:* Total of 317 workers.

**2. Work history: participants' time spent at job, site, and selected tasks, by occupation**

| | Number | % |
|---|---|---|
| **Present occupation/trade/union** | | |
| Laborer | 89 | 28.1 |
| Carpenter | 84 | 26.5 |
| Electrician | 21 | 6.6 |
| Ironworker | 47 | 14.8 |
| Operating engineer | 32 | 10.1 |
| Tunnel worker | 40 | 12.6 |
| Other | 4 | 1.3 |
| **Number of years at usual job** | | |
| <=5 | 75 | 23.7 |
| >5-15 | 114 | 36.0 |
| >15-20 | 57 | 18.0 |
| >20 | 59 | 18.7 |
| Missing information | 12 | 3.8 |
| *Mean (SD)=14.0 (9.4)* | | |
| *Range=1 to 46* | | |
| **Number of months on C09A4 site** | | |
| <=10 | 88 | 27.8 |
| > 10-18 | 73 | 23.0 |
| > 18-32 | 80 | 25.2 |
| > 32 | 76 | 24.0 |
| *Mean (SD)=21.8 (15.0)* | | |
| *Range=1.5 to 77* | | |
| **Tunneled/mined** | | |
| Yes | 114 | 36.0 |
| No | 188 | 59.3 |
| Missing information | 15 | 4.7 |
| **Broke through slurry walls** | | |
| Yes | 143 | 45.1 |
| No | 158 | 49.8 |
| Missing information | 16 | 5.1 |
| **Chipped/hammered caisson overpour** | 163 | 51.4 |
| Yes | 139 | 43.9 |
| No | 15 | 4.7 |
| Missing information | | |

*Note:* Total of 317 workers.

### 3. Relationship of physician-diagnosed asthma and symptoms consistent with asthma

| Workers reporting physician-diagnosed asthma | Workers showing symptoms consistent with asthma | | | |
|---|---|---|---|---|
| | Yes | No | Missing information | Total |
| **Yes–current** | 8 (80.0%) | 2 (20.0%) | 0 (0.0%) | 10 (100.0%) |
| **Yes-not current** | 5 (45.5%) | 5 (45.5%) | 1 (9.1%) | 11 (100.0%) |
| **No** | 67 (23.3%) | 206 (71.8%) | 14 (4.9%) | 287 (100.0%) |
| **Missing** | 1 (11.1%) | 3 (33.3%) | 5 (55.6%) | 9 (100.0%) |
| **Total** | 81 | 216 | 20 | 317 |

*Note:* “Physician-diagnosed asthma” includes a diagnosis at any time, not just during the project.

**4. Description of workers by present occupation, selected occupations**

| | Present occupation/trade/union | | | | | | P-value |
|---|---|---|---|---|---|---|---|
| | **Laborers** | **Carpenters** | **Electricians** | **Ironworkers** | **Operating engineers** | **Tunnel workers** | |
| **Demographics** | | | | | | | |
| Average (SD) age, in years | 40.8 (10.2) | 41.4 (9.1) | 38.1 (8.6) | 38.9 (8.6) | 45.2 (11.6) | 39.4 (8.0) | 0.0682 |
| Smoking status | | | | | | | **0** |
| % Never | 44.2% | 59.0% | 66.7% | 57.5% | 28.1% | 46.2% | |
| % Current | 38.4% | 27.7% | 0.0% | 27.7% | 25.0% | 38.5% | |
| % Former | 17.4% | 13.3% | 33.3% | 16.7% | 46.9% | 15.4% | |
| Average pack-years of cigarettes (SD) among ever smokers | 17.3 (14.8) | 15.1 (12.6) | 9.4 (9.7) | 21.1 (14.3) | 17.2 (22.4) | 17.5 (14.6) | 0.6647 |
| **Work history** | | | | | | | |
| Average # of months at site (SD) | 22.9 (15.4) | 21.5 (13.4) | 15.7 (19.9) | 21.3 (14.5) | 22.9 (16.2) | 22.4 (13.0) | 0.0901 |
| Average # of years at usual job (SD) | 13.6 (9.7) | 14.1 (7.7) | 13.5 (9.7) | 14.8 (9.2) | 20.1 (12.8) | 8.6 (5.4) | **<0.0001** |
| % Broke through slurry walls | 59.8% | 31.7% | 20.0% | 15.6% | 78.1% | 82.1% | < **0.0001** |
| % Tunneled/mined | 20.0% | 26.3% | 28.6% | 21.7% | 93.8% | 79.5% | **<0.0001** |
| % Chipped caisson overpour | 82.4% | 41.8% | 31.6% | 13.3% | 73.3% | 65.0% | **<0.0001** |
| **Respiratory outcomes** | | | | | | | |
| % Physician-diagnosed asthma | 8.2% | 7.1% | 0.0% | 2.1% | 9.7% | 5.6% | 0.0757 |
| % Symptoms consistent with asthma | 19.0% | 34.6% | 19.1% | 23.4% | 32.3% | 34.2% | 0.2945 |

*Note:* SD = standard deviation. P-values for categorical covariates are from a chi-square test (for % physician diagnosed asthma, exact chi-square test), and for continuous covariates from analysis of variance F-tests. Physician-diagnosed covers worker's history, not just during the project. Some participants – managers and trades included in "other" elsewhere in this report – are not included in this chart. Total of 89 laborers, 84 carpenters, 21 electricians, 47 ironworkers, 32 operating engineers, and 40 tunnel workers.

## 5. Logistic regression results for symptoms consistent with asthma

| | Unadjusted | | | Adjusted (n=270) | | |
|---|---|---|---|---|---|---|
| | **Odds ratio** | **95% CI** | **P-value** | **Odds ratio** | **95% CI** | **P-value** |
| **Age** | | | 0.07 | | | 0.186 |
| <= 35 | 1.00 | | | 1.00 | | |
| 35-40 | 1.58 | 0.78, 3.20 | | 1.45 | 0.61, 3.45 | |
| 40-50 | 1.39 | 0.71, 2.72 | | 1.25 | 0.56, 2.80 | |
| 50+ | 0.55 | 0.22, 1.35 | | 0.84 | 0.28, 2.49 | |
| **Smoking status** | | | 0.209 | | | **0.035** |
| Never | 1.00 | | | 1.00 | | |
| Current | 1.63 | 0.91, 2.91 | | **2.41** | **1.18, 4.92** | |
| Former | 0.96 | 0.47, 1.94 | | 0.91 | 0.35, 2.32 | |
| **Physician-diagnosed asthma** | | | **0** | | | **0.001** |
| Yes | **5.71** | **2.19, 14.90** | | **10.41** | **2.76, 39.31** | |
| No | 1.00 | | | 1.00 | | |
| **Tunneled/mined** | | | **0.03** | | | 0.692 |
| Yes | **1.85** | **1.09, 3.17** | | 1.20 | 0.49, 2.96 | |
| No | 1.00 | | | 1.00 | | |
| **Broke through slurry walls** | | | **0** | | | **0.016** |
| Yes | **2.13** | **1.25, 3.63** | | **3.32** | **1.25, 8.84** | |
| No | 1.00 | | | 1.00 | | |
| **Chipped caisson overpour** | | | 0.392 | | | 0.623 |
| Yes | 1.26 | 0.74, 2.13 | | 0.80 | 0.33, 1.93 | |
| No | 1.00 | | | 1.00 | | |
| **Present trade** | | | 0.258 | | | 0.103 |
| Laborer | 1.00 | | | 1.00 | | |
| Carpenter | **2.25** | **1.09, 4.66** | | **4.55** | **1.67, 12.99** | |
| Electrician | 1.00 | 0.30, 3.42 | | 2.42 | 0.51, 11.48 | |
| Ironworker | 1.29 | 0.52, 3.09 | | 3.13 | 0.89, 11.10 | |
| Operating engineer | 2.03 | 0.79, 5.20 | | 2.28 | 0.56, 9.33 | |
| Tunnel worker | 2.22 | 0.93, 5.32 | | 3.03 | 0.87, 10.50 | |
| Other | 1.42 | 0.14, 14.65 | | 0.64 | 0.03, 13.51 | |
| **Months at site** | | | **0** | | | **0.001** |
| <=10 | 1.00 | | | 1.00 | | |
| >10-18 | 1.05 | 0.54, 2.03 | | 0.62 | 0.27, 1.44 | |
| >18-32 | 0.50 | 0.24, 1.04 | | **0.25** | **0.10, 0.61** | |
| >32 | **0.30** | **0.13, 0.68** | | **0.21** | **0.08, 0.54** | |

*Note:* Total of 317 workers.