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## Original Article

## Occupational Tasks Influencing Lung Function and Respiratory Symptoms Among Charcoal-Production Workers: A Time-Series Study

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## ABSTRACT

**Background:** Tasks involved in traditional charcoal production expose workers to various levels of charcoal dust and wood smoke. This study aimed to identify specific tasks influencing lung function and respiratory symptoms.

**Methods:** Interviews, direct observation, and task/symptom checklists were used to collect data from 50 charcoal-production workers on 3 nonwork days followed by 11 workdays. The peak expiratory flow rate (PEFR) was measured four times per day.

**Results:** The PEFR was reduced and the prevalence of respiratory symptoms increased over the first 6–7 workdays. The PEFR increased until evening on nonwork days but not on workdays. Loading the kiln and collecting charcoal from within the kiln markedly reduced the PEFR and increased the odds of respiratory symptoms.

**Conclusion:** Tasks involving entry into the kiln were strongly associated with a short-term drop in the PEFR and the occurrence of respiratory symptoms, suggesting a need for the use of protective equipment and/or the operation of an effective kiln ventilation system.

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## 1. Introduction

Charcoal is an important fuel in many countries. A large amount of charcoal is consumed mostly in urban areas of developing countries, such as Zambia, northeastern Brazil, and Kenya. In Kenya, the charcoal industry, which provides domestic energy for 82% of urban and 34% of rural households, employs over 700,000 people [1–3]. Charcoal is a wood fuel made from burning wood in a low-oxygen environment [4,5]. In the traditional setting, charcoal production results in the emission of smoke and dust, from the burning of wood and husk, into the ambient atmosphere. Wood smoke contains particulate matter and other toxic compounds such as carbon monoxide, carbon dioxide, and nitrogen oxides [6,7]. Humans exposed to wood smoke, whether in domestic setting or occupationally, have been reported to have decreased lung function, and increased risks for respiratory

symptoms, asthma, and chronic obstructive pulmonary disease [7–13]. Thus, women who use wood as fuel for cooking have more cough, dyspnea, and asthma than those who use gas for cooking [14]. Workers exposed occupationally to smoke, such as firefighters, brick-kiln workers, and charcoal-production workers, also have been shown to have lower values of spirometry parameters, and increased prevalence of respiratory symptoms during and/or after exposure than before [8–10,15,16]. In Crete [9] and Thailand [10], charcoal workers were found to have significantly more respiratory symptoms and poorer lung function parameters than workers in nonexposed occupations, and these effects were more pronounced among charcoal workers who were smokers than among those who were nonsmokers [17].

In the traditional setting in Thailand, a charcoal-production plant consists of a number of kilns that are operated asynchronously, and each worker may perform a number of different

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tasks, the major tasks being carrying wood from the wood stack to place it beside the kiln, loading wood into the kiln, firing the kiln to start the pyrolysis process, and, after charcoal in the kiln has cooled down, collecting the charcoal and putting it into sacks or baskets. For any one worker, tasks performed may differ from day to day and several different tasks may be performed on the same day. Thus, the intensity of exposure to smoke and dust may be quite varied. Personal protective equipment is not used.

The aim of this study, therefore, was to identify the acute respiratory effects of the different tasks. A new analysis of time-series data (secondary data) previously collected to compare pulmonary function and respiratory symptoms of charcoal workers and rubber tappers [10] was undertaken. Identification of the specific occupational tasks that most influence lung function in the short term, as reflected by a reduction in the peak expiratory flow rate (PEFR) and occurrence of respiratory symptoms, could be useful for the rational planning and implementation of protective measures for these charcoal-production workers.

## 2. Materials and methods

Fifty charcoal-production workers (28 males and 22 females) who were willing to join the study were recruited from nine charcoal-production plants (3–7 workers per plant) in Ta Khun district, Surat Thani province, southern Thailand. Each charcoal plant included between five and 20 separate kilns, and the cycles of kiln loading, kiln firing, and charcoal collection were generally asynchronous among the kilns. All workers who had been employed in their current charcoal-production plant for at least 1 year were requested to join the study. Individuals who had hypertension, hypotension, ischemic heart disease, aneurysm in thorax or brain, cataract laser-assisted in situ keratomileusis eye surgery, or respiratory infection or who were pregnant at the time of the study were excluded. This study was approved by the Ethics Committee of the Faculty of Medicine, Prince of Songkla University. An explanation of the study was given to all participants and formal signed consent was obtained before any data were collected.

Data collection included interviews using a questionnaire, direct observation, and measurement of height, weight, blood pressure using an automatic blood pressure monitor, and PEFR using a portable peak flow meter with a range of 60–900 dm<sup>3</sup>/min (MicroPeak; CareFusion, Basingstoke, UK). A record form was used to record data, covering the PEFR, daily tasks undertaken, respiratory symptoms, and starting and stopping times of working each day. The questionnaire was adapted from the American Thoracic Society and Division of Lung Diseases of the National Heart and Lung Institute questionnaire [18], pilot-tested with 30 participants in a different district of Surat Thani province, and revised before using it to collect data in this study. In both the pilot and the actual study, the questionnaire data were collected by the investigator, who interviewed individuals face to face.

PEFR measurements were made on 14 consecutive days, with the first 3 days being nonwork days and the subsequent 11 days workdays. Each participant was measured four times in each day, namely in the morning before starting work, at midday, in the evening after finishing work, and before going to bed. Each time three measurements were made and recorded in units of dm<sup>3</sup>/min. Measurements were made by the researcher in the morning, at midday, and after work, but by the participant himself/herself before going to bed. The tasks performed each day and any respiratory symptoms (cough, sputum production, dyspnea, wheezing, nasal irritation, and nasal congestion) that were experienced during the day were recorded on a checklist after PEFR measurement after work by the researcher and before going to bed by the

participant. Each day, every symptom was coded as 1 if experienced and 0 otherwise.

Workers were instructed on how to make PEFR measurements. They were instructed to ensure that the PEFR meter was set to zero before making a measurement and to hold the meter by its handle, stand up straight, inhale rapidly but not forcefully, insert the mouthpiece, seal the lips, and exhale with maximum force as soon as the lips had sealed around the mouthpiece. The meter was then to be removed from the mouth and the reading recorded. The procedure was to be repeated twice. Finally, the mouthpiece was to be removed and discarded, and the meter wiped with alcohol.

### 2.1. Statistical analysis

Descriptive statistics were used to summarize the general characteristics of the participants. The maximum of the three PEFR readings at each measurement session was used for analysis [19]. The mean daily PEFR values over the 3 nonwork days, over all 11 workdays, and on each successive workday following the nonwork period were calculated. The mean PEFR at each time of day was also calculated for nonwork days and according to tasks performed on workdays.

Mixed-effects multiple linear regression modeling was used to estimate the independent effects of worker characteristics, cumulative day of work following the nonwork period, and interaction of time of day and tasks performed during the day on the PEFR; mixed-effects logistic regression modeling was used to identify worker characteristics, cumulative day of work following the nonwork period, and tasks influencing the occurrence of respiratory symptoms (cough, cough with phlegm, phlegm, dyspnea, wheeze, and sneeze). In these mixed-effects models, the worker was considered to be the random element and other variables to have fixed effects. For each of the multiple regression models, variables that showed some evidence of a relationship with outcome ( $p < 0.2$ ) in univariate analysis were initially included in the model, and the model was refined by backward removal of nonsignificant variables guided by value of the  $F$  test (linear regression model) or the change in log likelihood (logistic model) of successive models. Task and time of day in the linear model, and task in the logistic model were retained irrespective of the statistical significance of their contribution to the fit of the model. The significance of changes in the prevalence of each respiratory symptom over days of rest and work was evaluated using a Poisson model with robust estimates of standard error clustered on workers. Statistical significance was defined as  $p < 0.05$ .

## 3. Results

### 3.1. General characteristics of workers

Fifty charcoal workers (28 men and 22 women) with a mean age of 33.5 years (standard deviation 8.8 years) were included in the study. Most of the workers (92%) were migrants from other regions of the country. All were Buddhist, most of the males (26/28) and just one female were current smokers, and all but one worker had received no more than primary school education. All of them worked every day without a nonwork day other than that for religious festivals, which accounted for the three nonwork-day periods included in this study. The terms of hiring specified an 8-hour or 9-hour working day, but a majority of the males (86%) and a minority of the females (32%) regularly worked overtime for between 1 hour and 3 hours on days worked overtime (Table 1).

**Table 1**  
Demographic characteristics

Characteristics	Number (%)
Age (y), mean = 33.5, SD = 8.8	
Sex	
Male	28 (56.0)
Female	22 (44.0)
Marital status	
Single	5 (10.0)
Married	43 (86.0)
Divorced	1 (2.0)
Widowed	1 (2.0)
Religion	
Buddhist	50 (100.0)
Smoking	
Nonsmoker	23 (46.0)
Current smoker	27 (54.0)
Formal education level	
None	1 (2.0)
Primary school	48 (96.0)
Secondary school	1 (2.0)
Work time (d/wk), median = 7 (range 7, 7)	
Work time (h/d), median = 8 (range 8, 9)	
Regularly worked overtime	
No	19 (38.0)
Yes	31 (62.0)
Work overtime* (h/d), median = 2 (range 1, 3)	

\* On days worked overtime.  
SD, standard deviation.

### 3.2. Distribution of daily average PEFR and proportion of workers experiencing respiratory symptoms on nonwork days (combined) and on consecutive workdays

Fig. 1 shows the mean and 95% confidence interval of the daily average PEFR on nonwork days combined (“Day 0”) and on consecutive workdays (“Days 1–11”). There was an immediate drop in the median daily value of the PEFR on the 1<sup>st</sup> day of work following the nonwork period, and thereafter the decrease

continued reaching a minimum on the 6–7<sup>th</sup> working day after which it began to rise again.

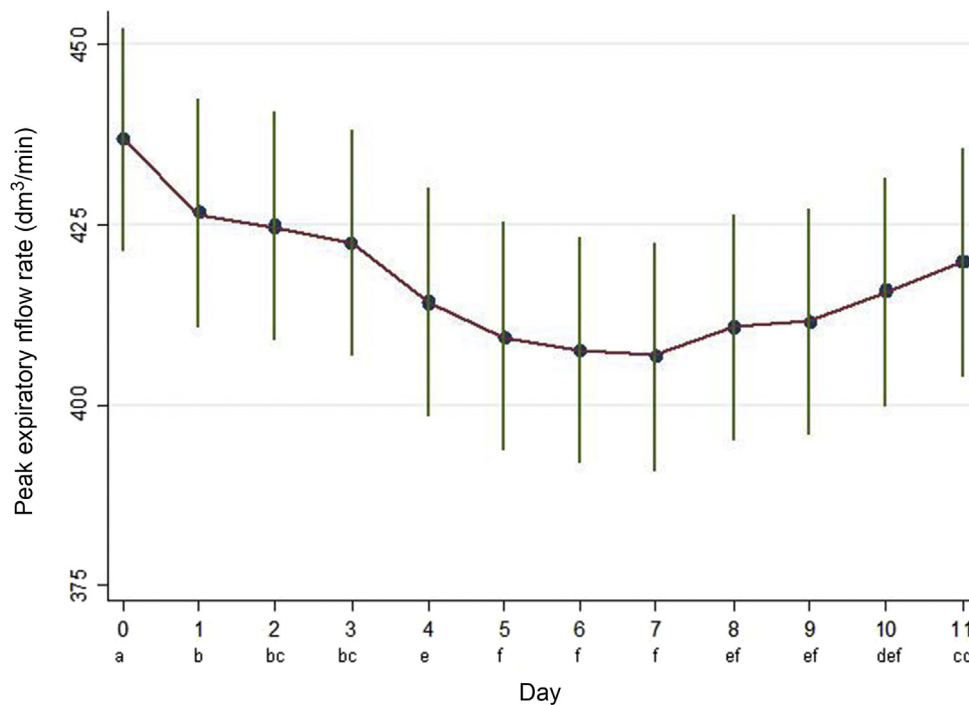
A similar pattern of the occurrence of respiratory symptoms was seen on consecutive workdays. The proportions of workers who experienced cough, cough with phlegm, phlegm alone dyspnea, wheeze, or sneeze increased on consecutive working days from Day 1 to Day 6 or 7, and decreased thereafter, although the decrease was only slight in case of workers with dyspnea and wheeze (Fig. 2).

### 3.3. Distribution of PEFR throughout the day according to main task of the day

The pattern of the PEFR throughout the day on nonwork days and on days when the main task differed is shown in Fig. 3. On nonwork days, the PEFR increased from morning to evening but decreased somewhat before retiring at night. By contrast, on workdays, a similar increase was either less or not evident, and when the main task of the day was loading the kiln or collecting charcoal from the kiln, the PEFR showed a marked decrease at midday and after work in the evening, but increased again at the before-bedtime measurement.

### 3.4. Predictors of the change in PEFR throughout the day according to daily task performed

Table 2 shows the independent relationship between daily task and the PEFR after adjustment for other predictors using a mixed-effects linear regression model. Overall, PEFR values [mean (95% confidence interval)] were 65.3 (40.7, 89.9) dm<sup>3</sup>/min higher among males than among females. The mean value at baseline conditions, namely, among females in the morning of nonwork days, was 390.7 (372.2, 409.3) dm<sup>3</sup>/min. The PEFR increased by 8.4 (5.3, 11.5) dm<sup>3</sup>/min at midday and by 13.5 (10.4, 16.6) dm<sup>3</sup>/min in the evening, but showed no further significant change thereafter. Each successive day up to Workday 7 [i.e.,  $-6.8 \cdot \text{day} + 0.5 \cdot (\text{day})^2$ ] is minimum at



**Fig. 1.** Distribution of model-derived daily average PEFR (dm<sup>3</sup>/min) of charcoal workers on nonwork days (Day 0) and consecutive workdays (Days 1–11). The filled circles and vertical lines represent means and 95% confidence intervals for all workers. Values of PEFR for each day not having a lowercase letter in common differ significantly ( $p < 0.05$ , mixed-effects linear regression model in which the worker is the random element). PEFR, peak expiratory flow rate.

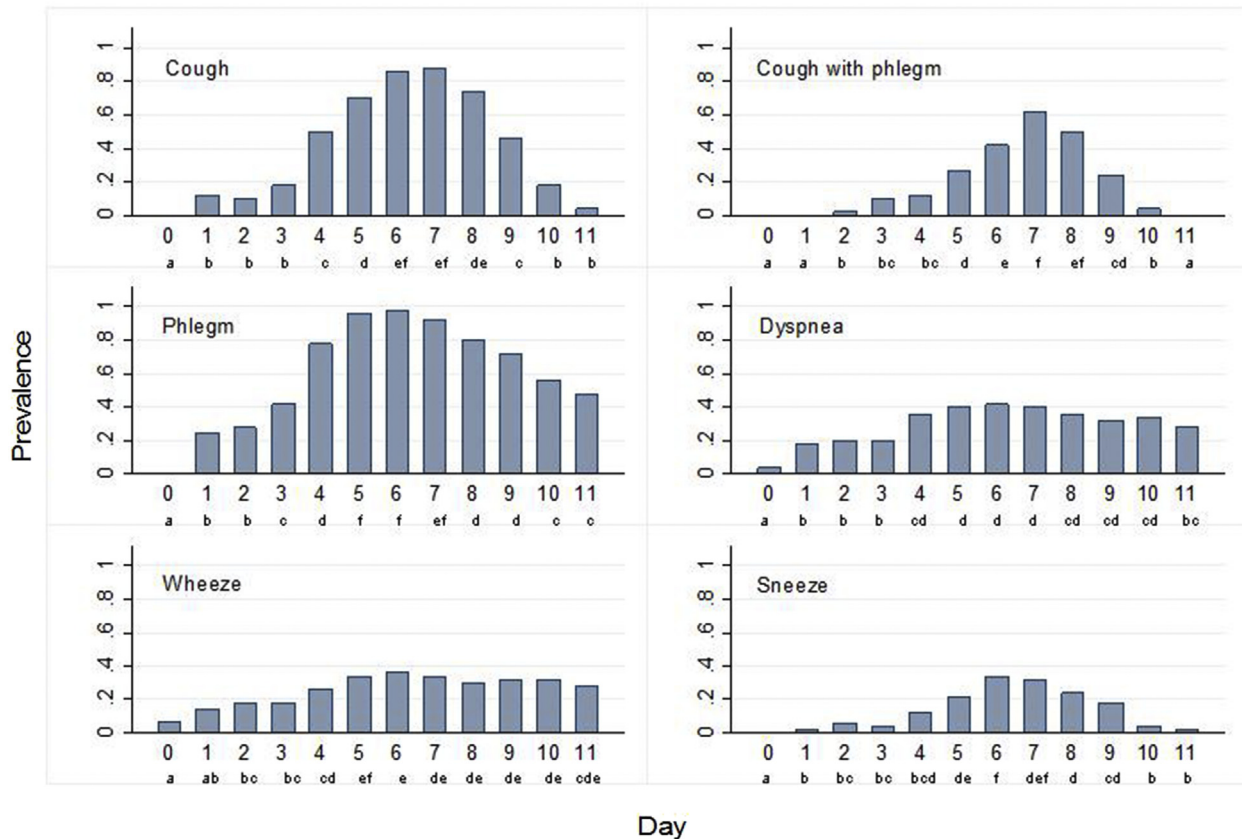


Fig. 2. Distribution of daily prevalence of charcoal workers experiencing respiratory symptoms on nonwork days (Day 0) and consecutive workdays (Days 1–11). Values of prevalence within each symptom not having a lowercase letter in common differ significantly ( $p < 0.05$ , Poisson regression model clustered on workers).

day = 7] was related to a decrease in the PEFR, and thereafter the PEFR recovered slightly. Among the charcoal-related tasks, loading wood into the kiln and collecting charcoal from inside the kiln were associated with large and statistically significant reductions in the change in the PEFR throughout the day compared with those on nonwork days [evening values of  $-18.2$  ( $-22.4, -14.0$ )  $\text{dm}^3/\text{min}$  and  $-17.1$  ( $-21.3, -13.0$ )  $\text{dm}^3/\text{min}$ , respectively]. The effects of carrying wood from the storage place to the outside of the kiln and firing the kiln were not so marked, and were not quite statistically significant. In addition, the level of PEFR on any day was influenced by the tasks performed on the previous day. PEFR values were slightly but significantly reduced when the previous day had been occupied by tasks such as carrying wood or loading wood into the kiln. No significant association of the PEFR with age was found. All but two of the male workers were smokers and all but one of the female workers were nonsmokers. As a result, it was not possible to distinguish the effects of smoking from that of sex.

### 3.5. Predictors of occurrence of respiratory symptoms according to daily task performed

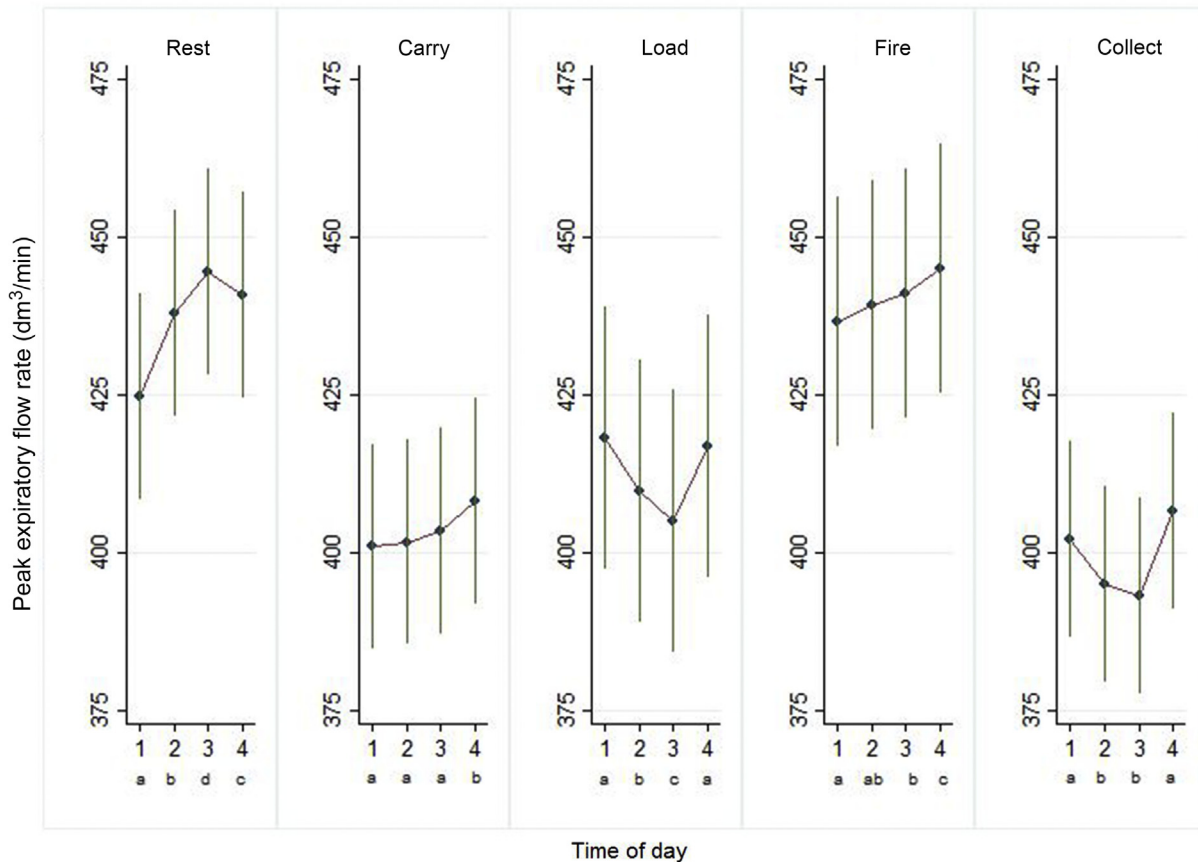
Table 3 shows the results of six separate mixed-effects logistic regression models, one for each respiratory symptom. As respiratory symptoms were recorded only once a day, there is no variable for time of day in the models. The odds ratios (ORs) associated with day and  $(\text{day})^2$  indicate that the probability of symptom occurrence increased with successive workdays up to the 6<sup>th</sup> or 7<sup>th</sup> consecutive workday. After adjusting for cumulative workday and, when statistically significant, smoking, and comparing with nonwork days, loading the kiln was associated with cough [OR 14.1 (4.6, 43.3)],

dyspnea [OR 13.4 (1.5, 122)], wheeze [OR 29.5 (1.7, 516)], and sneeze [OR 11.9 (2.9, 48.2)]; collecting charcoal with wheeze [OR 151 (7.3, 3,120)]; loading the kiln or collecting charcoal (not differentiated owing to small numbers) with cough with phlegm [OR 4.9 (1.8, 13.6)] and phlegm alone [OR 225 (53.1, 952)]; firing the kiln with phlegm [OR 4.0 (1.2, 13.7)]; and carrying wood to the outside of the kiln with cough with phlegm [OR 5.0 (2.0, 12.7)]. Thus, loading the kiln and/or collecting charcoal was associated with increased odds of each respiratory symptom. Carrying wood, however, was associated with a reduced odds of experiencing dyspnea [OR 0.1 (0.02, 0.8)]. In contrast to the effect on the PEFR, the tasks performed on the previous day showed no significant association with the occurrence of any of the respiratory symptoms and were therefore not retained in the logistic regression models. Similarly, neither sex nor age showed a significant association with the occurrence of the respiratory symptoms and were not retained in the models. Smoking showed only a slight, but not quite significant, positive association with the symptom of cough with phlegm [OR 2.4 (0.9, 6.1)].

## 4. Discussion

This study has confirmed the occurrence of short-term adverse effects on the PEFR and occurrence of respiratory symptoms associated with working at a charcoal-production plant, where workers are required to perform a variety of tasks and the processes conducted in different kilns within each plant are not synchronous. Tasks with the greatest effect were those that entailed entering the kiln, i.e., loading the kiln with fresh wood and collecting the already fired charcoal from the inside of the kiln. This may be the result of





**Fig. 3.** Distribution of model-derived PEFR ( $\text{dm}^3/\text{min}$ ) of charcoal workers by task and time of day. The times of day 1–4 refer to morning, midday, evening, and before bed, respectively. The filled circles and vertical lines represent means and 95% confidence intervals for all workers. Values of PEFR within each task for each time not having a lowercase letter in common differ significantly ( $p < 0.05$ , mixed-effects linear regression models in which the worker is the random element). PEFR, peak expiratory flow rate.

intense exposures to wood smoke and charcoal dust, which are likely to be at their highest concentrations in the interior of the kiln.

Numerous studies have shown a decrease in lung function parameters or an increased prevalence of respiratory symptoms associated with long-term domestic or occupational exposure to air pollutants, including wood smoke, and wood and other dust. Thus, the use of biomass fuels (especially wood) compared with liquid petroleum gas for cooking was identified as an important factor associated with a deterioration of pulmonary function (lowered PEFR) among females in western India [11]. Similarly, chronic domestic wood-smoke exposure among Nigerian women was associated with a lowered PEFR, with the magnitude of lowering being related to the duration of exposure [20]. Long-term exposure to inhaled particulate matter has also been shown to be associated with respiratory symptoms and decreased lung function [21–23].

The short-term effects detected in the current study are also consistent with those reported among charcoal-production workers before and during occupational exposure to smoke in Crete [9], and the cross-shift effects among firefighters in the USA [8]. However, most longitudinal studies of the respiratory responses to smoke exposure have focused on the responses to short-term exposures and not, as in our study of charcoal workers and a study of wildland firefighters in the USA [24], on the short-term responses to continued or repeated work-related daily exposure following a nonwork period.

Investigations of the short-term effects of exposure or the effects of short-term exposure, that is, over time periods of  $\leq 24$  hours, need to take into consideration the documented changes in lung function parameters that occur throughout the day even in

normal healthy unexposed individuals [25]. The occurrence of a circadian rhythm in the PEFR has long been known, and this has been used as a reference against which to compare the patterns seen among asthmatic patients. More recently, a circadian rhythm in the PEFR has also been described in healthy geriatric individuals in northern India [26]. The pattern of change in the PEFR in those studies was similar to that seen in our participants on their nonwork days.

Our study compared the changes of the PEFR throughout the day among workers exposed to different charcoal-production tasks or those unexposed on nonwork days. Within each major task conducted on a workday, the change was referenced to the morning value and compared with the corresponding change seen on nonwork days. This nonwork day pattern was markedly changed when the tasks involved entering the kiln, with the normal rise from morning to evening significantly reduced or even reversed. Furthermore, it was demonstrated that the previous day's task also influenced the level of PEFR, with the largest and most significant depression of the PEFR being associated with kiln loading on the previous day.

This carryover effect from one day to the next may explain the progressive drop in median PEFR values over the first 7 consecutive workdays of resuming work after a 3-day nonwork period. While not specifically examined in our study, in which 3 nonwork days were monitored prior to resuming work, the results suggest that PEFR values had recovered at least to some extent during nonwork period, as workers had been working each day until the nonwork period. Unfortunately, the specific tasks carried out on the days prior to the nonwork period were not recorded. Only one report of

**Table 2**Multivariate mixed-effects linear regression model of PEFR (dm<sup>3</sup>/min) among charcoal production workers

Variable	Coefficient*	95% CI	p <sup>†</sup>
Baseline (constant)	390.7	372.2, 409.3	–
Sex			
Male versus female	65.3	40.7, 89.9	<0.001
Time of day			
Morning	0 <sup>‡</sup>	–	<0.001
Noon	8.4 <sup>b</sup>	5.3, 11.5	
Evening	13.5 <sup>c</sup>	10.4, 16.6	
Night	13.1 <sup>c</sup>	10.0, 16.2	
Day of work			
Day	–6.8	–7.6, –5.9	<0.001
(Day) <sup>2</sup>	0.5	0.4, 0.6	
Previous day's task			
Carrying wood	–2.2	–4.4, 0.1	0.037
Loading kiln	–3.4	–5.8, –1.1	0.005
Firing kiln	1.9	0.0, 3.8	0.054
Collecting charcoal	–1.6	–3.6, 0.4	0.126
Task			
Carrying wood	3.1	–0.5, 6.6	0.090
Loading kiln	5.3	–1.7, 9.0	0.004
Firing kiln	5.8	2.4, 9.1	0.001
Collecting charcoal	5.8	2.3, 9.3	0.001
Interaction time × carrying wood			
Morning	0 <sup>‡</sup>	–	0.054
Noon	–4.4 <sup>b</sup>	–8.8, 0.0	
Evening	–6.0 <sup>b</sup>	–10.4, –1.6	
Night	–3.5 <sup>ab</sup>	–7.9, 0.9	
Interaction time × loading kiln			
Morning	0 <sup>‡</sup>	–	<0.001
Noon	–10.8 <sup>b</sup>	–15.0, –6.6	
Evening	–18.2 <sup>c</sup>	–22.4, –14.0	
Night	–11.3 <sup>b</sup>	–15.5, –7.1	
Interaction time × firing kiln			
Morning	0 <sup>‡</sup>	–	0.050
Noon	–3.7 <sup>ab</sup>	–7.8, 0.5	
Evening	–5.8 <sup>b</sup>	–9.9, –1.7	
Night	–2.7 <sup>ab</sup>	–6.8, 1.5	
Interaction time × collecting charcoal			
Morning	0 <sup>‡</sup>	–	<0.001
Noon	–12.2 <sup>c</sup>	–16.4, –8.1	
Evening	–17.1 <sup>d</sup>	–21.3, –13.0	
Night	–5.4 <sup>b</sup>	–9.6, –1.2	

\* Coefficients within each variable not having a superscript letter in common differ significantly ( $p < 0.05$ , Wald test).† Values of  $p$  are from Wald test.

CI, confidence interval; PEFR, peak expiratory flow rate.

similar time-series daily recording of respiratory effects during occupational exposure has been identified from the literature [24]. In that study, measurements of lung function in nonsmoker wild-land firefighters were made pre- and postshift over a period including both burn days and nonburn days, and the effect of cumulative exposure during the burn season was explored. Cross-shift differences in forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV<sub>1</sub>) did not differ significantly between burn days and nonburn days, but a progressive decline in these measurements was seen as the season progressed. Most studies of the effects of occupational exposure to wood smoke, however, have simply compared respiratory function and symptoms before exposure and after cessation of exposure [8,27–30], or between two time points during occupational exposure [9]. Others have conducted long-term follow-up studies [31], and still others have simply used one-time cross-sectional data [17].

Although the previous day's task was not found to influence the occurrence of respiratory symptoms on any day, there was nevertheless a progressive increase in the prevalence of respiratory symptoms on successive workdays up to the 6–7<sup>th</sup> consecutive workday, closely mirroring the reduction in the PEFR. The increasing prevalence was especially evident with cough, cough with phlegm, phlegm alone, and sneeze.

**Table 3**

Predictors of respiratory symptoms among charcoal production workers from mixed-effects logistic regression models

Variable	a-OR	95% CI	p*
Cough			
Day	12.3	7.3, 20.7	<0.001
(Day) <sup>2</sup>	0.82	0.75, 0.85	
Carrying wood	1.3	0.5, 3.2	0.633
Loading kiln	14.1	4.6, 43.3	<0.001
Firing kiln	1.3	0.5, 3.3	0.650
Collecting charcoal	1.5	0.6, 3.6	0.386
Cough with phlegm			
Day	31.3	11.9, 81.9	<0.001
(Day) <sup>2</sup>	0.87	0.72, 0.83	
Smoker	2.4	0.9, 6.1	0.067
Carrying wood	5.0	2.0, 12.7	0.001
Loading kiln and/or collecting charcoal	4.9	1.8, 13.6	0.002
Firing kiln	2.1	0.8, 6.0	0.157
Phlegm			
Day	4.9	3.0, 7.8	<0.001
(Day) <sup>2</sup>	0.81	0.86, 0.92	
Carrying wood	0.6	0.2, 2.4	0.512
Loading kiln and/or collecting charcoal	225	53.1, 952	<0.001
Firing kiln	4.0	1.2, 13.7	0.028
Dyspnea			
Day	9.6	4.5, 20.4	<0.001
(Day) <sup>2</sup>	0.85	0.86, 0.90	
Carrying wood	0.1	0.02, 0.8	0.024
Loading kiln	13.4	1.5, 122	0.021
Firing kiln	4.7	0.9, 24.1	0.063
Collecting charcoal	2.2	0.5, 10.0	0.302
Wheeze			
Day	3.3	1.5, 7.5	0.001
(Day) <sup>2</sup>	0.94	0.88, 1.00	
Carrying wood	0.9	0.1, 10.0	0.913
Loading kiln	29.5	1.7, 516	0.020
Firing kiln	2.7	0.3, 21.4	0.359
Collecting charcoal	151	7.3, 3,120	0.001
Sneeze			
Day	13.4	5.3, 33.6	<0.001
(Day) <sup>2</sup>	0.81	0.76, 0.87	
Carrying wood	2.5	0.6, 10.0	0.184
Loading kiln	11.9	2.9, 48.2	0.001
Firing kiln	4.3	1.0, 19.1	0.056
Collecting charcoal	1.4	0.4, 5.0	0.644

\* The  $p$  values are from Wald test or combined Wald test.

a-OR, adjusted odds ratio.

Similar to the effects of different tasks on the depression of the PEFR, loading the kiln and/or collecting charcoal—the two tasks requiring work within the kiln—was most closely associated with the occurrence of respiratory symptoms, especially cough, phlegm, dyspnea, wheeze, and sneeze.

Wood smoke has been reported to generate a complex mixture composed of liquids, solids, gases, and particles such as carbon monoxide, carbon dioxide, ammonia, nitrogen oxides, polycyclic aromatic hydrocarbons, sulfur oxides, benzene, methanol, styrene, phenols, aldehydes, and organic acids that contribute to the occurrence of respiratory symptoms and short-term decline in lung function [5–7]. Wood-smoke particles are generally smaller than 1  $\mu$ m and tend to be deposited in the peripheral airways, where they may have irritant and toxic effects [32–34]. Furthermore, nitrogen oxides, sulfur oxides, and aldehydes in wood smoke can produce short-term irritation of the eyes and mucous membranes of the upper respiratory tract, causing vascular membrane injury and leakage leading to pulmonary edema, bronchoconstriction, and increased infection rates [5]. This may explain the increased occurrence of cough, phlegm, dyspnea, sneeze, and wheeze seen in charcoal workers on days that they were occupied in loading a kiln and/or collecting charcoal after firing from within the kiln.

In view of these known deleterious effects of exposure to wood smoke, it may seem counterintuitive that in the current study, kiln firing was the task associated with a relatively small effect on the PEFR throughout the working day and a relatively small effect on

the occurrence of respiratory symptoms, significant only for the occurrence of phlegm. However, although the kilns kept burning for several days, the actual task of starting up or firing the kiln did not take long, and once the kiln was burning the workers moved to perform other tasks. Furthermore, it was observed that the smoke emitted from burning kilns was usually dispersed by local winds, so that the atmospheric concentration was rarely very high. Furthermore, firing of each kiln within a plant was not conducted simultaneously. Carrying wood from outside the kiln area to the side of the kiln, which involves spending much of the time away from the immediate vicinity of the kilns, was also associated with a relatively small effect throughout the day on the depression of the PEFR, although increasing the occurrence of cough with phlegm.

Apart from the demonstration of these adverse effects of certain charcoal-production tasks on the PEFR and occurrence of respiratory symptoms, it is also of interest that the depression of the PEFR and the increased occurrence of cough, cough with phlegm, phlegm alone, and sneeze began to recover after the first 6 days or 7 days following the nonwork period, suggesting the development of a degree of adaptation to the adverse working conditions over the 1<sup>st</sup> week of working following a nonwork period. Transient effects on FEV and on respiratory symptom lasting about 1 week were described among wildland firefighters, but these measures were made on individuals after cessation of exposure [28].

A number of limitations to this study should be considered. First, the sample size was small, which resulted in wide confidence intervals in the regression models. Second, although more than one task was sometimes performed on a given day, the time of day when the task was performed was not recorded consistently. This could have the effect of either diluting or overestimating the magnitude of relationship with change in the PEFR and occurrence of symptoms. Third, as mentioned above, the tasks performed on the days preceding the nonwork period were not recorded, thereby allowing only speculation on the improvement in respiratory function associated with stopping of work for a number of days. Lastly, while measurements in the morning, at midday, and in the evening and checklist completion in the evening were conducted by members of the research team, these measurements and recordings were performed by the workers themselves before going to bed at night. This might have introduced some errors or inconsistencies to the data.

Nevertheless, the study has merit in the completeness of the data, obtained from measurements taken four times a day for 14 days, including both 3 nonwork days and subsequent 11 consecutive days of working, affording some insight into the nature of short-term changes in respiratory function in relation to daily cycle, cumulative days in work, and type of task performed. In addition, the data were analyzed using mixed-effects regression models, which provide a powerful method for adjusting for correlations among repeated measures on each participant.

In conclusion, tasks involving entry into the kiln were strongly associated with a short-term drop in the PEFR during the working hours of the day and with the occurrence of respiratory symptoms on those days that these tasks were performed, compared with the conditions on nonwork days. The identification of high-risk tasks should provide a logical basis for safety recommendations such as the use of personal protective equipment when entering a kiln and/or the installation of an effective ventilation system in the kilns to be operated between burnings.

### Conflicts of interest

The authors declare that they have no conflicts of interest relevant to the study reported in this manuscript.

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