Epidemiologic evidence suggests that exposures to short-term ambient ozone are associated with consistent and reversible decrements in lung function among children (Burnett et al. 2001; Chen et al. 1999; Hoppe et al. 2003; Jalaludin et al. 2000), the elderly (Hoppe et al. 1995, 2003), and people with a history of respiratory diseases (Hoppe et al. 1995, 2003; Jorres et al. 1996; Kehrl et al. 1999). Recent studies also found that exposures to O₃ are related to healthy adults’ decreases in lung function, such as forced expiratory volume in 1 sec (FEV₁), forced vital capacity (FVC), and peak expiratory flow rate (PEFR) (Kinney and Lippmann 2000; Korrick et al. 1998; Naeher et al. 1999; Spektor et al. 1988). These effects usually occur at ambient O₃ concentrations between 30 and 80 ppb during high O₃ hours between 0900 and 1700 hr. Such O₃ concentrations are lower than the U.S. ambient air quality standards for O₃, which are an 8-hr average at 80 ppb and a 1-hr maximum at 120 ppb, and below the permissible exposure level for workers promulgated by the U.S. Occupational Safety and Health Administration (2004), which is an 8-hr time-weighted average of 100 ppb. Incidentally, the exposure duration between 0900 and 1700 hr described in previous studies happens to be the time when most mail carriers travel door to door to deliver mail and packages in Taiwan. Daytime ambient O₃ concentrations these mail carriers experience, therefore, are expected to be very close to their occupational exposures. Because potential health effects due to this particular exposure scenario have not been reported before, we conducted this study to assess whether exposure to O₃ at concentrations below current permissible levels will reduce mail carriers’ lung function.

**Materials and Methods**

**Study population.** The study group consisted of 43 mail carriers who were randomly selected from 215 full-time mail carriers working in a main post office of Taichung City, Taiwan. To cover a service area of approximately 10 km² and a half million residents, these mail carriers use either motorcycles or bicycles to deliver mail from 0900 to 1700 hr daily on preassigned delivery routes. A face-to-face questionnaire survey was performed in advance in September 2001 to obtain data from each mail carrier, including age; height; weight; smoking status; disease history of doctor-diagnosed asthma, bronchitis, and pneumonia; and incense burning and environmental tobacco smoke (ETS) exposures at home. Our field study took place from 14 November to 31 December 2001. The Institutional Review Board of National Taiwan University College of Public Health approved the research protocol, and written informed consent was obtained from each participant.

**Lung function measurement.** We chose PEFR as the outcome variable for lung function because it is highly correlated with FEV₁ in clinical diagnosis (Nowak et al. 1982) and widely used in epidemiology studies (Jalaludin et al. 2000; Krzyzanowski et al. 1992; Naeher et al. 1999; Peters et al. 1999). Each mail carrier was provided with a Midget peak expiratory flow meter (Medget Quan-ding Inc., Taipei City, Taiwan) to measure morning PEFR after awakening and night PEFR between 1000 and 1200 hr daily. Each mail carrier was trained to take three consecutive PEFR readings in the standing position in each measurement. The PEFR measurement was considered valid when the variation of three consecutive readings was < 10%. The best value of three readings was selected for use in further analysis. Our PEFR measurements were conducted between 14 November and 31 December 2001. The PEFR data of the first 3 days were used solely to validate our study subjects’ PEFR measuring technique and were not used in further data analyses. A daily maximum PEFR and daily deviation of PEFR for both morning and night PEFR data were used as outcome variables in our statistical models. Daily deviation of PEFR was defined as the difference between the daily highest PEFR reading and the 6-week average PEFR calculated according to the methods of Pope and Dockery (1992). We present here only the findings of night PEFR to keep our results as concise and informative as possible.

**Monitoring of ambient air pollutants.** To estimate the daily exposure of each mail carrier to air pollutants, we abstracted hourly air pollution levels of O₃, particulate matter < 10 µm in aerodynamic diameter (PM₁₀), and nitrogen dioxide from one air monitoring station in the center of each mail carrier’s delivery area according to their daily working hours. The air monitoring station operated in Taichung City, Taiwan, by the Taiwan Environmental Protection Administration (2005) also provided hourly meteorologic data on wind direction, wind speed, temperature, dew point, and precipitation. The locations of the air monitoring stations and post office in this study are shown in Figure 1. The environmental data were not used in further data analyses if there were > 20% of hourly values missing in a single day. The 8-hr average and maximum
values for O₃, NO₂, and PM₁₀ between 0900 and 1700 hr were calculated from the data obtained from this monitoring station to represent each subject’s daily exposures to air pollutants. We also summarized meteorologic variables of temperature and relative humidity for the same time segments.

**Statistical methods.** We used a two-step statistical model to estimate the association between PEFR and O₃ exposures. Multiple linear regressions (MLR) without air pollutants were first used to screen key PEFR-related personal covariates with a p-value < 0.25 for further analyses according to the methods of Peters et al. (1999) and Krzyzanowski et al. (1992). In the second step, linear mixed-effects models were used to estimate the pollution effects on PEFR adjusting for personal and meteorologic variables. Such mixed-effects models have the advantage of adjusting for invariant variables by fixed-effects models and accounting for individual differences by random-effects models. We treated subject’s sex; age; body mass index; history of diagnosed respiratory disease; smoking status; air pollutants O₃, PM₁₀, and NO₂; ambient temperature; and relative humidity as fixed effects and each subject as a random effect in the mixed-effects models. Each of the three air pollutants considered was first put into the linear mixed-effects models separately as single-pollutant models. All of the three pollutants were then jointly put into the linear mixed-effects models as multipollutant models. Air pollution levels with 0- to 3-day lags were used to estimate the time effects models because our MLR models without air pollutants found that these covariates were associated with PEFR. By contrast, covariates of incense burning and ETS were not included in our second-step models because they were not significantly associated with PEFR. Table 4 lists the results of single-pollutant mixed-effects models separately for O₃, PM₁₀, and NO₂. Only O₃ was consistently associated with decreases in night PEFR and the deviation in night PEFR among these three air pollutants. The night PEFR of the mail carriers was significantly reduced in association with 8-hr average O₃ concentrations with 0- to 2-day lags and maximum O₃ concentrations during exposure periods with 0- to 1-day lags. The deviation in night PEFR was reduced in association with both 8-hr and maximum O₃ concentrations with 0- to 2-day lags. Instead of consistent correlation between O₃ and PEFR, we found NO₂ effects on both night PEFR and night PEFR deviation at the 2-day lag only, and no PM₁₀ effects on either night PEFR or night PEFR deviation.

We then put O₃, PM₁₀, and NO₂ with 0- to 3-day lags in the multipollutant mixed-effects models to estimate the pollution effects on decrease in PEFR by adjusting co-pollutants and key meteorologic factors. We found that O₃ was associated with PEFR after adjusting for PM₁₀, NO₂, and other covariates. By contrast, PEFR reduction was not associated with either PM₁₀ or NO₂ in the multipollutant models.

![Figure 1. Map of Taichung City.](image)

**Table 1. Basic characteristics of 43 mail carriers participating in the study (PEFR measurement period from 17 November through 31 December 2001).**

| Characteristic                  | Male            | Female          | Total |
|--------------------------------|-----------------|-----------------|-------|
| No. of subjects (%)            | 39 (91)         | 4 (9)           | 43    |
| Age [years (mean ± SD)]        | 38.1 ± 9.6      | 30.7 ± 4.4      | 39 ± 6.7 |
| Work [years (mean ± SD)]       | 12.2 ± 6.7      | 11.3 ± 0.5      | 13 ± 6 |
| Height [cm (mean ± SD)]        | 169.0 ± 4.9     | 160.4 ± 8.4     | 167.9 ± 5.5 |
| Weight [kg (mean ± SD)]        | 66.8 ± 9.6      | 62.8 ± 5.3      | 65.8 ± 7.1 |
| Disease history                |                 |                 |       |
| Asthma [n (%)]                 | 0 (0)           | 0 (0)           | 0 (0) |
| Bronchitis [n (%)]             | 2 (5)           | 0 (0)           | 2 (5) |
| Pneumonia [n (%)]              | 1 (5)           | 0 (0)           | 1 (2) |
| Smoking status                 |                 |                 |       |
| Current smoker [n (%)]         | 15 (38)         | 0 (0)           | 15 (35) |
| Nonsmoker [n (%)]              | 24 (57)         | 4 (100)         | 28 (60) |
| ETS at home [n (%)]            | 9 (23)          | 0 (0)           | 9 (21) |
| Incense burning at home [n (%)] | 13 (33)         | 2 (50)          | 15 (35) |
| No. of PEFR measurements       | 986             | 87              | 1,073 |
As shown in Figure 2A, night PEFR and deviation in night PEFR were significantly decreased by O₃ exposures up to a 2-day lag after adjusting for co-pollutants and key personal covariates. Night PEFR was decreased by 0.54% for 0-day lag, 0.69% for 1-day lag, and 0.52% for 2-day lag. Compared with 8-hr O₃, 1-hr O₃ had comparatively less effect on decreasing night PEFR, which was 0.36% for 0-day lag and 0.44% for 1-day lag. As shown in Figure 2B, the effect of O₃ exposure on the deviation in night PEFR had the same time course as its effects on night PEFR. However, the effects of O₃ exposure on the deviation in night PEFR were smaller compared with its effects on night PEFR for the same time lag. Our multipollutant mixed-effects models thus showed that ambient 8-hr O₃ concentrations had greater and longer effects on decreasing PEFR than did maximum O₃ concentrations during exposure periods. No other covariate except ambient temperature was significantly related to night PEFR and the deviation in night PEFR in our multipollutant mixed-effects models. In addition, subjects’ disease history, including asthma, bronchitis, and pneumonia, had a negative but statistically insignificant influence on PEFR in our multipollutant mixed-effects models. We also found similar O₃ effects on morning PEFR deviation but not morning PEFR in our multipollutant mixed-effects models (data not shown).

### Discussion

This is the first study to demonstrate that there are effects of occupational O₃ exposures lagged 0–2 days on reducing mail carriers’ lung function. Such effects can be detected by using either PEFR or PEFR deviation as an indicator of lung function. After occupational exposures during daytime work, night PEFR measurements seem to be more sensitive to O₃ exposures than are morning PEFR measurements. Because none of our study subject’s daily O₃ exposure exceeded the hourly standard of 120 ppb, our study supports previous findings from studies in the United States and Canada of a dose–response relationship between lung function change and O₃ exposure at relatively low daytime ambient concentrations for healthy adults. Exercising healthy adults in New York City (USA) who were exposed to < 80 ppb O₃ were reported to have a 0.55-L/min decrease in their PEFR per 1 ppb O₃ (Spektor et al. 1988); healthy women exposed to 8-hr O₃ at 54 ppb in Connecticut and Virginia (USA) were reported to have a 0.083-L/min/ppb decrease in their PEFR per 1 ppb O₃ (Naether et al. 1999); farm workers in Fraser Valley (Canada) who were exposed to a 1-hr daily maximum O₃ of 40 ppb were reported to have 3.3-mL and 4.7-mL decreases in their FEV₁ and FVC, respectively, per 1 ppb O₃ (Brauer et al. 1996). A similar dose–response relationship between O₃ and PEFR reduction was also reported in some European studies. Male cyclists in the Netherlands who were exposed to < 60 ppb O₃ were reported to have 0.57-L/min decreases in PEFR per 1 ppb O₃ (Brunekeef et al. 1994); healthy workers and athletes in Germany

### Table 2. Summarized statistics for air pollutants and meteorologic data during the study period (14 November through 31 December 2001).

| Variable | No. | Mean ± SD | Minimum | Maximum |
|----------|-----|-----------|---------|---------|
| O₃ (ppb) | 44  | 25.6 ± 12.1 | 7.6 | 65.1 |
| PM₁₀ (µg/m³) | 43  | 74.7 ± 37.9 | 19.1 | 213.8 |
| NO₂ (ppb) | 43  | 30.0 ± 10.1 | 17.3 | 65.9 |
| Temperature (°C) | 45  | 19.1 ± 3.4 | 12.2 | 24.2 |
| Relative humidity (%) | 45  | 71.5 ± 6.6 | 59.0 | 88.0 |
| Maximum during exposure periods | 44  | 52.6 ± 18.8 | 5.6 | 95.5 |
| NO₂ (ppb) | 43  | 108.8 ± 44.8 | 11.4 | 249.0 |
| PM₁₀ (µg/m³) | 43  | 52.9 ± 21.8 | 14.0 | 91.6 |

*Mail carriers’ exposure periods are about 8 hr between 0600 and 1700 hr every working day.

### Table 3. Pearson correlation coefficients for air pollutants and meteorologic data during the study period (14 November through 31 December 2001).

| Variable | O₃ | PM₁₀ | NO₂ | Temperature | Relative humidity |
|----------|----|------|-----|-------------|------------------|
| O₃      | 1.00 |      |      |             |                  |
| PM₁₀    | 0.211 | 1.00 |      |             |                  |
| NO₂     | 0.083 | 0.854** | 1.00 |             |                  |
| Temperature | 0.010 | 0.402** | 0.353* | 1.00 |                  |
| Relative humidity | -0.413** | 0.088 | -0.063 | 0.460** | 1.00 |

*p < 0.05; **p < 0.01.

### Table 4. Regression coefficients (95% CIs) of individual pollutants on PEFR estimated by single-pollutant linear mixed-effects models.

| 8-hr average for exposure period | Night PEFR | Hourly maximum for 8-hr exposure period |
|---------------------------------|------------|---------------------------------------|
| O₃                              | Lag 0      | Lag 1       | Lag 2       | Lag 3       | Lag 0      | Lag 1       | Lag 2       | Lag 3       |
| PM₁₀                            | -0.33**    | -0.38**     | -0.37**     | -0.22       | -0.33**    | -0.38**     | -0.37**     | -0.22       |
| NO₂                             | 0.02       | 0.04        | 0.04        | 0.02        | 0.01       | 0.01        | 0.01        | 0.02        |
| O₃                              | 0.09       | 0.19        | 0.26        | 0.08        | 0.01       | 0.01        | 0.01        | 0.02        |
| PM₁₀                            | -0.06       | -0.04       | -0.04       | -0.08       | -0.01      | -0.01       | -0.01       | -0.02       |
| NO₂                             | -0.02       | -0.02       | -0.02       | -0.02       | -0.02      | -0.02       | -0.02       | -0.03       |

*p < 0.05; **p < 0.01.
who were exposed to < 80 ppb \( O_3 \) were also reported to have decrements in their FEV\(_1\) (Hoppe et al. 1995). Our study also further reported acute effects of \( O_3 \) on hospitalization for acute respiratory diseases in children less than 2 years of age. Am J Epidemiol 153:444–452. Castillejos M, Gold DR, Dockery DW, Tosteson T, Baum T, Speizer FE. 1992. Effects of ambient ozone on respiratory function and symptoms in Mexico City schoolchildren. Am Rev Respir Dis 145:276–282.

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