ORIGINAL ARTICLE

Unflued gas heaters and respiratory symptoms in older people with asthma

PJ Franklin,1,2 J Loveday,1,2 A Cook1,2

ABSTRACT

Background Unflued gas heaters (UFGHs) and cookers are a major contributor to air pollution in homes. Gas appliances have been associated with adverse respiratory outcomes in children and, less consistently, adults. There have been very few studies on the effects of gas appliances on the respiratory health of older people.

Objectives This study investigated the daily lung function and respiratory symptoms of older people (>55 years of age) who did and did not use an UFGH as a primary source of heating.

Methods 71 patients with asthma were recruited for the study. Each patient participated for one 12-week winter period. All patients recorded daytime and nighttime symptoms in a diary and completed morning and evening peak flow and forced expiratory volume in 1 s for the study period. General estimating equations were used to measure the associations between symptoms and lung function outcomes and same and previous day (lag 1) UFGH exposure.

Results Same and previous day (lag 1) UFGH exposure was associated with significantly increased ORs for wheeze and dyspnoea compared with days on which no heating was used. Furthermore, there were significant increases in the average odds of reported wheeze and dyspnoea per hour of UFGH heater use. Small but significant reductions in morning to evening peak flow and forced expiratory volume in 1 s were observed on the days an UFGH was used compared with days when other heating was used or there was no heating.

Conclusion Exposure to UFGHs may have a detrimental effect on symptoms and lung function in older people with mild to moderate asthma.

INTRODUCTION

Unflued gas cookers and heaters are a major source of nitrogen dioxide (NO2), nitrous acid and carbon monoxide (CO) indoors.1 They can also emit formaldehyde and produce water vapour.2 In Australian homes combustion gases from unflued gas heaters (UFGHs), particularly NO2, can be significantly elevated during their operation, with peak concentrations reaching as high as 700 μg/m3.3 Although high peak NO2 concentrations can be obtained when using an unflued gas stove,4 UFGHs have been shown to be the major source of both indoor concentrations and personal exposure to NO2 in Perth, Western Australia, where the study was conducted.5

Exposure to gas appliances or indoor NO2 has been associated with an increase in respiratory symptoms in children and worsening of asthma in children and adults.6 The Institutes of Medicine (US) recently concluded that NO2 is one of the few indoor pollutants for which there is sufficient evidence of a positive association between NO2 and asthma exacerbations.6 However, the findings remain inconsistent,7 and the Institutes of Medicine recommended future research to target population subgroups that are likely to be most exposed to determine the relationship between exposure of indoor NO2 and asthma.6

Older people, particularly those with existing cardio-respiratory diseases, may be more prone to the effects of air pollution than younger age groups.8 Few studies have addressed the adverse effects of indoor air pollution on respiratory health in older people.9 Some studies have, directly or indirectly, investigated the effect of either gas appliances10 11 or indoor NO212 13 on respiratory health in older age groups, but the results are conflicting. Older people, on average, spend more hours at home than other age groups (with the exception of infants),14 especially if they have a chronic illness.15 As ageing is associated with a decline in body thermoregulation and impaired peripheral temperature perception,16 older people have a greater need for heating during the winter.17 An increased need for heating in winter, combined with reduced home ventilation, can contribute to an accumulation of indoor pollutants, raising the risk of exposure to combustion products.9 The aim of the study was to investigate if using an UFGH during winter is detrimental to the respiratory health of older people with asthma.

METHODS

Subjects and protocol

Patients with asthma over 55 years of age were recruited from a patient database at the Lung Institute of Western Australia (LIWA). Apart from age, inclusion criteria were a history of physician-diagnosed asthma with evidence of symptoms in the past 12 months. Exclusion criteria were current smoking and the presence of respiratory comorbidities, such as doctor-diagnosed chronic obstructive pulmonary disease (COPD).

The study was conducted over two consecutive 12-week winter periods (2007 and 2008) but each patient only participated for one winter season. On recruitment, baseline lung function (spirometry) was measured and patients completed a questionnaire. During the 12-week study period people were asked to complete a daily respiratory symptom diary in the morning and evening. Patients also recorded the use of heaters and cookers during each day. All patients were provided with an electronic lung...
function monitor to measure morning and evening lung function. Patients were visited every 2 weeks to collect and replace completed diaries. The study was approved by the University of Western Australia Human Research Ethics Committee.

Techniques
Baseline lung function
Baseline spirometry was measured, in accordance with the American Thoracic Society guidelines, in the patient’s home using a portable spirometer (EasyOne Spirometer, ndd Medizintechnik AG, Zurich, Switzerland). Up to five measurements were collected to obtain at least two technically satisfactory manoeuvres. Quality grades of C or greater were accepted. Measurements were recorded for forced vital capacity, forced expiratory volume in 1 s (FEV₁), peak flow (PEF) and mid-expiratory flows (FEF25–75). Data were downloaded using Easyware software (Easyware V2.9, ndd Medizintechnik AG, Zurich, Switzerland). Predicted values were calculated using published reference values.

Baseline questionnaire
Two questionnaires were completed by the patients on the first home visit. The first questionnaire asked about the home environment, including primary heating and cooking fuels, age of house, distance of home from busy roads, and presence of pets. The second questionnaire included questions on asthma severity (intermittent/mild or persistent), age at asthma diagnosis, seasonal asthma and medication. The questionnaire was based on severity criteria specified by the Australian National Asthma Council and has been used previously.

Symptom diary
Self-reported respiratory symptoms were recorded separately for each day and night on a 14-day diary. Patients were asked to indicate the presence and severity of symptoms on a scale of 0–3, with 0 = none, 1 = mild, 2 = moderate, 3 = severe. Symptoms included wheeze, cough and dyspnoea. Patients completed the diary at night (for daytime symptoms) and on first rising in the morning (for night-time symptoms). Reliever medication usage was also recorded. Patients were asked to record if, and for how long, a heater or cooker was used when they were at home on each day. If patients had more than one type of heater they were asked to specify the type of heater that was used on a particular day.

Daily lung function
Patients were provided with an electronic lung function monitor (PiKo-I, Ferraris Cardiorespiratory Co, Louisville, Colorado, USA) to measure lung function first thing in the morning and before retiring in the evening. Patients were instructed to measure lung function prior to taking any asthma medication. The PiKo-I measures FEV₁ and PEF and has been compared favourably with the mini-Wright PEF metre. Patients were trained in using the monitors during the first home visit. At least three, and up to a total of five, measurements were collected in the morning and evening and recorded in the diary.

Statistical analyses
Baseline data
Baseline lung function, age at the time of the study, age at first diagnosis of asthma and asthma severity parameters were compared among patients who used an UFGH as the primary heating source and those who had other heaters using Student t tests, Mann–Whitney U tests and χ² tests.

Study data
Symptom frequencies (wheeze, cough and dyspnoea) and mean PEF and FEV₁ measurements across the entire study period were compared for the following exposure groups: days on which UFGHs were used versus days on which other forms of heating were used; days on which UFGHs were used versus days on which no heaters of any kind were used; and days on which other heaters were used versus days on which no heaters of any kind were used. Daily heater use was analysed as a dichotomous ‘yes/no’ variable for each measurement day. Relationships between daily hours of heater use and both symptoms and lung function were also investigated separately for UFGHs and other heaters. Same day and previous day (lag 1) analyses were conducted.

For symptom frequency, daytime and night-time symptoms were combined and the presence and severity were collapsed into dichotomous variables (none/mild and moderate/severe). The percentage of measurement days with symptoms was assessed for each patient. Use of asthma reliever medication (yes/no) on each measurement day was also assessed.

Lung function was assessed in two ways. First, as the daily difference, as a percentage, from the mean for each patient across the whole study period. This was analysed separately for morning and evening PEF and FEV₁, although only the evening values were assessed for same day exposures. Second, changes from morning to evening for PEF and FEV₁ were investigated using the following calculation:

\[
\text{Morning PEF/FEV₁} - \text{evening PEF/FEV₁} \times 100
\]

Only same day exposures were assessed for morning to evening change. Analyses were also conducted for each patient to determine intra-individual variability of FEV₁ and PEF over the study period. All lung function variables were normally distributed.

Generalised estimating equations (GEE) with an autoregression AR(1) (within-subject) correlation structure were used for advanced analysis. Analyses were conducted to investigate daily lung function and symptoms with daily heater use, as a dichotomous variable and reported hours of use. All GEE estimates were adjusted for other factors, including age and gender, use of gas cookers (yes/no), smoking in the home (yes/no), meteorological conditions and ambient NO₂. Meteorological records for ambient daily temperatures and relative humidity, and outdoor NO₂ concentrations were obtained for each study day from urban monitoring stations. Further, both calendar day and the relative day of the study were included in the models. For the GEE models, Gaussian models with identity link functions were used for percentage changes in PEF and FEV₁ relative to the overall mean for each patient. This relative ‘intra-individual’ measure was used in preference to absolute lung function values, which can vary among patients because of differences in height, age and other attributes unrelated to the exposure of interest. For dichotomised outcomes binomial models with logit link functions were used to derive ORs. Missing and incomplete data were assessed for each patient. Residual analyses were conducted to identify outlying measurements. All statistical analyses were conducted with Stata/MP 10.0.

The study had at least 80% power (with type I error probability α = 0.05) to detect differences in risk estimates of symptoms with an OR of at least 1.30. For lung function measurements, the study had at least 80% power to detect...
Clinical parameters


Table 1 Baseline characteristics of patients

<table>
<thead>
<tr>
<th>Baseline characteristics</th>
<th>UFGH (n = 33)</th>
<th>Other heating (n = 38)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex (F/M)</td>
<td>18/15</td>
<td>23/15</td>
<td>0.641</td>
</tr>
<tr>
<td>Age (years)*</td>
<td>70.0</td>
<td>67.5</td>
<td>0.132</td>
</tr>
<tr>
<td>(64.0–71.0)</td>
<td>(66.0–76.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occupation (prof/semi/trades) †</td>
<td>19/6/7</td>
<td>21/11/4</td>
<td>0.345</td>
</tr>
<tr>
<td>Socioeconomic Index* ‡</td>
<td>83.0</td>
<td>81.0</td>
<td>0.867</td>
</tr>
<tr>
<td>(61.0–91.5)</td>
<td>(67.5–94.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline lung function measurements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Pred FVC§</td>
<td>96.9 (21.7)</td>
<td>98.5 (20.1)</td>
<td>0.492</td>
</tr>
<tr>
<td>% Pred FEV₅§</td>
<td>76.0 (16.1)</td>
<td>79.3 (25.9)</td>
<td>0.467</td>
</tr>
<tr>
<td>% FEV₅/FVC§</td>
<td>64.3 (10.0)</td>
<td>64.0 (14.3)</td>
<td>0.930</td>
</tr>
<tr>
<td>% Pred PEF§</td>
<td>87.1 (22.3)</td>
<td>90.7 (26.0)</td>
<td>0.383</td>
</tr>
<tr>
<td>Clinical parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asthma severity</td>
<td>17/15¶</td>
<td>18/20</td>
<td>0.301</td>
</tr>
<tr>
<td>(intermittent/persistent)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily inhaled corticoid steroid use</td>
<td>28/33 (85%)</td>
<td>34/38 (90%)</td>
<td>0.316</td>
</tr>
<tr>
<td>Ex-smokers</td>
<td>17/33 (53.1%)</td>
<td>15/37 (46.9%)</td>
<td>0.253</td>
</tr>
<tr>
<td>Age at asthma diagnosis (years)*</td>
<td>23.0 (5.0–63.0)</td>
<td>36.0 (13.5–55.0)</td>
<td>0.316</td>
</tr>
<tr>
<td>Seasonal asthma</td>
<td>21/33 (65.7%)</td>
<td>19/38 (50.0%)</td>
<td>0.334</td>
</tr>
<tr>
<td>Symptoms occurring primarily in winter</td>
<td>16/32 (50%)</td>
<td>13/35 (37.1%)</td>
<td>0.164</td>
</tr>
</tbody>
</table>

*Median (IQR).
† Prof, professional; semi, semi-professional; trades, tradesperson.
‡ Index of socio-economic disadvantage based on residential address.
§ Mean (SD).
¶ Missing data point.
UFGH, unflued gas heater; FEV₅, forced expiratory volume in 1 s; FVC, forced vital capacity; PEF, peak expiratory flow; Pred, predicted.

RESULTS

Baseline data

Seventy-seven patients were recruited into the study. Two patients were excluded due to comorbidities and four withdrew because they could not complete the requirements of the study. A full set of data were analysed for 71 patients. All patients were Caucasian with similar socioeconomic backgrounds, as determined by last or current occupation and residential address (table 1). Thirty-three (46.5%) patients used UFGHs as their primary source of heating. Primary heating fuel for the ‘other’ group included electricity (n=25), flued gas (n=9), oil (n=2), closed wood heater (n=2) and open fireplace (n=1). One patient did not use any heating. Flued gas was included in the ‘other’ group as this has previously been shown not to increase indoor NO₂ concentrations.⁶ There were no significant differences between the two groups with regards to age at time of study, differences of 2.8% change from the average subject measurement in the exposed (UFGH) group for PEF, and 4% change from the average subject measurement in the exposed (UFGH) group for FEV₁ (with type I error probability α=0.05).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Symptom frequency (%) and lung function on days with and without heating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Days UFGH used (n=1713 days)</td>
</tr>
<tr>
<td>Symptoms*</td>
<td></td>
</tr>
<tr>
<td>Wheeze</td>
<td>13.4 (2.2–37.5)</td>
</tr>
<tr>
<td>Cough</td>
<td>0.0 (0.0–3.4)</td>
</tr>
<tr>
<td>Dyspnoea</td>
<td>0.0 (0.0–2.1)</td>
</tr>
<tr>
<td>Lung function†</td>
<td></td>
</tr>
<tr>
<td>morning PEF (litres/min)</td>
<td>310 (111)</td>
</tr>
<tr>
<td>evening PEF (litres/min)</td>
<td>313 (107)</td>
</tr>
<tr>
<td>morning–evening change PEF (%)</td>
<td>1.86 (5.73)</td>
</tr>
<tr>
<td>evening FEV₁ (litres)</td>
<td>1.90 (0.57)</td>
</tr>
<tr>
<td>morning–evening change FEV₁ (%)</td>
<td>0.63 (5.53)</td>
</tr>
</tbody>
</table>

*Median (IQR).
† Mean (SD).
UFGH, unflued gas heater; FEV₁, forced expiratory volume in 1 s; PEF, peak expiratory flow.

There was no difference in ambient conditions on days the different heaters were used. There were also no differences in the patterns of usage for the different types of heaters. UFGHs were used on 64% of days and other heaters were used on 67% of days. The daily average (SD) number of hours of heater use on those days was 5.3 (1.9) h and 5.4 (0.3) h, respectively.

Symptoms

Symptom frequencies for the study period are presented in table 2. Using the fully adjusted GEE model, positive associations were observed between a number of symptoms and UFGH use (table 3). ORs were significantly elevated comparing UFGH days with days on which no heaters were used for wheeze (same day and lag 1), cough (lag 1) and dyspnoea (same day and lag 1). There was no effect on reliever medication usage. The odds of dyspnoea were significantly elevated with the use of other heaters compared with no heating at lag 1 (table 3).

ORs for wheeze (same day and lag 1) and dyspnoea (same day and lag 1) for hours of heater use were elevated for UFGH users compared with no heating at lag 1 (table 3). Using the fully adjusted GEE model, positive associations were observed between a number of symptoms and UFGH use (table 3). ORs were significantly elevated comparing UFGH days with days on which no heaters were used for wheeze (same day and lag 1), cough (lag 1) and dyspnoea (same day and lag 1). There was no effect on reliever medication usage. The odds of dyspnoea were significantly elevated with the use of other heaters compared with no heating at lag 1 (table 3).

Lung function

Raw lung function variables for the different heaters used are presented in table 2. In the fully adjusted GEE model there were

Table 3 Adjusted ORs (95% CI) of symptom occurrence usage by heater type

<table>
<thead>
<tr>
<th></th>
<th>Wheeze</th>
<th>Cough</th>
<th>Dyspnoea</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Same day</td>
<td>Lag 1</td>
<td>Same day</td>
</tr>
<tr>
<td>UFGH versus other heater used (n=1713 vs 2421 days)</td>
<td>1.21 (0.99 to 1.48)</td>
<td>1.22 (1.00 to 1.50)*</td>
<td>0.77 (0.53 to 1.11)</td>
</tr>
<tr>
<td>UFGH used versus no heating (n=1713 vs 1388 days)</td>
<td>1.25 (1.05 to 1.50)</td>
<td>1.22 (1.01 to 1.49)</td>
<td>1.38 (0.91 to 2.09)</td>
</tr>
<tr>
<td>Other heater used versus no heating (n=2421 vs 1388 days)</td>
<td>1.01 (0.88 to 1.17)</td>
<td>1.03 (0.89 to 1.20)</td>
<td>1.15 (0.83 to 1.59)</td>
</tr>
</tbody>
</table>

Adjusted for age, gender, exposure to tobacco smoke, exposure to cooking gas, ambient temperature, humidity and external NO₂ levels.

*Significant finding (p<0.05).
UFGH, unflued gas heater.
no declines in PEF or FEV₁ (morning or evening) relative to the subject mean for same day or lag 1 UFGH use (table 5). However, when analysing exposure by hours of use there were small but significant percentage declines, relative to the subject mean, for morning PEF (−0.24% per hour of use, −0.41 to −0.07) and FEV₁ (−0.21, −0.38 to −0.03) for previous day UFGH use (table 6).

There was a significant decrease in the morning to evening changes in PEF and FEV₁ when UFGHs were used compared with other heater use and no heater use (table 5).

### Missing data

Patterns of the missing and incomplete data were assessed to determine if there was any consistent pattern of absent results. One patient did not undertake lung function but completed all other data. Missing data were left missing.

### DISCUSSION

There are very few data on the effects of heating sources on the symptoms of older people with pre-existing respiratory disease. The use of UFGHs is considered a risk for symptoms in children 

There was evidence that any (UFGH and other) heater use was associated with increased dyspnoea, cough and wheeze. There were also associations with increased symptoms and small changes in lung function in older people with asthma. There was also evidence of an exposure–response relationship between UFGH use and both lung function and respiratory symptoms. These findings are suggestive of an adverse effect of UFGH in older people with existing respiratory illness.

There is a large body of literature on the adverse impacts of UFG appliances on respiratory symptoms and exposure to gas appliances in older people but the results are also conflicting. Only two other panel studies have investigated relationships between indoor NO₂ and gas appliances and daily respiratory symptoms in adults with asthma. Smith et al. reported associations between personal concentrations of NO₂ and symptoms in children with asthma but not in adults over the age of 50 years. This study investigated UFGH use because this is the major predictor of concentrations of NO₂ in homes where the study was conducted.

In this study we observed an association between UFGH use and wheeze, cough and dyspnoea. Furthermore, there were increased odds for reported wheeze and dyspnoea with increasing hours of UFGH use. Increased wheeze, cough and dyspnoea are commonly reported respiratory problems in previous studies, although associations are not consistent. A few cross-sectional studies have assessed respiratory symptoms and exposure to gas appliances in older people but the results are also conflicting. Only two other panel studies have investigated relationships between indoor NO₂ and gas appliances and daily respiratory symptoms in adults with asthma. Smith et al. reported associations between personal concentrations of NO₂ and symptoms in children with asthma but not in adults over the age of 50 years. This study investigated UFGH use because this is the major predictor of concentrations of NO₂ in homes where the study was conducted.

The increased odds of symptoms with UFGH use were observed mostly when compared with no heater use, although wheeze was also increased when compared with other heater use. There was evidence that any (UFGH and other) heater use was associated with increased dyspnoea and, therefore, other factors, such as indoor temperature, may be important. However, for wheeze and dyspnoea an exposure response relationship with hours of UFGH, but not other heater use, was evident, suggesting that emissions from these heaters may be important. Emissions of combustion pollutants from UFGHs can remain high during the operation of the appliance. Heater use and exposure to UFGHs may be an important risk factor for respiratory symptoms in adults.

### Table 5 Adjusted ORs (95% CI) of symptom occurrence per hour of use for heater type

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Same day</th>
<th>Lag 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cough</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheeze</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exposure to gas stove</th>
<th>Same day</th>
<th>Lag 1</th>
</tr>
</thead>
</table>


symptoms were recorded in the same diary and it is possible that this may lead to a reporting bias. However, if people were aware of the health effects of using UFGHs they would be less likely to use this type of heating.

In this study there were small but significant decreases in lung function associated with UFGH use. This included a decrease in the morning to evening change in PEF and FEV<sub>1</sub> as the hours of UFGH use increased but not with increasing hours of other heater use. Data on the effect of NO<sub>2</sub> on lung function are inconsistent. Some epidemiological studies have reported small but significant decrements in lung function associated with exposure to NO<sub>2</sub> or gas appliances, whereas others have found no association. The findings of an across day change in lung function when using an UFGH may be analogous to a cross-shift effect. To some degree the results are consistent with a study by Ng et al. who reported a decrease in PEF (3.4%) in non-smoking women with asthma after cooking on gas stoves. However, in that study found an actual decrease in lung function, while we observed a reduced increase in morning to evening lung function when compared with no heater and other heater use.

As with respiratory symptoms, we observed a dose–response relationship between lung function and hours of UFGH use, but not other heater use. Morning PEF and FEV<sub>1</sub> decreased with increasing hours of UFGH use on the previous day. Ng et al. also reported an association between increasing NO<sub>2</sub> levels during cooking and the post-cooking fall in PEF. An exposure–response relationship may indicate a real, albeit small, effect. As this was not evident with other heater use it is more likely to be related to combustion gases rather than indoor temperature. We did not have data on indoor NO<sub>2</sub> or temperature to investigate this further.

Patients in this study generally had mild to moderate symptoms and were still reasonably active. None of the patients were confined to their homes because of the severity of their disease. The effects of UFG appliances on older people with more severe symptoms or who are less mobile will be important to determine if this modifiable risk factor contributes to ongoing respiratory morbidity in older people.

Acknowledgements The authors would first and foremost like to acknowledge all the patients who participated in the study. We would also like to acknowledge the Lung Institute of Western Australia (LIWA) where we were able to identify the patients. The study was funded by the CRC for Asthma and Airways.

Funding Australian Government research funding.

Competing interests None.

Ethics approval Ethics approval was provided by University of Western Australia Human Research Ethics Committee.

### Table 6 Percentage (95% CI) lung function changes per hour of heater use

<table>
<thead>
<tr>
<th>Table 6 Percentage (95% CI) lung function changes per hour of heater use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PEF</strong></td>
</tr>
<tr>
<td><strong>Same day</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Hour of UFGH use (n=33 patients)</td>
</tr>
<tr>
<td>Hour of other heater use (n=38 patients)</td>
</tr>
</tbody>
</table>

*Adjusted for age, gender, exposure to tobacco smoke, exposure to cooking gas, ambient temperature, humidity and external NO<sub>2</sub> levels.

Contributors PF designed the study, helped in recruitment and data collection and was the principal author of the manuscript. He is guarantor. JL undertook most of the recruitment and data collection and cleaning, and contributed to the drafting of the paper. AC undertook most of the analyses; wrote the statistical analysis section of the manuscript and contributed to the drafting of the paper.

Provenance and peer review Not commissioned; externally peer reviewed.

### REFERENCES

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