Effect of Whole-Body Exposure to Cold and Wind on Lung Function in Asthmatic Patients

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To assess the effect of subfreezing temperature and wind on lung function in asthmatic patients, an exposure to subfreezing temperature at rest, a moderate exercise challenge at subfreezing temperature, and a similar exercise challenge at room temperature were performed in 19 stable asthmatic subjects in an environmental chamber with an artificial wind. The mean maximal falls in FEV₁ were 5.3, 11.7, and 4.8 percent, respectively. The two challenges at subfreezing temperature caused statistically significant changes in FEV₁, but the exercise challenge at room temperature had no effect. A large variation in the sensitivity to cold was found. The time courses of the responses varied between the challenges, suggesting at least partially different mechanisms. The results indicate that even moderate exercise can cause severe bronchoconstriction in certain stable asthmatic subjects at climatic conditions similar to the Scandinavian winter. The importance of reflex mechanisms causing bronchoconstriction in physiologic conditions is discussed. (Chest 1994; 105:1728-31)

AFV=area under the expiratory flow-volume curve

Asthmatic patients often complain of breathing difficulties should they perform physical exercise in cold weather. The interaction of exercise and cold usually has been studied in experimental conditions, with the patients breathing through a heat exchanger system. However, these kind of experimental conditions are not necessarily physiologic and do not correspond to the situation in everyday life. In cold weather, the entire body, not just the respiratory tract, is exposed to cold. Furthermore, in everyday life, exercise intensity usually is lower than that used in most experimental studies. There are only a few studies in which the effects of cold air have been studied in physiologic conditions using an environmental chamber, and in these studies the coldest temperatures have been over 10°C. During winter-time, however, the weather often is much colder, eg, in Scandinavia. To objectively measure the effects of subfreezing weather combined with wind, we performed a series of experiments in an environmental chamber on a group of stable asthmatic subjects, who all reported that cold weather worsened their asthmatic symptoms.

PATIENTS AND METHODS

The patients were recruited from the outpatient clinic of pulmonary diseases of Kuopio University Hospital. Twenty-two clinically stable asthmatic subjects were selected because all of them reported that cold weather worsened their symptoms of asthma when performing physical exercise outdoors. Nineteen subjects completed the study. One patient discontinued because of a common cold and two for causes not related to the study. Table 1 shows the basic characteristics of the subjects.

The subjects were not allowed to take β₂-agonists for 6 h, anticholinergic agents for 24 h, and theophylline preparations for 24 h before each challenge. They had not used any short-term oral corticosteroid medications for at least 1 month before the study. The use of inhaled corticosteroids was unchanged. All subjects gave their informed consent for the study. The study was approved by the ethical committee of the University of Kuopio, Kuopio, Finland.

Study Design

The study was carried out from September to December 1991. It consisted of three different challenges carried out on separate days, always at the same time of the day. The effect of subfreezing temperature at rest and the effect of moderate exercise in two climatic conditions on the lung function were studied. The changes in lung function were measured by a flow-volume spirometer. The cold exposure at rest was always performed first, and the two exercise challenges followed in a random order. To assess the workloads for each patient, a treadmill test without spirometric measurements was carried out before the exercise challenges.

The effect of subfreezing ambient temperature at rest was studied in an environmental chamber with dimensions of 32 m³. The subjects sat there for 10 min breathing tidally through the nose. There was a 2 to 4 m/s turbulent airflow to mimic wind in the chamber, and the mean temperature was −20.6°C (range, −21.9 to −19.4). The subjects were fully dressed in a way they considered appropriate for a cold wintery day. They wore woollen hats and gloves, but the face was uncovered. The recovery time after the exposure was spent at room temperature and humidity, as in the next two challenges. Before the exposure, three maximal expiratory flow-volume curves were taken with a pneumotachograph spirometer (Medikro 101, Medikro LTD, Kuopio, Finland).
Table 1—Subject Characteristics

<table>
<thead>
<tr>
<th>No.</th>
<th>Age, yr</th>
<th>Sex</th>
<th>Atopy*</th>
<th>Medication†</th>
<th>FEV1, L (% Predicted)</th>
<th>Minute Ventilation at Target Grade, L/min</th>
<th>Grade, %†</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36</td>
<td>M</td>
<td>+</td>
<td>BC</td>
<td>4.53 (97)</td>
<td>45.2</td>
<td>12.5</td>
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<tr>
<td>2</td>
<td>40</td>
<td>F</td>
<td>−</td>
<td>BCAT</td>
<td>3.23 (101)</td>
<td>31.4</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>47</td>
<td>F</td>
<td>−</td>
<td>BC</td>
<td>2.80 (94)</td>
<td>32.3</td>
<td>2.5</td>
</tr>
<tr>
<td>4</td>
<td>43</td>
<td>M</td>
<td>+</td>
<td>BC</td>
<td>4.48 (109)</td>
<td>. . .</td>
<td>12.5</td>
</tr>
<tr>
<td>5</td>
<td>40</td>
<td>M</td>
<td>+</td>
<td>BT</td>
<td>4.21 (97)</td>
<td>53.2</td>
<td>10.0</td>
</tr>
<tr>
<td>6</td>
<td>22</td>
<td>F</td>
<td>+</td>
<td>BCT</td>
<td>3.06 (82)</td>
<td>51.8</td>
<td>7.5</td>
</tr>
<tr>
<td>7</td>
<td>56</td>
<td>M</td>
<td>+</td>
<td>BCA</td>
<td>3.90 (108)</td>
<td>47.3</td>
<td>10.0</td>
</tr>
<tr>
<td>8</td>
<td>30</td>
<td>F</td>
<td>−</td>
<td>B</td>
<td>3.31 (93)</td>
<td>33.3</td>
<td>2.5</td>
</tr>
<tr>
<td>9</td>
<td>45</td>
<td>M</td>
<td>−</td>
<td>BC</td>
<td>3.87 (96)</td>
<td>45.1</td>
<td>7.5</td>
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<tr>
<td>10</td>
<td>35</td>
<td>F</td>
<td>+</td>
<td>BC</td>
<td>3.31 (90)</td>
<td>34.3</td>
<td>7.5</td>
</tr>
<tr>
<td>11</td>
<td>20</td>
<td>M</td>
<td>+</td>
<td>B</td>
<td>3.71 (83)</td>
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<td>12.5</td>
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<tr>
<td>12</td>
<td>22</td>
<td>M</td>
<td>+</td>
<td>BC</td>
<td>3.84 (96)</td>
<td>60.6</td>
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<tr>
<td>13</td>
<td>48</td>
<td>F</td>
<td>−</td>
<td>BCA</td>
<td>2.69 (89)</td>
<td>47.3</td>
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<td>14</td>
<td>22</td>
<td>F</td>
<td>+</td>
<td>BC</td>
<td>2.94 (79)</td>
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<tr>
<td>15</td>
<td>16</td>
<td>F</td>
<td>+</td>
<td>BC</td>
<td>3.21 (94)</td>
<td>35.0</td>
<td>5.0</td>
</tr>
<tr>
<td>16</td>
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<td>F</td>
<td>+</td>
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<tr>
<td>17</td>
<td>28</td>
<td>M</td>
<td>+</td>
<td>BC</td>
<td>4.60 (96)</td>
<td>41.4</td>
<td>15.0</td>
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<tr>
<td>18</td>
<td>37</td>
<td>F</td>
<td>−</td>
<td>BC</td>
<td>3.14 (95)</td>
<td>54.7</td>
<td>5.0</td>
</tr>
<tr>
<td>19</td>
<td>45</td>
<td>M</td>
<td>+</td>
<td>BCT</td>
<td>3.55 (90)</td>
<td>36.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Mean±SD</td>
<td>35±11</td>
<td>. . .</td>
<td>. . .</td>
<td>. . .</td>
<td>3.58 (94)±0.8 (7.9)</td>
<td>43.5±8.5</td>
<td>7.9±4.0</td>
</tr>
</tbody>
</table>

*Atopy: +, if subject had at least one positive skin reaction to common allergens.
†B, inhaled β2-sympathomimetics; C, inhaled corticosteroids; A, inhaled anticholinergic agent; T, theophylline preparations.
‡Grade, the target grade of the treadmill.

After the exposure, two flow-volume curves were determined immediately and at 5, 10, and 20 min thereafter.

To assess the individual workloads for the following two exercise challenges, a treadmill (constructed by Kuopio University, Instrument Laboratory, Kuopio, Finland) test was carried out. This test was performed according to the method described by Balke in the text by Jones7 at room temperature and humidity. The subjects were lightly dressed. The speed of the treadmill was 5.3 km/h as in the following two exercise challenges. The grade was increased by 2.5 percent at 1-min intervals to achieve a target pulse level which was equal to or higher than 70 percent of the estimated maximal pulse level (0.7×[205−1/2Xage]). This moderate workload was assumed to correspond to the everyday physical stress patients encounter. The grade of that pulse level was recorded and used in the following two exercise challenges. Minute ventilation was measured continuously during the test (Medikro Ergospirometric System, Medikro OY, Kuopio, Finland). Those grades and corresponding minute ventilation values for each subject are expressed in Table 1.

The effect of moderate exercise at subfreezing ambient temperature was studied in the same environmental chamber as described previously. The subjects walked on a treadmill (Cardio Exercise Treadmill, Model 18-54, Quinton Instruments, Seattle) for 10 min. The grade was increased in 2 steps, each lasting 2 min, to the target grade lasting for 6 min. The heart rate was recorded every minute. There was, again, a 2 to 4 m/s turbulent airflow in the chamber and the mean temperature was −20.1°C (range, −21° to −19.4°C). The clothing and the spirometric measurements were similar to those described for the cold exposure at rest.

To assess the influence of ambient temperature on the exercise-induced bronchoconstriction, an identical exercise protocol was carried out at room temperature. The mean temperature was 20.6°C (range, 18.9 to 21.7°C) and the mean humidity, 25.7 percent (range, 12.4 to 58.2 percent). The subjects were lightly dressed in a way they considered appropriate for a summery day. The spirometric measurements were similar to those in the other two challenges.

Statistical Analysis

The largest FEV1 of the three baseline flow-volume curves was recorded. At each time point after a challenge, the best of two FEV1 values was recorded. The area under the expiratory flow-volume curve (AFV) values was recorded in the same way. All figures in the results section are means ± SEM and the probability value less than 0.05 was accepted as a level of significance.

The influences of each challenge separately on FEV1 and AFV were analyzed by multivariate analysis of variance. Between the challenges, baseline FEV1 and AFV values, percentage changes at all time points, and percentage maximal changes were

![Figure 1](http://journal.publications.chestnet.org/pdfsaccess.ashx?url=/data/journals/chest/21695/ on 06/19/2017)
RESULTS

Both the magnitudes and the time courses of the responses differed between the challenges. The changes in FEV₁ are shown in Figure 1. The AFV was found to be a more sensitive indicator of bronchoconstriction than FEV₁. Thus, the differences in the time courses between the challenges are more clearly seen in Figure 2, which shows the changes in AFV.

The cold exposure at rest caused a significant fall in FEV₁ (p<0.01). The responses were small, maximally 5.3±1.0 percent and were greatest immediately after the exposure to cold, then gradually disappearing.

Also, the exercise challenge at -20°C caused a significant fall in FEV₁ (p<0.01). The bronchoconstriction could already be observed immediately after the exercise, but the maximal fall in FEV₁ (11.7±3.1 percent) occurred usually at 5 min after the challenge. There was a large variation in the responses between the patients. Only 6 of the 19 patients (No. 1, 4, 6, 12, 17, and 19 [Table 1]) had greater than a 10 percent fall in FEV₁. All of them were atopic. The largest individual response was a 56 percent fall in FEV₁.

In contrast, the exercise challenge at room temperature did not cause statistically significant changes in FEV₁. The responses were small, and the mean maximal fall was 4.8±2.0 percent. No bronchoconstriction was present immediately after the exercise. The time point of maximal response in FEV₁ varied greatly, usually appearing at 5 to 10 min after the challenge. Expressed in AFV, the response was maximal at 10 min after the challenge.

The maximal percentage falls in FEV₁ differed significantly between the challenges (p<0.01). This was due to the greater responses following the exercise challenge at -20°C compared with the other two challenges. The exercise-induced bronchoconstriction at -20°C was two and one half-fold to that observed at room temperature. The changes in FEV₁ differed significantly between the challenges at all time points (0.5, 10, 20 min, p<0.01 for each time point).

A significant positive correlation was found between the maximal falls in FEV₁ after the cold exposure at rest and the enhancement of cold ambient air on the response to exercise (r=0.567, p<0.05 [Fig 3]).

Maximal heart rates during the two exercise challenges did not differ significantly (145±4/min at -20°C and 140±3/min at room temperature).

DISCUSSION

Our study shows that cold climatic conditions, such as those common during the winter in Scandinavia, undoubtedly affect pulmonary function even in stable asthmatic patients. Indeed, a very moderate level of exercise, which had no significant effect on FEV₁ at room temperature, caused an almost 12 percent mean decrease in FEV₁ at -20°C. In addition, we noticed that even sitting at -20°C caused a greater bronchoconstriction than moderate exercise at room temperature.

The mean responses to all challenges were small, but nevertheless they may have clinical significance. The level of exercise in our study was only moderate. This was chosen deliberately to match the physical stress patients meet in their daily life, for example when hurrying to catch a bus. Another point of view

![Graph showing the relationship between maximal falls in FEV₁ and cold exposure to ambient air](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21695/)

FIGURE 3. Relationship between the maximal falls in FEV₁ after exposure to cold ambient air at rest (C) and the enhancement of cold ambient air on the response to exercise (CE-WE). The enhancement was calculated for each subject as: maximal percentage fall in FEV₁ after the exercise challenge at cold ambient air temperature minus maximal percentage fall in FEV₁ after exercise challenge at room temperature.

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is the fact that the patients were in a stable condition. If the study population had included more labile patients, their responses would almost certainly have been greater.

There was, however, a wide variation in the sensitivity to subfreezing temperatures among the asthmatic subjects. Although the mean falls in FEV1 were not large, some of our patients had severe asthmatic attacks after moderate exposure at \(-20^\circ\text{C}\). None of the patients had symptoms after a similar exercise challenge at room temperature. All patients who had over 10 percent falls in FEV1 used inhaled steroids, suggesting that despite the presence of efficient anti-inflammatory treatment, cold winter weather may remain a problem for certain asthmatic subjects. These findings are in agreement with those of Millqvist et al., who reported in their questionnaire study that a great majority, two thirds of asthmatic subjects, experienced increased difficulty in breathing in cold Scandinavian weather.

The potentiation of exercise-induced asthma by cold air is a well-known phenomenon, which is thought to be mainly caused by an enhancement of hyperventilation-induced airway drying. We found it, therefore, more surprising that even sitting at rest in a subfreezing temperature caused a greater bronchoconstriction than moderate exercise at room temperature. The bronchoconstriction associated with a whole-body exposure to cold air at rest is far less well documented than exercise-induced asthma. It is thought to be caused by a neural reflex initiated by the inhalation of cold air during the exposure or by the cooling of the skin of the face during the exposure. The most likely explanation may be the facial cooling mechanism, but in these studies, the skin of the face has been cooled by ice packs, hardly a physiologic way to achieve this result. In our study, the skin of the face was cooled by cold air. There was also a light turbulent flow of air in the chamber mimicking wind. In our patients, also the nose and the upper airways were exposed to cold during nasal tidal volume breathing.

We feel that neural reflex mechanisms may at least partly be operating also during exercise in a cold environment. In our study, there was a clear difference between the challenges in the time courses of the responses. It is worthy of note that during the cold exposure at rest, the peak response was observed immediately after the challenge. The response to exercise in the cold was intermediate in its time course, whereas after the exercise at room temperature, there was no immediate bronchoconstriction. In addition, there was a positive correlation between the response to cold exposure at rest and the enhancement of the exercise-induced bronchoconstriction by cold air. The aim of our study was not, however, designed to study the mechanisms involved. Different study settings are needed to evaluate the possible role of reflexes in these responses.

In summary, our results indicate that for certain stable asthmatic subjects even a moderate level of exercise can cause a significant bronchoconstriction at climatic conditions similar to those encountered in the Scandinavian winter. These kinds of climatic conditions cause greater bronchoconstriction at rest than moderate exercise at room temperature. Our findings suggest that cold windy weather has effects on lung function which cannot be explained by the enhancement of the hyperventilation-induced airway drying alone. The reflex mechanism may be more important in physiologic conditions than has been previously thought.

REFERENCES

11. Horton DJ, Chen WY. Effects of breathing warm humidified air on bronchoconstriction induced by body cooling and by inhalation of methacholine. Chest 1979; 75:24-8