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Humidity influences exercise capacity in subjects with exercise-induced bronchoconstriction (EIB)☆

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Summary
Rationale: Exercise-induced bronchoconstriction (EIB) increases in cold and dry air and decreases in humid air in subjects with asthma. Few reports have reported on the effect of humid environment upon exercise capacity in subjects with EIB.
Objective: The primary aim of the present study was to examine the effect of changing the humidity of the environmental air upon exercise capacity measured by peak oxygen uptake ($\dot{V}O_{2\ peak}$), peak ventilation ($\dot{V}E_{peak}$) and peak running speed ($\dot{V}_{peak}$) and secondarily to assess the influence of environmental humidity upon EIB in subjects suffering from EIB.
Methods: Twenty subjects (10–45 years old, male/female:13/7) with diagnosed EIB performed exercise testing under standardised, regular environmental conditions, 20.2 °C (±1.1) and 40% (±3.3) relative humidity [mean (±SD)], and under standardised humid environmental conditions; 19.9 °C (±1.0) and 95% (±1.7) relative humidity in random order on separate days. Lung function was measured before and 1, 3, 6, 10 and 15 min after exercise. Heart rate (HR), oxygen uptake ($\dot{V}O_2$), respiratory gas exchange ratio (RER), breathing frequency (BF) and minute ventilation ($\dot{V}E$) were measured during exercise.
Results: $\dot{V}O_{2\ peak}$ and $\dot{V}_{peak}$ increased significantly from 40% to 95% relative humidity of the environmental air, 4.5% and 5.9%, respectively ($P = 0.001$). HR_{peak} increased significantly in the humid environment, while BF_{peak} decreased significantly. RER_{peak} and $\dot{V}E_{peak}$ did not change significantly. Post-exercise reduction in FEV_1 (ΔFEV_1) and FEF_{50} (forced expiratory flow at 50% of FVC) (ΔFEF_{50}) significantly decreased after exercise in a humid environment as compared to regular conditions, ΔFEV_1: 12% (7,17) vs. 24% (19,29) [mean (95% confidence intervals)], respectively, ΔFEF_{50}: 20% (12,29) vs. 38% (30,46), respectively ($P < 0.001$).

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Conclusion: Exercise capacity ($\dot{V}O_{2\ peak}$ and $\dot{V}_{peak}$) markedly improved during exercise in humid air in subjects with EIB, whereas EIB was reduced to the half.

Introduction

Exercise-induced bronchoconstriction (EIB) is common in asthmatic children and adolescents and has been stated to occur in as much as 70–90% of untreated asthmatics.[1,2] As EIB influences daily life activities and sports activities in children and adolescents, an accurate assessment of EIB is important to enable optimal choice of treatment. EIB is best assessed by a standardised exercise test, commonly used is running on a treadmill for 6–8 min at a submaximal workload.[3–5] Lately it has been maintained that an exercise load corresponding to 95% of estimated maximum heart rate (HR_{max}) (220 beats min^{-1} - age) is preferable to obtain a high sensitivity of the test.[6–8]

EIB consists of bronchoconstriction occurring immediately or soon after physical exercise and is mainly thought to be caused by the increased ventilation during exercise. Two main hypotheses have been proposed to explain the relationship between exercise and EIB. Gilbert and McFadden[9] suggested that airway cooling due to respiratory heat loss with resulting rewarming by secondary hyperemia and pulmonary vasodilatation is the probable cause of EIB. Airway cooling also stimulates airways receptors, causing bronchoconstriction through a reflex pathway.

Anderson[10] suggested that respiratory water loss due to increased ventilation is the main stimulus to provoke EIB. The water loss causes increased osmolarity in the extracellular fluid in the respiratory mucous membrane, with a secondary influx of extracellular ions (Cl^- and Ca^{2+}) into the cells. Activation of adenylcyclase and phospholipase with new formation of mediators as well as release of preformed mediators from mast cells and other inflammatory cells in the airways are thought to cause bronchoconstriction.[10] Variation in environmental conditions as temperature and humidity of the inspired air influences the degree of bronchoconstriction after exercise. Inspiring cold and dry air during exercise leads to increased bronchoconstriction.[11–13] Warm, humid air has been reported to reduce EIB,[14–17] but, on the other hand, Zainudin et al.[18] found no significant relationship between different humidity levels (41–90% relative humidity) and EIB in Malaysian school children, 7–12 years of age.

The influence of a humid environment upon exercise capacity in asthmatic subjects has so far not been properly investigated. Kallings et al.[16] did not find any difference in $\dot{V}O_2$ or $\dot{V}E$ during exercise in six asthmatic subjects in humid climate as compared to dry, cold climate. Eschenbacher et al.[19] found that the workload in watts performed per $L\,min^{-1}$ oxygen consumed was significantly higher under cold and dry conditions compared to hot and humid conditions in eight male asthmatic subjects.

However, it is not known if increased humidity of the environmental air, known to reduce EIB occurring mainly after exercise, also may influence $\dot{V}O_2$ or $\dot{V}E$ during running, or if there is a relationship between the magnitude of EIB and $\dot{V}O_2$ and $\dot{V}E$ during exercise.

Such knowledge is needed for giving optimal advice and treatment to asthmatic children and adolescents competing in different sports, especially endurance sports, and also as related to regular physical training of asthmatic children and adolescents.

The null hypothesis of the present study was that there is no difference in exercise capacity in subjects suffering from EIB exercising under regular, indoor conditions (20 °C and 40% relative humidity) as compared to exercising under humid conditions (20 °C and 95% relative humidity).

The primary aim of the present study was to investigate if conditioned, humid air, 20 °C and 95% relative humidity as compared to regular, indoor environmental conditions, 20 °C and 40% relative humidity influence exercise capacity measured by peak oxygen uptake ($\dot{V}O_{2\ peak}$), peak ventilation ($\dot{V}E_{peak}$) and peak running speed ($\dot{V}_{peak}$) during exercise in subjects with EIB.

The secondary aim was to assess the influence of humidity upon EIB, and if there was any relationship between the changes in EIB to changes in exercise capacity.

Material and methods

Design

The present study was randomised, cross-over with one test for exercise-induced bronchoconstriction (EIB-test) in a standardised, regular indoor environment, 20.2 °C (±1.1) and 40% (±3.3) relative humidity [mean (±SD)], and another test in a standardised humid environment 19.9 °C (±1.0) and 95% (±1.7) relative humidity on two different test days. Intervals of at least 48 h were required between each of the two tests. There were three study days in total. On day one, all subjects underwent an EIB-test to assess if they satisfied the inclusion criterion, a reduction in forced expiratory volume in 1 s (FEV_1) ⩾10% from before to after exercise. If satisfying the inclusion criterion, the subjects were randomised consecutively to one of the two climate blocks according to random order generated by a computer programme. Eleven subjects were tested under regular indoor conditions first and nine subjects under humid conditions the first test day. The study could not be blinded because the subjects could immediately feel which climate they went into. The present study is part of a larger study also investigating the effect of changes in barometric pressure[20] and temperature.

The study was performed according to the principles stated in the Declaration of Helsinki. The Regional Medical Ethics committee approved the study.

Ambient conditions

On study days 2 and 3 the subjects performed exercise testing according to identical test protocols. The exercise tests were performed in a conditioned pressure chamber (Norwegian Sub diving Techniques A/S, Haugesund, Norway) with temperature 20.2 (±1.1) and relative humidity of 40% (±3.3) on one of the study days, and temperature 19.9 (±1.0) and relative humidity of 95% (±1.7) on the other study day. The barometric pressure during the exercise tests was 98.7 kPa (±1.1) or 740 mmHg (±8).

Subjects

Twenty subjects, 10–45 years of age, with documented EIB (⩾10% decrease in FEV_1 after a standardised EIB-test) were included into the study. The EIB-test on the screening day was performed under standardised, regular indoor conditions. Exclusion criteria consisted of any other diseases or use of any regular medication which might influence test results and any respiratory tract infection during the last 3 weeks before study inclusion. Another exclusion criterion was if the FEV_1 baseline measurement varied more than 5% between the two test days.

Seventeen of the 20 subjects were atopic as defined by positive skin prick test (SPT). Seven subjects used regular inhaled steroids, and 10 subjects used regular daily long-acting inhaled β_2-agonists. Seventeen subjects used short-acting β_2-agonists on demand, one subject used oral theophylline, and two subjects used daily leukotriene antagonist. Four subjects used antihistamines, whereas nine subjects were without any regular asthma medication.

Five subjects participated in competitive sports, 14 participated in regular physical activity in school or leisure time, and one subject rarely or never participated in physical activity.

Methods

Lung function

Lung function was measured by maximally forced expiratory flow volume loops (Masterlab, Erich Jaeger®, Germany). FEV_1, forced vital capacity (FVC), and forced expiratory flow at 50% of FVC (FEF_{50}) were measured before exercise, 1, 3, 6, 10, 15 min after exercise and 15 min after inhaled salbutamol (5 mg mL^{-1}; 0.05 mg kg^{-1}). All lung function measurements were performed in a regular, indoor environment outside the climatic chamber.

All manoeuvres complied with the general acceptability criteria of The European Respiratory Society.[21] Predicted lung function values, when used, were according to Zapletal et al.[22]

EIB-test

EIB was determined by running on a motor-driven treadmill ("Bodyguard" 2313, Sweden) for 8 min at a submaximal workload (6,7). The inclination of the treadmill was 5.3%. The speed of the treadmill ($\dot{V}$) was adjusted during the first 4 min to achieve a workload corresponding to the maximum speed the subjects were able to keep the last 4 min, at about 95% of estimated maximum heart rate (220 beats min^{-1} - age). If the subjects indicated that higher speed was necessary to achieve exhaustion after 8 min, the running speed was adjusted also after 5 and 6 min. The estimated maximum heart rate is elaborated from epidemiological studies and it is a circumstantial estimation for individual subjects. The standard deviation for maximum heart rate during exercise has been reported to be ±10 beats min^{-1}.[23] Therefore, the exercise workload was standardised by a combination of 95% of estimated maximum heart rate and the test leader's evaluation of exhaustion after 8 min. Oxygen uptake ($\dot{V}O_2$), minute ventilation ($\dot{V}E$), breathing frequency (BF) and respiratory exchange ratio (RER) were measured 5, 6 and

7 min after starting exercise test. The EIB-test protocol used in our study is different from a standard, incremental protocol to determine $\dot{V}O_{2\ peak}$. However, a previous study showed no difference in $\dot{V}O_{2\ peak}$ between the two test protocols.[24] Douglas bags were used for collecting gas samples of the expired gas.[25] The variations reported for the Douglas-bag method used with cycle ergometry are 2.3–2.5% for daily variations and 3.3–5.1% for between days variations.[26] The Douglas-bag system was chosen because of technical problems with the automatic equipment for measuring $\dot{V}O_2$ in the humid environment in the chamber. The automatic measurements were unstable and not reproducible.

The subjects, wearing a nose clip, breathed through a Hans Rudolph mouthpiece (2700 Series; Hans Rudolph Inc., USA). Expiratory gas samples were taken for at least 30 s and analysed for oxygen and carbon dioxide content (Oxygen analyzer model S-3A/1 and Carbon dioxide analyzer model CD-3A; Ametek Inc., USA). The volume, temperature and pressure of the expired gas were measured at the time the air was analysed (''Ventilation measuring system'', model S-430, KL-Enginering, Northridge, California, USA). The heart rate was recorded electronically and registered every minute (Polar Sports tester PE 3000®, Polar Electro OY, Kempele, Finland).

Anti-asthmatic medication were withheld before the exercise tests. Inhaled short-acting β_2-agonists and sodium cromoglycate were withheld for 8 h prior to testing; inhaled long-acting β_2-agonists, theophylline and leukotriene antagonists for the last 72 h, anti-histamines for the last 7 days and orally administered glucocorticosteroids for the last month.[27]

Maximum percentage reduction in FEV_1 after exercise test was calculated by: (pre-exercise FEV_1−minimum post-exercise FEV_1)/(pre-exercise FEV_1) × 100%. Minimum post-exercise FEV_1 was the lowest recorded value at 1, 3, 6, 10 or 15 min after exercise test. Similar calculations were performed for FEF_{50} and FVC. The highest recorded HR, $\dot{V}O_2$, $\dot{V}E$, BF and RER values during exercise test were determined as HR_{peak}, $\dot{V}O_{2\ peak}$, $\dot{V}E_{peak}$, BF_{peak} and RER_{peak}. Peak tidal volume ($V_{t\ peak}$) during exercise was calculated by $\dot{V}E_{peak}\,BF^{-1}_{peak}$.

Assuming that the inhaled air during exercise is fully saturated with vapour and reaches the temperature of 37 °C, the respiratory water loss during the last 3 min of exercise was calculated by using a web-based on-line calculator designed by the Department of Physics and Astronomy, Georgia State University, Atlanta, based on empirical fit for density data.[28]

Skin prick test

The SPT was performed according to the Nordic guidelines[29] with the following prevalent ambient allergens: moulds (Cladosporium herbarum), house dust mites (Dermatohagoideus pteronyssimus), dog dander, cat dander, birch pollen, grass pollen (timothy), mug worth pollen, milk, shrimp and hen's egg white (Soluprick, ALK, Copenhagen, Denmark). To be considered allergic to an allergen, a positive SPT of at least ++ (1/2 of the reaction to histamine 10 mg mL^{-1}) was required. The size was recorded by measuring (maximum+minimum diameter (mm)) × 2^{-1}.

Statistical analysis

Demographics are given as mean values and standard deviation (SD) and results as means with 95% confidence intervals (CI). Differences between the two tests were analysed by standard *t*-tests for paired samples when satisfying normal distribution. Correlation was calculated by Pearson's correlation coefficient. The bronchoconstrictor response following exercise was measured as the maximum per cent fall in FEV_1 and FEF_{50} from before to after exercise and the area under the curve (AUC) as per cent fall of the pre-exercise value in FEV_1 time^{-1}, up to 15-min post-exercise, using the trapezoid rule. Identical analysis was made for FEF_{50}. If FEV_1 or FEF_{50} increased from baseline after exercise, the corresponding area was subtracted from the AUC measurements. All tests were two-tailed with a significance level of 5%.

Based upon $\dot{V}O_{2\ peak}$ and FEV_1 as main variables, with pre-existing knowledge of the variation of these variables and assuming a power of 80%, a sample size of 20 subjects was calculated to obtain a significance level of 5%.[30]

Statistical analyses were performed with Statistical Package for Social Sciences (SPSS) version 11.0.

Results

Demographic data and baseline lung function are given in Table 1. Baseline lung function (FEV_1, FEF_{50}, and FVC) did not differ significantly on the two test days.

Exercise capacity, $\dot{V}O_{2\ peak}$ and $\dot{V}_{peak}$, increased significantly, 4.5% and 5.9%, respectively, during exercise in humid air. $\dot{V}O_{2\ peak}$ from 46.5 ml kg^{-1} min^{-1} (43.9, 49.9) [mean (95% CI)] to 48.6 ml kg^{-1} min^{-1} (45.5, 52.5), respectively, and $\dot{V}_{peak}$ from 10.2 km h^{-1} (9.3, 10.7) to 10.8 km h^{-1} (10.0, 11.3), respectively ($P = 0.001$) (Table 2). HR_{peak} also significantly increased under humid

Table 1 Demographic data and baseline lung function (% of predicted) before exercise in standard, regular environment, 20.2 °C (±1.1) and 40% (±3.3) relative humidity [mean (±SD)] and in a standard humid environment, 19.9 °C (±1.0) and 95% (±1.7) relative humidity of the 20 subjects included in the study.

Variables	Mean ± SD	(Range)
Age (years)	24 ± 10.3	(10–45)
Gender ♀/♂	7/13	
Bodyweight (kg)	66.2 ± 19.1	(34–111)
Height (cm)	171.1 ± 11.0	(149–197)
Baseline FEV_1 (% predicted), 40% rel.hum.	100 ± 13.6	(79–122)
Baseline FEV_1 (% predicted), 95% rel.hum.	100 ± 15.7	(77–127)
Baseline FEF_{50} (% predicted), 40% rel.hum.	74 ± 20.0	(45–111)
Baseline FEF_{50} (% predicted), 95% rel.hum.	77 ± 22.4	(44–115)
Baseline FVC (% predicted), 40% rel.hum.	106 ± 12.5	(84–137)
Baseline FVC (% predicted), 95% rel.hum.	105 ± 14.2	(80–135)

Data are given as mean ± standard deviation with range in parentheses.

Table 2 Peak oxygen uptake ($\dot{V}O_{2\ peak}$), peak heart rate (HR_{peak}), peak respiratory exchange ratio (RER_{peak}), peak breathing frequency (BF_{peak}), peak minute ventilation ($\dot{V}E_{peak}$) and peak running speed ($\dot{V}_{peak}$) during exercise test under standardised, regular conditions, 20.2 °C (±1.1) and 40% (±3.3) relative humidity [mean (±SD)] and under standardised humid conditions, 19.9 °C (±1.0) and 95% (±1.7) relative humidity ($n = 20$).

Variables	40% relative humidity	95% relative humidity	Mean difference (95% CI)	Significance (*P*)
$\dot{V}O_{2\ peak}$ (ml kg^{-1} min^{-1})	46.5	48.6	−2.13 (−3.30, −0.96)	0.001
HR_{peak} (beats min^{-1})	186	189	−3.20 (−5.17, −1.23)	0.003
RER_{peak}	1.03	1.00	0.03 (−0.01, 0.07)	ns
BF_{peak}(breath min^{-1})	46	43	2.22 (1.11, 3.33)	<0.001
$\dot{V}E_{peak}$ (L min^{-1})	99	100	−1.00 (−5.11, 3.11)	ns
$V_{t\ peak}$ (L breath^{-1})	2.24	2.34	−0.10 (−0.18, −0.031)	0.008
$\dot{V}_{peak}$ (km h^{-1})	10.2	10.8	−0.66 (−1.01, −0.31)	0.001

Values are given as mean and mean difference between the groups with 95% confidence intervals in parentheses.
ns = not significant.

conditions ($P = 0.003$), while BF_{peak} significantly decreased ($P < 0.001$) (Table 2). There were no significant differences in mean $\dot{V}E_{peak}$ and RER_{peak} during exercise between the two climatic conditions (Table 2).

The increase in $\dot{V}O_2$ from 5 to 7 min differed significantly between the two test climates, 2.8 ml kg^{-1} min^{-1} (1.9, 3.6) under regular conditions vs. 4.4 (3.5, 5.3) under humid conditions, respectively ($P = 0.001$). Also the increase in running speed differed significantly from 5 to 7 min between regular and humid conditions ($P < 0.001$). No significant differences were found in the increase of $\dot{V}E$, HR or BF from 5 to 7 min between the two climates.

Maximum reduction in FEV_1, FEF_{50}, FVC and AUC changed significantly after exercise in the humid environment as compared to regular, indoor conditions ($P \leqslant 0.002$). Maximum reduction in FEV_1 as per cent of baseline lung function after exercise in humid environment was half of the reduction in FEV_1 after exercise under regular conditions, 12% (7,17) vs. 24% (19,29), respectively ($P = 0.0007$) (Table 3).

Maximum reduction in FEF_{50} as per cent of baseline lung function was also almost reduced to the half after exercise in humid environment, 20% (12,29) compared to exercise under regular conditions, 38% (30,46) ($P = 0.0004$) (Table 3). AUC for FEV_1 decreased after exercise in humid environment, 103.3 (163.9, 42.8) vs. exercise under regular conditions, 249.5 (316.9, 182.2), respectively ($P = 0.001$).

Calculated respiratory water loss during the last 3 min of exercise under regular indoor conditions was 10.4 g (9.3, 11.5) vs. 7.8 g (6.8, 8.8) in humid environment, respectively ($P < 0.001$).

No significant correlation was found between reduction in lung function after exercise and water loss during the last 3 min of exercise. Neither was

Table 3 Difference (Δ) in maximum reduction in FEV_1, FEF_{50} and FVC (% of baseline) after exercise test under standardised, regular conditions, 20.2 °C (±1.1) and 40% (±3.3) relative humidity [mean (±SD)] and under standardised humid conditions, 19.9 °C (±1.0) and 95% (±1.7) relative humidity ($n = 20$).

Variables	40% rel. humidity	95% rel. humidity	Significance (*P*)
ΔFEV_1 (%)	24 (19,29)	12 (7,17)	0.0007
ΔFEF_{50} (%)	38 (30,46)	20 (12,29)	0.0004
ΔFVC (%)	15 (11,19)	9 (5,12)	0.002

Values are given as mean with 95% confidence intervals in parentheses.

there any significant correlation between maximum reduction in lung function after exercise (measured by FEV_1, FEF_{50}) or AUC or water loss during exercise and increased $\dot{V}O_{2\ peak}$ in the humid environment.

Discussion

The present study demonstrated that exercise capacity measured by $\dot{V}O_{2\ peak}$, $\dot{V}_{peak}$ and HR_{peak} increased significantly during exercise under humid environmental conditions compared to regular indoor conditions. BF_{peak} was decreased in humid climate, whereas $\dot{V}E_{peak}$ and RER_{peak} did not differ (Table 2).

The reduction in FEV_1 after exercise in humid environment was reduced to the half compared to after exercise under standard, regular conditions. Similar findings were made for reduction in FEF_{50}. However, even under humid climatic conditions there was still a significant EIB compared to the baseline lung function. Mean FEF_{50} at baseline was only 74% and 77% of predicted (Table 1), and this demonstrates the presence of peripheral airway obstruction in this group of asthmatics. Only seven out of 20 subjects used anti-inflammatory treatment (inhaled steroids).[31] The relatively large age range of the subjects in the present study reflects the period of life extending from school-age to adulthood, where human beings are physically active and spending time to physical activity.

The standardisation of the exercise load was based upon the screening test of the individual subjects aiming a submaximal to maximal exercise load as assessed by HR. The speed of the treadmill thus becomes a measure of performance during the two different climatic conditions.

Kallings et al.[16] reported on $\dot{V}O_2$ measurement in subjects with asthma during exercise in a humid environment compared to a dry, cold environment. They did not find any differences in HR, $\dot{V}O_2$, $\dot{V}E$, RER, CO_2 elimination or subjective ratings of perceived exertion and breathlessness between the two climates. Also Eschenbacher et al.[19] investigated the effect of changing temperature and humidity in an environmental chamber upon lung function and work capacity in eight healthy and eight asthmatic subjects. The workload in their study was adjusted for the subsequent environmental exposure in order to keep $\dot{V}E$ similar for each subject on the different test days. They did not find any difference in $\dot{V}O_2$ or HR at submaximal workloads. However, only six and eight subjects, respectively, were included in their studies, and their results can only be used for generation of hypotheses for further investigations. The workload, ventilation and the oxygen demand were probably too low to discover any difference in $\dot{V}O_2$. In the present study, the differences in $\dot{V}O_2$, $\dot{V}$, HR and BF first occur when the subjects were close to their maximal aerobic capacity (Table 2 and Fig. 1).

$\dot{V}O_2$ did not differ significantly between the two climatic conditions after 5 min exercise, but $\dot{V}O_2$ increased significantly more from 5 to 7 min in the humid environment compared to regular environment (Fig. 1). A similar pattern is shown for the running speed. These findings support that there is no significant difference in $\dot{V}O_2$ at submaximal workloads, but that the humid environment improves $\dot{V}O_2$ especially during maximum aerobic performance.

No correlation was found between maximum reduction in lung function after exercise or water loss during exercise and the increase in $\dot{V}O_{2\ peak}$ in the humid compared to the standard, indoor environment. Although a significant reduction in FEV_1 from baseline to 1 min after exercise was found in the regular environment but not in the humid environment, no correlation was found to the increased $\dot{V}O_{2\ peak}$ in the humid environment. FEF_{50} did not change from baseline to 1 min after exercise in any of the environmental conditions (Fig. 2). Many previous reports have concluded that bronchoconstriction occurs after exercise,[3,6,32,33] and thus it should not be expected that $\dot{V}O_{2\ peak}$ is influenced by bronchoconstriction during exercise. Nevertheless, the understanding of the present study might have been improved if tidal breathing loops had been recorded during exercise.

The breathing pattern seems to be different during exercise in the humid as compared to the regular indoor environment. BF_{peak} was reduced during exercise in humid environment with no difference in $\dot{V}E_{peak}$. Peak tidal volume ($V_{t\ peak}$) increased significantly in the humid environment (Table 2). Consequently the subjects had a slower and deeper breathing pattern in the humid environment. All except two subjects reported spontaneously that breathing during exercise in the humid environment was much easier as compared to the regular indoor conditions. This is in agreement with the fact that the subjects ran faster with increased

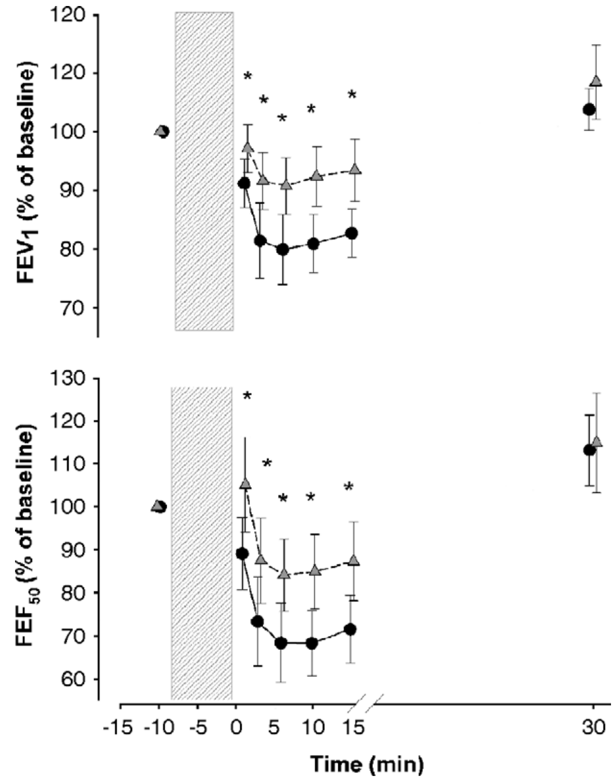

Figure 2 Lung function (FEV_1 and FEF_{50}) before, 1, 3, 6, 10 and 15 min after exercise and 15 min after inhaled salbutamol under standard, regular conditions, 20.2 °C (±1.1) and 40% (±3.3) relative humidity [mean (±SD)] (●) and under standard humid conditions (19.9 °C (±1.0) and 95% (±1.7) relative humidity) (Δ) ($n = 20$). Results are given as mean with 95% confidence intervals (*statistical significance).

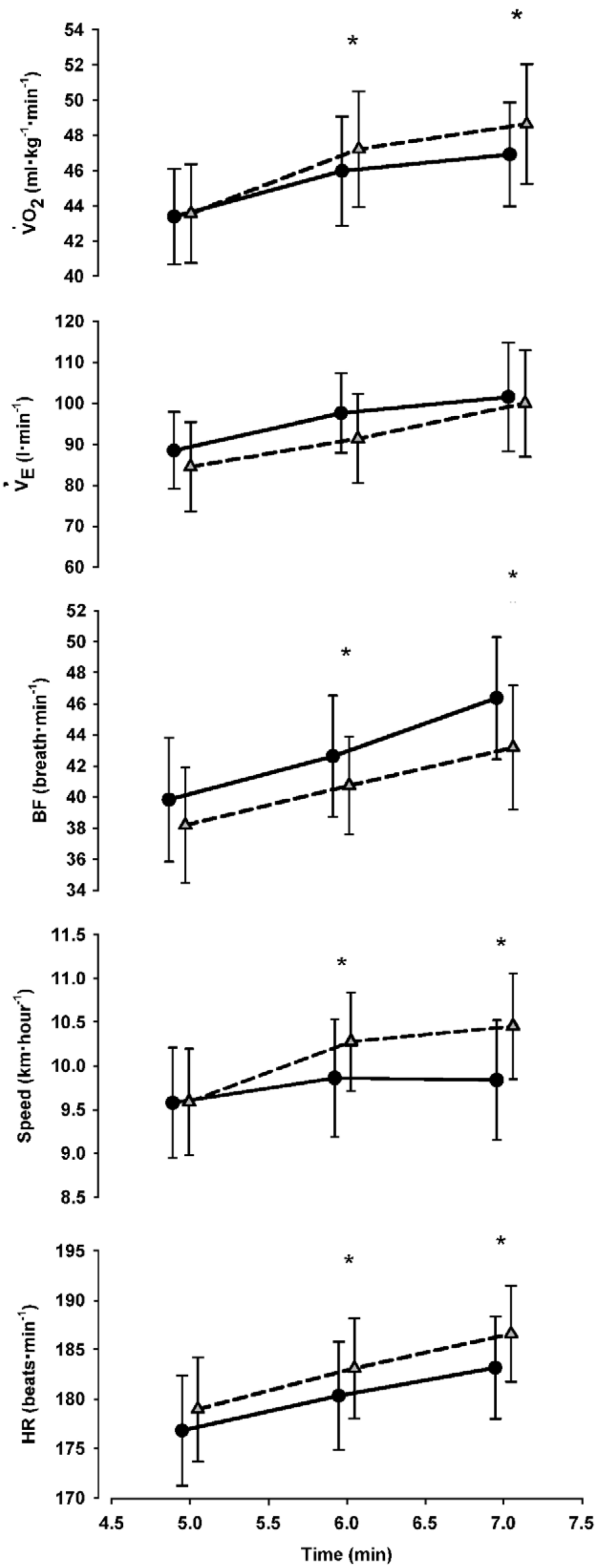

Figure 1 Oxygen uptake ($\dot{V}O_2$), minute ventilation ($\dot{V}E$), breathing frequency (BF), running speed ($\dot{V}$) and heart rate (HR) after 5,6 and 7 min exercise test under standard, regular conditions, 20.2 °C (±1.1) and 40% (±3.3) relative humidity [mean (±SD)] (●) and under standard humid conditions, 19.9 °C (±1.0) and 95% (±1.7) relative humidity (Δ) ($n = 19$). Results are given as mean with 95% confidence intervals (*statistical significance).

$\dot{V}_{peak}$, HR_{peak} and $\dot{V}O_{2\ peak}$ with less effort (no change in RER_{peak} and $\dot{V}E_{peak}$) in the humid environment. The mechanism of increased $\dot{V}O_{2\ peak}$ in the humid environment is unknown, but we observed in the present study a different breathing pattern when the subjects were close to maximum aerobic capacity.

Humid environmental conditions thus seem to have a protective effect on EIB. The respiratory water loss was significantly decreased in humid environment compared to regular, indoor conditions, but there was still a significant loss of water from the airways. Air of 37 °C fully saturated with vapour contains 44 g H_2O/m^3. Air of temperature 20 °C with 40% relative humidity contains 6.9 g H_2O/m^3 and air of 20 °C and 95% relative humidity contains16.4 g H_2O/m^3.[28] With increasing ventilation rates during exercise, the water loss increases. The reduced loss of water from the airways is probably the main reason of the protective effect on EIB in a humid environment.[14–17]

Bar-Or et al.[15] suggested that EIB is more likely in dry air (25% relative humidity and about 25–26 °C) than in humid air (90% relative humidity and 25–26 °C), possibly due to heat loss at the airway mucosa caused by evaporation. Also Boulet and Turcotte[17] reported that EIB was influenced by the changes in water content during and after exercise. In their study, 12 mild asthmatics performed a 6 min steady state exercise at 80% of maximum workload in four different environmental conditions. They repeated that bronchoconstriction following exercise was minimal if exercise was performed in humid air with the recovery periode in dry air, and maximal if the exercise was performed in dry air with recovery in humid air.[17] The recovery period in our study took place in standard environmental conditions and according to Boulet and Turcotte[17] the best recovery environment to protect against EIB. Kallings et al.[16] concluded that cold, dry air provoked more bronchoconstriction than room-tempered humid air (60% relative humidity). Their study also supports our findings, although they used PEF measurements only as lung function variable, and their exercise test differed and consisted of only 3 min cycling at an intensity of 40% of maximal capacity followed by 6 min cycling at 80–85% of maximal capacity.[16]

On the other hand, Zainudin et al.[18] reported no significant relationship between different humidity levels, (41–90% relative humidity) and EIB (defined as reduction in $FEV_1 \geqslant 15\%$) among Malaysian school children. Their humidity levels were naturally occurring and not standardised. Their study was performed as a cross-sectional study with a main objective to determine the prevalence of EIB in a population of school children living in a humid, tropical climate in the inner city of Kuala Lumpur.

The test procedure, the use of drugs before testing and ambient conditions were precisely standardised in the present study. The ambient conditions were similar during the two test days except for the relative humidity. Several of the earlier reports included fewer subjects, and neither the exercise workload nor the ambient conditions were standardised.

In conclusion, exercising in a humid environment improves exercise capacity as measured by $\dot{V}O_{2\ peak}$ and $\dot{V}_{peak}$, and protects against EIB in subjects suffering from EIB.

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