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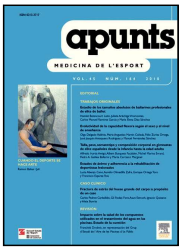

ORIGINAL ARTICLE

Ergometry and climate change

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Abstract
Introduction and objectives: In the short history of ergonomics (approximately 50 years) there have been notable changes in the atmosphere that we breathe, such as large, medium and small particles, as well as the gas composition, with increases in carbon dioxide (CO_2) of about 125%. This situation becomes worse within the buildings where the physiology exercise laboratories are located.

The objective of this study was to determine how these atmospheric changes affect humans during exercise.
Methods: A comparative study was conducted by means of 2 paired ergometric bicycle tests on 13 subjects (12 males and 1 female). One was carried out in the normal laboratory situation (indoor), and the repeat was done in the same laboratory, with a bubble with a system that filtered large, medium and small particles, breathing the air outside the laboratory (outdoor). The parameters that were controlled were: the maximum power achieved on the ergometric bicycle expressed in watts (W), the ergospirometer parameters (VO_{2max}, VCO_{2max}, VE_{max}), cardiological parameters: heart beats per minute and 2-hydroxypropanoic acid (La^{++}) levels and arterialised capillary blood glucose.
Results: The ergospirometer and cardiac parameters, or those associated with the power achieved on the ergometric bicycle did not change statistically, when we compared the two situations studied. However, the subjects did have higher levels of arterialised capillary lactate (+117%) 3 min after finishing the indoor situation test (7.55±1.81 vs 6.44±1.76 mMol/dl, $P<0.016$; n=13).

We observed identical behaviour in the capillary blood glucose levels, which showed an increase of 112% in the usual situation (indoor) compared to those in the purified (outdoor) air bubble (blood glucose: 90.0±12.2 mg/dl vs 82.15±6.94 mg/dl; $P>0.054$ (not significant, n=13).
Discussion: The blood gas analysers for metabolic studies can be calibrated in different atmospheres and correctly determine the capacities and potential energy of these

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subjects, despite the atmospheric changes. The metabolic changes were sufficient to compensate for the different atmospheres compared, and enabled a similar level of physical performance to be expressed in the effort test and also in the cardiac behaviour during the same, considering the levels of contamination in a laboratory near Barcelona.

Conclusions: The subjects were able to adapt to the atmospheric changes owing to the gradual contamination. No differences were seen in the two situations established in the metabolic gas analyses under effort, and neither were there any changes in cardiac behaviour. The maximum potential obtained in the laboratory did not change. But, metabolically, a price was paid for atmospheric contamination, as shown by the higher mobilisation of glucose in capillary blood, and also in the higher production of capillary lactate under the conditions of the study.

PALABRAS CLAVE
CO_2;
Dióxido de carbono;
Hipercapnia exógena;
Contaminación atmosférica;
Cambio climatico;
Ácido láctico;
Lactato

Ergometría y cambio climático

Resumen

Introducción y objetivos: En la corta historia de la ergometría moderna (50 años aprox.) se han producido notables cambios en la atmósfera que respiramos, a nivel de grandes, medianas y pequeñas particulas tambien a nivel de la composición gaseosa, con aumentos del Gas Carbónico (CO_2) en torno al 125%. Esta situación se agrava dentro de los edificios que es donde se ubican los laboratorios de fisiología del esfuerzo.

El objeto del presente estudio fue comprobar cómo afectan estos cambios atmosféricos, a los humanos durante el esfuerzo.

Métodos: Se realizó estudio comparativo mediante 2 pruebas cicloergométricas, apareadas, en 13 sujetos (12 ♂+1 ♀). Una se hizo en la situación habitual del laboratorio («indoor») y la replica se hizo en el mismo laboratorio, dentro de una burbuja con un sistema de filtrado de grandes, medianas y pequeñas partículas, tomando el aire del exterior del laboratorio, (aire libre «outdoor»). Los parámetros que se controlaron fueron: la poténcia máxima conseguida en el cicloergómetro y expresada en vatios (W), los parámetros ergoespirométricos (VO_{2max}, VCO_{2max}, VE_{max}), los parámetros cardiológicos: ritmo cardíaco por minuto y los niveles de ácido 2-hidroxipropanóico (La^{++}) y la glicemia en sangre capilar arterializada.

Resultados: No se modificaron estadísticamente los parámetros ergoespirométricos, cardiacos, así como los relativos a la potencia alcanzada en el ciloergómetro, cuando comparamos las 2 situaciones estudiadas. Sin embargo los sujetos mostraron un mayor nivel de lactato arterial capilarizado (+117%) a los 3 min de finalizar la prueba en situación *indoor* (7,55 ± 1.81 vs 6,44 ± 1,76 mMol/dl, $p < 0,016$; n = 13).

Idéntico comportamiento observamos en los niveles de glucosa en sangre capilar que mostraron un incremento del 112% en la situación habitual *(indoor)* en comparación con los de la burbuja de aire purificado y exterior (glicemia: 90,0 ± 12,2 mg/dl vs 82,15 ± 6,94 mg/dl; $p > 0,054$ no significativo, n = 13).

Discusión: Los analizadores de gases para estudio metabólico fueron capaces de calibrarse en diferentes atmósferas y determinar correctamente las capacidades y potenciales de estos sujetos, a pesar de los cambios atmosféricos. Las adaptaciones metabólicas fueron suficientes para compensar las diferencias atmosféricas comparadas y permitieron un nivel similar de prestaciones físicas expresadas en la prueba de esfuerzo y también en el comportamiento cardíaco expresado durante la misma atendiendo a los niveles de contaminación en un laboratorio cercano a Barcelona (NE spam).

Conclusiones: Los sujetos fueron capaces de adaptarse a los cambios atmosféricos debidos a la progresiva contaminación. No mostraron diferencias en las dos situaciones planteadas en el *análisis metabólico de gases en esfuerzo*, y tampoco hubo cambios en el comportamiento cardíaco. No se modificó la potencia máxima obtenida en el laboratorio. Pero metabólicamente se pagó un precio por la contaminación atmosférica, como muestra la mayor movilización de glucosa en la sangre capilar y también en la mayor producción de lactato capilar en las condiciones del estudio.

Introduction

Despite the widespread journalistic coverage afforded to ecological and environmental topics,[4,5,9] very few studies have been dedicated to the effect of environmental pollution on oxygen (O_2) and carbon dioxide (CO_2) levels[9,10,31,32,33] and the levels of large, medium and small pollutant particles on humans,[1,2,6,7] although rather more studies have been performed in animals.[3,8,11] Likewise, very few studies have concerned the chemical identification of these pollutants and other volatile compounds.[12] Nowadays we are aware of the subtle but continual changes to the composition of the atmosphere which have occurred thanks to the systematic measurements of its gaseous composition performed since the 1950s on the island of Mauna Loa.[5]

At the start of the aforementioned study, environmental CO_2 levels were of the order of 300 ppmv (parts per million by volume) on Mauna Loa, whereas they are currently close to 400 ppmv at the same site.[4] The acceptable levels of oxygen and carbon dioxide in the workplace have also been established internationally.[15,17-19,28-30]

The research which led to modern-day ergometry goes back more than 50 years, when Per Olof Astrand (P.O.Astrand) first defined the basis and parameters for stress tests with exhaled gas analysis. In such tests, the gas (O_2 and CO_2) analysers are calibrated on the basis of environmental levels of 20.9% oxygen and 0.03% carbon dioxide (300 ppmv CO_2).

No officially recorded environmental CO_2 levels are available for Catalonia,[8] but our own observations have led to values of 450–650 ppmv CO_2 in the most favourable, open-air environments (table 1). Values of 750–900 ppmv CO_2 are often found in buildings, and these can increase further when people are present. A similar situation occurs in confined natural[13,24,25] and artificial environments.[18] Indeed, medical problems other than those caused by altitude adaptation[14,23] and the effects of training[26-28] or smoking[21,22] are increasingly being reported.

The manufacturers of ergometric gas analysers recommend a single calibration at the beginning of the working session. However, our observations after the first test show that environmental CO2 levels can easily reach 1500–2000 ppmv, thus suggesting that a deviation in the parameters for all the stress tests should be taken into account. This observation could account for the findings of numerous studies whose results did not agree with the proposals formulated by the pioneers of ergometry. (For example, the value for the respiratory coefficient).

A recent study reported the impact of metal pollution on small mammals in the Barcelona region (increased Pb, Cd, Mg, Zn, Cu and Cr levels) and the higher number of genotoxic effects found in these animals.[8,11]

Other studies have assessed the effect of PM 2.5 (small pollutant particles) on the increased lifespan of people living in three cities where this type of pollution has decreased.[12] A negative impact on life expectancy of around 14 months has also been reported in the Barcelona region (NE Spain) as a result of exposure to suspended atmospheric pollutants.[20]

The present study assesses the impact of breathing particle-free external air on ergometric tests in comparison with the air present in the confined atmosphere of a physiological stress-test laboratory.

Table 1 CO_2 levels recorded in the open air outside the laboratory in which the study was performed

External analyser	
Day	CO_2 ppmv
24/04/2009	486
28/04/2009	750
29/04/2009	690
27/04/2009	640
Mean	**641.5**
SD	113

Definitions

Exogenous hypercapnia: hypercapnia resulting from an excess of CO_2 coming from the outside of the organism.

Materials and methods

A group of 15 volunteers, all of whom were undergoing vocational Physical Education training, was selected; 13 of them completed all tests.

All volunteers signed the corresponding informed consent. This study was approved by the Clinical Research Ethics Committee of the Catalan Sports Administration. All subjects underwent a medical check-up prior to the test to assess their suitability for exercise.

None were found to be suffering from any chronic, heart or lung disease, or any other disease which could affect their physical performance. The subjects were split into two groups depending on the order in which they performed the tests.

The physiological profile of the test subjects is detailed in table 2.

An Ergoselec200 ergocycle (Ergoline GmbH & Co. KG) was used during the maximum-type ergometric tests. Data were collected whilst the subjects were performing two identical stress tests, one in the laboratory under winter conditions (HC) (windows closed and door unlocked for free movement into and out of the laboratory) and the other inside a bubble (BC) fitted with a particle-filtration system under a slightly positive partial pressure (+92−93-5 hPa) to ensure, together

Table 2 Physiological profile of the test subjects

	Age	Weight	Height	BMI	Sex
Mean	**21.69**	**73.13**	**174.58**	**23.98**	**1♀ + 12 ♂**
SD	5.6	10.43	7	2.92	

with the design of the bubble, permanent replacement of the air inside the bubble with external air (O2 Bubble, Trilanz S.L., Barcelona). The gases exhaled during the ergometric tests were analysed metabolically using an MS-CPX/SBx/CPx analyser (Jaeger, Cardinal Health, Germany). The heart rate and trace were monitored continually during the ergometric test and recovery period using a 12-lead heart monitor (MS Medcard, Sorinnes, Belgium). An arterial capillary blood sample was collected three minutes after finishing the test for subsequent determination of the L-2-hydroxypropanoic acid (La^{++}) (Lactate Pro ARKRAY, Inc, Kyoto, Japan) and blood glucose levels (GlucocardGmeter, ARKRAY, Inc., Kyoto, Japan).

Five subjects performed the HC test one week before the BC test and nine subjects performed these tests in reverse order.

The oxygen and carbon dioxide content of the air at a distance of 80 cm from the ergospirometer's mouthpiece was also measured during both tests using a Multipleno Gas detector (MultiRAE-IR, Rae systems Inc., San Jose, USA). Finally, the difference in the composition of the air at a distance of 80 and 130 cm from the airways under winter conditions (HC) was compared.

Statistical study: the means and standard deviations (SDs) for the different parameters under the two test conditions were determined and the differences quantified. A regression analysis was performed between paired data for the different cases. Student's t-test was used to test the null hypothesis for the data obtained under each experimental condition and the degree of significance determined for the difference between the two. All calculations were performed using Microsoft Excel®.

Results

The air breathed in by the volunteers was found to be significantly different in terms of CO_2 content upon comparison of the baseline value with that obtained after the stress tests under both test conditions (see table 3 and 3b).

The initial CO_2 levels inside the bubble (made from inert plastic, with continual replacement with filtered external air at a slightly positive partial pressure) and at a distance of 80 cm from the airways remained acceptable considering the industrial and transport-related surroundings of the laboratory. This was not, however, the case for the laboratory under winter conditions, where the values at the start of the test and at the time of maximum stress increased by a factor of two on average (655±60 vs. 1326±269 ppmv CO_2; $p \leq 6.0\times10^{-8}$), and at the end of the stress tests when comparing the situation inside and outside the bubble (1423±253 vs. 2162±636 ppmv CO_2; $p \leq 0.00047$).

The situation as regards environmental oxygen was as follows: tables 4 and 4b.

The initial oxygen levels inside the Bubble and at a distance of 80 cm from the airways remained acceptable considering the industrial and transport-related surroundings of the laboratory (20.86±0.09% O_2). In the laboratory under winter conditions, the initial oxygen levels were affected slightly, but significantly, with respect to those in the bubble (20.75±0.19% O_2; $p \leq 0.03$). The atmospheric oxygen levels upon finishing the stress test were statistically significantly different (laboratory: 20.47±0.15% O_2 vs. bubble: 20.78±0.18% O_2; $p \leq 5.82\times10^{-5}$).

A difference in the composition of the air at a distance of 80 and 130 cm from the mouthpiece of the ergospirometer was also observed. An oxygen level of 20.52±0.04% was detected at 80 cm and a level of 20.87±0.09% at a distance of 130 cm, with the difference between the two being statistically significant ($p \leq 1.4\times10^{-6}$). Similarly, a CO_2 level of 2662±186 ppmv was detected at 80 cm and a level of 1206±264 ppmv at 30 cm, with the difference between the two again being statistically significant ($p \leq 6.5\times10^{-6}$; fig. 1).

Results for the ergospirometric parameters

The ventilation, as measured using the spirometer, showed no significant differences between the maximum ventilation at the end of the stress test under both test conditions. Thus, whereas the test subjects had a mean ventilation of 116.5±19.2 L/min under normal laboratory conditions, the mean ventilation in the bubble was 117.4±18.9 L/min.

The maximum oxygen consumption, as measured using the exhaled gas analyser, showed no significant differences between the oxygen uptake rates at the end of the stress test under both test conditions. Thus, whereas the test

Table 3b Significance of the differences between the different situations compared

T-test p<	(1) vs. (3)	6.00675×10^{-8}
T-test p<	(2) vs. (4)	0.000473413
T-test p<	(1) vs. (2)	8.48649×10^{-5}
T-test p<	(4) vs. (3)	2.07319×10^{-7}

Table 3 CO_2 levels before and after the stress tests under the two test conditions; n=13

	External baseline (1)	External final (2)	Bubble baseline (3)	Bubble final (4)
Mean	1326.00	2162.00	655.00	1423.57
SD	258.79	636.09	60.44	253.19

Baseline: just before starting the stress test.
Final: at the time of maximum stress.
Units: ppmv CO_2.

Table 4 Oxygen levels before and after the stress tests under the two test conditions; n=13

	External baseline (1)	External final (2)	Internal baseline (3)	Internal final (4)
Mean	20.75	20.47	20.86	20.78
SD	0.19	0.15	0.09	0.18

Baseline: just before starting the stress test.
Final: at the time of maximum stress.
Units: % O_2.

Table 4b Significance of the differences between the different situations

T-test p<	(1) vs. (3)	0.033007459
T-test p<	(2) vs. (4)	5.82826×10^{-5}
T-test p<	(1) vs. (2)	2.63265×10^{-5}
T-test p<	(4) vs. (3)	0.046794771

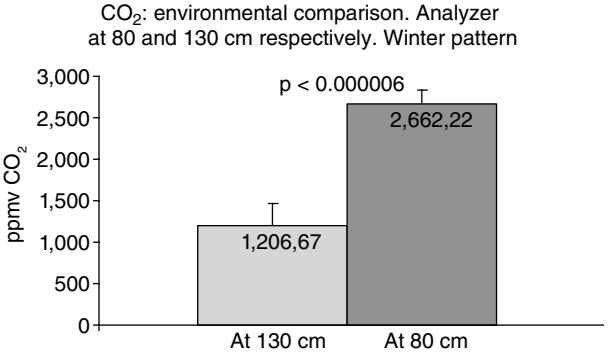

Figure 1 Values at the end of the stress test.

subjects had a mean uptake of 3342.7±521 mL/min under normal laboratory conditions, the mean uptake in the bubble was 3427.8±664 mL/min.

The CO_2 production rate showed no significant differences between the maximum production rate at the end of the stress test under both test conditions. Thus, whereas the test subjects produced a mean of 3964±656 mL/min of CO_2 under normal laboratory conditions, the mean production in the bubble was 3924±692 mL/min.

Furthermore, there were no significant differences between the values of the O_2 and CO_2 recovery curves at minutes 1, 2 and 3 of the recovery period.

We also determined whether there were any differences from a respiratory coefficient of 1 (RC=1). No statistically significant differences were found as regards the power demand (in Watts) during the stress test corresponding to this level.

Cardiac parameters

None of the cardiac parameters showed any significant difference, either during the stress test or in the subsequent recovery period, which allowed the null hypothesis to be rejected.

Likewise, none of the mechanical power-related parameters determined using the cycloergometer showed any statistically significant difference for either of the test conditions.

In metabolic terms…

...the subjects showed a higher level of (+117%) at three minutes after finishing the stress test under winter conditions than in the bubble (7.55±1.81 vs. 6.44±1.76 mmol/dl, p<0.016; n=13).

A similar behaviour was found for capillary blood glucose levels, which were 112% higher under winter conditions (indoor) than in the purified air bubble and outdoors (blood glucose level: 90.0±12.2 vs. 82.15±6.94 mg/dl; p>0.054 not significant, n=13).

Discussion

Despite the difference in the composition and pollution levels of the air in the two test conditions, the gas analyser, with its self-calibration system, showed no significant differences between the ergospirometric parameters maximum oxygen consumption (VO_{2max}) and maximum CO_2 production, as shown by the results detailed above. Therefore, despite the pollution levels and rarified nature of the air under laboratory conditions (indoor), metabolic analysis of exhaled gases can continue to be considered useful and reliable.

Thus, the rarification level of the air in the laboratory resulted in a statistically insignificant increase of less than 1% in the maximum ventilation (VE in L/min). This is in accordance with the lack of detectable symptoms in healthy volunteers subjected to the degree of rarification observed in this study. This finding is in contrast to the symptoms and subjective sensations experienced in confined natural environments (potholes and caves) in the same geographical region[13] (NE Barcelona, Spain) where the air is much more rarified (15–19% oxygen and 2000–40,000 ppmv CO_2)

Nevertheless, a clear and statistically significant difference was found between subjects exposed to subacute air in the physiology laboratory and those in the bubble of purified air in terms of blood glucose and lactate levels in capillarised arterial blood. Thus, despite the difference not being statistically significant, the air-pollution and -rarification level in the laboratory resulted in a 12% increase

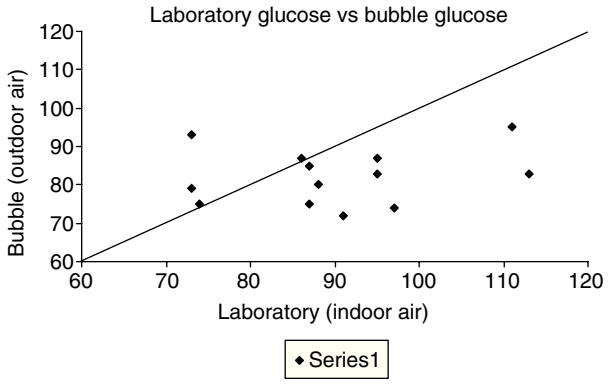

Figure 2 Blood glucose levels upon completion of the test under the two test conditions.

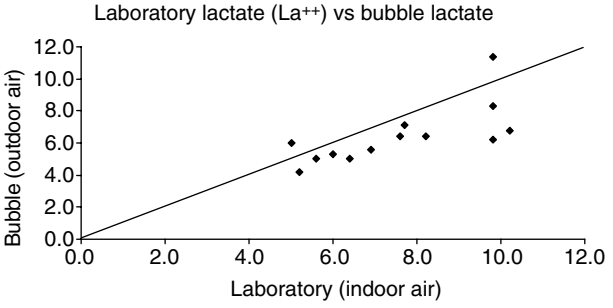

Figure 3 Lactate levels upon completion of the test under the two test conditions.

in the glucose levels in capillarised blood upon completion of the ergometric test under normal laboratory conditions with respect to the levels found after completion of the test in the bubble of purified air (fig. 2).

Likewise, the L-2-hydroxypropanoic acid (La^{++}) level was 17% higher in capillarised blood upon completion of the ergometric test under normal laboratory conditions with respect to the levels found after completion of the test in the bubble of purified air. Both these differences were statistically significant. The La^{++} level is considered to be a good indicator of anaerobic metabolism[16] and thus shows a greater metabolic depletion when the volunteers performed the stress test under normal laboratory conditions (fig. 3).

The metabolic adaptations were sufficient to compensate for the environmental differences between the two test conditions, thereby allowing a similar degree of physical performance during the stress test as well as a similar cardiac behaviour.

Findings from the present study

When inside the bubble (made from inert plastic, with continual replacement with filtered external air at a slightly positive partial pressure), the air breathed by the volunteers was similar in terms of CO_2 content to that found in the surrounding geographical region (Barcelona, NE Spain), whereas that breathed under normal laboratory conditions had a two- to threefold higher CO_2 content.

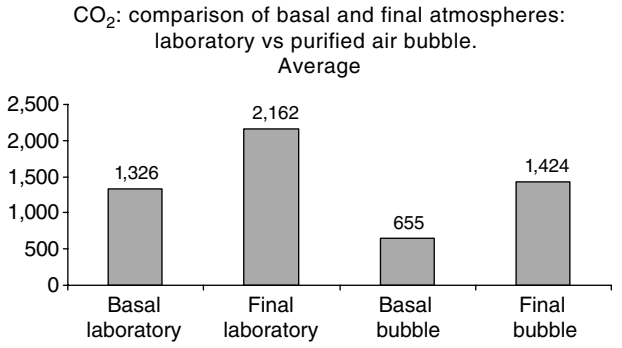

Figure 4 CO_2: comparison of baseline and final levels: laboratory vs. purified air bubble. Average.

The air breathed by the volunteers inside the bubble (made from inert plastic, with continual replacement with filtered external air at a slightly positive partial pressure) had an oxygen content of close to 20.9% content, whereas that breathed under normal laboratory conditions had an oxygen content of between 20.4% and 20.6% (fig. 4).

The L-2-hydroxypropanoic acid (La^{++}) level in capillarised arterial blood was significantly lower when the volunteers performed the stress test inside the bubble (made from inert plastic, with continual replacement with filtered external air at a slightly positive partial pressure).

Conclusions

1. The use of a bubble (O_2 bubble, Zonair 3D) has allowed the adverse environmental conditions found in the stress physiology laboratory, generated by both climate change and the biomass present in the laboratory itself, to be improved.
2. This study has allowed the environmental impact of the two situations studied (inside and outside the bubble) to be quantified and has provided new metabolic data which should be taken into account by stress-medicine and -biology professionals.
3. The human volunteers who performed the stress tests under the two conditions studied were able to adapt and provided similar values for the different parameters chosen to measure physical condition and degree of physical preparation. Despite this, statistically significant differences were observed for one parameter, namely lactate in capillarised arterial blood, which is known to be a good indirect marker of the metabolic pathways used.
4. The differences found in capillarised arterial blood lactate levels for the two test conditions studied indicate a greater use of anaerobic metabolism when the ergometric tests were performed under normal winter laboratory conditions with the windows closed.
5. An inert plastic bubble, with continual replacement with filtered external air at a slightly positive partial pressure, has therefore been shown to be useful and practical for the performance of standard ergometric tests in a stress physiology laboratory.

Conflict of interest

The authors hereby declare that they have no conflict of interest.

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