



Effects on ventilation and exercise endurance of inspired CO₂ and UBA-like resistance

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To answer part of the larger question,

“Should breakthrough CO_2 be allowed to climb above 0.5%?”

we measured respiratory variables and endurance while subjects exercised at 85% peak oxygen consumption, dry and at sea level, with combinations of

- inspired CO_2 and
- breathing resistance (R) like that of an underwater breathing apparatus (UBA).



Subjects



Experiments were done in three phases with different subjects

	Phase 1 CO₂ in air, no R	Phase 2 CO₂ in air, ±R	Phase 3 CO₂ in O₂, ±R
Participants finishing	10 men, 2 women	10 men, 2 women	12 men, 0 women
Endurance data n =	9	10	10
End tidal CO ₂ n =	11	11	12
Ventilatory data n =	10	10	12
Subject characteristics. Median values, with minimum to maximum in parentheses.			
Age (years)	35.5 (27– 40)	38.5 (32 – 47)	37.5 (20 – 40)
Height (cm)	175 (160 – 190)	173 (160 – 185)	183 (169 – 193)
Body mass (kg)	82 (73–107)	81 (62–107)	87 (70 – 114)



Resistance Elements

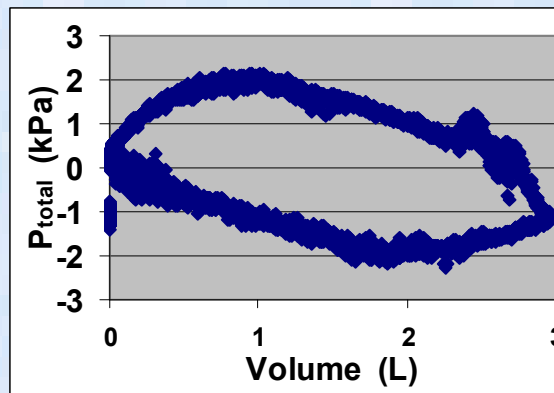


Resistances (R) shared characteristics of the MK 16 UBA at 50 fsw, but were designed for the maximum acceptable work of breathing.

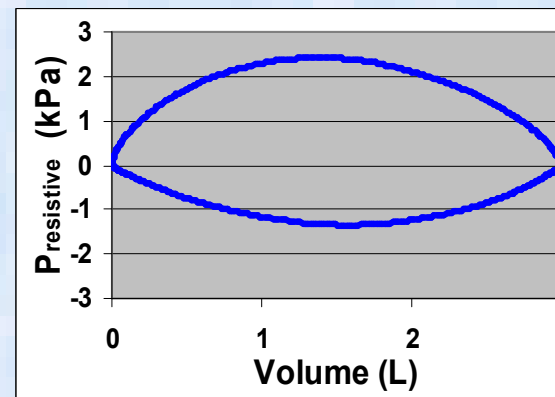
- Pressure - flow characteristics
Inspiratory: turbulent (plugs with holes); Expiratory: laminar (stretched cloth).
- At target V_E , Peak $P_{\text{expiratory}} \approx 2 \cdot \text{peak } P_{\text{inspiratory}}$

With $V_E = 90$ L/min

from the MK 16 at 50 fsw:



from test resistance:



Moderate R: $\text{WOB}/V_T = 3$ J/L with $V_E = 100$ L/min. Hole size 14.1 mm (0.56 in).

High R: $\text{WOB}/V_T = 3$ J/L with $V_E = 80$ L/min. Hole size 12.3 mm (0.48 in).



Methods



Cycle ergometer exercise

- Peak rate of oxygen consumption ($\text{VO}_{2 \text{ peak}}$) was measured first.
- All other tests were conducted at nominally 85% $\text{VO}_{2 \text{ peak}}$ until voluntary termination.
- The order of conditions was varied. Subjects were initially blind to conditions.
- End tidal CO_2 , minute ventilation (V_E), etc. were measured at the mouth using a COSMED breath-by-breath analyzer.
- Endurance time and the reason the subject gave for stopping were recorded.

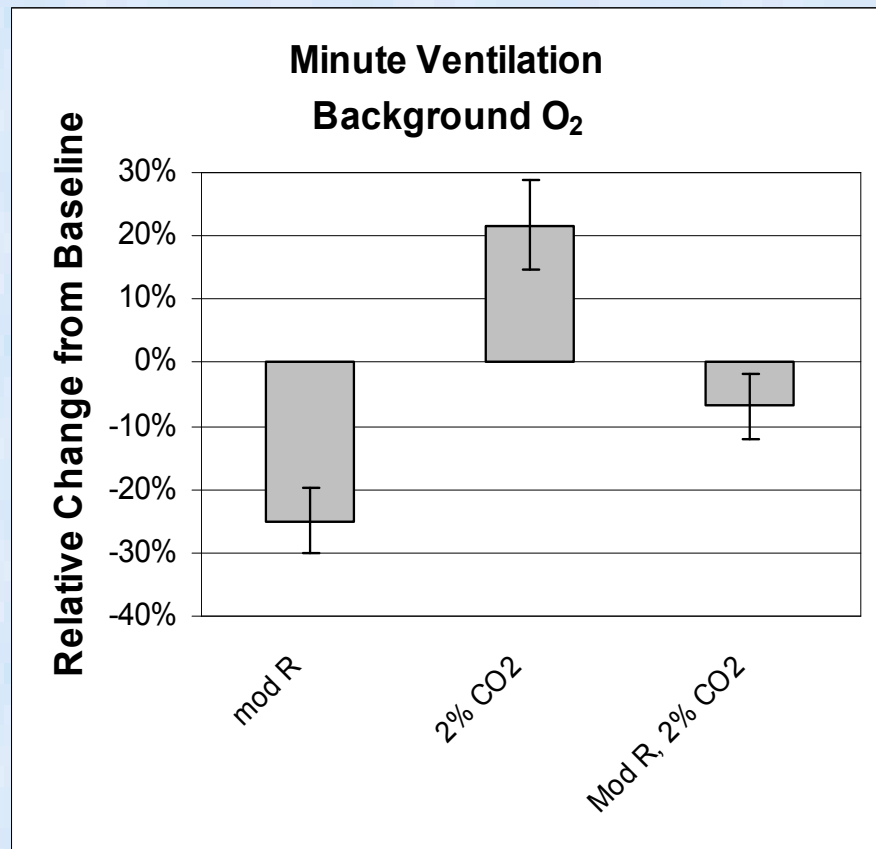
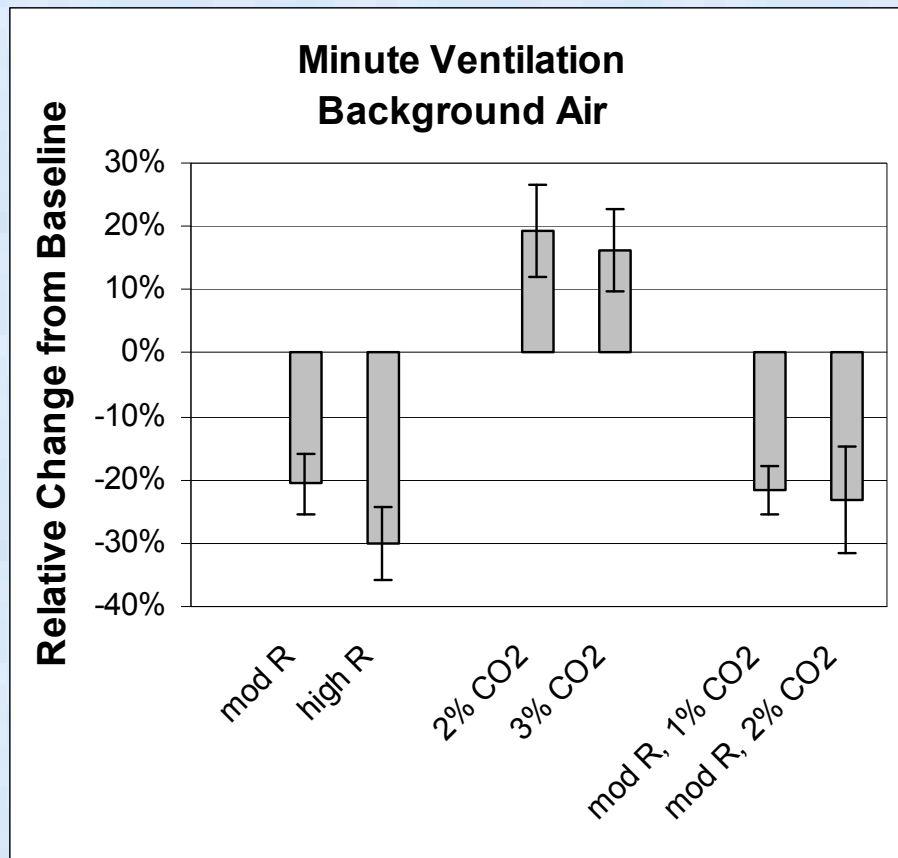
	Background air				Background O_2	
	0% CO_2	1% CO_2	2% CO_2	3% CO_2	0% CO_2	2% CO_2
No resistance	All Phases	Phase 1	Phase 1	Phase 1	Phase 3	Phase 3
Moderate resistance	Phase 2	Phase 2	Phase 2		Phase 3	Phase 3
High resistance	Phase 2					



Results



Minute ventilation (V_E)
Mean change from control

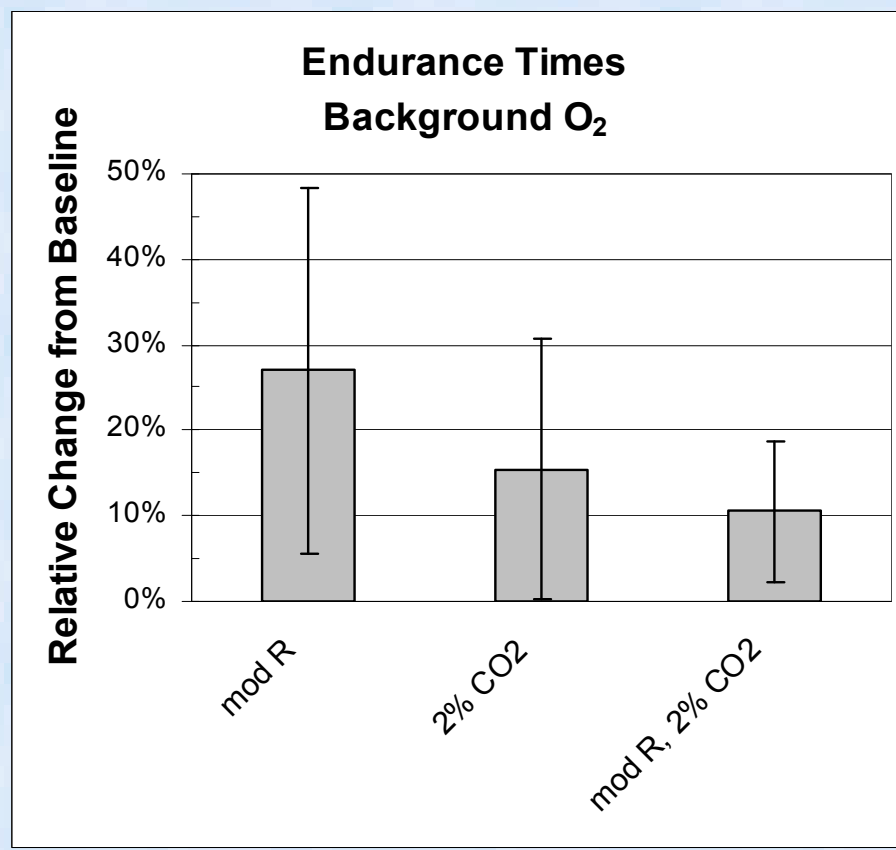
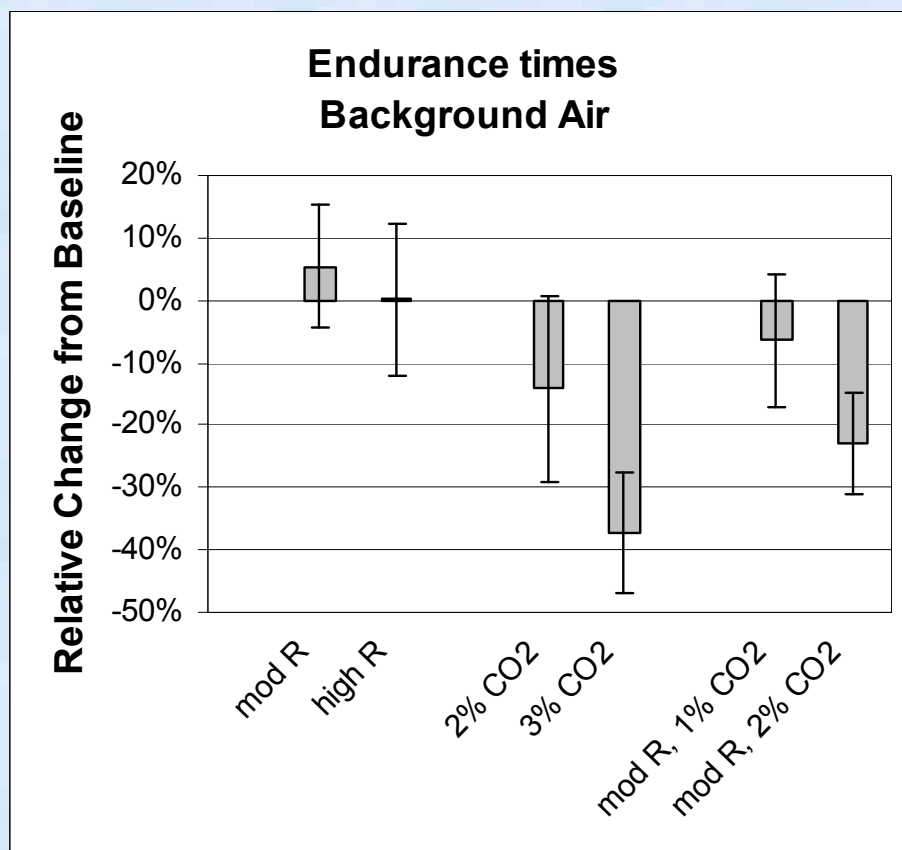




Results



Endurance times
Mean change from control

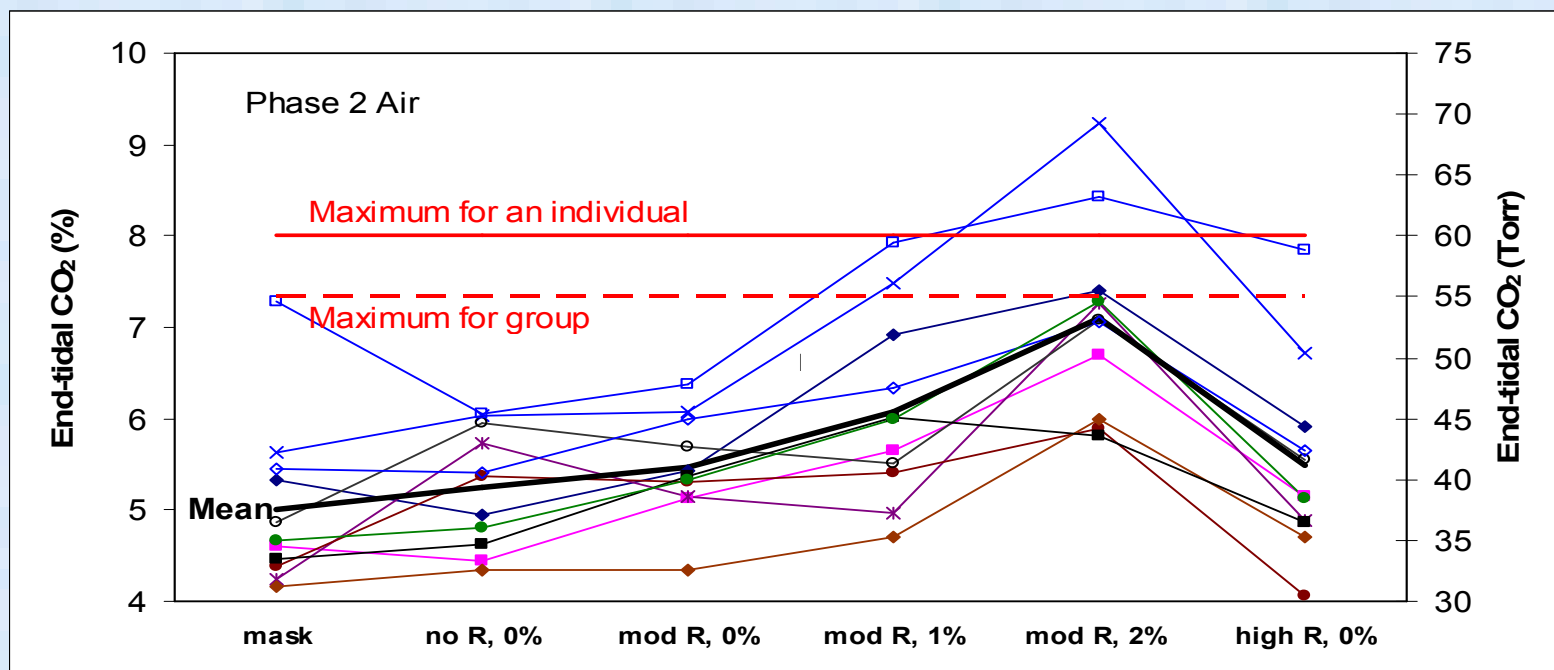




Results



Changes in end-tidal CO_2
Inspired CO_2 and R, air





Results



Contingency tables, hypercapnia and symptoms

Moderate R, 2% CO₂ in air

	$F_{ET}CO_2 \geq 7\%$	$F_{ET}CO_2 < 7\%$
Symptoms	3	0
No symptoms	4	4

Moderate R, 2% CO₂ in O₂

	$F_{ET}CO_2 \geq 7\%$	$F_{ET}CO_2 < 7\%$
Symptoms	4	1
No symptoms	5	2

Symptoms = headache, tunnel vision (n=1), altered mental state (n=1)



Results



Endurance times

Individual changes from control

Gas	Condition R CO ₂		Number of subjects with endurance time reductions of		
			≥10%	≥20%	≥30%
Air	Moderate	0%	4	2	0
	High	0%	6	3	2
	None	2%	4	4	2
	None	3%	7	6	4
	Moderate	1%	4	3	3
	Moderate	2%	6	5	4
O ₂	Moderate	0%	3	2	1
	None	2%	3	3	2
	Moderate	2%	3	2	0



Conclusions



With breathing resistance like that of the MK 16 at 50 fsw and heavy work, 2% inspired CO_2 is excessive.

- With background air
 - endurance time was reduced by 20% in 50% of subjects and by 30% in 40% of subjects, and
 - $F_{\text{ET}}\text{CO}_2 \geq 7\%$ in 64% of subjects
 - 27% had symptoms of hypercapnia.
- With background O_2
 - endurance time was reduced by 20% in only 20% of subjects, but
 - $F_{\text{ET}}\text{CO}_2 \geq 7\%$ in 75% of subjects, and
 - 42% had symptoms of hypercapnia.

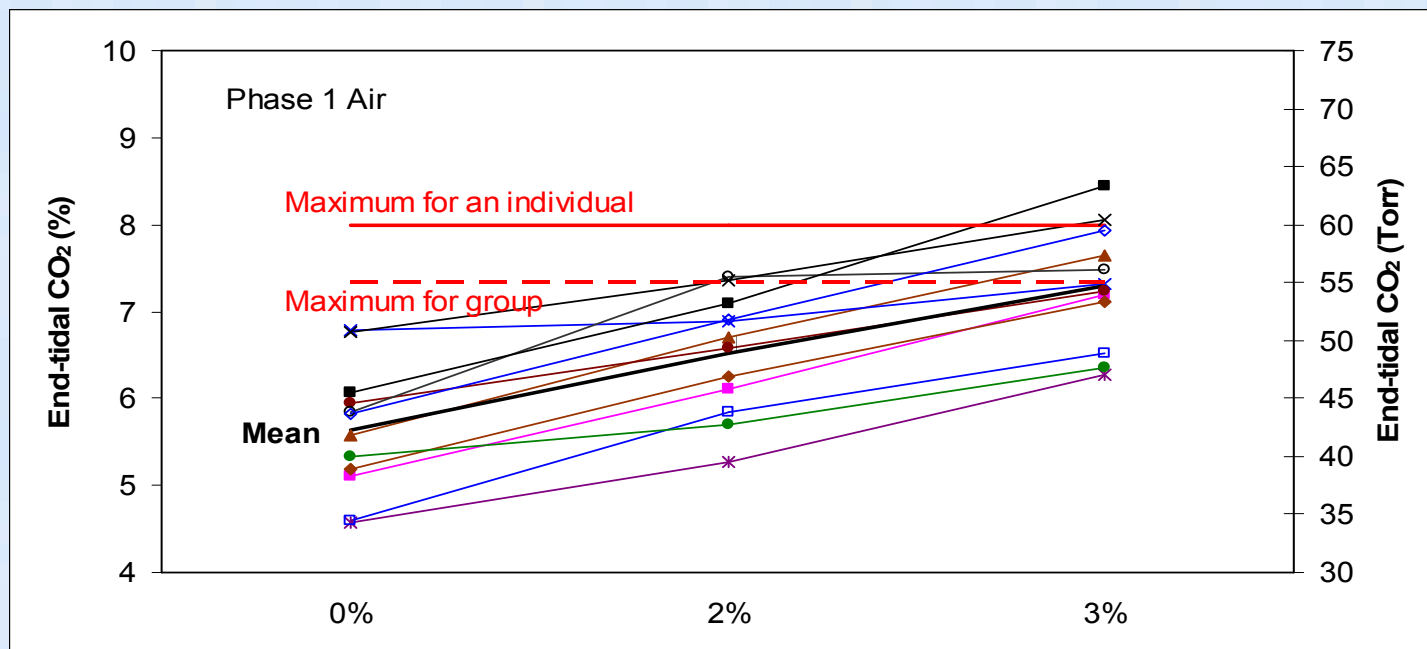




Results



Changes in end-tidal CO_2
Inspired CO_2 , no R, air





Results



Changes in end-tidal CO_2
Inspired CO_2 with or without R, O_2

