

Physiological Evaluation of Air-Fed Ensembles during Treadmill Walking

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Introduction

- An air-fed ensemble (AFE) is an encapsulating suit with an external source of breathing air which provides respiratory protection without the use of a tight-fitting facepiece.
- NIOSH has developed a concept paper for the certification of AFE, including measuring inhaled O₂ and CO₂ during human subject testing.
- Human research has been supplemented with Automated Breathing and Metabolic Simulator (ABMS) testing (Figure 1).
- The current study evaluated the physiologic stresses of AFE in wearers and on the ABMS during rest, low-, and moderate-intensity treadmill exercise.

Methods

- To set work rates, 14 male subjects walked at oxygen uptake levels of 1.0 (LOW) and 2.0 L/min (MOD). Six women walked at 0.8 (LOW) and 1.7 L/min (MOD).
- Subjects then wore two different air-fed ensembles (AFE-A and AFE-B) and one two-piece supplied-air ensemble (C) at rest and while walking for 6 min at each treadmill setting (Figure 2). Inhaled O₂ and CO₂, pressure and temperature were measured.
- At the end of each 6-min MOD walk, the air-supply to each ensemble was shut off while the subject continued to walk, and the time for minimum inhaled CO₂ concentration to reach 2.0% or maximum O₂ to drop below 19% was measured.
- ABMS testing using men's metabolic values was also performed for each ensemble. Oxygen uptake for the HIGH work rate was 3.0 L/min.

Table 1. Women's results (n = 6)

Work Rate	Min Inhaled CO ₂ (%)	Ave Inhaled CO ₂ (%)	Ave Inhaled O ₂ (%)	Ave Exhaled Press (mmH ₂ O)	Ave Inhaled Press (mmH ₂ O)	Dry-Bulb Temp (°C)
AFE-A						
REST	0.2	0.7	20.0	14	12	25.1
LOW	1.0	2.2	18.1	13	10	26.6
MOD	1.2	2.9	17.8	14	8	27.4
AFE-B						
REST	0.5	1.3	19.4	6	4	24.2
LOW	1.0	2.4	17.9	6	4	25.8
MOD	1.1	2.5	18.1	7	2	26.1
Supplied-Air C						
REST	0.1	0.5	20.3	2	1	21.6
LOW	0.1	0.8	19.9	3	0	21.9
MOD	0.3	0.7	20.0	5	-3	22.4

Results

- Women's results are shown in Table 1 and men's and ABMS test results are shown in Table 2. Data from the last minute of each work rate were examined. At intensities above REST, minimum inhaled CO₂ concentration was greater than 1% and average inhaled O₂ concentration was less than 19% in AFE-B during both ABMS and men's testing and in AFE-A and AFE-B during women's testing.
- Inhaled CO₂ concentrations trended lower, average inhaled O₂ concentration trended higher and inhaled gas temperatures trended lower in Supplied-Air C than in either AFE. Inhaled CO₂ concentrations trended higher and average inhaled O₂ concentration trended lower in women as compared to men.

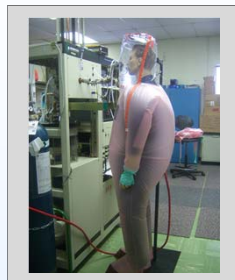


Figure 1. ABMS testing of AFE-A ensemble

Table 2. Men's (n = 14) and ABMS (n = 6) test results

Work Rate	Min Inhaled CO ₂ (%)		Ave Inhaled CO ₂ (%)		Ave Inhaled O ₂ (%)		Ave Exhaled Press (mmH ₂ O)		Ave Inhaled Press (mmH ₂ O)		Dry-Bulb Temp (°C)	
	Human Subject	ABMS	Human Subject	ABMS	Human Subject	ABMS	Human Subject	ABMS	Human Subject	ABMS	Human Subject	ABMS
AFE-A												
REST	0.2	0.0	0.5	0.3	20.3	20.7	14	15	12	14	25.3	23.4
LOW	0.4	0.1	1.2	0.4	19.2	20.6	14	16	10	13	26.0	24.3
MOD	0.6	0.5	1.7	0.7	18.8	20.2	15	18	8	9	26.4	26.1
HIGH	N/A	0.7	N/A	1.1	N/A	19.8	N/A	19	N/A	5	N/A	26.2
AFE-B												
REST	0.4	0.2	0.9	0.5	19.6	20.5	4	4	4	4	25.5	25.5
LOW	0.9	0.5	1.7	0.8	18.5	20.0	5	5	2	3	26.8	26.4
MOD	1.4	1.5	2.3	1.9	18.0	19.0	7	6	0	0	27.3	28.1
HIGH	N/A	2.3	N/A	2.9	N/A	18.0	N/A	7	N/A	-3	N/A	28.5
Supplied-Air C												
REST	0.1	0.0	0.4	0.2	20.0	20.6	3	2	1	1	22.2	24.9
LOW	0.2	0.0	0.6	0.2	19.8	20.7	5	2	1	0	22.8	25.7
MOD	0.4	0.2	0.8	0.4	19.8	20.4	7	4	-1	-3	23.2	27.2
HIGH	N/A	0.5	N/A	0.7	N/A	20.0	N/A	4	N/A	-6	N/A	27.6

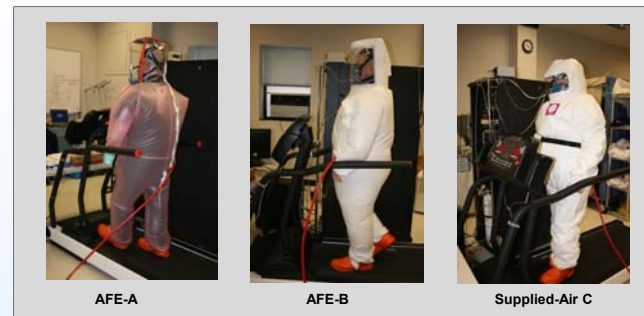


Figure 2. Treadmill walking with ensembles AFE-A, AFE-B and Supplied-Air C

Discussion

- Supplied-air ensembles typically supply breathing gas only to the head of the wearer. AFE's whole-body encapsulation results in much larger dead space volumes and, therefore, lower inhaled O₂ and greater CO₂ concentrations and greater inhaled gas temperatures.
- Lower inhaled O₂ and greater CO₂ concentrations seen in women's testing may be due to women's smaller body volume relative to AFE volume compared to men.
- Negative inhalation pressures were observed in AFE-B and Supplied-Air C during ABMS testing at the HIGH work rate; however, these measurements were made at the mouth and may not represent a significant risk of inward leakage.
- The mean times for minimum inhaled CO₂ concentrations to increase to 2% after the air supply was shut off were 39, 36, and 29 sec for AFE-A, AFE-B and Supplied-Air C, respectively. During these short periods, the ensembles collapsed around the subjects and visors fogged, which may have implications for emergency escapes while wearing the ensembles.

Conclusions

- Inhaled CO₂ concentrations trended lower, average inhaled O₂ concentration trended higher, and inhaled gas temperature trended lower in Supplied-Air C than in either air-fed ensemble.
- Minimum inhaled CO₂ concentration was $\geq 1.5\%$ and average inhaled O₂ concentration was less than 19% for AFE-B for the MOD walk during both human and ABMS testing.
- Inhaled CO₂ concentrations trended greater and average inhaled O₂ concentrations trended lower in women as compared to men.
- When air-supply was shut off during walking, the time taken for minimum inhaled CO₂ concentration to reach 2.0% was < 40 sec for all three ensembles.
- Inhaled CO₂ and O₂ concentrations were comparable for human and ABMS testing.
- Results may be used to assist with the development of certification procedures for air-fed ensembles.

Disclaimer

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