Prevention of Facial Cold Injury with a Passive Heat and Moisture Exchanger

Igor B. Mekjavic[1] **& Ola Eiken**[2]
[1]Department of Automation, Biocybernetics and Robotics, Jozef Stefan Institute,
Jamova 39, SI-1000, Ljubljana, Slovenia;
[2]Swedish Defence Research Agency, Karolinska Institutet,
Berrzelius v. 13, SE-17177 Stockholm, Sweden.

Contact person: igor.mekjavic@ijs.si

ABSTRACT

The present study evaluated the thermodynamic characteristics of a prototype respiratory heat and moisture exchanger (HMS), particularly its ability to prevent cold injury to the face. The HME comprised a thermally insulated oro-nasal mask with a cylindrical heat and moisture exchanger protruding from the centre of the mask. The heat exchanging unit contained an aluminium "honeycomb" structure providing a surface area of 478.5 cm^2 *for exchange of heat and moisture between the inspired and expired air. A breathing simulator was used to simulate the temperature and humidity of the expired air. The HME was strapped to the head of a manikin, whose mouth was connected to the respiratory simulator. The entire arrangement was placed in a climatic chamber. We evaluated the efficiency of the HME at two different rates of ventilation (11.3 and 28.0* $L.min^{-1}$*), and at five different ambient conditions (-24, -14, -4, 8, and 22 °C). The efficiency of the HME was evaluated by determining the performance coefficient (PC) under each condition:* $PC(\%) = (T_{in}-T_a)/(T_{ex}- T_a) \times 100$*; where* T_{in}, T_{ex}, *and* T_a *are the temperatures of the inspired, expired and ambient air, respectively. In all subzero ambient conditions, the HME was able to maintain the temperature within the oro-nasal mask above 20°C. By maintaining mask temperature above 20°C in subzero temperatures, the HME can effectively eliminate the risk of freezing cold injury (FCI) of the facial region.*

1.0 INTRODUCTION

The benefits of inspiring humidified gas has long been recognised, and applied in many clinical and industrial breathing systems. Inspiring dry gas may cause irritation of the airways and also enhance respiratory heat loss. As a consequence, a number of respiratory heat and moisture exchangers have been developed to provide warm and moist inspiratory gas. There have been two main approaches in designing such devices. Active heat and moisture exchangers heat and humidify the inspired gas by passing the inspired air through a heated water bath. Passive heat and moisture exchangers are designed to capture the heat and moisture of the expired air, and transfer it to the inspired air.

The possibility of humidifying and heating inspired air in subzero ambient conditions can benefit personnel working in such environments [1,2]. Whereas the HMEs for clinical use have been subject to much scrutiny and evaluation, similar evaluation of HMEs for subzero ambients is lacking.

The present study evaluated the efficiency of a prototype HME over a range of simulated ambient temperature conditions by using a breathing simulator.

Mekjavic, I.B.; Eiken, O. (2005) Prevention of Facial Cold Injury with a Passive Heat and Moisture Exchanger. In *Prevention of Cold Injuries* (pp. 9-1 – 9-4). Meeting Proceedings RTO-MP-HFM-126, Paper 9. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.asp.

2.0 METHODS

Principle of Operation of Prototype Heat and Moisture Exchanger

The prototype heat and moisture exchanger comprises a thermally insulated oro-nasal mask with a cylindrical heat and moisture exchanging unit protruding from the centre of the mask. The heat exchanging unit contains a honeycomb aluminium structure (Goodfellow Corp., Malever, PA), providing a total surface area of 478.5 cm^2 for the exchange of heat and moisture between the expired and inspired air. The expired air cools, as it passes through the aluminium honeycomb structure, thus transferring heat to the aluminium walls. As the gas cools, water condenses and is retained in the honeycomb structure-shaped cells. On inspiration, the heat and moisture retained by these cells is transferred to the colder and drier gas. Thus, the HME minimises the total loss of respiratory heat and moisture.

Experimental Arrangement

A breathing simulator provided two levels of ventilation: 11.25 and 28.00 $L.min^{-1}$, simulating rest and light exercise conditions, respectively. The breathing simulator was hydraulically driven piston, whose frequency and displacement could be controlled. The former simulating respiratory frequency, and the latter tidal volume. For the purpose of the present evaluation, the tidal volume was kept constant at 1.5 L and only the frequency varied to achieve the two levels of simulated respiration.

The breathing simulator was connected to a valve arrangement, such that the expired gas was drawn through a water bath and subsequently the HME. On inspiration, the gas was drawn via respiratory tubing to the breathing simulator. The temperature of the water bath was maintained at a level ensuring that the expired gas was approximately 37°C, and saturated with water vapour. The HME was strapped to the head of a manikin, whose mouth was connected via respiratory tubing to the breathing simulator. The entire arrangement was placed in a climatic chamber maintained at the desired temperature. The temperature of the ambient air was monitored in close proximity to the HME.

The temperature within the oro-nasal mask of the HME was measured with a copper-constantan thermocouple, and recorded at 0.9s intervals with a Hewlett Packard Data Acquisition System (Model HP 3497A, Hewlett Packard, Andover, MA). At any given temperature, the measurements were made over a one-minute period at two levels of ventilation. The time was found to be adequate to attain a steady state level of inspired and expired temperatures.

The HME was evaluated for two levels of ventilation, at average (SD) ambient temperatures of –24 (0.3), -13.8 (0.5), -3.8 (0.3), 8.2 (0.1) and 21.7 (0.03).

Analysis

The efficiency of the HME was evaluated by determining its performance coefficient (PC) under each condition, as suggested by Johnson et al. [3], whereby:

$$PC (\%) = (Tin - Ta) / (Tex - Ta) \times 100$$

where,

Tin (°C) = inspired air temperature
Tex (°C) = expired air temperature
Ta (°C) = ambient air temperature

3.0 RESULTS

Results of the trial conducted at –24°C are presented in Fig. 1. The graph represents the temperature within the oro-nasal mask during resting breathing (11.25 L.min^{-1}). As can be seen from the graph, expired air temperature was maintained 34.9 (0.4)°C, and inspired air temperature at 22.2 (0.2)°C. When the ventilation was increased to 28.00 L.min^{-1}, expired air temperature was 36.3 (0.7), and inspired air temperature at 24.9 (0.6)°C. Thus, for this condition, the passive HME was capable of elevating the inspired air temperature by 47.4 (0.6) °C (Fig. 2). The humidity within the oro-nasal mask was maintained near saturation throughout the trial.

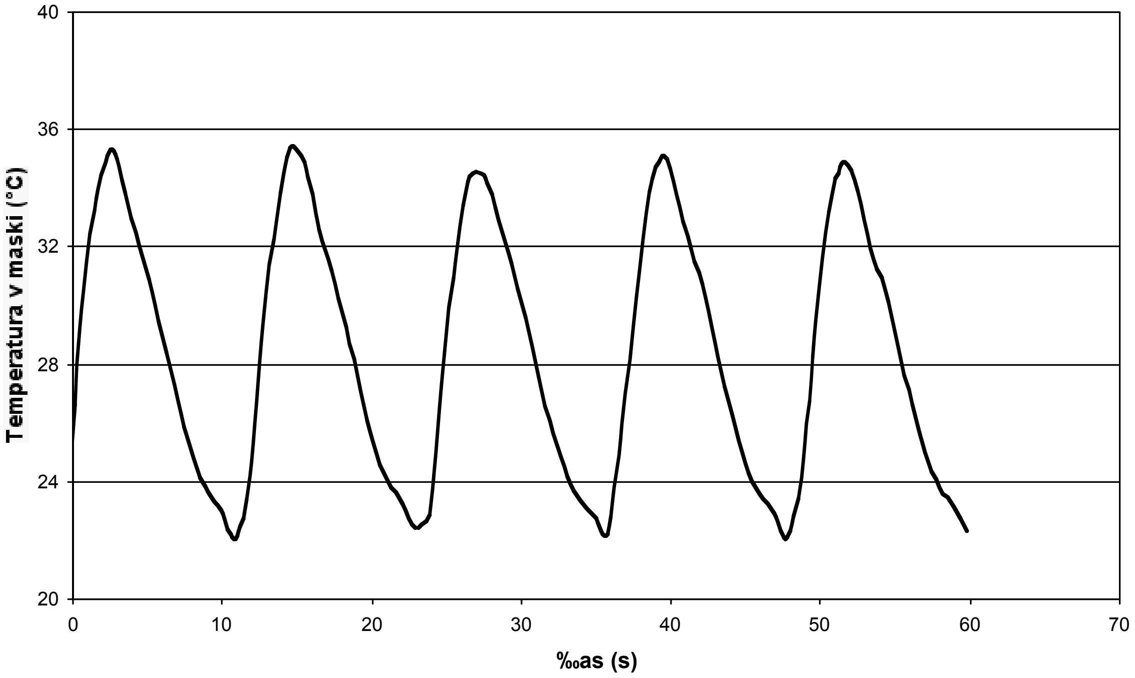

Fig. 1: The temperature of the air within the oro-nasal mask (°C; y axis) as a function of time (seconds; x axis) during simulated resting respiration (11.25 L.min^{-1}) in –20°C.

The performance coefficients (PC), calculated according to equation 1, for all conditions tested are presented in Table 1.

Table 1: Performance coefficients of the prototype HME for a range of ambient temperatures, at breathing rates of 11.25 and 28.00 L.min^{-1}.

Ta (°C)	PC (%)	
	V_E = 11.25 L.min^{-1}	V_E=28.00 L.min^{-1}
-24.0	78.4 (0.8)	80.6 (0.6)
-13.8	78.1 (0.4)	86.7 (1.2)
-3.8	73.1 (0.3)	84.2 (1.3)
8.2	63.9 (0.2)	77.9 (2.1)
21.7	44.1 (0.5)	67.9 (3.9)

4.0 CONCLUSIONS

The prototype HME is capable of effectively reducing respiratory heat loss in sub-zero ambient conditions. The performance coefficients determined for the prototype HME are well above those reported for 17 different type of cold weather masks evaluated by Johnson et al. [3].

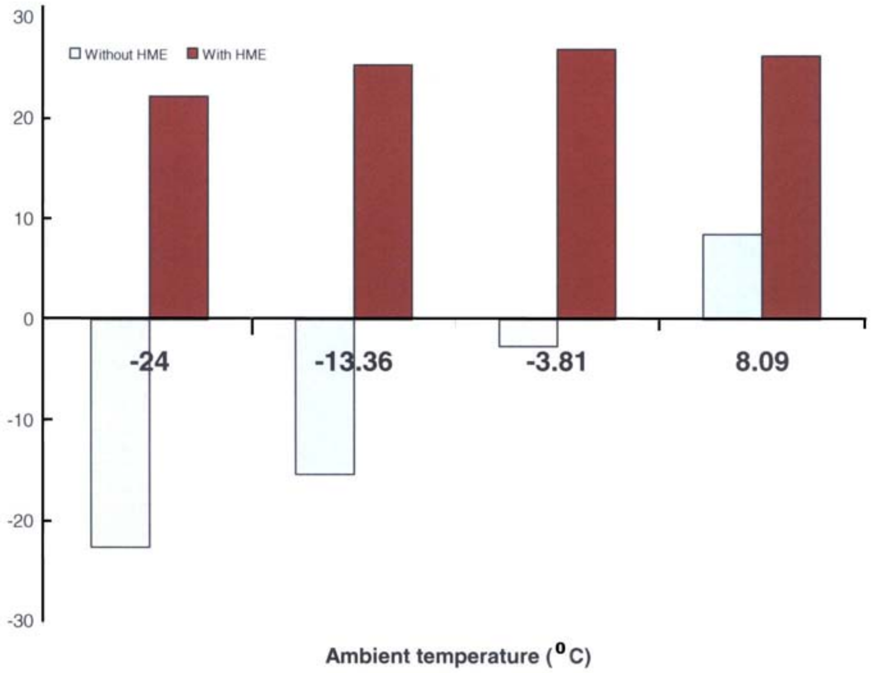

Fig. 2: Temperature within the oro-nasal mask with and without the prototype HME, for a range of ambient temperatures at a ventilation rate of 11.25 L.min^{-1}.

The utility of devices capable of heating and humidifying inspired air has been evaluated for a variety of applications. Inhalation of warm moist air prevents cold induced bronchostriction [1], but does not provide any improvement in the rewarming of hypothermic individuals [2], nor in selective heating of the central nervous system [4]. Thus, the most obvious benefit of passive heat and moisture exchangers is preventing any decrease in facial temperatures, as reflected in the oro-nasal mask temperature in the present study, to levels that may cause cold injury.

REFERENCES

[1] Eiken O, Kaiser P, Holmer I, Baer R (1989). Physiological effects of a mouth-borne heat exchanger during heavy exercise in a cold environment. Ergonomics 32: 645 – 653.

[2] Mekjavic IB, Eiken O (1995). Inhalation rewarming from hypothermia: An evaluation in –20°C simulated field conditions. Aviat. Space Environ. Med. 66: 424 – 429.

[3] Johnson DL, Bos CJ, Rivington RN, Dodge P (1987). A technical and functional assessment of cold weather masks in severe cold conditions. Research and Standards Division, Bureau of Radiation and Medical Devices Report.

[4] Mekjavic IB, Rogelj K, Radobuljac M, Eiken O (2002). Inhalation of warm and cold air does not influence brain stem or core temperature in normothermic humans. J. Appl. Physiol. 93: 65-69.