HEAT TRANSFER CHARACTERISTICS OF ROWING HEADGEAR WITH RADIANT HEAT FLOW

Bogerd, C.P.[1,2], Brühwiler, P.A.[1] & Heus, R.[3]
[1]Empa, Swiss Federal Laboratories for Materials Testing and Research
[2]Institute of Human Movement Sciences and Sport, ETH Zurich, Switzerland
[3]TNO Defense, Security and Safety

Contact person: bogerd@nielsbogerd.com

INTRODUCTION

Radiant heat gain to the head has recently been shown to affect sensation in human subjects (Buyan et al., 2006). However, only one published study has been conducted on the influence of radiant heat gain for sports headgear (Ishigaki et al., 2001). One could assume that reducing heat stress by shielding solar radiation using sports headgear would increase thermal comfort, and possibly decrease heat strain, as often shown in studies in which heat stress on the head is reduced by artificial cooling (Nunneley et al., 1971; Williams and Shitzer, 1974). A baseball-style cap is often used among athletes competing under sunny conditions. However, in spite of the numerous studies on understanding and optimizing forced convective heat loss in, e.g., bicycle helmets, no study has examined a baseball-style cap on heat transfer.

In this study we focus on the performance of two types of rowing headgear by examining the forced convective heat loss and radiant heat gain. We compare typical baseball-style caps to a prototype rowing headgear (PRH) recently developed with the idea of minimizing radiant heat gain to the head without hindering convective and evaporative heat loss (Bogerd et al., 2005). We used a thermal manikin headform (Brühwiler, 2003) to measure the net heat transfer of the headgear under non-sweating conditions, with and without radiation, isolating the effects of forced convective heat loss and radiant heat gain.

Figure 1: All headgear configurations. From left to right: NUDE, PRH, CW, and CB.

METHODS

A thermal manikin headform (Brühwiler, 2003), placed at the exit of a wind tunnel in a climate chamber, was used to estimate net heat transfer from a human head while wearing the headgear studied. The surface temperature of the headform was set to 35 °C, and the power needed to maintain this temperature in steady state was recorded. This heating power corresponds to the net heat transfer. Values for the scalp and face sections were obtained separately. The setup was equipped with a frame holding a heat lamp to simulate radiant heat flow. For a more thorough description of the setup, see Brühwiler (2003).

Measurements on the following headgear configurations were carried out (Fig 1): The bald head form (NUDE), the PRH, a white 100% cotton baseball-style cap (CW), and a slightly different black 100% cotton cap (CB). All headgear configurations were measured in two radiant heating arrangements: without (NoRad), and with the heat lamp directly above (90° below horizontal, or "Rad").

The climate chamber was set to an ambient temperature of 22.0 ± 0.1 °C and relative humidity of 50 ± 1%; a baseline radiant temperature of 22.0 °C was assumed. A wind speed of 4.0 ± 0.1 $m \cdot s^{-1}$ was set, measured (MiniAir2, Schiltknecht, Gossau, Switzerland) beside the headform. A 150 W heat lamp (T228, Osram, München, Germany) was used as (nonuniform) radiant heat source. The lamp created a heat flow to the head of 18.7 W (approximately 675 $W \cdot m^{-2}$). According to manufacturer data, the spectrum emitted by the lamp ranged from approximately 500 nm to more than 2500 nm, with 7% of the power in the visible region and the remaining 93% in the infrared (wavelengths > 800 nm).

Each condition was measured three times and on separate occasions. Two datasets were collected:

i) Forced convective heat loss: fresh placement of the headgear in a given configuration (XX) between measurements, from which the forced convective heat loss was calculated ($NUDE_{NoRad} – XX_{NoRad}$);

ii) Radiant heat gain: no fresh placement of the headgear between consecutive measurements of the same headgear configuration in arrangements NoRad and Rad, from which the radiant heat gain was calculated ($XX_{NoRad} – XX_{Rad}$).

MANOVA was used to test for statistical differences, with headgear configuration and radiation arrangement as independent variables. A Sheffé test was used for post hoc comparisons if a significant difference was found ($p < 0.05$). The statistical analysis was carried out with SPSS 13.0 for Windows.

RESULTS AND DISCUSSION

All average net heat transfer data are visualized in Fig 2. The term "net" here is so defined that positive values occur for transfer away from the headform, which also means that larger values imply less heat stress. The NUDE configuration with radiant heat gain is the benchmark for the performance of the headgear in rejecting such heat gain. The PRH_{rad} facilitates 1.3 times more combined heat transfer than $NUDE_{Rad}$ ($p < 0.01$). The caps reduced combined net heat transfer compared to $NUDE_{Rad}$ ($p < 0.01$). No differences were found between the caps. The net heat transfer in the face section was very similar for all headgear configurations and radiant arrangements.

Since the headgear largely covered the scalp section, larger headgear-dependent differences are found there. All headgear studied reduce net heat transfer in the scalp section, in the absence of radiant heat gain, whereas only the PRH shows higher values than the nude headform with radiant heat gain (an increase of 17.5 W).

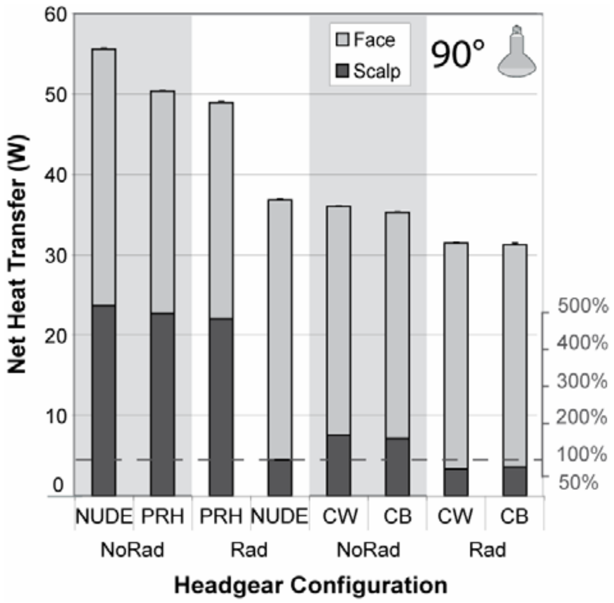


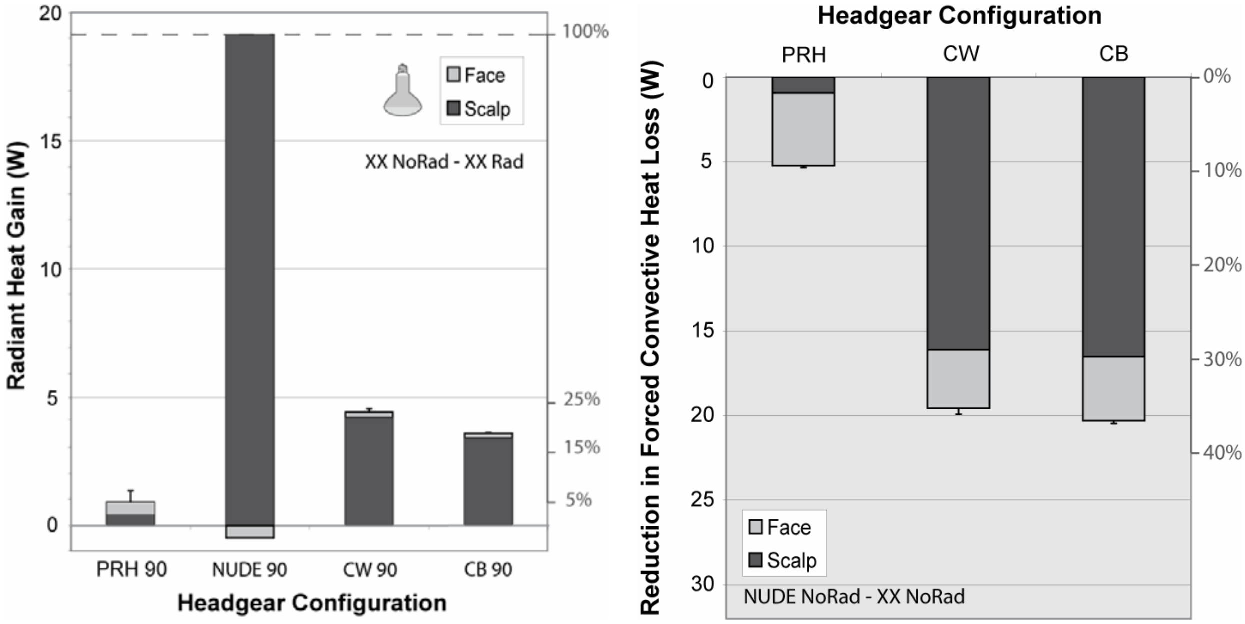
Figure 2: Net heat transfer (Q_n), for all headgear configurations and radiant arrangements. The right hand y-axis indicates relative difference to Q_n–scalp of $NUDE_{Rad}$. The error-bars indicate one standard deviation.

The headgear reduced radiant heat gain relative to $NUDE_{Rad}$ by as much as 95% - 76% (Fig 3a). Interestingly, despite their brims, the caps allow the higher impinging heat gain compared to PRH_{Rad} in the face section in this arrangement. Larger differences are found for forced convective heat loss (Fig 3b). The PRH reduced forced convective heat loss by 9%, most of which occurred in the face section. Both CW and CB reduced forced convective heat loss by ~36%.

CONCLUSIONS

Based on the results we conclude that the prototype rowing headgear (Bogerd et al., 2005) constitutes a large improvement over conventional baseball-style caps under the studied conditions, and for persons with little or no hair. Forced convective heat loss was found to be of primary importance, but radiant heat gain was also found to be relevant.

However, currently it remains unclear if qualitatively similar results can be expected at other conditions, e.g., different radiant angles, or with hair, and how these results relate to comfort perception and possibly heat strain of athletes.



(a) (b)

Figure 3: Radiant heat gain (a), and reduction in forced convective heat loss relative to NUDE (b). The right hand y-axis indicates relative difference with values for the scalp of NUDE. The error-bars indicate one standard deviation.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to TNO Science and Industry for providing the prototype rowing headgear.

REFERENCES

Bogerd, C.P., Heus, R. and Willems, J.W.M., 2005. A sun shading headgear used by a Dutch Olympic sculler: A comparative study. In proceedings of the 11th International Conference on Environmental Ergonomics (edited by I. Holmér, K. Kuklane and C. Gao), pp. 396-399. Ystad, Sweden.

Brühwiler, P.A., 2003. Heated, perspiring manikin headform for the measurement of headgear ventilation characteristics. Meas. Sci. Technol. 14, 217-227.

Ishigaki, T., Fujishiro, H., Tsujita, J., En, Y., Yamato, M., Nakano, S. and Hori, S., 2001. Relationship between helmet temperature and tympanic temperature during American football practice. Jpn. J. Phys. Fit. Sports Med. 50, 333-338.

Nunneley, S.A., Troutman, S.J., Jr. and Webb, P., 1971. Head cooling in work and heat stress. Aerosp. Med. 42, 64-68.

Williams, B.A. and Shitzer, A., 1974. Modular liquid-cooled helmet liner for thermal comfort. Aerosp. Med. 45, 1030-1036.