Eur J Appl Physiol (2004) 92: 698–701
DOI 10.1007/s00421-004-1114-5

ORIGINAL ARTICLE

Paul A. Brühwiler · Charline Ducas · Roman Huber
Phillip A. Bishop

Bicycle helmet ventilation and comfort angle dependence

Accepted: 9 January 2004 / Published online: 12 May 2004

Abstract Five modern bicycle helmets were studied to elucidate some of the variations in ventilation performance, using both a heated manikin headform and human subjects ($n = 7$). Wind speed and head angle were varied to test their influence on the measured steady-state heat exchange (cooling power) in the skull section of the headform. The cooling power transmitted by the helmets varied from about 60% to over 90% of that of the nude headform, illustrating the range of present manufacturer designs. Angling the head forward by 30° was found to provide better cooling power to the skull (up to 25%) for three of the helmets and almost equal cooling power in the remaining two cases. Comparisons of skull ventilation at these angles with human subjects strongly supported the headform results.

Keywords Helmet · Ventilation · Manikin headform · Bicycle · Wind

Introduction

It is generally taken for granted that bicycle helmets give a large degree of protection to their wearers, many of whom are involved in serious accidents each year (Ellis et al. 2000; Swart 2003). Bicycles, and thus helmets, are most often used when the weather is warm, and for this reason the issue of ventilation is quite important, since it can influence the willingness of people to wear helmets (Gisolfi et al. 1988; Sheffield-Moore et al. 1997; Ellis et al. 2000). There has been one report that helmets adversely affected psychomotor performance (Rodahl et al. 1992). No other physiological effects of the extra heat load implicit for the wearer of a cycling helmet in warm conditions have been shown to lead to negative health consequences (Gisolfi et al. 1988; John and Dawson 1989; Sheffield-Moore et al. 1997). The head is well-established as a region of particular sensitivity to thermal comfort (Schvartz 1970; Kissen et al. 1971; Nunneley et al. 1971, 1982; Desruelle and Candas 2000). It is therefore clear that efforts to improve the ventilation properties of bicycle helmets could result in increased usage because of greater comfort. However, no systematic studies of such helmets have been published to-date, with the exception of sporadic efforts in the general press (Ellis 2001; Kaufmann 2003).

The purpose of this study was to determine the impact of helmet angle and air speed on the cooling power and comfort of cycling helmets. We report here the first results from a study of the ventilation of five (out of an ensemble of 24) bicycle helmets of recent design. We employed a heated manikin headform to obtain the steady-state values of heat exchange, or cooling power, using a wind tunnel in a climate chamber to control the test conditions. Human subjective experience was also investigated in tests focusing on the effect of the head angle to evaluate the headform results.

Methods

Figure 1 shows the 30° measurement configuration for the present study. The headform is adapted from a polyester shop-window manikin, and corresponds approximately to an average human male head of size 58 cm. As also seen, it was mounted at the mouth of a small wind tunnel; the entire apparatus was placed in a climate chamber. The surfaces of the headform were maintained at an average temperature of 35°C. Further general details and characterization of the experimental set-up can be found in Brühwiler (2003).

An air temperature of 25°C and relative humidity of 65% were chosen for this study as being representative

P. A. Brühwiler (✉) · C. Ducas · R. Huber
Swiss Federal Laboratories for Materials Testing and Research (EMPA), Lerchenfeldstrasse 5, 9014 St. Gallen, Switzerland
E-mail: Paul.Bruehwiler@empa.ch

P. A. Bishop
Human Performance Laboratory, University of Alabama, Tuscaloosa, Alabama, USA

Fig. 1 *Left* Side view of a typical measurement in the present study. The headform is covered with a thin fabric hood, and angled at 30° to simulate a typical riding position; *right* rear view, facing into the wind tunnel

of practical conditions. The head was either vertical (0° tilt) or angled forward 30° to approximate the typical head attitude of a rider in the mountains. Two wind speeds were selected: 1.6 m/s (~6 km h^{-1}) and 6.1 m/s (~22 km h^{-1}), to simulate "slow" (or uphill) and "fast" riding situations, respectively. The data were acquired as time traces of the heating power, and the steady-state values were determined by averaging, typically, the last 20 min of the phase under consideration. The measurements were repeated twice after intervening time periods and other measurements to test the effects of reproducibility, which typically corresponded to a range of about 1.5 W (±2 standard deviations). Since the intrinsic repeatability of the nude headform was typically better than 0.2 W (Brühwiler 2003), the present value of measurement variability is attributed primarily to small air temperature variations (0.1°C), which the climate chamber was not capable of eliminating. We also noted the difficulty in placing the helmet in exactly the same manner on the headform for each new measurement, which also contributes negatively to the reproducibility but which can be expected to roughly correspond to situations of actual use.

Eight subjects were chosen initially for the present series of tests; one was eliminated from consideration due to an inability to differentiate among the helmets. The tests were carried out with the subjects' heads placed in the location of the headform, i.e., with almost identical surroundings. The subjects ranged in age from 21 to 46 years, with two women, and were all in good health. The weather outdoors was similar to that in the climate chamber, minimizing acclimatization problems. After preliminary studies, the wind speed was selected to be 10 km h^{-1} so as to avoid thermal discomfort at higher speeds due to overcooling but to still attain enough thermal sensitivity for the measurements. As shown below, the headform results were not strongly dependent on the wind speed so that this choice should not have affected the helmet rankings by the subjects, if they were sensitive to the same parameters. The five helmets were tested in two series of measurements carried out after a 15-min acclimatization period. The two series were carried out consecutively within a period of about 30 min, with the helmets randomly ordered within each series and with the subjects obtaining as little knowledge as possible of which helmet they were wearing. Each was instructed to adopt head angles of 0° and 30° as often as desired until an opinion could be formed of which angle provided the better ventilation to the area of the head covered by the helmet. A value position on a horizontal line was to be marked – to the left indicating better performance at 0°, and to the right at 30°. The distances from the centers of the lines were later converted to numbers, with left and right corresponding to negative and positive, respectively, and possible maximum values of 10. We considered the first series as an acclimatization to the measurement, which was supported by the greater variability among the subject ratings, and therefore report the results of the second series below.

Results and discussion

The five helmets which were selected from the ensemble of 24 represent extremes of absolute cooling power performance, as well as head angle dependence. Data from the skull headform measurements for these helmets, and for all four condition combinations are shown in Fig. 2. The nude (no helmet) headform exhibits the largest cooling power, and there is a substantial spread between best and worst. The ordering shown was arbitrarily selected as an approximate average ranking for the two wind speeds at the 30° angle, with increasing performance from left to right. The fact that the ranking applies almost equally well at both wind speeds emphasizes the lack of wind speed dependence of the

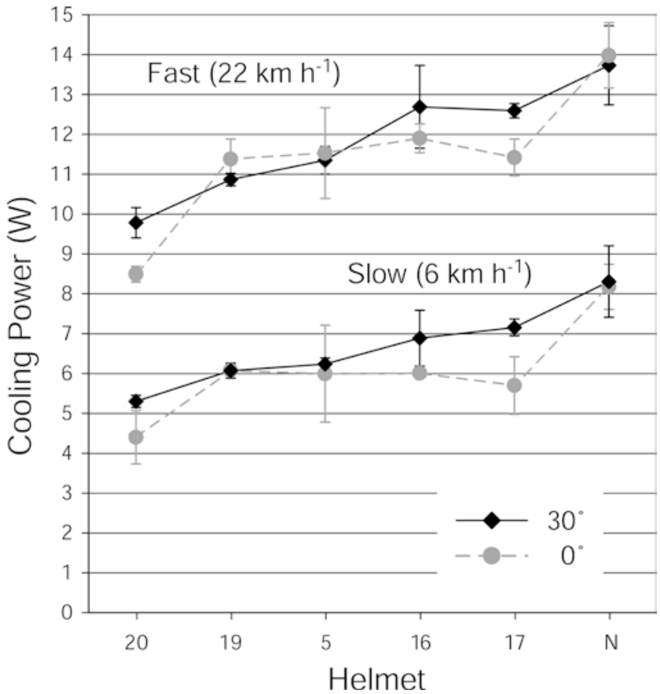

Fig. 2 Cooling power for the nude headform in the skull region for the indicated helmets at the given wind conditions and angles. *N* denotes the nude headform (no helmet). The lines are provided to ease comparison of the trends at different wind speeds and head angles

relative cooling power of the helmets in the tested range. The ranking characterizes the results at 0° tilt less well, but is in partial agreement. Since the cooling power in the face section varied relatively little from helmet to helmet, we do not present those data here.

In Fig. 2, we see that helmet 16 is clearly better than no. 17at 0°, and approximately equal at 30°. Helmets 19 and 5 show little or no variation with respect to angle, whereas the others showed a strong improvement in ventilation as the headform was tilted forward.

For the subject tests we chose to focus on the angle variation, rather than on the absolute cooling power, in order to minimize the effects of inter-helmet comparisons for the subjects. We reasoned that a subject could more easily discern the effects of changing the head angle than the effects of changing helmets. The results, shown in Table 1, are in quite good agreement with the headform data: helmets 16, 17 and 20 were ranked much better at 30° than at 0° whereas helmets 5 and 19 were found to show little variation. Differences within each of the two groups of helmets were not detectable with the present subject ensemble.

To summarize, we show that there were large variations in the skull cooling power of modern bicycle helmets, which extends to the variation in performance as a function of the forward tilting angle of the head. There were, however, small variations in the relative cooling power among the helmets as a function of wind speed, for the typical speeds chosen in this study. The human

Table 1 Ventilation performance rated by the subjects for the indicated helmets (from 0 to 10 maximum), at a wind speed of 10 km h^{-1}. Positive values indicated better results at 30°, negative at 0°. The trimmed mean is the mean after removing the two most distant outlier values, and the standard deviation (*SD*) was also calculated in this manner

Helmet #	Median	Trimmed Mean	SD
20	2	2.5	0.6
19	0	0.6	0.8
5	0	−0.2	1.1
16	3	2.9	2.0
17	3	2.0	0.9

subject ratings were in quite good agreement with the headform measurements in terms of which angle yielded better ventilation for a given helmet. This strongly suggests that the headform measurements yield parameters which are directly relevant for a "general subject". The angle dependence of the ventilation efficiency suggests that optimization of this characteristic for the average user could be improved by considering the riding style of the wearer. These issues, and the connection of the absolute cooling performance to human performance and comfort, remain to be understood.

Acknowledgements We gratefully acknowledge the enthusiastic participation of the subjects in this study, B. Wüst for setting up subject tests, and M. Weder, M. Richards, R. Rossi, and G. Havenith for helpful discussions.

References

Brühwiler PA (2003) Heated, perspiring manikin headform for the measurement of headgear ventilation characteristics. Meas Sci Technol 14:217–227

Desruelle AV, Candas V (2000) Thermoregulatory effects of three different types of head cooling in humans during a mild hyperthermia. Eur J Appl Physiol 81:33–39

Ellis A (2001) Cool helmets. Bicycling Aust 1:56–68

Ellis AJ, Bertolini AF, Thompson LA (2000) A review of research on bicycle helmet ventilation. Sports Eng 3:185–194

Gisolfi CV, Rohlf DP, Navarude SN, Hayes CL, Sayeed SA (1988) Effects of wearing a helmet on thermal balance while cycling in the heat. Physician Sportsmed 16:139–146

John D, Dawson B (1989) The effects of wearing two different cycling helmets on thermoregulatory responses to prolonged submaximal exercise in hot, dry conditions. J Hum Mov Stud 16:203–214

Kaufmann K, Schlecking T (2003) Kopfsache. Mountain Bike 4:38–46

Kissen A, Hall J, Klemm F (1971) Physiological responses to cooling the head and neck versus the trunk and leg areas in severe hyperthermic exposure. Aerosp Med 42:882–888

Nunneley SA, Troutman SJ Jr, Webb P (1971) Head cooling in work and heat stress. Aerosp Med 42:64–68

Nunneley S, Reader DC, Maldonado RJ (1982) Head temperature effects on physiology, comfort, and performance during hyperthermia. Aviat Space Environ Med 53:623–628

Rodahl K, Bjørklund RA, Kulsrud A-H, Klüwer LD, Guthe T (1992) Effects of protective helmets on body temperature and psychomotor performance. In: Havenith G (ed) 5th Int Conf Environ Ergon. TNO Soesterberg,, Maastricht, The Netherlands, pp 98–99

Schvartz E (1970) Effect of a cooling hood on physiological responses in a hot environment. J Appl Physiol 29:36–39

Sheffield-Moore M, Short KR, Kerr CG, Parcell AC, Bolster DR, Costill DL (1997) Thermoregulatory responses to cycling with and without a helmet. Med Sci Sports Exerc 29:755–761

Swart R (2003) The history of bicycle helmets. http://www.helmets.org/history.htm. Cited 25 April 2004