Available online at www.sciencedirect.com

International Journal of Industrial Ergonomics 36 (2006) 11–16

International Journal of INDUSTRIAL ERGONOMICS

www.elsevier.com/locate/ergon

# Facial warming and tinted helmet visors

Munkhbayar Buyan[a], Paul A. Brühwiler[a,*], Andris Azens[b,1], Greger Gustavsson[b,1], Richard Karmhag[b,1], Claes G. Granqvist[b]

[a]Empa, Materials Science and Technology, Lerchenfeldstrasse 5, CH-9014 St. Gallen, Switzerland
[b]Department of Engineering Sciences, The Ångström Laboratory, Uppsala University P.O. Box 534, SE-751 21 Uppsala, Sweden

Received 17 July 2004; received in revised form 10 June 2005; accepted 17 June 2005
Available online 18 August 2005

## Abstract

Tinted helmet visors have found applications in several areas as a means of reducing visual strain under bright conditions. For motorcyclists, new technologies which can rapidly change the level of tinting promise to make such visors more accessible, which is necessary to avoid safety risks. For these users, it is often important to minimize the heat load on the body. We studied the changes in the heat load on the face as a function of motorcycle helmet visor configuration (normal and tinted) using a thermal head manikin and ($n = 8$) human subjects. Good agreement was found between the measured and perceived heat load, and this load was greatly reduced for moderate tinting levels. The optical transmission properties of the visor configurations largely explain the results. Our results suggest that visors optimized for infrared rejection would likely be perceived as an improvement.

## Relevance to industry

The production of motorcycle and other tinted helmet visors could be aimed at multiple benefits, viz, visual and thermal protection and comfort. The role of comfort in the use of such products is important for industry, as well as knowledge of how to assess such effects.

*Keywords:* Visor; Helmet; Motorcycle; Comfort; Heat strain

## 1. Introduction

There are many occupations and activities that routinely require a high degree of protection in the case of an accident. For motorcyclists, astronauts, many automobile racing drivers, and some airplane and helicopter pilots, e.g., this entails wearing a suit covering the body at all times, including a helmet which, for optimal protection, covers the face as well. Disadvantages of this protection are often a reduction in the free flow of air to the face (see, e.g. Brühwiler et al., 2005; Lee et al., 2001 for recent reviews) and a much higher level of heat insulation for the entire body. The latter issue has been investigated extensively and has led to testing of devices in order to introduce external sources of cooling to the body (Nunneley and Maldonado, 1983) and to study the effects on performance (Færevik and Reinertsen, 2003; Walker et al., 2001). This has also led to suggestions of airflow criteria through protective garments in order to remove the metabolic heat generated by a typical wearer (Kaufman, 2001).

The possibility that such protective clothing could represent a positive factor for the human heat balance has been discussed much less for these occupations, presumably because the heat burden of the environment has generally played a secondary role for the performance (Færevik and Reinertsen, 2003; Walker et al., 2001). Nevertheless, the face and/or head often remain in direct thermal contact with the environment in many applications of such protective clothing, which can strongly affect the real and perceived heat load on the body (Nielsen et al., 1987; Nunneley et al., 1982). If the head is covered by a

---

*Corresponding author. Tel.: +41 71 274 7767; fax: +41 71 274 7762.
*E-mail address:* paul.bruehwiler@empa.ch (P.A. Brühwiler).

[1] Present address: ChromoGenics Sweden AB, c/o Uppsala University Holding, SE-75183 Uppsala, Sweden.

0169-8141/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.ergon.2005.06.005

helmet designed for impact protection, there will be much less heat transfer to the environment as a consequence of the high thermal insulation normally provided by such helmets as a side effect of using foamed polymers for shock absorption. If the surrounding air is cooler than the body, or if the wearer is perspiring, this brings about a diminished heat transfer, which reduces the comfort level, and perhaps therefore cognitive abilities, of the wearer. This is a problem which could be solved with a dedicated, active cooling and/or air-conditioning system, a solution which is, however, not always possible to implement owing to portability or other constraints (Kaufman, 2001). A widely known example of this difficulty is found for the case of motorcyclists, who most often choose to ride in warm weather, rely on wind cooling for their comfort, and may experience accident-causing cognitive difficulties connected with equipment limitations in this regard (Chinn et al., 2003).

Focusing on motorcycle helmets, a brief inspection shows that modern ones are supplied with a number of vents for improving airflow over the rider's face. These vents lead to obvious enhancements in the comfort delivered through oxygenated (Brühwiler et al., 2005) and flowing air. Another aspect of comfort and safety relevant to such helmets emerges in sunny conditions, under which the standard transparent visor is often sub-optimal, and since sun visors—such as those found in cars—are not available, motorcyclists frequently employ tinted visors or sunglasses. The safety aspects of these can be questioned, since even when appropriately tinted for uses in the sun their effect is generally too strong when moving into conditions of low lighting, as when entering a tunnel. There are, however, new concepts which promise rapid electronic control of the tint level (Azens et al., 2003; Taheri et al., 2000), thus suggesting that tinted visors will become even more common in the future for motorcyclists; they are an established form of protection for military pilots (Morris et al., 1991; Young et al., 2000). Aside from increased visual comfort and safety, one could imagine that improved physical comfort in the form of reduced solar radiant transmission through such visors is possible.

We have studied the level of power which can be felt as heat transmitted through a standard motorcycle visor outfitted with a tintable foil (Azens et al., 2003), with the object of investigating the magnitude of such heating reductions. We compared optical data to heat transfer measured with a thermal head manikin (Brühwiler, 2003), and to the perceptions of ($n = 8$) human subjects, and found good agreement. This shows that the reduction in heat load on the face is a parameter which should be considered when designing integral helmet visors.

## 2. Materials and methods

The approach to visor tinting studied here is based on an electrochromic foil material capable of varying its optical absorptance between widely separated extrema (Granqvist et al., 2003). The construction, and details of the function of the foil, have been described elsewhere (Azens et al., 2003). It was mounted with double-sided tape on the surface of a standard polycarbonate motorcycle helmet visor, which was part of a large-sized helmet from a well-known manufacturer. The foil tint was controlled with a small voltage applied at the edges. For the present study, we chose a voltage of 1.5 V for 30 s in one polarity to achieve a moderately darkened foil, and 1.5 V for 30 s in the opposite polarity to bring back the foil to the lightest tint; these states will be designated "dark" and "light" in the rest of the paper. There is a large difference in the optical transmission between the pristine visor and the light condition; to try to understand how sensitive subjects are to such changes, the dark condition was chosen to exhibit a smaller difference. The optical transmission of the visor with and without tintable foil, as well as the reflectivity of the manikin material, was characterized using a Perkin Elmer Lambda 19 spectrometer.

For measuring heat flux through the visor in a realistic geometry, the helmet was placed on a thermal head manikin described previously (Brühwiler, 2003). Changes in radiant heat flux were measured in terms of the steady-state power impinging on the manikin surface. A reduction in the steady-state power emitted from the manikin relative to condition (a) in Fig. 1 is therefore equal to the increase in radiant power transmitted through the visor. A cloth was taped around the base of the helmet, extending downward about 40 cm, to minimize the flow of air under the rim, which also mimics common practice among motorcyclists of wearing airtight jackets with scarves or other wind protection about the neck. A lamp[2] which simulates the solar spectrum (Beeson, 1978) was used as a light source and was mounted on the roof at the exit of a wind tunnel (Brühwiler, 2003). The manikin was set 75 cm back from that point to enable a sufficiently large solid angle for the radiation, as shown in Fig. 2. The lamp was aimed at an angle of about 25° below horizontal, towards the face of the manikin. This produced a heat flux at the middle of the helmet visor (detector plane vertical) of $200 \pm 10\,\mathrm{W\,m^{-2}}$, which is close to the value on a typical, moderately humid summer day in central Europe (about $550\,\mathrm{W\,m^{-2}}$ with the detector directly aimed at the sun; $270\,\mathrm{W\,m^{-2}}$ with the detector plane vertical). These conditions are semi-arbitrary, since often the sun will shine from a higher angle, and therefore less radiant load will strike the face; nevertheless, the geometry shown in Fig. 2 is realistic for riders in mountainous areas traveling uphill, and hence can be taken to represent a stronger condition which is likely to be frequently encountered in reality. As a baseline for the measurements, the visor was covered with the electrochromic foil and three layers of Al foil, which reduced the radiant heat load to below detectable limits, and which gave a result identical to that of using four layers of Al foil to within 0.2%. The four visor

---

[2] General Electric model CSI 99-1222.

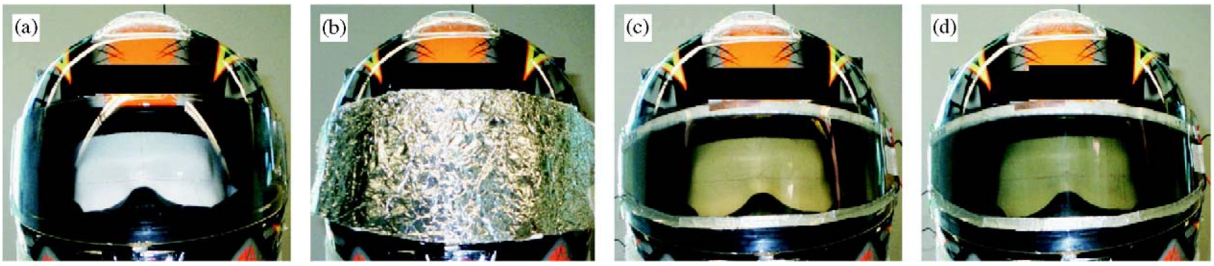

Fig. 1. Studied visor configurations: (a) pristine, (b) covered with electrochromic foil and three layers of Al foil, (c) covered with electrochromic foil in the minimum-tint condition, and (d) covered with the electrochromic foil in the moderately darkened condition. The helmet is shown mounted on a standard shop-window manikin head.

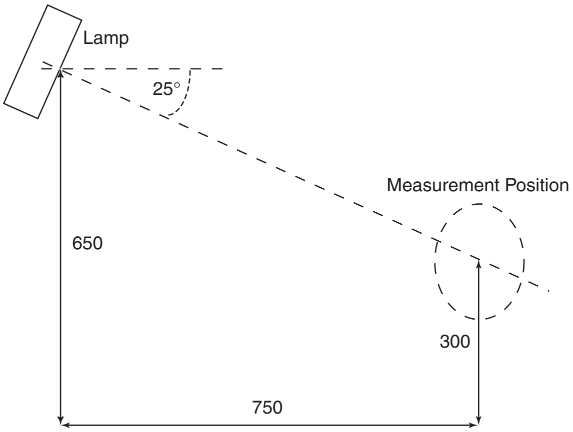

Fig. 2. Schematic of the measurement set-up. The solar lamp was mounted at the end of the wind tunnel, with wind coming from the left. Each subject (or thermal manikin) was placed to have his/her head at the position indicated by the oval. All measurements in mm.

configurations studied are shown in Fig. 1. The climate conditions were 20° C and 65% RH, and the wind speed was nominally $8.3\,\mathrm{m\,s^{-1}}$ at the wind tunnel exit. The absolute wind speed was not important in the manikin measurements, since it was used only to establish a baseline condition for the radiant heat transfer measurement. Because only the visor was changed, the resulting changes in the power values reflect the purely radiant contributions to the heat load.

The subject tests were carried out under identical climatic conditions, with the heads of the subjects placed similar to the manikin. The eight subjects comprised three women and five men between the ages of 22 and 38, all in good health, some of whom had motorcycling experience. The wind speed was reduced to $3\,\mathrm{m\,s^{-1}}$ since the subjects wore normal clothing; they would otherwise have been uncomfortable even with the cloth fixed to the base of the helmet by tape. Since motorcycle riders optimize their thermal comfort in practice using scarves, etc., we chose not to vary the effects of wind speed in the present study, on the assumption that this parameter is largely under the control of the wearer of a helmet. A pair of pads, which fully covered the eyes, was worn by each subject to minimize the perception of lighting variations to the extent possible. The subjects were informed of the existence of four conditions to be tested. To facilitate consistency in the ratings, they were exposed to condition (b) and told to define that to be “0” on a scale of perception of 0–10 (Fig. 1(b)), and then exposed to condition (a), which was to be defined as “5” (Fig. 1(a)); the subjects remained unaware of the exact nature of the second of these conditions, but were told that the baseline condition (b) would be repeated later in the tests. Each condition ((a), (c), and (d) in Fig. 1) was then introduced twice in random order after a period of about 10 s with condition (b); the subject perceptions were queried at 10 and 30 s after establishing the given condition. Statistical analyses were carried out using standard software.[3]

## 3. Results

### 3.1. Manikin measurements

The radiant power absorbed by the manikin in the given configurations can be appreciated from the results in Table 1. As explained in Section 2, the steady-state power decreases upon increasing the radiant heat load, and the power transmitted onto the face due to radiant sources is the (negative) difference with respect to the baseline condition. All differences measured were found to be significant, as indicated in the table caption. We find that the normal polycarbonate visor transmits about 2.3 W in the measured configuration, which we define as the full radiant heat load for our configuration. The light foil strongly reduced the transmitted power, by almost 40% compared to the case of a standard visor, to 1.4 W. As could be suspected from the minor tint difference in the dark foil, a further, significant reduction of only 9% in transmitted power, to 1.2 W, was found in that case.

### 3.2. Subject study

A summary of the subject study results is presented in Table 2. Surveys with slightly different conditions gave similar results. The light foil reduces the subject heat perception, consistent with the manikin measurements. However, the subjects could on average not detect a

---

[3] SPSS, Version 13.0.1.

Table 1
Steady-state heating in the face section of the thermal manikin for the indicated conditions, also converted to power transmitted through the visor and to a percentage relative to the maximum transmitted power

| Visor configuration | Steady-state power, face (W) | Difference from baseline (W) | Relative load (%) |
|---|---|---|---|
| (b) Al foil (baseline) | $6.60 \pm 0.05$ | — | — |
| (a) Normal visor | $4.27 \pm 0.05$ | $2.33 \pm 0.16$ | 100 |
| (c) Light foil | $5.17 \pm 0.05$ | $1.43 \pm 0.16$ | 61 |
| (d) Dark foil | $5.42 \pm 0.05$ | $1.18 \pm 0.16$ | 51 |

The confidence intervals indicated for the steady-state power are the maximum standard deviation of the four conditions. The differences were analyzed via one-way ANOVA, and the confidence intervals determined using a Tukey-HSD post hoc multiple comparison of means ($p = 0.05$). All differences were significant at $p < 0.001$ except for the comparison (c)–(d), which was significant at $p < 0.02$. Relative load is given merely as a guide for comparison of the differences, in terms of condition (a). See the discussion in the text.

Table 2
Subject ratings of the indicated configurations

| Visor configuration | Mean rating | Relative rating (%) |
|---|---|---|
| (a) Normal visor | $5.72 \pm 1.43$ | 100 |
| (c) Light foil | $3.43 \pm 1.59$ | 60 |
| (d) Dark foil | $3.39 \pm 1.57$ | 59 |

Analysis using one-way ANOVA with a Tukey-HSD post hoc comparison of means finds that conditions (c) and (d) are both significantly different from condition (a) at $p < 0.001$, but not mutually significantly different at $p < 0.05$. See the text for more details.

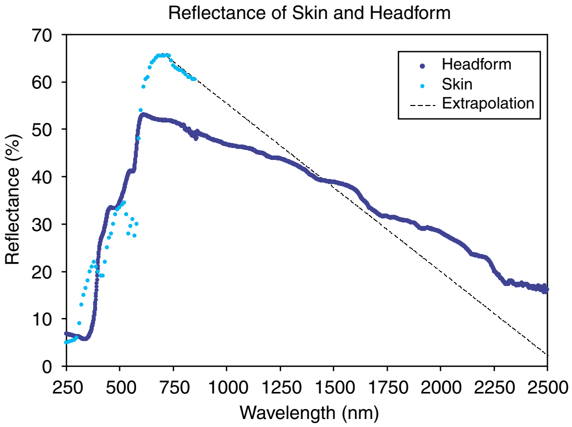

Fig. 3. Spectral reflectance of human skin (Caucasian erythematous) and of a sample of the material from which the manikin was made. The dashed line indicates how the skin data were extrapolated in the long-wavelength region. See the text for more details.

significant difference between the light and dark foils. This suggests that for many persons the small change in heat load between the two conditions would not influence the thermal comfort level. Several subjects perceived the heat load to increase in the order found with the manikin, whereas several others experienced difficulty in comparing the conditions, as apparent from the large variability in their ratings. The good agreement between the relative rating and the relative heat load, especially for the difference between conditions (a) and (c), shown in Table 1 suggests that the manikin results reflect the perceived heat load rather accurately.

### 3.3. Optical characterization

In order to try to understand the good agreement between the results in Tables 1 and 2, we analyzed the optical properties of the visor, foil, manikin, and human skin to see if an explanation purely in terms of solar radiation impinging on the face is sufficient. We considered the problem of transmission loss through the visor and foil as well as absorption in the skin or manikin surface. The latter was calculated from data in the literature for human skin (Anderson et al., 1981) and from a measurement on a piece of polyester from the same source as the manikin[4]; data are shown in Fig. 3. The almost linear variation with wavelength in the 700–850 nm range for human skin was extrapolated throughout the displayed interval by visually matching a line to the data, using the overlapping region as shown. The overall shapes and areas of the two curves are similar, though the distributions in the infrared region have different slopes; the differences nevertheless average out, with values being 29.7% for skin and 31.5% for the manikin, in the 750–2500 nm wavelength range. This is consistent with similar values for the static dielectric constant of the manikin and human skin previously noted (Brühwiler, 2003), and motivates our use of the present extrapolated curve.

We multiplied these data with the spectral transmission of the different visor configurations and the emitted spectrum of the lamp in Table 3 in order to analyze the full problem of the power absorbed in the skin. Since the (simulated) solar spectrum is not uniform, there is a priori the possibility that certain spectral regions could be more important than others in determining the heat load. The minor differences in the curves of Fig. 3 have no impact on the final result, since they tend to cancel in the range considered, suggesting that a person can expect to absorb the same level of power as the manikin. The range of extrapolation of the skin absorption data corresponds

---

[4] We note that this piece of polyester did not have the thin resin coating which has been applied to the manikin. Based on the good agreement for the variation in heat absorption measured with the manikin, and that predicted in Table 3 below, we assume that the effect of the resin is minor for the present comparison.

Table 3
Optical parameters of visor configurations, skin, and manikin surface as a function of wavelength range, and power of the lamp, as well as values for the solar power (all lamp and solar power value percentages taken from Beeson (1978))

| Wavelength range (nm) | | 280–320 | 320–400 | 400–520 | 520–640 | 640–780 | 780–2500 | Total | |
|---|---|---|---|---|---|---|---|---|---|
| Net visor transmission (%) | (a) Normal | 0.1 | 30.0 | 91.5 | 92.4 | 92.9 | 67.4 | | |
| | (c) Light | 0.1 | 3.2 | 39.2 | 62.4 | 66.2 | 39.9 | | |
| | (d) Dark | 0.1 | 2.7 | 31.6 | 47.2 | 46.5 | 30.3 | | |
| Test lamp spectral power (%) | | 0.1 | 4.2 | 13.3 | 24.7 | 17.5 | 40.2 | | |
| Solar spectral power (%) | | 0.45 | 5.6 | 17.9 | 16.6 | 15.5 | 44.0 | | |
| Absorption (%) | Manikin | 93.9 | 90.0 | 67.6 | 52.9 | 48.2 | 68.5 | | |
| | Skin | 90.7 | 80.8 | 71.9 | 56.4 | 35.5 | 70.3 | | |
| Predicted absorbed power (%) | (a) Manikin | 0 | 1.1 | 8.2 | 12.1 | 7.8 | 18.5 | 47.8 | (100%) |
| | Skin | 0 | 1.0 | 8.7 | 12.9 | 5.8 | 19.0 | 47.4 | (100%) |
| | (c) Manikin | 0 | 0.1 | 3.5 | 8.2 | 5.6 | 11.0 | 28.4 | (59%) |
| | Skin | 0 | 0.1 | 3.8 | 8.7 | 4.1 | 11.3 | 28.0 | (59%) |
| | (d) Manikin | 0 | 0.1 | 2.8 | 6.2 | 3.9 | 8.4 | 21.4 | (45%) |
| | Skin | 0 | 0.1 | 3.0 | 6.6 | 2.9 | 8.6 | 21.1 | (45%) |

The resultant predicted absorbed power values using the lamp are summed to give the total values to the right. The totals in parentheses have been re-expressed as percentages, with 100% for configuration (a), to better enable comparison with the results in Tables 1 and 2.

closely to the column 780–2000 nm in Table 3, so that the effects of possible errors in our extrapolation procedure should emerge in this spectral region. We note that the net transmitted power in this region is about 40% for human and manikin in all visor configurations; the similarity is, as noted above, consistent with the similar dielectric functions of skin and polyester, suggesting that the errors incurred through extrapolation of the skin data are within reasonable bounds.

Looking at the relative absorption as a function of configuration, we see that the rating of configuration (c) is similar to that in Tables 1 and 2 at about 60%, whereas configuration (d) is predicted to have a slightly lower absorption than the one observed with the manikin. We cannot explain this minor deviation, but consider this level of agreement satisfactory given the present uncertainties. Focusing on the more sensitive manikin results, the calculated and observed changes as a function of configuration largely follow the corresponding changes in the transmission, with better agreement as the wavelength increases. This can be attributed to the qualitatively similar variations in transmission in the different wavelength regions.

## 4. Discussion

The results of the present study indicate that a noticeable degree of thermal comfort for a motorcyclist or other integral helmet wearer can be achieved by proper choice of the optical properties of the visor. More importantly, the heat load is reduced in rough proportion to the level of tinting, suggesting that the beneficial heat-reduction side effect which accompanies any tinting will automatically be optimized by the user with control over this parameter, with possible exceptions for tinting methods which have different spectral characteristics. A visor which limited its transmission in the optical region in a controllable manner and completely quenched the infrared and ultraviolet regions would be a more ideal exploitation of these results. The power reduction achievable is not large compared to the typical heat exchange at the head at normal room temperature of about 10 W (Brühwiler, 2003; Clark and Toy, 1975), and so the present results do not have a bearing on heat strain, but power levels of this size are clearly detectable by human subjects, as shown by the present data in the face region and a previous study in the scalp region (Brühwiler et al., 2004). Considering the sensitivity of the face to the thermal environment (Desruelle and Candas, 2000) and the preference of many motorcyclists to ride in warm, sunny conditions, any tinting of the visor which does not reduce visual safety can be deemed desirable. A motorcyclist irritated by thermal discomfort may be more easily distracted, and thus at greater risk of accidents. Since a darkened visor which satisfies this constraint in bright sunlight is nevertheless a danger when the lighting conditions change rapidly, our investigation emphasizes the attractiveness of technologies which offer safe control of the degree of tinting of the visor. If such visors were available for other applications, such as firefighter protective helmets, the prospect of reducing heat stress becomes relevant, as well, since the radiant load can be well over ten times that of the sun, and is often horizontally directed (Rossi, 2003). In other situations requiring exposures to high heat loads, e.g., in foundries, protection of the eyes and/or face is necessary to reduce the risk of injury, but is not consistently applied (Gomes et al., 2002). The possibility to rapidly and simply change the optical and infrared transmission of lenses and comfortable visors could potentially improve this kind of work environment, as well. It remains to be seen whether and under which conditions the presently available technologies (Azens et al., 2003; Taheri et al., 2000) could be applied in such environments.

## 5. Summary

We have shown that helmet visor tinting can reduce the actual and perceived heat load on the wearer by reducing the transmission of solar radiation. This will in general have positive results for the comfort of the wearer, which could have positive safety consequences. It emphasizes the utility of technologies which can rapidly change the level of tinting. We have focused on motorcycle helmets, for which comfort improvement is the main consequence of using a tinted visor; this is a benefit which could also have safety implications, and in which there is an established market potential.

## Acknowledgements

We gratefully acknowledge E. Hinder and M. Camenzind for help with the optical measurements, S. Derler for critically reading the manuscript, N. Mattle for construction work, and the Seminar für Statistik of the ETH-Zürich for help with the statistical analyses.

## References

Anderson, R.R., Hu, J., Parrish, J.A., 1981. Optical radiation transfer in the human skin and applications in in vivo remittance spectroscopy. In: Marks, R., Payne, P.A. (Eds.), Bioengineering and the Skin. MTP Press Ltd., Lancaster pp. 253–265.

Azens, A., Gustavsson, G., Karmhag, R., Granqvist, C.G., 2003. Electrochromic devices on polyester foil. Solid State Ion 165, 1–5.

Beeson, E.J.C., 1978. The CSI lamp as a source of radiation for solar simulation. Lighting Research and Technology 10, 164–166.

Brühwiler, P.A., 2003. Heated, perspiring manikin headform for the measurement of headgear ventilation characteristics. Measurement Science and Technology 14, 217–227.

Brühwiler, P.A., Ducas, C., Huber, R., Bishop, P.A., 2004. Bicycle helmet ventilation and comfort angle dependence. European Journal of Applied Physiology 92, 698–701.

Brühwiler, P.A., Stämpfli, R., Huber, R., Camenzind, M., 2005. $CO_2$ and $O_2$ concentrations in integral motorcycle helmets. Applied Ergonomics 36, 625–633.

Chinn, B., Canaple, B., Derler, S., Doyle, D., Otte, D., Schuller, E., et al., 2003. Final report of the action COST 327: Motorcycle safety helmets. European Commission, Directorate General for Energy and Transport, Brussels, pp. 44–53.

Clark, R.P., Toy, N., 1975. Natural convection around the human head. Journal of Physiology—London 244, 283–293.

Desruelle, A.V., Candas, V., 2000. Thermoregulatory effects of three different types of head cooling in humans during a mild hyperthermia. European Journal of Applied Physiology and Occupational Physiology 81, 33–39.

Færevik, H., Reinertsen, R.E., 2003. Effects of wearing aircrew protective clothing on physiological and cognitive responses under various ambient conditions. Ergonomics 46, 780–799.

Gomes, J., Lloyd, O., Norman, N., 2002. The health of the workers in a rapidly developing country: effects of occupational exposure to noise and heat. Occupational Medicine (London) 52, 121–128.

Granqvist, C.G., Avendaño, E., Azens, A., 2003. Electrochromic coatings and devices: survey of some recent advances. Thin Solid Films 442, 201–211.

Kaufman, J.W., 2001. Estimated ventilation requirements for personal air-cooling systems. Aviation Space and Environmental Medicine 72, 842–847.

Lee, S.M.C., Bishop, P.A., Schneider, S.M., Clapp, L.L., Williams, W.J., Conza, N., et al., 2001. Simulated shuttle egress: role of helmet visor position during approach and landing. Aviation Space and Environmental Medicine 72, 484–489.

Morris, A., Temme, L.A., Hamilton, P.V., 1991. Visual-acuity of the United-States navy jet pilot and the use of the helmet sun visor. Aviation Space and Environmental Medicine 62, 715–721.

Nielsen, R., Berglund, L.G., Gwosdow, A.R., Dubois, A.B., 1987. Thermal sensation of the body as Influenced by the thermal microclimate in a face mask. Ergonomics 30, 1689–1703.

Nunneley, S., Maldonado, R., 1983. Head and/or torso cooling during simulated cockpit heat stress. Aviation Space and Environmental Medicine 54, 496–499.

Nunneley, S., Reader, D.C., Maldonado, R.J., 1982. Head temperature effects on physiology, comfort, and performance during hyperthermia. Aviation Space and Environmental Medicine 53, 623–628.

Rossi, R., 2003. Fire fighting and its influence on the body. Ergonomics 46, 1017–1033.

Taheri, B., Palffy-Muhoray, P., Kosa, T., Post, D.L., 2000. Technology for electronically varying helmet-visor tint. Proceedings of SPIE 4021, 114–119.

Walker, S.M., Dawson, B., Ackland, T.R., 2001. Performance enhancement in rally car drivers via heat acclimation and race simulation. Comparative Biochemistry and Physiology A—Molecular and Integrative Physiology 128, 701–707.

Young, P.A., Perez-Becerra, J., Ivan, D., 2000. Aircrew visors and color vision performance: a comparative and preliminary pilot study analysis. Aviation Space and Environmental Medicine 71, 1081–1092.