Solar ultraviolet protection provided by human head hair

A.V. Parisi[1,*], D. Smith[2], P. Schouten[1] and D.J. Turnbull[1]

[1] Department of Biological and Physical Sciences, Faculty of Sciences, University of Southern Queensland, Toowoomba, Australia 4350.

[2] Faculty of Business, University of Southern Queensland, Toowoomba, Australia 4350.

* To whom correspondence should be addressed at: parisi@usq.edu.au

ABSTRACT

The solar erythemal UV irradiances through human hair and the protection from UV provided by human head hair have been investigated for a solar zenith angle (SZA) range of 17^o to 51^o for the conditions of a head upright in full sun, a head upright in shade and a head in full sun tilted towards the sun. The two hair lengths investigated were 49.1±7.1 mm for the short type and 109.5±5.5 mm for the long type. For the head upright in full sun, the irradiances through the hair ranged from 0.75 to 1.4 SED/h for SZA less than 25^o and less than 0.6 SED/h in shade. The ultraviolet protection factor (UPF) ranged from approximately 5 to 17 in full sun, with the UPF increasing with higher SZA. The longer hair provided a lower UPF than the shorter hair and for the head oriented towards the sun, there was a marginally lower UPF than for the upright head. This research shows that the UV exposure limits to the scalp through hair can be exceeded within short timeframes and provides important information to assist employers to comply with Workplace Health and Safety legislation.

INTRODUCTION

Australia has the highest rate of skin cancer in the world (1). Various authoritative sources (2) confirm the greatest risk factor in developing melanoma and non melanoma skin cancer (NMSC) is the number of severe sunburns and cumulative exposure to UV radiation from the sun. Skin cancer is Australia's most expensive cancer with estimated amounts of $264 million and $30 million spent in Australia during 2001 on NMSC and melanoma respectively (3).

No migrant group has a higher risk of melanoma than Australian-born residents, due to the strong Anglo-Celt heritage of a substantial portion of the Australian population and the limited natural skin pigmentation as protection against UV inherent in this population group (4). Estimates of lifetime risk for melanoma in Australia are one in 29 (5).

The American Academy of Dermatology (6) reports over 75% of all skin cancer deaths can be attributed to melanoma. It is also estimated that around 200 melanomas per year are caused by occupational exposures in Australia (7) and therefore it follows that outdoor workers are especially vulnerable to this carcinogen.

The Australian Bureau of Statistics (8) reported an estimated 1.2 million Australian workers were outdoor workers, and there are over 300 occupations in Australia which require mainly outdoor work. Outdoor workers are exposed to 5–10 times more UV radiation from the sun (4) than other workers. Males are twice as likely to die from melanoma, in all likelihood because of the higher rate of men in outdoor jobs (4).

From the Australian census in 2006, among the biggest groups of outdoor workers are over 175,000 farmers or farm managers, almost 120,000 construction/mining labourers, and almost 100,000 farm, forestry and garden workers. Research also supports this in identifying a significantly higher incidence of melanoma (sites include the head) in rural and remote area workers, compared to workers in metropolitan areas (9). Further, melanomas of the head and neck are associated with chronic patterns of sun exposure (10) which may be exacerbated by outdoor lifestyle preferences and enduring perceptions about tanned skin reflecting good health.

In order to reduce the risks of the incidence of skin cancer, the UV minimisation strategies of the use of hats, shade, clothing, sunglasses and sunscreens are widely promoted, along with the avoidance of the sun during the peak UV irradiance times (11). These prevention strategies are essential for outdoor workers, along with the general population. 'Essential' is used in a precise way here to reflect that the employer is bound by Workplace Health and Safety (WHS) legislation to eliminate or limit the amount of exposure of the employee to harmful UV. The amount of UV reduction provided by each of these strategies has been investigated by different researchers (12-17). In addition to these strategies, any other aspects of personal lifestyle and behaviour that can increase protection from UV radiation need to be explored.

In particular, previous research has tested the hypothesis that hair can protect against melanoma on the head and neck (18) by finding that hair reduced the UV exposures to the ear by 81%. The incidence rates of melanomas to the top of the head or the scalp are also significant with one study reporting 13% of the melanomas in a study group of 534 patients being located on the scalp (19). The fall of the hair on the scalp may be different to that on the ear. Consequently, the UV protection provided to the scalp may be different to that provided to the ear and this warrants further investigation. Furthermore, the UV protection provided by hair may be influenced by the tilt of the head with respect to the sun and it may be influenced by whether the subject is in shade or full sun, which influences the relative proportions of direct and diffuse UV radiation.

Consequently, this paper will aim to quantify the protection to the scalp from solar UV radiation provided by human head hair. This will be investigated for a male hair style of two lengths of hair in two colours for the influences of solar zenith angle for the conditions of an upright head in sun, a head in sun and oriented towards the direction of the sun and an upright head in shade.

MATERIALS AND METHODS

UV Measurements. The UV measurements were undertaken with a portable broadband meter (model 3D V2.0, Solar Light Co., Philadelphia, USA) with a response approximating the erythemal action spectrum (20). For this meter, the sensor can be connected via a cable to the detector, allowing the detector to be remotely located from the sensor. This meter was calibrated to a UV spectroradiometer (model DTM300, Bentham Instruments, Reading, UK) calibrated to the National Physical Laboratory, UK standard and wavelength calibrated against the UV spectral lines of a mercury lamp. The UV spectrum to a horizontal plane measured on 2 March every 30 minutes between 8.45 am and 12.15 pm at 0.5 nm increments was weighted with the erythemal action spectrum to provide the erythemal irradiances. The erythemal UV irradiances were concurrently measured with the meter to allow calibration of the meter in units of SED/h. The unit of SED is a standard erythemal dose and is defined as 100 J/m^2 of erythemally effective UV (21).

Hair pieces made of real human hair (supplier, Harstel Pty Ltd, Melbourne) of two distinct colours and two hair lengths (short and long) were employed. The two hair colours used were grey and dark brown. The two lengths were 49.1±7.1 mm for the short type and 109.5±5.5 mm for the long type. These colours and styles were chosen as they are common hair colours and styles currently seen in the Australian population. Each measurement was made with the hair on each respective hair piece combed in the same particular style so the amount of hair obstructing the sensor was kept constant throughout the period of the research.

An adult life size manikin head form (supplier, Apex Models, Brisbane) was employed for the fitting of the hairpiece and the measurement of the UV irradiances through the hair. In order to reduce the amount of disturbance to the hair, the sensor and associated cable of the meter were threaded up inside the head form and out through a 1 cm diameter hole drilled on the top of the scalp. Each of the hair pieces was placed in turn on the manikin head form in a reproducible location on the head. Each hair piece had a small hole cut into its netting base in order to allow the sensor to be positioned under the hair without being obstructed by the hair net holding the hair to the hair piece. Figure 1 shows the experimental setup of the head form and sensor with and without a hair piece.

All measurements were made at a Southern Hemisphere site at the University of Southern Queensland, Toowoomba, Australia (27.5^{o} S, 151.9^{o} E, 693 m altitude) on the dates of the 25th January 2008, 8th February 2008 and the 2nd March 2008. Ozone levels at these times were 263 Dobson Units (DU) on the 25th January, 274 DU on the 8th February 2008 and 258 DU on the 2nd March. These ozone levels were obtained using the Ozone Monitoring Instrument (22). Aerosol levels were not obtained as they are assumed to be negligible at the site as Toowoomba is a high altitude region with relatively little anthropogenic pollution output. Local cloud coverage over each of the three measurement days was estimated to be between 0 to 3 okta. When cloud coverage was present in the sky during a measurement sequence, it was low in the sky where it could not obscure the solar disc in any way.

Measurement Sequence. Over each day, the influence of changing solar zenith angle (SZA) was investigated by running a series of measurements throughout the early morning, mid morning and noon for an upright head in full sun. Over the entire measurement campaign, the SZA ranged from a maximum of 51^o to a minimum of 17^o. For each series of measurements on each day, the following sequence was undertaken, starting at each half hour from approximately 8:45 am to 12:30 pm:

1. Headform with no hair piece and the erythemal UV irradiance to the scalp measured;
2. UV irradiance measured to scalp of headform with the short brown hair piece placed on top of it;
3. UV irradiance measured to scalp of headform with the long brown hair piece placed on top of it;
4. UV irradiance measured to scalp of headform with the short grey hair piece placed on top of it;
5. UV irradiance measured to scalp of headform with the long grey hair piece placed on top of it;
6. The measurements on the headform with no hair piece were repeated.

The sequence of measurements was repeated for the head in shade and oriented towards the direction of the sun. The orientation and inclination of the head changed as the SZA and solar azimuth changed during the measurement period. This was undertaken only for SZA larger than 25^o as for smaller SZA, the irradiances were similar to those for an upright head. Similarly, the sequence of measurements was repeated in shade. The shade was provided by a shade umbrella with a diameter of 1.8 m and a height at the apex of 2.1 m. In this case, the head was upright and located each time in the approximate centre of the shade.

The entire sequence lasted for approximately 12 to 15 minutes from start to finish. The change in SZA over this period was assumed to be minimal. Measurements were only undertaken if the solar disc was clear of cloud.

Ultraviolet Protection. The ultraviolet protection factor (UPF) provided by the hair in each case was calculated using the expression:

$$UPF = \frac{UV_{nohair}}{UV_{hair}}$$

where UV_{hair} is the erythemal UV measured for each hair piece and UV_{nohair} is the erythemal UV measured on the head form with no hair and taken as the average of irradiance measurements 1 and 6 in the measurement sequence. For the remainder of this manuscript, UV erythemal irradiance will be referred to simply as UV irradiance.

RESULTS

Erythemal Irradiances Through the Hair

The erythemal UV irradiances in units of SED/h to the scalp through the hair for the cases of an upright head in full sun, an upright head in shade and a head in full sun and oriented in the direction of the sun are provided in Figure 2 for the different SZA. The UV irradiances through the hair decrease with SZA for the cases of full sun with the head upright and oriented towards the sun. For the head upright the irradiances ranged from 0.75 to 1.4 SED/h for a SZA less than 25^o. In shade, these irradiances through the hair were reduced to less than 0.6 SED/h.

Ultraviolet Protection

The UPF for each hair type with the head in the upright position in full sun and a changing SZA are shown in Figure 3. The UPF ranges from approximately 5 to 17 with a general increase in the UPF with SZA. The UPF is generally higher for the shorter hair than it is for the longer hair. At a sub-tropical site, exposures in summer in full sun to a horizontal plane over a day when averaged over the month of January were as high as 66 SED/day (23). The range of UPF values found in this research show that for a worker who is outdoors for a day in these circumstances and not wearing a hat, the exposures to the scalp through the hair can range from 3.9 SED to 13.2 SED. Similarly, when averaged over the winter month of July, the exposures in full sun over a day are 17 SED/day (23), resulting in exposures of 1 to 3.4 SED over a day to the scalp for an unprotected head.

Influence of Hair Length and SZA

The influence of the length of the hair is shown in Figure 4 where the UPF for each hair type and each of the three positions of the head has been averaged over the range of SZA. The error bars represent ± one standard error of the data. The longer hair provides a lower UPF than the shorter hair and when the head is towards the sun, there is a marginally lower UPF. The UPF of the hair in the shade is lower than in full sun, however the UPF for the shade has been calculated as the ratio of the irradiance in the shade to that through the hair in the shade. Consequently, the irradiance in the shade has already been reduced compared to that in full sun and the resulting irradiances to the scalp in the shade are lower as seen in Figure 2 (b).

The UPF of the hair on the upright head in full sun for each hair type averaged for the SZA ranges of 16 – 25^{o}, 26 – 35^{o} and greater than 36^{o} are provided in Figure 5. The error bars represent ± one standard error. For each hair type, the UPF increases with SZA. For an SZA greater than 36^{o}, the UPF for any of the hair types is higher by a factor of 1.6 to 1.9 compared to the SZA range of 16 – 25^{o}.

DISCUSSION

This research has quantified the solar erythemal UV irradiances through human hair and the protection from UV provided by human head hair for an SZA range of 17^{o} to 51^{o} under the conditions of a head upright in full sun, a head upright in shade and a head in full sun tilted towards the sun. The influence of the different skin types or the dermatological effect of the solar UV that penetrates the hair to the scalp was not considered as the focus of the research was the UV protection provided by human head hair. Data were collected for the three conditions for long and short grey and brown hair by measuring the erythemal irradiances beneath the hair and on a head with no hair to allow comparison of the two irradiances for the range of SZA. Further cases of red and blond hair types and how they compare to the brown and grey hair types can be considered in a future research investigation. At this point in time it is assumed that the data obtained for the gray hair type could be used as a predictor for the UPF due to blond and red hair. Additionally, this work could be extended to detail the exposure received by bald individuals, primarily those with Hamilton classification type III to VII. The two sets of irradiances were measured within a short time of each other so that any changes in atmospheric conditions or other influencing factors were minimal. The influencing factor that can change the UV irradiances significantly over several minutes is cloud and in order to eliminate this confounding effect, the data were collected when the solar disc was clear of cloud.

The UPF provided by the shorter hair was generally higher by a range of 2 to 5 than that provided by the longer hair for all three conditions of the head, as seen in Figure 3. The reason for this is that with the longer hair, there is more parting of the hair, which results in a greater surface area of the scalp susceptible to sun exposure in comparison to the shorter hair which tends to be more upright. This higher degree of parting for the longer hair provided the lower UPF.

The data displayed in Figure 2 show that for an SZA greater than approximately 45^o, the use of shade does not provide any significant difference in irradiances through the hair compared to the upright head in full sun. However, this changes for a SZA less than approximately 45^o with a rapid increase in irradiances through the hair for the upright head in full sun compared to shade. Irradiances through the hair in the shade generally flattened out and in some cases dropped slightly as the SZA decreased. Overall, the results showed that the shorter hair provided the higher UV protection in the shade. For the case of short brown hair in Figure 4, the UPF in the shade is comparable to the condition of the head oriented towards the sun. This is coincidental and irradiances to the scalp for the case in the shade are lower as the UPF in the shade is calculated relative to the horizontal plane in shade.

As the SZA increases the UPF also increases in full sun for all hair types by approximately 4 to 7, which is shown clearly in Figure 5. The reason for this is that the UV on a receiving plane is comprised of a direct UV and a diffuse UV component. The relative proportion of the diffuse to direct UV increases with increasing SZA with a resulting increase in the probability that the hair will intercept the UV radiation. Similarly, for the head oriented towards the sun, the UPF is marginally lower than that for an upright head in the sun as there is a higher relative proportion of direct UV incident on the head for the case of the head oriented towards the sun.

The results show that there can be significant exposures to the scalp through hair. Exposure limits to UV are recommended in the Radiation Protection Standard produced by (2) and these are based on the recommendations of the International Non-Ionizing Radiation Committee. For a high UV index of 14, the time taken to exceed the exposure limit to a horizontal plane is 6 minutes. The UPF of the hair in full sun ranged from 5 to 17, giving a time of 30 to 102 minutes to exceed the exposure limit through the hair. Similarly for a low UV index of 6, the time to exceed the exposure limit to a horizontal plane is 13 minutes, providing a time of 65 to 221 minutes to exceed the exposure limit through the hair.

Workplace Health and Safety legislation in the various States and Territories of Australia specify a duty of care owed by the employer, which includes monitoring of the workplace and the health of individual employees, and extends to the provision of information, training, instruction and supervision to limit risk (24). While many employers may be aware of the inherent dangers of working outdoors, there is less familiarity with the short timeframes within which substantial skin damage to the scalp can occur due to exposure to UV. This study further attests to the fallacy that a full head of hair offers effective protection from UV, a misperception which anecdotal accounts suggest may be prevalent in the outdoor worker set. In order to discharge legal obligations owed to employees under the various Acts, greater vigilance is required, particularly in terms of the monitoring of exposure times and forms of protection. Furthermore, as this research has shown, a simple shade structure does not provide sufficient protection from damaging UV irradiances, especially at higher ranges of SZA. To combat this it is recommended that not only do outdoor workers seek shade during their duties and breaks, but also wear a broad brimmed hat with a long back flap in order to enhance protection of the scalp.

This paper further supports the importance of a greater rigour in the areas of supervision, instruction, and training. Cavalier attitudes to skin protection against excessive UV exposures among the more vulnerable outdoor occupations are likely to create blockages in the legal system as Australia and other developed countries embrace a rather more litigious business environment. Acts of negligence on the part of employers have the potential to erode confidence in businesses that contravene the Act, notwithstanding there are also costs to organisation's reputations. An improved understanding of the solar UV environment as provided by the findings of this research, for the specific case of the UV protection provided by human head hair will contribute to more effective strategies to limit harm from UV that could go some way to avoiding such blockages.

Acknowledgements: *The authors acknowledge the technical support within the Faculty of Sciences, USQ for this project.*

References

1. Australian Life Scientist (2004) New trial for progen melanoma therapy. Available at: http://www.biotechnews.com.au/index.php/id;1931992542. Accessed on 17 March 2008.

2. ARPANSA (Australian Radiation Protection and Nuclear Safety Agency) (2006) Occupational exposure to ultraviolet radiation. Radiation Protection Series Publication No. 12.

3. Australian Institute of Health and Welfare (AIHW) (2005) Health system expenditures on cancer and other neoplasms in Australia, 2000–01. AIHW cat. no. HWE 29.Canberra: AIHW (Health and Welfare Expenditure Series no. 22).

4. Allen, F. (1998) *Health Psychology: theory and practice.* Allen & Unwin, Australia.

5. McCarthy, W.H. (2004) The Australian experience in sun protection and screening for melanoma. *J. Clin. Oncol.* **86**, 236.

6. American Academy of Dermatology (2008) 2008 fact sheet. Available at: http://www.aad.org/media/background/factsheets/fact_melanoma.html Accessed on 13 March 2008.

7. Fritschi, L. and T. Driscoll (2006) Cancer due to occupational exposure in Australia. *Aust. New Zeal. J. Publ. Health.* **30(5)**, 213-9.

8. Australian Bureau of Statistics (2001) Untitled document. Available at: http://www.health.nsw.gov.au/pubs/2001/pdf/skincancer_11-24.pdf Accessed on: 17 March 2008.

9. Science Alert (2007) Rural lifestyle increase cancer risk.

Available at: http://www.sciencealert.com.au/news/20072806-16047-2.html

Accessed on: 17 March 2008.

10. Whiteman, D.C., M. Stickley, P. Watt, M.C. Hughes, M.B. Davis, and A. Green (2006) Anatomic site, sun exposure, and risk of cutaneous melanoma. *J. Clin. Oncol.* **24(19)**, 1.

11. Australian Government Department of Health and Aging (2008) National skin cancer awareness campaign

Available at:

http://www.skincancer.gov.au/internet/skincancer/publishing.nsf/Content/home

Accessed on: 15 March 2008.

12. Diffey, B.L., P.R. Tanner, P.J. Matts and J.F. Nash (2000) In vitro assessment of the borad-spectrum ultraviolet protection of sunscreen products. *J. Am. Acad. Dermatol.* **43(6)**, 1024-1035.

13. Diffey, B.L. and J. Cheeseman (1992) Sun protection with hats. *Brit. J. Dermatol.* **127**, 10-12.

14. Turnbull, D., A.V. Parisi and J. Sabburg (2003) Scattered UV beneath public shade structures during winter. *Photochem. Photobiol.* **78(2)**, 180-183.

15. Grant, R.H., G.M. Heisler and W. Gao (2002) Estimation of pedestrian level UV exposure under trees. *Photochem. Photobiol.* **75(4)**, 369-376.

16. Sliney, D.H. (2001) Photoprotection of the eye – UV radiation and sunglasses. *J Photochem. Photobiol. B: Biol.* **64**, 166-175.

17. Gies. P. (2007) Photoprotection by clothing. *Photodermatol. Photoimmunol. Photomed.* **23**, 264-274.

18. Green, A.C., M. Kimlin, V. Siskind and D.C. Whiteman (2006) Hypothesis: hair cover can protect against invasive melanoma on the head and neck (Australia). *Cancer Cause. Control.* **17**, 1263-1266.

19. Urist, M.M., C.M. Balch, S. Soong, G.W. Milton, H.M. Shaw, V.J. McGovern, T.M. Murad, W.H. McCarthy and W.A. Maddox (1984) Head and neck melanomas in 534 clinical stage 1 patients. *Ann. Surg.* **200**, 769-775.

20. CIE (International Commission on Illumination) (1987) A reference action spectrum for ultraviolet induced erythema in human skin. *CIE J*. **6**, 17-22.

21. Diffey, B.L., C.T. Jansen, F. Urbach and H.C. Wulf (1997) The standard erythema dose: a new photobiological concept. *Photodermatol. Photoimmunol. Photomed.* **13**, 64-66.

22. Ozone Monitoring Instrument (OMI) (2008) Ozone data
Available at: http://jwocky.gsfc.nasa.gov/ozone/ozone_v8.html
Accessed on: 15 March 2008).

23. Parisi, A.V., M.G., Kimlin, J.C.F. Wong, R. Lester and D. Turnbull (2000) Reduction in the personal annual solar erythemal ultraviolet exposure provided by Australian gum trees. *Radiat. Prot. Dosim.* **92(4)**, 307-312.

24. CCH (2002) *Australian Master and Environment guide 2003.* CCH Australia ltd., Sydney.

Figure Captions

Figure 1 - The setup of the head form and sensor without a hair piece (A) and with a hair piece (B).

Figure 2 – The erythemal irradiances in units of SED/h to the scalp through the hair for (a) an upright head in full sun, (b) an upright head in shade and (c) a head in full sun and oriented in the direction of the sun.

Figure 3 – The UPF for each hair type with the head in the upright position in full sun for a changing SZA.

Figure 4 – The UPF averaged over the range of SZA for each hair type in full sun with the head upright, the head in shade with the head upright and the head in sun and pointed towards the sun. The error bars represent ± one standard error.

Figure 5 – The UPF for the upright head in full sun for each hair type averaged for the SZA ranges of 16 – 25 degrees, 26 – 35 degrees and greater than 36 degrees. The error bars represent ± one standard error.

A) **B)**

Figure 1 - The setup of the head form and sensor without a hair piece (A) and with a hair piece (B).

(a)

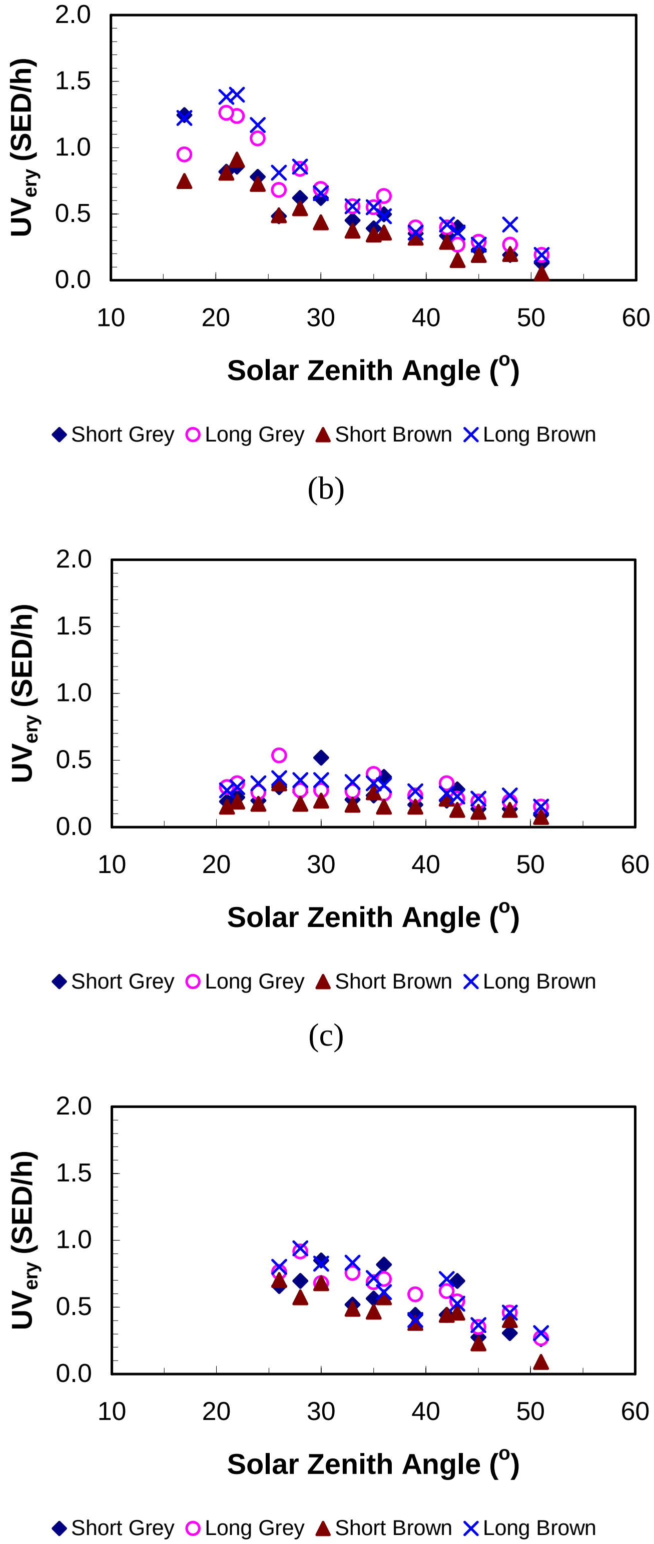

Figure 2 – The erythemal irradiances in units of SED/h to the scalp through the hair for (a) an upright head in full sun, (b) an upright head in shade and (c) a head in full sun and oriented in the direction of the sun.

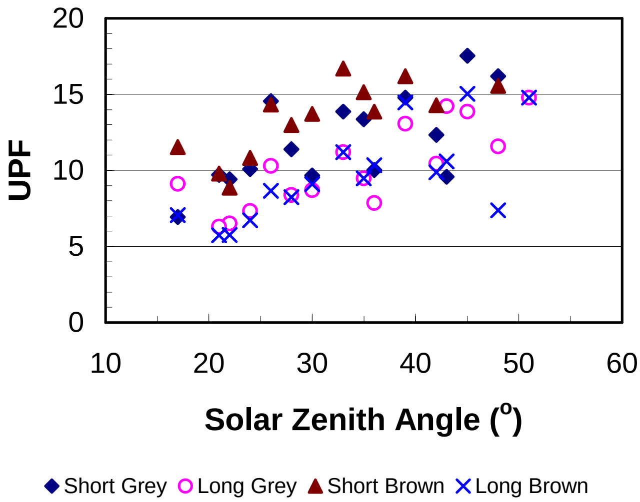

Figure 3 – The UPF for each hair type with the head in the upright position in full sun for a changing SZA.

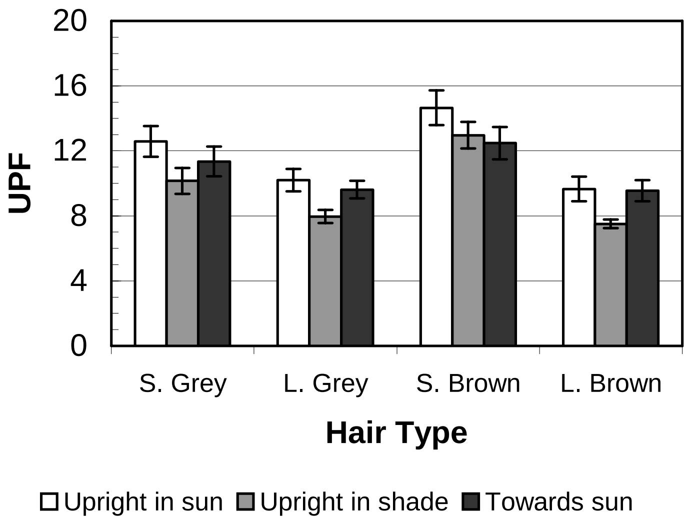

Figure 4 – The UPF averaged over the range of SZA for each hair type in full sun with the head upright, the head in shade with the head upright and the head in sun and pointed towards the sun. The error bars represent ± one standard error.

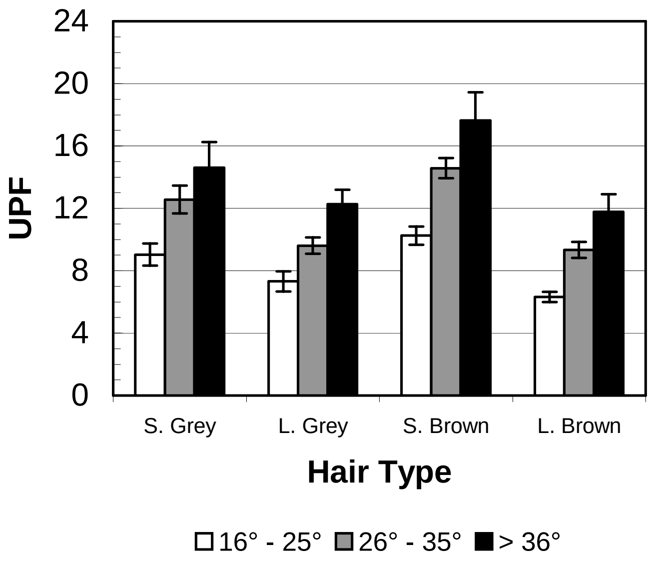

Figure 5 – The UPF for the upright head in full sun for each hair type averaged for the SZA ranges of 16 – 25 degrees, 26 – 35 degrees and greater than 36 degrees. The error bars represent ± one standard error.