FIELD BASED MEASUREMENTS OF PERSONAL ERYTHEMAL ULTRAVIOLET EXPOSURE THROUGH A COMMON SUMMER GARMENT

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Abstract

The research in this paper quantifies the solar erythemal UV exposures to the skin through a common summer garment during outdoor activities. The erythemal exposures under the garment for the wet white garment exceeded a MED (minimum erythemal dose) at some anatomical sites in summer for a two hour period. An erythemal exposure of 1.7 MED, in excess of the occupational limit for UV exposure, was measured under the white garment during swimming for a one hour period. Clothing must form an important component of a UV protection strategy. However, it must be realised that total UV protection is not provided and significant UV exposures may be received beneath the garment, particularly for a white garment in the wet state. This re-enforces the necessity of a combination of several UV prevention strategies to minimise UV exposure.

Keywords: erythema; ultraviolet; garment; UPF

INTRODUCTION

The high ambient ultraviolet (UV) irradiances in Australia (1,2), coupled with a lifestyle often centred on the outdoors and a generally fair skinned ancestry all may be contributing factors to Australia having the highest incidence rates of non-melanoma and melanoma skin cancer in the world. Additionally, UV exposure is associated with skin photoaging. High skin cancer rates are also a major health problem in other countries, for example New Zealand and the United States. There is an obvious necessity to reduce both the occupational and recreational sun exposure of the population. Clothing has been recommended as a UV preventative strategy for humans (3). An ultraviolet protection factor (UPF) has been developed and employed for providing an indication of the UV protection provided by clothing (4) and an Australian/New Zealand standard formulated (5). The technique for determining UPF’s has been intercompared across five different laboratories with good agreement (6).

Fabric properties affecting the UV transmission through clothing have been determined as construction, weight, fibre type, stretch, hydration, wash and wear, colour and UV absorbers in the material (7-11). The effect of stretch and wetting on the UPF of elastane fabrics has been investigated (12). Previous research has compared spectrophotometric determination of the UV protection provided by fabrics with human skin measurements of the protection (13). Polysulphone dosimeters were employed to measure the UPF's of various T-shirts on manikins in the laboratory using the UV in a phototherapy cabin (14). This research and the measurement of UPF have been performed in the laboratory. Holman et al. (15) reported the usage of polysulphone dosimeters to estimate the proportion of ambient UV received under a polyester shirt, cotton T-shirt and woollen jumper as 11, 5 and 0.2% respectively. The purpose of the research in this paper was to measure the personal solar UV exposures to the skin through a common summer garment, namely a T-shirt at a number of different human anatomical sites in a field situation during wear and during outdoor activities.

MATERIALS AND METHODS

Ultraviolet Protection Factor

The UPF has been defined by Gies et al. (6) as:

$$UPF = \frac{UVBE}{UVBE_P} = \frac{\sum_{UV} S(\lambda)A(\lambda)\Delta\lambda}{\sum_{UV} S(\lambda)A(\lambda)T(\lambda)\Delta\lambda} \qquad (1)$$

where UVBE is the erythemal irradiance of the source, $UVBE_P$ is the erythemal irradiance through the garment material, S(λ) is the source spectral irradiance, measured with a spectroradiometer at a wavelength increment of Δλ, A(λ) is the erythemal action spectrum and T(λ) is the spectral transmission of the garment.

The garments employed were a 100% cotton black and 100% cotton white T-shirt, both in a dry and wet condition. The UPF of many materials increases after the first time they are wet (8). To prevent the UPF of the garments changing during the research, all measurements of the UPF were after the first wetting. The spectral transmission of the garments was measured for the UV from a 250 Watt quartz tungsten halogen (QTH) lamp (model GEC A1/235, Lawrence and Hanson Co., Mort St., Toowoomba, Australia) at a distance of 9 cm from the entrance optics of a spectroradiometer. The lamp was powered by a current regulated power supply (model TPS 23010, Topward Electric Instruments, Nilsen Instruments, Brisbane, Australia) at 9.500 ± 0.005 A.

The UV source spectrum and the UV spectrum transmitted through each of the materials were measured with a spectroradiometer based on a dual holographic grating (1200 lines/mm) monochromator (model DH10, Jobin Yvon Co., France) and a UV sensitive photomultiplier tube detector (model R212, Hamamatsu Co., Japan), temperature stabilised to 15.0 ± 0.5 ^{o}C. The input optics of the spectroradiometer are provided by a 15 cm diameter integrating sphere (model OL IS 640, Optronics Laboratories, Orlando, USA) to allow collection of both the transmitted and scattered radiation. The spectroradiometer was wavelength and irradiance calibrated with the irradiance calibration traceable to the Australian National UV standard at the National Measurement Laboratory, Lindfield, Australia.

Erythemal Exposures Through Garment

A human size manikin rotating on a platform at 1 to 2 revolutions per minute has been employed to simulate an upright human outdoors. This follows the established procedure of previous researchers to model human outdoor activities in a predominantly upright stance (16). The manikin was deployed on a level surface in an open grassed field at the University of Southern Queensland (USQ) campus, Toowoomba, (latitude, 27.5 ^{o}S) Australia.

The erythemal UV exposures to a number of anatomical body sites underneath the garment material and erythemal UV exposures above the garment material have been measured with polysulphone dosimeters. The usage of polysulphone dosimeters has been described previously (17). The overall size of the dosimeter holder is 3 cm x 3 cm with a central aperture of 1 cm^2 that is covered with polysulphone. The polysulphone dosimeters used in this study have been calibrated to the solar spectrum against a Biometer (model

501, Solar Light Inc., USA) that has in turn been calibrated against the spectroradiometer. The optical absorbance of the polysulphone film at 330 nm was measured in a spectrophotometer (model UV 160, Shimadzu, Co., Kyoto, Japan). This occurred before and after exposure at four sites over the polysulphone film for each dosimeter in order to reduce any errors due to minor differences in the polysulphone film thickness.

The measurements using the manikin in the field were performed firstly in winter, 1998 and repeated again in summer, 1998 and late spring to summer of 1999. For the winter measurements, the manikin was outfitted with the white T-shirt on 10 August and with the black T-shirt on 11 August. Both periods of exposure were from approximately 9:00 Australian Eastern Standard Time (EST) to 15:00 EST. At noon on these days, the average solar zenith angle was approximately 43^o. Polysulphone dosimeters were attached to the T-shirt material on the left and right shoulders, centre of the upper and lower back, chest and hip. At each of these sites, a dosimeter was also attached underneath the garment and offset by approximately 2 cm from the one on top of the garment in order to prevent shading. This was repeated on 17 August and 18 August for the white and black T-shirts respectively. On these latter two days, the solar zenith angle at noon was approximately 41^o and the T-shirts were wet when they were initially placed on the manikin and then wet at approximately 30 minute intervals for the duration of the exposure period from approximately 9:00 EST to 15:00 EST. Any differences in the ambient UV radiation between the days were accounted for by employing Equation (1) and the unprotected erythemal UV exposures above the material for each site to calculate the respective UPF’s.

The measurements were performed in a similar manner with two manikins wearing the dry white and black T-shirts respectively on each day of 9 December 1998 and 25 November 1999 and with the two manikins wearing the wet white and black T-shirts on each day of 11 December 1998 and 2 December 1999. On the latter two days, the T-shirts were again wet at approximately 30 minute intervals for the duration of the exposure period. On all four days the exposure period was restricted to between approximately 11:00 EST and 13:00 EST for the peak UV irradiance times of the day and the solar zenith angle at noon was approximately 6^o to 8^o.

Personal Erythemal Exposures Through Garment

The method of determining the human erythemal UV exposure through the material as described above has been extended to measure personal erythemal UV exposures through the garment worn by human volunteers during outdoor activities. The same black and white T-shirts as used previously were each worn in summer by two volunteers jogging and two volunteers swimming in a public swimming pool. During the exposure period, subject A was jogging with the black T-shirt (21 December between 12:15 and 13:05 EST), subject B was jogging with the white T-shirt (22 December between 12:10 and 13:05 EST), subject C was swimming with the black T-shirt (22 December between 13:45 and 14:50 EST) and subject D was swimming with the white T-shirt (27 December between 10:52 and 11:52 EST). A polysulphone dosimeter was attached to the top of the garment on the left shoulder and left upper arm and underneath the garment at these same sites, but offset by approximately 2 cm.

RESULTS

Spectral Transmission

The spectral irradiances of the UV source and the source transmitted through the black and white garment in the dry and wet state along with the spectral transmission are provided in Figure 1. In general, the garment material provides broad spectrum protection, but it is not total protection. The white garment in both the wet and dry states has a peak in the transmission at approximately 315 nm and the transmission starts to rise at wavelengths higher than 380 nm. The black garment in both the wet and dry state reduced the UV irradiance by the greater proportion at all wavelengths compared to the white garment.

Erythemal Exposures

The average for each site of the UPF measured in the field for the black and white colours in the wet and dry state are provided in Table 1. A UPF of greater than 50 was reported as 50+. For the sites with a UPF of less than 50, the error is represented as one standard error in the mean. Previous research (17) has shown an error of the order of 10% associated with erythemal exposures due to solar radiation measured with polysulphone dosimeters. The highest UPF was provided by the black dry garment with a UPF of 50+ to all of the sites except for the hip. The lower UPF at this site may have been due to the bracket that was attached to the hips to hold the manikin upright, raising the garment at this point and allowing additional UV to the site. For the black wet garment, the UPF was lower at the shoulders where the garment would have been stretched compared to the other sites. In general, the lowest UPF was provided by the white wet garment. The ratio of the UPF for each different site for the dry compared to the wet state ranged from 4.8 to 1. This range is most likely due to the varying degrees of stretch of the garments at the different sites in both states as no attempt was made during the fitting of the garments to the manikins to standardise the degree of stretch between the garments and at the different sites. This was done specifically in order to closer resemble the real life case where generally no attempt is made to provide even degrees of stretch of a garment over the body. Additionally, there are different degrees of drying of the garment at each site between the times of wetting the garment due to the differences in drying rates at the various body sites due to their varying orientations with respect to the sun.

The range of erythemal exposures beneath the garment for the two hour exposure periods in late spring to summer are provided in Table 2. The erythemal exposures are provided in units of MED where one MED is defined as the amount of biologically effective UV required to produce barely perceptible erythema after an interval of 8 to 24 hours following UV exposure (18). Again the highest exposure beneath the garment was received with the white garment in a wet state with an exposure range of 0.54 to 1.8 MED for the left shoulder. These are relatively high exposures over the period with the higher value above 1 MED. The wet state of the garment may be due to a person engaging in an outdoor water sport or alternatively a person profusely sweating during vigorous activity. The difference between the exposures to the right shoulder compared to the left shoulder for the black garment may be due to one of the dosimeters under the garment being placed under the seam of the garment. This is a thicker part of the garment with resultant lower exposures below it.

The ratio of the exposure to each site beneath the garment to the exposure to the vertex of the head are provided in Figure 2 for the white and black garments in the dry state. The error bars are one standard error of the mean. For the white garment, the ratios ranged from 0.007 to 0.045 compared to 0.002 to 0.009 for the dry black garment.

Personal Erythemal Exposures

The personal erythemal exposures during the outdoor activities of jogging and swimming to the shoulder and upper arm beneath the cotton garments are provided in Table 3. Generally, the higher erythemal exposure to the skin below the garment was received during the swimming activity. For this activity, the white garment allowed an exposure to the skin of 1.7 MED in a period of 60 minutes compared to exposures of 0.15 and 0.43 MED to the shoulder and upper arm respectively in a period of 55 minutes for the black garment. During the swimming activity, the UPF for the white garment was lower with a value of 4 compared to that for the black garment with a UPF of 7 and 50+ for the upper arm and shoulder sites respectively. The higher UPF on the shoulder may have been due to the higher protection at the shoulder seam of the garment.

For the jogging activity, the UPF of the garment was in general higher than for the swimming activity, however, the black garment had a lower UPF than the white garment with values of 23 and 42 for the upper arm and shoulder respectively compared to 31 and 47 respectively for the white garment. This is due to the black garment causing the subject to perspire more profusely than for the white garment. Consequently, the black garment was wetter than the white garment while jogging with the resultant lower than expected UPF for the black garment.

DISCUSSION

The UPF of clothing has been measured by previous researchers in the laboratory; however, the research presented in this paper has measured the erythemal exposures due to solar UV radiation through a common summer garment in the field during outdoor activities. As previously found, the erythemal exposures were higher for the wet state of the garment and higher for the white garment compared to the black garment. However, this research has found a relatively high erythemal UV exposure to the skin below the garment for the wet white T-shirt. For the late spring to summer period, the exposures exceeded a MED at some anatomical sites in summer for a two hour period. An erythemal exposure of 1.7 MED was measured for the white garment during swimming. This is in excess of the occupational limit for UV exposure (19).

The stretch of the garment over the body while it is worn alters the UPF. This stretch is a result of the weight of the garment while being worn and for the swimming activity due to the drag of the garment through the water. Additionally, the UPF for the black garment in the wet and dry state was higher than that for the white garment, however, while jogging, the UPF measured on the human in the field while jogging for the black garment was less than that for the white garment.

Clothing must form an important component of a UV protection strategy. It generally provides broad spectrum protection and it does not require reapplication like a sunscreen during the course of the day. However, it must be realised that total UV protection is not provided and significant UV exposures may be received beneath the garment, particularly for a white garment in the wet state. Strategies to minimise UV exposure must employ a combination of strategies including avoidance of the sun, clothing, sunscreen, hats, sunglasses and shade.

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Table 1 – The UPF measured in the field for each garment. The error is one standard error in the mean.

	Field UPF			
	White Dry	Black Dry	White Wet	Black Wet
Left Shoulder	20 ± 2	50+	8 ± 2	28 ± 5
Right Shoulder	17 ± 4	50+	17 ± 11	32 ± 4
Upper back	31 ± 10	50+	7 ± 2	50+
Lower back	14 ± 2	50+	13 ± 4	50+
Chest	24 ± 13	50+	5 ± 2	50+
Left Hip	31 ± 8	32 ± 13	9 ± 3	50+

Table 2 – The range of erythemal exposures below the garments for the specific sites during the two sets of summer measurements.

	Erythemal Exposures (MED)			
	White Dry	Black Dry	White Wet	Black Wet
L. Shoulder	0.48 – 0.48	0.02 – 0.09	0.54 – 1.8	0.07 – 0.27
R. Shoulder	0.43 – 0.46	0.02 – 0.05	0.12 – 0.68	0.15 – 0.18
Upper back	0.03 – 0.15	0.0 – 0.01	0.41 – 0.59	0.0 – 0.01
Lower back	0.06 – 0.19	0.0	0.12 – 0.40	0.0 – 0.04
Chest	0.04 – 0.25	0.02 – 0.05	0.25 – 0.47	0.0 – 0.01
Hip	0.03 – 0.06	0.02 – 0.03	0.11 – 0.35	0.0 – 0.07

Table 3 – The personal erythemal exposures and the UPF to the shoulder and upper arm beneath the cotton garment.

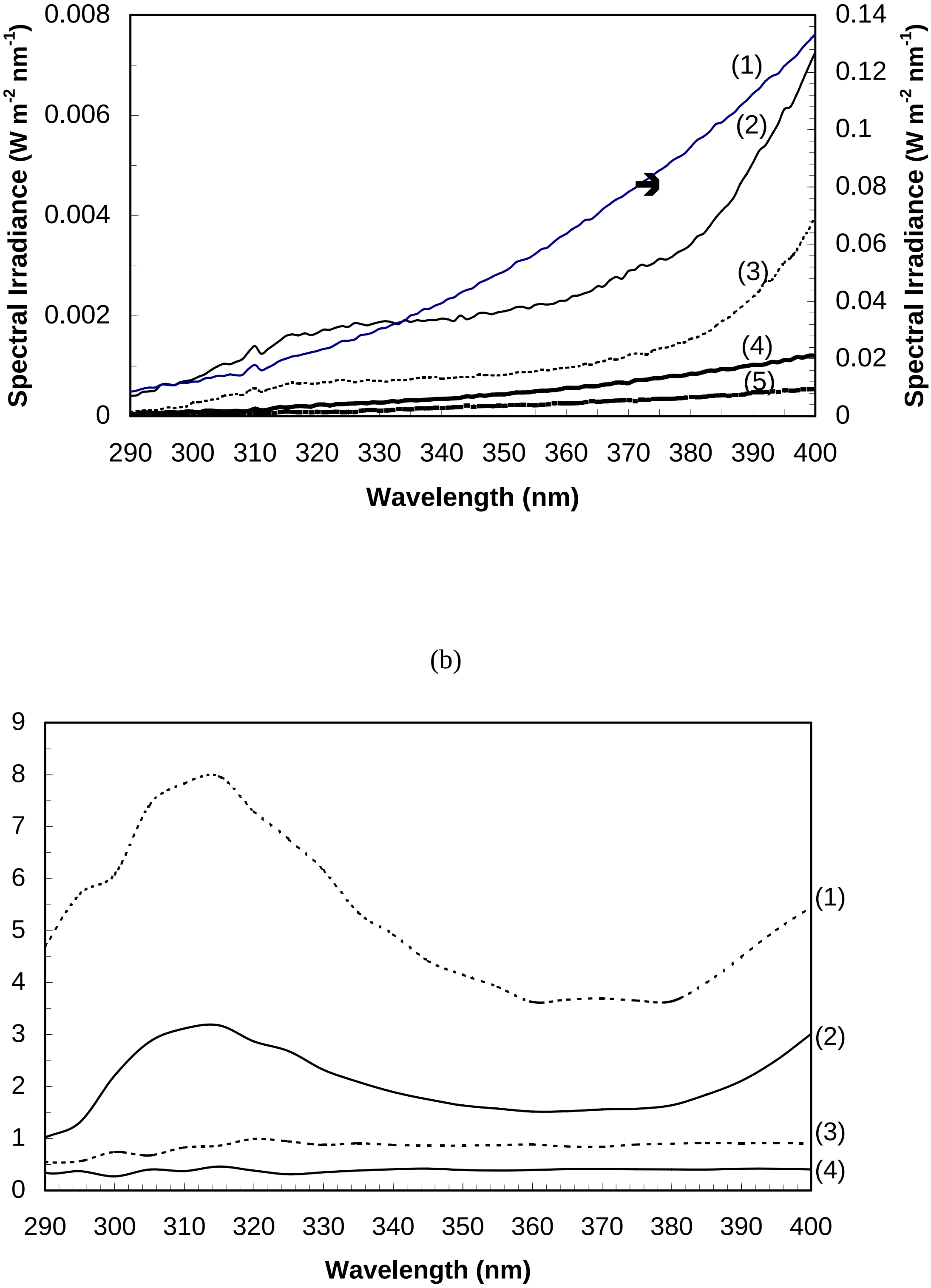
	Erythemal Exposures (MED)				UPF			
	White Jogging	Black Jogging	White Swimming	Black Swimming	White Jogging	Black Jogging	White Swimming	Black Swimming
Shoulder	0.08	0.12	1.7	0.15	47	42	4	50+
Upper arm	0.16	0.13	1.7	0.43	31	23	4	7

FIGURE CAPTIONS

Figure 1 – (a) UV spectral irradiances for the (1) UV QTH lamp (right axis), (2) white, wet, (3) white, dry, (4) black, wet and (5) black, dry garments and (b) the spectral transmission for the (1) white, wet, (2) white, dry, (3) black, wet and (4) black, dry garments.

Figure 2 – Ratio of the exposure to each site beneath the white dry and black dry garment compared to the exposure to the vertex of the head. The error bars are the standard error in the mean.

(a)


0.008
0.006
0.004
0.002
0
Spectral Irradiance (W m-2 nm-1)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Spectral Irradiance (W m-2 nm-1)
(1)
(2)
(3)
(4)
(5)
290 300 310 320 330 340 350 360 370 380 390 400
Wavelength (nm)

(b)

9
8
7
6
5
4
3
2
1
0
Transmission (%)
(1)
(2)
(3)
(4)
290 300 310 320 330 340 350 360 370 380 390 400
Wavelength (nm)

Figure 1

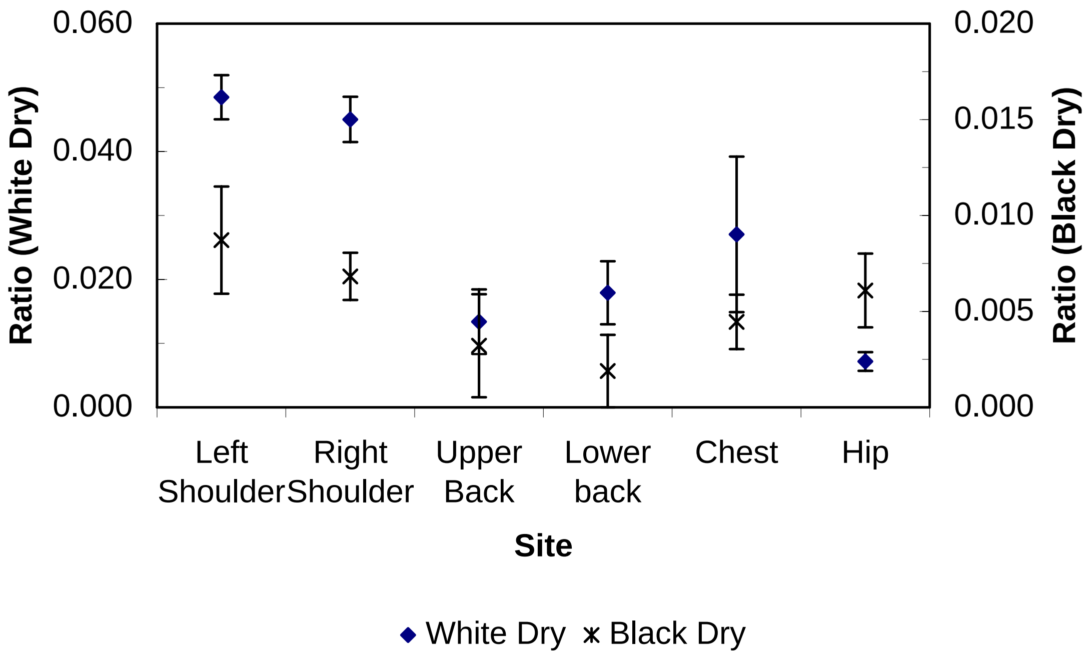

0.060
0.040
0.020
0.000
Ratio (White Dry)
0.020
0.015
0.010
0.005
0.000
Ratio (Black Dry)
Left Shoulder
Right Shoulder
Upper Back
Lower back
Chest
Hip
Site
White Dry
Black Dry

Figure 2