PRE-VITAMIN D_3 EFFECTIVE UV TRANSMISSION THROUGH CLOTHING DURING SIMULATED WEAR

A. V. Parisi [1)] and C. A. Wilson [2)]

[1)]A. V. Parisi, Department of Biological and Physical Sciences, University of Southern Queensland, Toowomba, Australia; and [2)]C. A. Wilson, Clothing and Textile Sciences, University of Otago, Dunedin, New Zealand

Corresponding author

A. V. Parisi

Department of Biological and Physical Sciences,

University of Southern Queensland,

Toowomba, 4350, Australia.

Ph: 61 7 4631 2226, Fax: 61 7 4631 2721, Email: parisi@usq.edu.au

PRE-VITAMIN D_3 EFFECTIVE UV TRANSMISSION THROUGH CLOTHING DURING SIMULATED WEAR

Abstract

Background/purpose: Clothing is an important protective layer used to reduce UV exposures to the skin surface. However, not all UV exposure is linked to detrimental health effects with some exposure to UVB wave lengths below 316 nm required for the synthesis of pre-vitamin D_3. The aim of the current research was to investigate the effect of fabric type, color, fit and wetness on the transmission of pre-vitamin D_3 effective UV through garments during simulated wear, in a high UV exposure environment.

Methods: Dosimeters fabricated from polysulphone film were positioned at 8 selected body sites on the skin surface and clothing surface of identically designed, loose and fitted, black and white T-shirts made up in two knitted fabric types and tested when both dry and when drying after initial wetting (n=3 replicates). The T-shirts were placed on manikins set to simulate humans in the sun between 09:30 and 12:30 EST during the Southern Hemisphere summer period. The post-exposure absorbance was measured and the dosimeters were calibrated for biologically effective UV for pre-vitamin D_3 synthesis with a UV spectroradiometer. The effect of fit, fabric type, color and wetness on pre-vitamin D_3 effective UV transmission during simulated wear was assessed.

Results: Irradiances varied among body sites with the highest erythemal exposures to a horizontal plane over the three hour period reaching approximately 14.5 MED while the highest exposure under the garment was 0.22 MED which may not be above the threshold for pre-vitamin D_3 synthesis for the time period investigated. Fabric and fit were the main variables affecting transmission of pre-vitamin D_3 effective UV. Some interactions were identified between the fabric color and wetness and between fabric type and color however, while significantly modifying transmission these effects were small.

Conclusion: Transmission of pre-vitamin D_3 effective UV occurred through the high UPF knitted fabrics investigated. However, the length of exposure will influence whether the irradiances are sufficient to be above the threshold for pre-vitamin D_3 synthesis. The main effect on transmission of pre-vitamin D_3 effective UV was the fit of the T-shirt and its fabric type (probably structure) rather than color or degree of wetness.

Key words: fit, dosimeters, wetness, color, fabric, pre-vitamin D_3

1 Introduction

Sunlight exposure has in recent years been subjected to predominantly negative publicity with attention focusing on the detrimental effects of exposing the skin to ultraviolet radiation. In particular the harmful effects of UVB radiation (280-320 nm) have been highlighted (1). However, solar UV also has beneficial health effects. Vitamin D, produced by the skin in the presence of sunlight, plays an important role in calcium metabolism and is essential for good bone development, prevention of rickets in children and osteoporosis, osteomalacia, and fractures in the elderly (2). As early as the 1920s sunlight was being advocated for the treatment of diseases such as rickets (3). Other reported health effects include prevention of insulin dependent diabetes, cancer (e.g. prostate, breast and colorectal cancer), autoimmune diseases, and multiple sclerosis, which show geographic distributions in rate and mortality that may be negatively correlated with the body's vitamin D levels and exposure to solar radiation (2, 4, 5).

Sources of vitamin D include dietary (e.g vitamin D_2 from plant, and vitamin D_3 from animal, sources) and synthesis sources. Assumption that both vitamins D_3 and D_2 are both of equal nutritional value has been questioned (6) with dietary sources varying in their contribution towards vitamin D reserves. Thus the importance of synthesis of pre-vitamin D_3 in the skin as a result of the action of ultraviolet light on 7-dehydrocholesterol (7-DHC) (7) and then the conversion of pre-vitamin D_3 into vitamin D_3 by a thermally induced process is increased (2). The action spectrum for the synthesis of pre-vitamin D_3 shows that only wavelengths below 316 nm are effective (8) with the UVA wavelengths (320 – 400 nm) not involved in the synthesis of pre-vitamin D_3 in humans. The threshold of UVB exposure to the full body in order to produce a significant increase in serum vitamin D_3 has been determined to be 18 mJ/cm^2 (9). In terms of a minimum erythemal dose (MED), 25 to 30% of a MED exposure to the hands, face and arms has been given as sufficient to produce the bodies vitamin D requirements (10).

The use of sunscreens (11), clothing (12, 13), darker pigmentation of the skin, age and latitude (2) have all been established as reducing the synthesis of pre-vitamin D_3 as a result of UV exposure. The same UV exposures to a twenty year-old person and to a seventy year-old person results in approximately 25% of the vitamin D_3 produced in the older person compared to the younger person while during winter at high latitudes above 37^o, there is minimal to no synthesis of vitamin D_3 due to UV exposure (2). At lower latitudes, vitamin D deficiency and insufficiency (8% and 23% respectively) have been reported in adults living in the sub-tropical latitudes of South East Queensland, Australia (14); in elderly living in the Sydney metropolitan area, Australia (15) and in Turkish populations living in Central Anatolia (16); and in recent immigrants to Australia from China and the Middle East (15).

Researchers interested in UV transmission through clothing and textiles generally from the perspective of protecting the skin surface, have investigated the effect of fiber content (17, 18), structure (18); color (17, 19, 20); wetness (21) and extension (22, 23) on transmission commonly using laboratory testing of new, relaxed flat fabrics. More recently, the effect of fabric, color, fit, and wettedness on UVB and UVA transmission through clothing has been measured during simulated wear (24).

Hutchinson and Hall (25) evaluated flat relaxed fabric from the perspective of whether the amounts of UV transmission between 11:00 and 13:00 h GMT might contribute to cutaneous synthesis of the vitamin D precursor, cholecalciferol using polysulphone dosimeters and concluded that synthesis was possible. Subsequent research that employed the conversion of 7-DHC in cuvettes exposed to solar UV transmitted through different fabrics indicated that clothing diminished pre-vitamin D_3 production (12). Matsuoka et al. (13) also investigated the serum vitamin D_3 production of clothed subjects exposed to approximately one MED and six MED and concluded that for these exposures the clothing prevented the synthesis of pre-vitamin D_3. This current research extends these previous studies with the aim of investigating the effect of fabric type, color, fit, and wetness on the transmission of pre-vitamin D_3 effective UV through identically styled T-shirts during simulated wear in a high UV exposure environment.

2 Method

Dosimeters

Dosimeters fabricated from polysulphone film (26) of approximately 40 micron thickness were employed to evaluate the biologically effective UV transmitted through fabric and thus available for pre-vitamin D_3 synthesis. The holder of the dosimeters was 3 cm x 3 cm in size and the film, produced at the University of Southern Queensland was attached over the opening in the holder that had a size of approximately 1.3 cm x 1.6 cm. The change in optical absorbance of the polysulphone due to UV exposure (ΔA_{330}) was measured at 330 nm at four locations over the dosimeter in a spectrophotometer (model 1601, Shimadzo Co., Kyoto, Japan). The post-exposure absorbance was measured at a standardized time following exposure to minimize any error associated with the post-exposure ‘dark reaction’ of the polysulphone (26).

The dosimeters were calibrated for biologically effective UV for pre-vitamin D_3 synthesis with a calibrated UV spectroradiometer (Bentham Instruments, Ltd, Reading, UK) that measures the solar spectral UV irradiance from 280 to 400 nm in 0.5 nm increments, every five minutes of the day. The dosimeters were subjected to a series of solar UV exposures on a horizontal plane while measuring the solar UV spectrum. The exposures were on a relatively cloud free day between the solar zenith angles of 37^o and 10^o. The biologically effective UV irradiances were calculated employing:

$$UVBE = \sum_{UV} S(\lambda)A(\lambda)\Delta\lambda \qquad Wm^{-2} \tag{1}$$

where $S(\lambda)$ is the spectroradiometer measured UV spectrum, $A(\lambda)$ is the appropriate action spectrum, $\Delta\lambda$ is the wavelength increment of the measured spectral irradiance, namely 0.5 nm and the summation is from 290 to 400 nm. The action spectra employed were that for pre-vitamin D_3 synthesis (8) to calculate the pre-vitamin D_3 effective UV

(UV_{D3}) and that for the erythemal action spectrum (27) to calculate the erythemal UV (UV_{ery}). The respective irradiances were calculated with equation (1) for each five minute spectral scan and Simpson's rule employed to calculate the exposures. These exposures were related to the change in absorbance to provide a calibration curve for the dosimeters. The calibration curve obtained for pre-vitamin D_3 effective UV is provided in Figure 1. The fitted curve has an R^2 value of 0.99.

Garments

The garments used were identically designed T-shirts constructed in two sizes (loose and fitted) and in two commonly available low UV transmission knit fabrics (cotton/elastane jersey and polyester eyelet (fiber content as claimed by the manufacturer). Each fabric and size was also constructed in both black and white colors, thus three replicates of a total of eight shirts were tested both when dry and after wetting. Fabric characteristics are given in Table 1 (24).

Prior to construction, fabrics were pre-treated to stabilize dimensions and the dry fabrics were rested flat on a cutting surface for 24 hours prior to cutting and sewing. Cutting conditions and pre-treatment is described in detail in Wilson and Parisi (24).

A standardized method of wetting the garments was employed (24). In summary, the garments were wetted using a domestic washing machine set on a delicate cycle, cold water setting (without detergent) with a medium/low water level and slow spin (28). Reference specimens (300mm x 300mm) of stable, plain weave, 100% cotton (315.61±1.10g/m^2, 19x19 yarns/10mm, 0.82±0.03mm thick) fabric were included in each wash load to enable consistency of wetting to be assessed. The garments and reference materials were weighed in their sealed bags under ambient conditions prior to and after wetting (24, 29). All garments were then transported to the test location in their sealed bags.

Simulated wear

The arrangement of garments during wear was simulated using two life-size manikins in a standing position (24). The manikins were of similar size and differed by less than 4% in key body dimensions. While the manikins were indoors, eight polysulphone dosimeters, used to measure the UV_{D3} transmitted through the fabric, were taped on each of the manikins at the anatomical sites of:

Front: shoulder *(anterior surface* immediately below the clavicle), chest (superior end of sternum), and torso (*near the unbilcal*); Back: shoulder (above shoulder blade), mid-back (*at level of posterior auxiliary folds)*, torso (*below chest line)*, and hip (at maximum circumference); Arm: upper arm *(lateral surface midway between the acromion and elbow).*

These dosimeters were then covered by test garments assigned to each manikin in a random fashion in order to minimize any effect due to manikin size or shape differences. To measure the UV_{D3} incident at each of the sites above the garment, a second set of eight dosimeters on each manikin displaced approximately 20 mm horizontally from the dosimeter location under the garment was taped to the upper surface of the garments. Additionally, two dosimeters were taped on the top of the head on a horizontal plane to measure the ambient UV.

A UV impenetrable cover was placed on the clothed manikins with the deployed dosimeters prior to moving them to the test position in an open unshaded area at the University of Southern Queensland (latitude, 27.6°S), Australia. The manikins were mounted on a platform that rotated the manikins at approximately 1 to 2 revolutions per minute and the cover removed. Each exposure session was between 09:30 and 12:30 Australian Eastern Standard Time (EST) during the Southern Hemisphere summer period of 16 December 2003 to 12 February 2004. The solar zenith angle over the exposure sessions from 09:30 to 12:30 EST ranged from 5 to 39°. The temperature and relative humidity during the measurement sessions were 27.5±5.5°C, 39±15% R.H. respectively.

Statistical analysis

The evaluated levels of pre-vitamin D_3 effective UV transmitted through the garments (n=3 replicates for each variable combination) during simulated wear were described (mean ($\overline{X}$), standard deviation (s.d.) and coefficient of variation (CV%)) for all variables of interest. The effect of the experimental factors on pre-vitamin D_3 was identified using univariate analysis of variance (ANOVA) and the relationship between UVB transmission and estimated pre-vitamin D_3 synthesis determined using Pearson correlation (30, 31).

3 Results

Distribution of pre-vitamin D_3 effective UV

The site distribution of mean pre-vitamin D_3 effective UV over all garment surfaces is provided in Figure 2 a, and the distribution under all of the garments in Figure 2 b. The distributions are the average for each respective site of all of the exposures between December 2003 and February, 2004 over the three hour periods of simulated wear from 09:30 to 12:30 EST. The highest erythemal exposures on a horizontal plane reached approximately 14.5 MED. The sites above the garment with the highest irradiances were the shoulders, chest and arms, whereas under the garment, the sites with the highest irradiances were the front and back shoulder positions, chest and hip. The highest erythemal UV exposure over the three hour period under the garment was 0.23 MED. The results in the next section investigate the influence of fabric type, color, fit and wetness on the pre-vitamin D_3 effective UV under the garment in order to apply these to the cases where there is a longer exposure period.

Transmission of pre-vitamin D_3 effective UV during simulated wear

Over the three hour period of simulated wear from 09:30 to 12:30 EST, the means (and s.d.) of the transmitted pre-vitamin D_3 effective UV exposures for the different fabric types, fit and color affected the evaluated transmission of pre-vitamin D_3 effective UV ($F_{1,31}$=209.75, $p \leq 0.001$; $F_{1,31}$=40.46, $p \leq 0.01$, $F_{1,31}$=10.00, $p \leq 0.01$ respectively) (Figure 3). Color, which did not significantly affect UVB transmission during simulated wear (24) did affect transmission of pre-vitamin D_3 effective UV. More UV_{D3} transmission occurred under white than black T-shirts (Figure 3 c). Wetting of the T-shirt at the beginning of the simulated wear period did not directly affect the evaluated UV_{D3} transmission ($F_{1,31}$=0.44, NS) but did modify the effect of color ($F_{1,31}$=4.65, $p \leq 0.05$) (Figure 4a) resulting in a decreased transmission of pre-vitamin D_3 effective UV through the black T-shirt which was drying during wear compared to when worn dry throughout the test period. It should be noted however, that while statistically significant the effect was small and it may be of little practical importance.

Of greater influence on the transmission of pre-vitamin D_3 effective UV was the effect of color and fabric type ($F_{1,31}$=31.74, $p \leq 0.001$) (Figure 4b). Transmission through the jersey was greatest when black, while it was greatest through the white fabric when made in the eyelet structure. The effect of fit also varied according to the fabric type ($F_{1,31}$=10.59, $p \leq 0.01$; Figure 5) with fitted shirts associated with greatest transmission and with fit having the greatest effect when combined with eyelet fabric.

Overall, all variables interacted to affect the transmission of pre-vitamin D_3 effective UV (Figure 6). Fabric type, color, wetness and fit effects modified transmission significantly ($F_{1,31}$=13.37, $p \leq 0.001$). Thus, the effect of the variables with the greatest influence on synthesis, i.e. fit and fabric type, can be modified by color choice and the extent of wetness (Figure 6). In the current work, less pre-vitamin D_3 was generally transmitted through loose than fitted shirts. The main effect on transmission of pre-vitamin D_3 effective UV was the size of the T-shirt and its fabric type rather than its color or the degree of wetness.

4 Discussion

The research reported in this paper investigates the effect of fabric type, color, fit, and wetness on the transmission of pre-vitamin D_3 effective UV through two types of garments during simulated wear in a high UV exposure environment. The distribution of the UV_{D3} over the torso was modified under the garments compared to that above the garments. This is due to the fabric covering modifying skin exposure and due to differences in transmission characteristics due to fit and extension. For example, the hip site for the fitted garment had negative ease i.e. the garment was stretched to fit the body while the hip site dimension in the loosely fitted garment included both wearing and design ease but may still have been more fitted over the hips than other sites within the same loosely fitted garment.

Previous research (13) has found that a whole body exposure of 6 MED through clothing failed to produce an increase in serum vitamin D_3. Another study (12) employing fabric covered cuvettes of 7-DHC found that the higher the number of threads per unit area, the less the amount of converted 7-DHC. Both Salih (12) and Matsuoka et al., (13) were investigating transmission through woven fabrics not matched for production variables such as thickness, sett or mass per unit area. Thus it is not possible to identify whether effects are due to fiber type or structural differences. However, the contrast between findings by Salih (12) and Matsuoka et al., (13) who investigated woven fabrics and those of Hutchinson and Hall (25) and the results of the present study where transmission through more extensible knitted fabrics was examined, suggests structural differences may be affecting transmission of pre-vitamin D_3 effective UV. Further work is recommended to determine the relative importance of structural and fiber effects.

For the exposure time and the low UV transmission fabrics employed in this research, there may not have been sufficient pre-vitamin D_3 effective UV transmitted through the garments over the three hour exposure period to initiate pre-vitamin D_3 synthesis. However, for double the exposure periods, or exposure over a different time frame (e.g. 11:00-13:00 h GMT as used by Hutchinson and Hall (25)), the pre-vitamin D_3 threshold may be exceeded. It is for these circumstances, e.g. longer exposure times or exposure during high UV incidence, where the results from this research on the effects of fabric type, color, fit, and wetness on the transmission become important.

The transmission of pre-vitamin D_3 effective UV during simulated wear was affected by fabric type, fit and color of the garment. More UV_{D3} transmission occurred under the eyelet, polyester fabric than the jersey, cotton/elastane fabric, and more under the fitted than the loose T-shirts. Such a finding is consistent with the relationship between UVB transmission fabric and fit reported by Wilson and Parisi (24). The difference between color significantly influencing the transmission of UV_{D3}, whereas it was not a significant influence for erythemal UV transmission may be attributed to this current study considering pre-vitamin D_3 effective UV wavelengths, namely shorter than 316 nm. The UVB wavelengths referred to in the previous study includes longer wavelengths. Such potential interaction between color (or dye) and UV is consistent with the effect of fabric and color on UVB transmission and may reflect different interactions between the dye and fiber (21, 24).

The main effect on UV transmission was the size of the T-shirt rather than its color or degree of wetness. Irrespective of fabric type more pre-vitamin D_3 effective UV was transmitted through fitted than loose T-shirts. However, loose fitting shirts resulted in a proportionally greater reduction in synthesis in the eyelet than the jersey fabric. In the absence of controlled manufacture of the fabrics to match physical and structural properties, it is not possible to identify how the physical properties of the fabric or fiber affected their behavior. The effect of color was more fabric specific with higher levels synthesized under the white than the black eyelet while the reverse was true for the jersey fabric.

For the cases of long exposures in a high UV exposure environment, further work is required to measure the serum 25-hydroxyvitamin D_3 of individuals wearing garments of the type used in this research. Additionally, further testing employing dosimeters during simulated wear on a wider range of fabric types and colors in a high UV exposure environment is required to clarify the relationship between UVB transmission and synthesis of pre-vitamin D_3 ($r=0.85$, $p\leq0.001$) during wear and how they are modified by fabric selection (in particular fabric structural properties) and user choices is recommended.

5 Acknowledgements

The support of the University of Otago (provision of Research and Study Leave); the University of Southern Queensland, Toowomba, Australia (through appointment of C. A. Wilson as an Honorary Visiting Scholar, Centre for Astronomy, Solar Radiation and Climate); Orca™ New Zealand for supply of cotton T-shirts; Assistance of colleagues in the Clothing and Textile Sciences Department, and B. E. Niven, Centre for Applications of Statistics and Mathematics, University of Otago, for statistical guidance; are gratefully acknowledged.

6 References

1. Albert M R, Ostheimer K G. The evolution of current medical and popular attitudes toward ultraviolet light exposure: Part 3. J Am Acad Dermatol 2003: 49: 1096-1106.

2. Holick M F. Sunlight and vitamin D for bone health and prevention of autoimmune diseases, cancers, and cardiovascular disease. Am J Clin Nutr 2004: 80: S1678-S1688.

3. Albert M R, Ostheimer K G. The evolution of current medical and popular attitudes toward ultraviolet light exposure: Part 2. J Am Acad Dermatol 2003: 48: 909-918.

4. Schwartz G G. Multiple sclerosis and prostrate cancer: What do similar geographies suggest. Neuroepidemiology 1992: 11: 244-254.

5. John E M, Dreon D M, Koo J, Schwartz G G. Residential sunlight exposure is associated with a decreased risk of prostrate cancer. J Steroid Biochem Mol Biol 2004: 89-90: 549-552.

6. Trang H M, Cole D E C, Rubin L A, Pierratos A, Siu S, Vieth R. Evidence that vitamin D_3 increases serum 25-hydroxyvitamin D more efficiently than does vitamin D_2. Am J Clin Nutr 1998: 68: 854-858.

7. Bray J J, Cragg P A, MacKnight A D C, Mills R G. Lecture notes on human physiology. 4th ed. Oxford: Blackwell Science, 1999.

8. Webb A R. Vitamin D synthesis under changing UV spectra. In: Young A R, Bjorn L O, Moan J, Nultsch W, eds. Environmental UV photobiology. New York: Plenum Press, 1993: 185-202.

9. Matsuoka L Y, Wortsman J, Haddad J G, Hollis B W. In vivo threshold for cutaneous synthesis of vitamin D_3. J Lab Clin Med 1989: 114: 301-305.

10. Holick M F. Vitamin D: Importance for bone health, cellular health and cancer prevention. Biologic effects of light 2001. Dordrecht: Kluwer Academic Publishers, 2002: 155-174.

11. Matsuoka L Y, Ide L, Wortsman J, MacLaughlin J A, Holick M F. Sunscreens suppress cutaneous vitamin D_3 synthesis. J Clin Endocrinol Metab 1987: 64: 1165-1168.

12. Salih F M. Effect of clothing varieties on solar photosynthesis of previtamin D_3: An *in vitro* study. Photodermatol Photoimmunol Photomed 2004: 20: 53-58.

13. Matsuoka L Y, Wortsman J, Dannenberg M J, Hollis B W, Lu Z, Holick M F. Clothing prevents ultraviolet-B radiation-dependent photosynthesis of vitamin D_3. J Clin Endocrinol Metab 1992: 75: 1099-1103.

14. McGrath J, Kimlin M G, Saha S, Eyles D, Parisi A V. Vitamin D insufficency in South-east Queensland. Med J Aust 2001: 174: 150-151.

15. Brock K, Wilkinson M, Cook R, Lee S, Bermingham M. Associations with vitamin D deficiency in "at risk" Australians. J Steroid Biochem Mol Biol 2004: 89-90: 581-588.

16. Atli T, Gullu S, Uysal A R, Erdogan G. The prevalence of vitamin D deficiency and effects of ultraviolet light on vitamin D levels in elderly Turkish population. Arch Gerontol Geriatr 2005: 40: 53-60.

17. Davis S G, Capjack L, Kerr N, Fedosejevs R. Clothing as protection from ultraviolet radiation: Which fabric is most effective. Int J Dermatol 1997: 36: 374-379.

18. Cox Crews P, Kachman S. Influences on UVR transmission on undyed woven fabrics. Text Chem Colorist 1999: 31: 17-26.

19. Wang S Q, Kopf A W, Marx J, Bogdan A, Polsky D, Bart R S. Reduction of ultraviolet transmission through cotton T-shirt fabrics with low ultraviolet protection by various laundering methods and dyeing: Clinical implications. J Am Acad Dermatol 2001: 44: 767-774.

20. Srinivasan M, Gatewood B M. Relationship of dye characteristics to UV protection provided by cotton fabric. Text Chem Colorist Dyestuff Reporter 2000: 32: 36-43.

21. Gambichler T, Hatch K L, Avermaete A, Altmeyer P, Hoffman K. Influence of wetness on the ultraviolet protection factor (UPF) of textiles: In vitro and in vivo measurements. Photodermatol Photoimmunol Photomed 2002: 18: 29-35.

22. Parisi A V, Kimlin M G, Mulheran L, Meldrum L R, Randall C. Field-based measurements of personal erythemal ultraviolet exposure through a common summer garment. Photodermatol Photoimmunol Photomed 2000: 16: 134-138.

23. Moon R, Pailthorpe M. Effect of stretch and wetting on the UPF of elastane fabrics. Australas Text 1995: 15: 39,41-42.

24. Wilson C, Parisi A V. Protection from solar erythemal ultraviolet radiation — simulated wear and laboratory testing. Text Res J 2005: Under review.

25. Hutchinson G, Hall A. The transmission of ultra-violet light through fabrics and its potential role in the cutaneous synthesis of vitamin D. Hum Nutr: Appl Nutr 1984: 38A: 298-302.

26. Davis A, Deane G H W, Diffey B L. Possible dosimeter for ultraviolet radiation. Nature 1976: 261: 169-170.

27. CIE (International Commission on Illumination) Research Note. A reference action spectrum for ultraviolet induced erythema in human skin. CIE J 1987: 6: 17-22.

28. Laing R M, Wilson C A, Gore S, Carr D J. Development of comparable methods for wetting using a Wascator and a domestic washing machine (Fisher and Paykel Smartdrive, model GW511, excellence). Clothing and Textile Sciences. Dunedin, New Zealand: University of Otago, 2003.

29. British Standards Institution. BS EN 29073-1:1992; ISO 9073-1:1973. Methods of test for nonwovens. Part 1. Determination of mass per unit area. London: British Standards Institution, 1992.

30. Ott L, Mendenhall W. Understanding statistics. 4th ed. Boston: Duxbury Press, 1985.

31. SPSS Inc. Statistical Package for Social Sciences, Version 6.1.1. Chicago: SPSS Inc, 1995.

Table 1

Descriptions of dry pre-treated fabrics

Construction	Fiber content*	Color	Thickness (mm)		Mass per unit area (g/m^2)		Interstitial space (%)		Cover	UVB % transmission		UPF		UPF rating
			Mean	s.d.	Mean	s.d.	Mean	s.d.		Mean	s.d.	Mean	s.d.	
'Eyelet' i.e. Double jersey eyelet modification														
	Polyester	Black	0.67	0.01	132.47	0.26	3.00	0.24	97.00	0.78	0.35	46.32	5.17	40
		White	0.98	0.02	131.31	0.14	2.84	0.18	97.16	1.16	0.40	30.91	2.17	30
'Jersey' i.e. Double jersey														
	Cotton/elastane	Black	1.18	0.04	214.78	0.13	0.00	0.00	100.00	0.68	0.05	585.77	124.82	50+
		White	0.92	0.02	258.18	0.04	0.00	0.00	100.00	0.48	0.29	548.44	22.42	50+

* Manufacturer stated

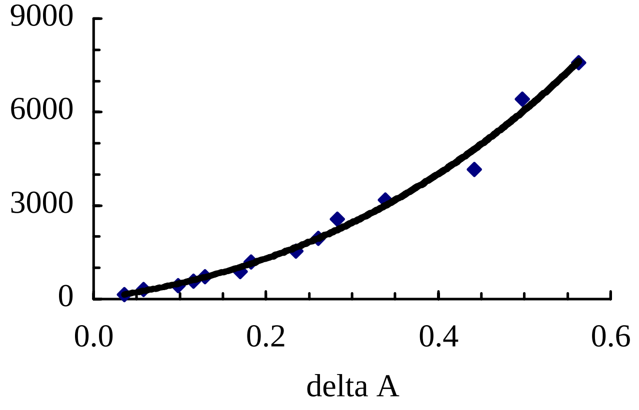
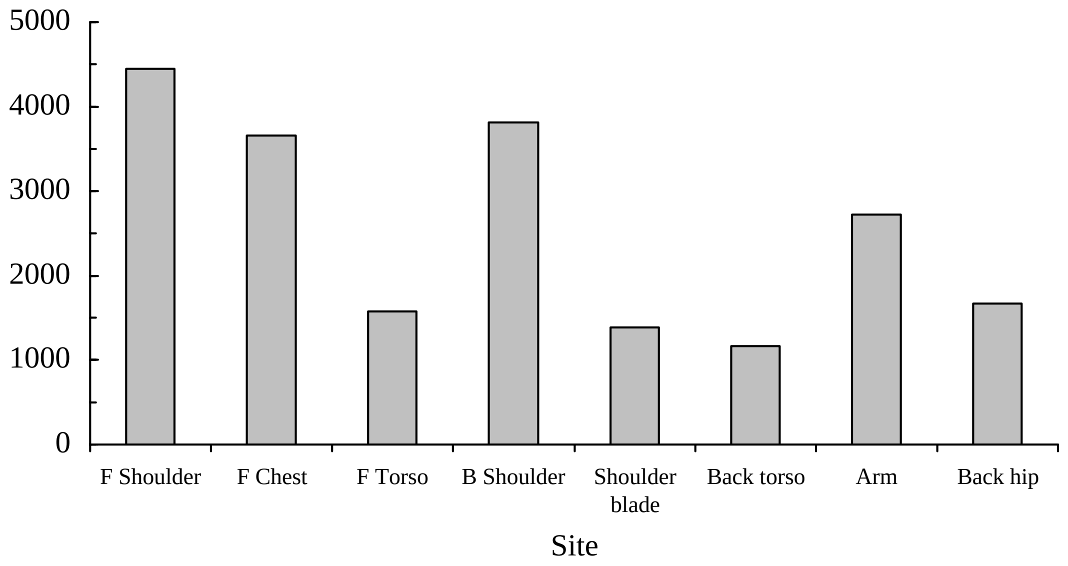


Figure 1 - Calibration curve of the dosimeters for pre-vitamin D_3 effective UV.

a



b

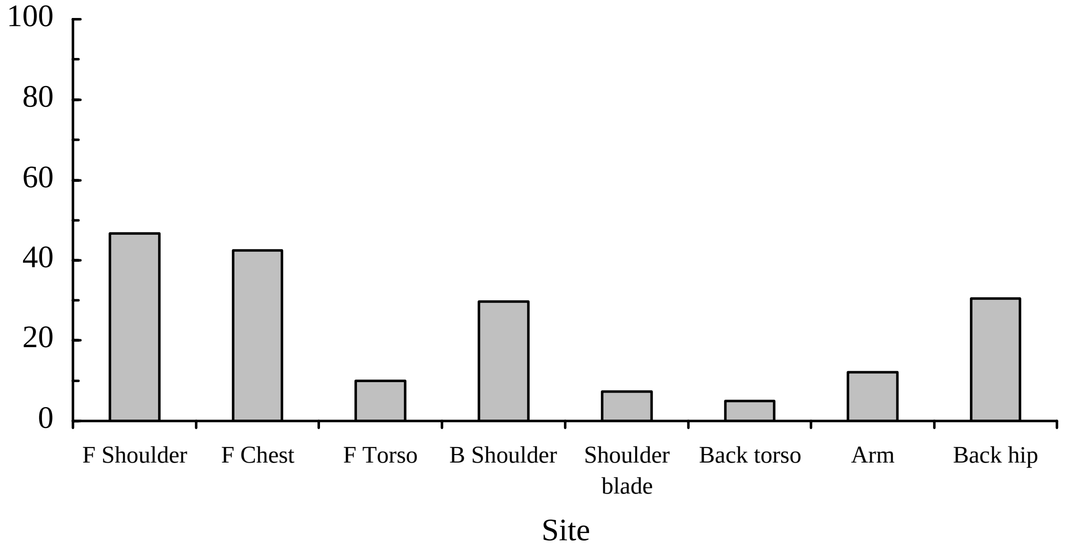
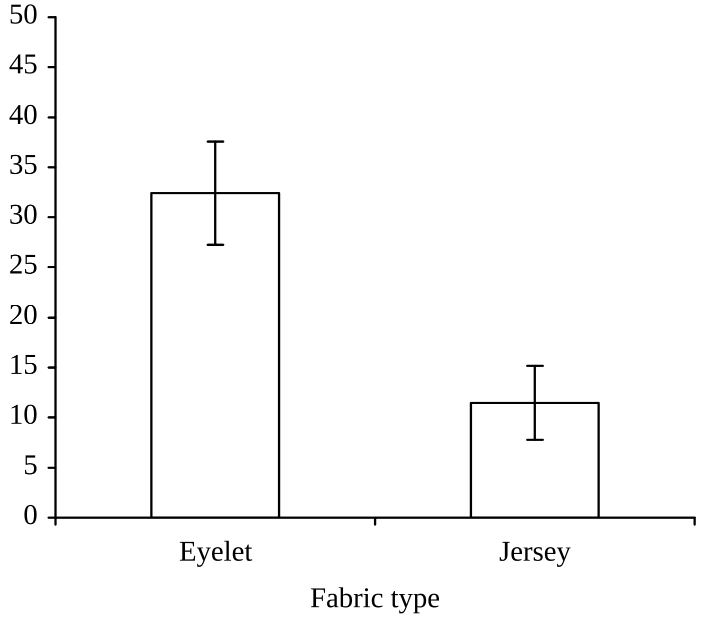


Figure 2 – Mean pre-vitamin D_3 effective UV at each of the body sites: a) above the garment, and b) under the garment.

a Fabric



b Fit

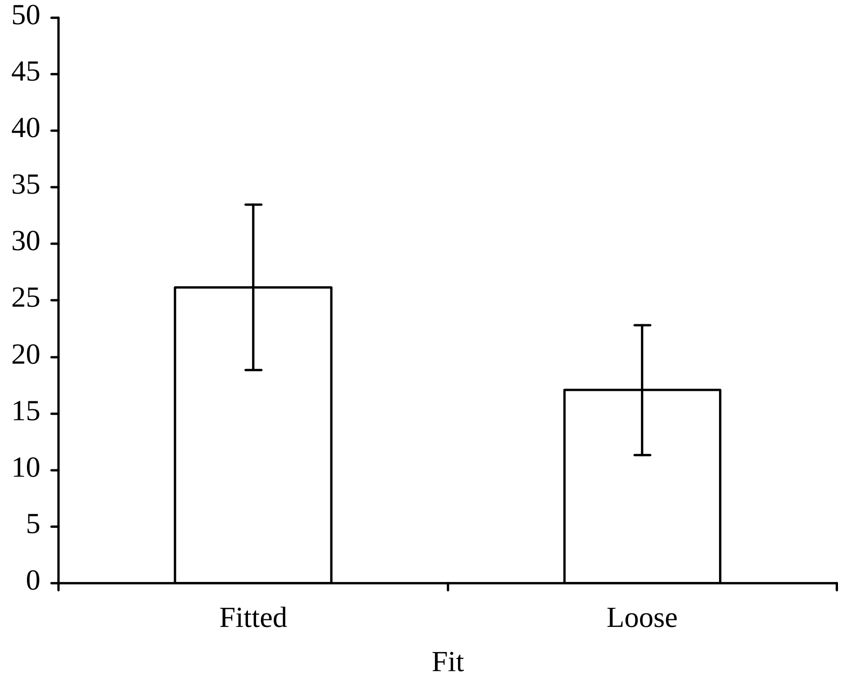


Figure 3 - Mean transmitted pre-vitamin D_3 effective UV (showing s.d. bars) — differences due to fabric type, fit and color.

c Color

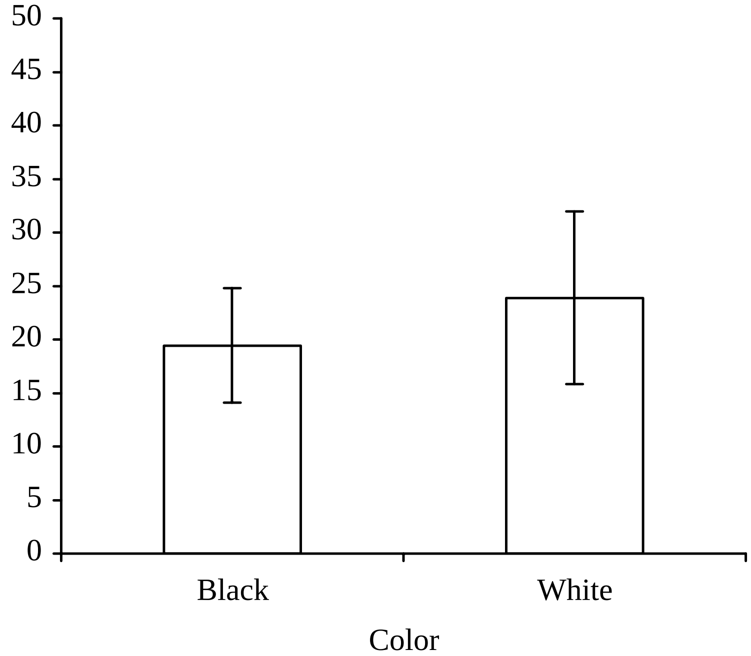
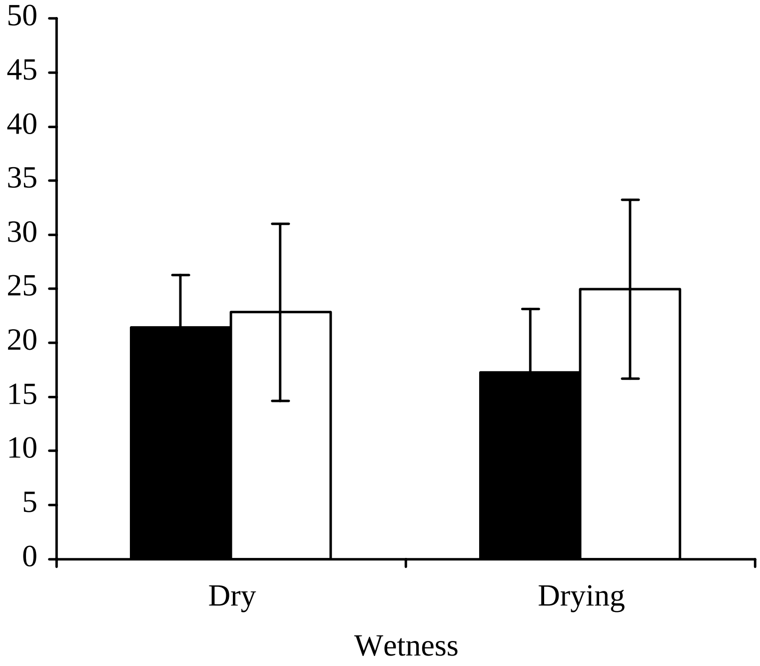


Figure 3 cont. - Mean transmitted pre-vitamin D_3 effective UV (showing s.d. bars) — differences due to fabric type, fit and color.

a Wetness and color



b Fabric and color

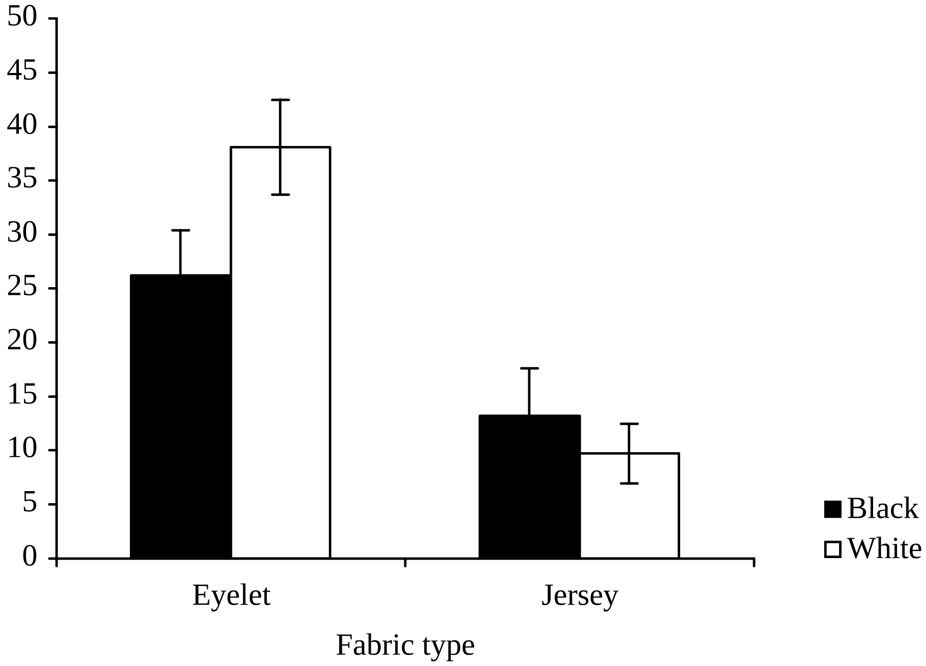


Figure 4 - Mean estimated pre-vitamin D_3 synthesis (showing s.d. bars) determined during use — effect of wetness on color, and color of fabric.

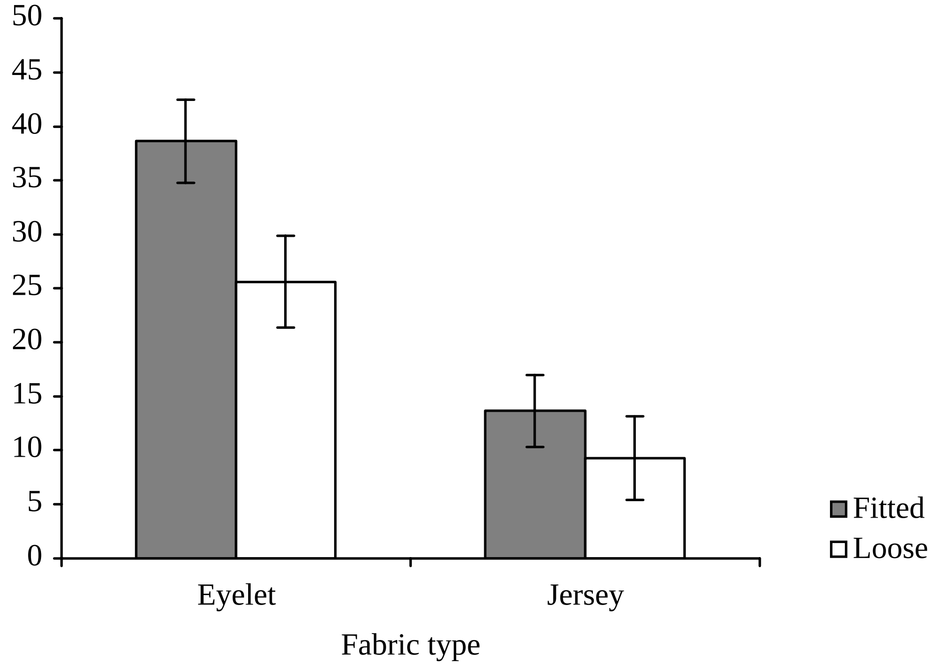
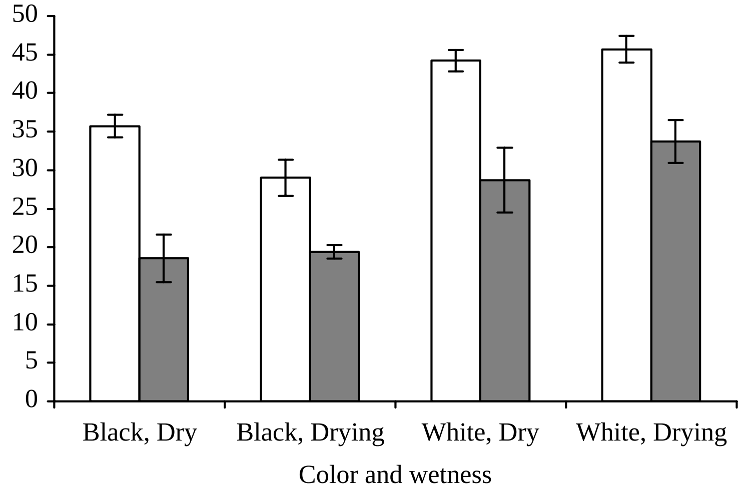


Figure 5 - Effect of eyelet and jersey T-shirts and their fit on mean estimated pre-vitamin D_3 synthesis (showing s.d. bars).

a Eyelet



b Jersey

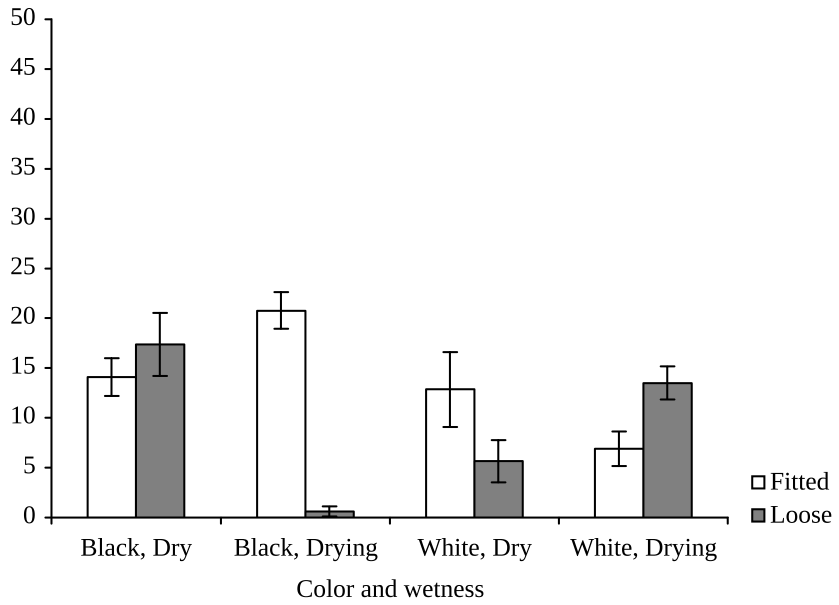


Figure 6 - Mean (with s.d. bars) estimated pre-vitamin D_3 synthesized through eyelet and jersey T-shirts during simulated use — differences between fabrics, product sizes, colors and wetness.