Patterns in the Received Facial Ultraviolet Exposure of School Children Measured at a Sub-tropical Latitude[‡]

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Abbreviations: ΔA_{330}, change in polysulphone absorbency at 330 nm; ER, exposure ratio; PS, polysulphone; SED, standard erythemal dose; SZA, solar zenith angle; UPF, ultraviolet protection factor; UV_{ery}, erythemally effective ultraviolet radiation.

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ABSTRACT

Polysulphone dosimeters have been employed to measure the erythemally effective UV exposure to the vertex, nose, cheek, chin and side facial sites of 45 volunteer high school students from Hervey Bay, Australia (25.3°S 152.9°E). The results of a series of 1 hour outdoor sport trials (basketball and soccer) found the mean student facial exposure, determined as the arithmetic average of facial site exposures of unprotected students (no hat) to protected students (hat) varied from 140 ± 82 Jm^{-2} (1σ), to 99 ± 33 Jm^{-2} (1σ) respectively. All hourly student facial exposures recorded over the study period were found to exceed the National Health and Medical Research Council's adopted safe daily limit of 30 Jm^{-2}. Facial exposure relative to the received ambient UV increased to the nose at higher (winter) Solar Zenith Angles (SZA) compared with lower (summer) SZA ranges for both protected and unprotected students. The protection offered by the broad-brimmed hats was reduced significantly to the lower chin facial site at the higher SZA range, indicating that the style of hat used offers best protection in summer to the upper facial regions at most risk of receiving a high exposure when no hat protection is used. Variations to specific student facial exposure sites were measured between both basketball and soccer players. Variation in student facial exposure was further examined with respect to cloud cover and comparisons to manikin headform measurements were also made. The study results indicate that hats alone are not adequate forms of sun protection in a school environment. Schools aiming to achieve acceptable safe limits of facial exposure may need to further consider the effectiveness of hat protection with increasing SZA, cloud cover and head position relative to the sun that is specific to the scheduled outdoor activity.

INTRODUCTION

School playgrounds present a significant health risk to children in Australia for the development of environmental solar ultraviolet induced disease. The risk is most significant in Queensland, Australia, having the highest incidence rates of non-melanoma skin cancer and cutaneous malignant melanoma in the world (1-2). In Queensland, a proportionately high fair skinned population, high solar altitudes due to geographical latitude, and a high number of sunshine days contribute to high levels of ambient UV (3-4). Lower ozone concentrations and proximity to the sun during the Southern hemisphere summer further contribute to an increase in ambient UV in comparison to Northern hemisphere latitudes (5-6).

Children, having unacclimatised skin and being potentially exposed to the sun during school hours at times of peak solar ultraviolet irradiance increase their risk of receiving acute and long term damage associated with excessive exposure to solar ultraviolet radiation. Campaigning by the various state Cancer Councils has resulted in the development of safer practice in Australian schools and the broader community (7), although awareness of the risks associated with exposure to UV does not always result in safer behavioural practice among school populations. In a behavioural study conducted across three primary schools in Perth, Western Australia, the use of hats by school children providing quality protection was observed to be often less than 30% (8). Furthermore, while it has been well documented that childhood exposure to UV is crucial to the potential development of skin cancers later in life, (9-11) behavioural trends among school aged children show a decrease in ‘sun safe’ practices

with age, particularly among adolescents (12-15) and a reluctance from high schools compared with the early childhood and primary school sectors to formalize safe sun policies (16).

Solar UV exposure and its subsequent influence on school children in Queensland has been estimated previously using a personal diary approach to estimate exposure relative to the recorded ambient UV (6). Additional work has been done to estimate exposure to children using personal diaries and polsulphone film badges, again to estimate exposure relative to ambient UV exposure measured within the proximity of student study sites (17-19). Parisi et al. (20) utilized personal diaries and full body manikins to estimate cumulative exposure to children in south-east Queensland. Personal polysulphone badges have been employed to measure shade use by primary school children (21). Rosenthal et al. (22) measured UV expose to children during a summer camp in the United States using dosimeters placed directly on the skin compared with ambient measurements measured with polysulphone dosimeters, while Diffey et al. (23) using personal polysulphone badges, determined exposure to primary and secondary school children over a three month summer period in England.

Few studies however have determined UV exposure received directly to the human face. This has largely been due to the impracticality compared with the convenience of manikins. It is recognized that relative to whole body incidence, facial skin cancers are the most common with non melanoma skin cancers occurring more frequently than cutaneous malignant melanoma (24). The incidence of the treatment of non-melanoma skin cancer has been reported at more than five times the rate recorded for all other types of cancer (25), and shows a clear increase in incidence with decreasing latitude (26-27). While the specific

aetiology of facial cancers cannot be directly related to solar UV facial exposure distribution (28), the approximate facial exposure ratio can remain as much as 25% of the ambient UV (29), thus having significant potential to cause damage to the human face. These findings indicate a need for further research into personal facial UV exposure measurement. Hats are perhaps one of the most convenient methods of reducing personal facial exposure to solar UV. Studies involving manikin headforms have shown a clear reduction in UV exposures to facial sites when hat protection is used (30-32). This research addresses the need for more quantitative data on human facial exposures to human subjects and assesses the protective effectiveness of broad-brimmed hats on humans and manikins within a school environment.

MATERIALS AND METHODS

Polysulphone (PS) dosimeter badges were utilised to record erythemally effective (33) ultraviolet radiation (UV_{ery}) over the range 280 to 400 nm to five facial regions on subjects using and not using broad-brimmed hat protection while playing sport in a school playground. Playground exposure times were set to 1 hour and taken to represent the shortest time students were likely to be exposed to UV during a school day on which they may be required to participate during an outdoor lesson. The facial regions tested included the forehead, nose, chin, cheek, jaw, temple, and ear lobe. Exposures received to the vertex of the head were also recorded. The jaw, temple and ear lobe position were considered as a single region and referred to as a side measurement. The side classification was implemented due to little data being collected from student exposures to the ear and temple regions and because of the

similarity in facial topography for each of the side site locations oriented in a near perpendicular plane relative to the horizon.

PS Dosimetry

Dosimeter badges were manufactured from PS film cast at the University of Southern Queensland to an approximate thickness of 40 µm and adhered to small cardboard holders measuring 10x15 mm with a clear circular aperture of 6 mm. The change in PS film absorbency was recorded at 330 nm (ΔA_{330}) before and after playground field exposures (spectrophotometer model UV1601, Shimadzu Co. Kyoto, Japan). Post exposure measurements of PS film absorbency were recorded at least 24 h after exposure to allow for the PS dark reaction following exposure to solar UV (34). Dosimeter ΔA_{330} measurements were calibrated to the UV_{ery} using a PS calibration curve technique (35). The calibration curve employed for this research (Fig. 1) was developed from a series of three horizontal plane field calibrations measured using a portable Robertson-Berger meter (Solar light Co., Philadelphia, PA 19126) taken during mid spring and late summer and calibrated to a calibrated UV spectroradiometer (model DTM300, Bentham Instruments, Reading, UK). Spectroradiometer measurements at set intervals were weighted erythemally (33), converted to an exposure and expressed in standard erythemal dose (SED) where 1 SED represents 100 Jm^{-2} of UV_{ery} (36). Given the possibility for the seasonal variation in PS film exposure response (37), winter UV_{ery} exposures presented in this research are likely to be higher than exposures quoted here, however the spring-summer response curve of Figure 1 is used in this research as it better represents the lower limit of possible exposure.

To determine the uncertainty in the dosimeter badges used, variation in measured UV_{ery} with increasing ΔA_{330} was recorded in an open environment at the University of Southern Queensland (27.5°S 151.9°E) (Fig. 2, Fig. 3 and Fig. 4). The total maximum uncertainty in the measurement of the UV_{ery} was determined to be in the order of $\pm 24\%$ (Fig. 4) including the uncertainty estimate of 6.3% based on the spectroradiometer wavelength response and irradiance stability (38). The uncertainty estimate of the dosimeters used in the study exceeds the coefficient of variation of 10% calculated by Diffey (35) for PS dosimeters not exceeding a ΔA_{330} of 0.3, however is within the upper limit of 30% further specified by Diffey (35) for a ΔA_{330} less than 0.4. The maximum ΔA_{330} recorded over the study period was 0.345.

To facilitate comparison in the facial exposure with variations in ambient UV received over the trial period, exposure ratios (ER) have also been presented in the data. In this instance ER expresses exposure as a percentage relative to the maximum received exposure based on the erythemally weighted polysulphone calibration approximation (39):

$$ER = \frac{(9\Delta A_{330}{}^{3} + \Delta A_{330}{}^{2} + \Delta A_{330})}{(9\Delta A_{330\max}^{3} + \Delta A_{330\max}^{2} + \Delta A_{330\max})} \times 100 \quad (1)$$

Here, the maximum received exposure causing the largest change in absorbance (ΔA_{330max}) was the ΔA_{330} recorded for dosimeters placed typically at a vertex site.

Trial Site

UV_{ery} exposures to facial sites were recorded on both student volunteers and manikin headforms though not simultaneously so as to not compromise student safety (Fig. 5 and Fig. 6). The manikin headforms, included for general comparison with human ER were positioned in an upright position and placed on a rotating frame completing approximately two revolutions every minute. Two identical headforms were placed on the rotating frame, namely the control headform, with no hat protection and another wearing a broad-brimmed hat. Dosimeters were placed on a horizontal plane on the rotating platform and on the manikin headform vertex, forehead, nose, cheek, chin, jaw, temple, and ear lobe. Each headform on the frame was positioned such that the vertex reached a height of approximately 90 cm above ground level. Surface albedo contributions to manikin facial sites may be taken to represent sitting height rather than standing height and were expected to maximise facial exposure due to surface albedo.

The manikin frame was positioned in a central location of both a basketball court and soccer field. The variation in protected and unprotected facial exposure due to the asphalt basketball court and grass soccer field was tested in a series of 1 hour trials run over a twelve month period. Both the soccer and basketball trial regions were located adjacent to one another within the grounds of Hervey Bay State High School (25.3^{o}S 152.9^{o}E). The trial region was located well away from large buildings. The nearest surface objects were low blocked agricultural sheds located approximately 20 m from the basketball court and a tree line located

approximately 30 m from the soccer field. The position of the manikin frame located within each trial environment is shown in Figure 7 and Figure 8.

Study Group

Forty five volunteer students were selected from the high school population from across all year levels (aged 12 to 17 years) in accordance with the University of Southern Queensland's human research ethics committee guidelines. Participants were required to take part in 1 hour basketball or soccer trials. Each trial held over the twelve month study period was conducted during normal school lesson times. A series of nine trials, five soccer and four basketball were conducted over the study period. These trials included variations in solar zenith angle (SZA), (range 9^{o}-55^{o}) and cloud cover conditions (ranging from clear to total cloud cover during trial periods). Typically trials involved groups of ten students playing sport, five students each wore broad-brimmed hats of the same type and size and the control group of five students had no hat protection. Prior to playing sport, students were instructed in correct dosimeter handling procedure and asked to place dosimeters on their face using 'bandaids' (small plastic adhesive bandages). The placement locations were left to students provided dosimeters were positioned at either the forehead, nose, cheek, chin or side of the face. To reduce sweat damage to the cardboard dosimeter frames, students placed dosimeters on top of an underlying bandaid so that each facial dosimeter did not come into contact with the skin. Students were given 10 minutes to apply facial dosimeters prior to playing sport. This was achieved during the first 10 minutes of the school's normal 70 minute lesson period giving 1 hour of sport time. The number of dosimeters placed on the face was dependent on the total number that could be

placed within the 10 minutes of student preparation time, typically this was no more than two dosimeters. Dosimeters were attached under building shade before moving to the trial area approximately 200 m away. Once students reached the designated trial area (basketball court or soccer field) they were required to stay in that area, including break times, for the entire hour. Dosimeters at the end of each 1 hour trial were removed on site and stored immediately in envelopes impervious to UV. Removal of adhesive bandaids from dosimeter badges was conducted indoors prior to post exposure measurement and was not performed by students in the field.

RESULTS

Variation in facial UV_{ery} exposure with sport

The maximum received UV_{ery} recorded over each 1 hour student trial varied from between 9.0 SED to 1.4 SED with the recorded minimum facial exposure being 0.5 SED. These results are comparable with the results of Vishvarkarman et al. (40), reporting an annual vertex exposure received by central Queensland physical education teachers of 340 ± 71 kJm^{-2}, the approximate equivalent of a daily UV_{ery} exposure of 16.6 ± 3.5 SED, assuming there are approximately 205 days in a school calendar year. Table 1 lists the protected and unprotected student UV_{ery} facial exposure and corresponding facial exposure ratio. The table includes each trial SZA range, the OMI satellite interpolated estimate of total column ozone for Hervey Bay (Dobson Units) (41), and the observed cloud cover (estimated in eighths). Mean UV_{ery} exposure is listed specific to each facial site and mean ER is given relative to the maximum received trial exposure. For all

but trial 9, the maximum exposure was received at a vertex dosimeter site. Where applicable, mean distribution t-test 90% confidence limits are provided for comparison with the mean facial site exposure, where the confidence limits are specified by the range:

$$\bar{x} - t_{.95}\frac{s}{\sqrt{N-1}} < \mu < \bar{x} + t_{.95}\frac{s}{\sqrt{N-1}} \qquad (2),$$

And also listed as:

$$\pm t = t_{.95}\frac{s}{\sqrt{N-1}} \qquad (3)$$

Where $\bar{x}$ is the sample mean, μ the expected population mean, s the sample standard deviation, N the facial site sample size, $\pm t$ the minimum and maximum 90% confidence limit and $t_{.95}$ the confidence coefficient for the t probability distribution. Dosimeter damage, loss during sport, and variation in the number of student volunteers available for each study trial account for the relatively small data samples collected at each facial region and variability in the listed confidence limits.

The highest exposures were recorded for students playing basketball. High UV_{ery} exposure received for students playing basketball is however likely to be attributed to high solar elevations at the time of exposure resulting in a reduction in the total UV atmospheric path and is not likely to be linked to higher surface albedo. Surface albedo was recorded using a portable Robertson-Berger meter (Solar Light Co., Philadelphia, PA 19126) at a height of approximately 30 cm. The measured albedo of the basketball court varied over the study period with the average albedo determined to be 5.2%, $1\sigma \pm 0.4\%$, compared with the soccer field average of 3.6%, $1\sigma \pm 0.5\%$ This difference in surface albedo is too small to make a

significant contribution to the ambient UV. A plausible explanation for the differences in facial exposure received while playing sport on the two different surfaces is likely to be due to SZA, variation in atmospheric conditions and variation in body position when playing the different sports.

Examples of variation in received facial exposure due to variation in head position were evident in measured facial ER for protected and unprotected students playing basketball and soccer. The chin and nose in particular, are noted as having ERs of 54% (chin) and 44% (nose) for protected basketball players compared with an average ER of 8% (chin) and 29% (nose) for protected soccer players experiencing similar high cloud cover conditions with the maximum chin and nose ERs recorded for protected soccer players being 26% and 35% respectively, both measured on a clear day. Forehead and cheek ERs were however lower for protected basketball players compared with protected soccer players. This may be due to cheek and forehead facial positions being closer to shade provided by the broad-brimmed hats reducing the possibility for significant variation between basketball and soccer players. Unprotected basketball players also experienced high nose ERs, averaging 51% compared with 44% for soccer players when averaged across all trials, although cheek and chin exposures for soccer players were higher than those recorded for unprotected basketball players. However, as might be expected for unprotected players, similar ERs were measured across cheek and chin sites and differed by no more than 3% when ERs for the lowest ambient UV_{ery} trial were omitted. The omission of trial 9 in the determination of facial ER variance for cheek and chin facial sites may be justified given trial 9 exposures show significantly higher ERs compared with all other trials due to little variance in low facial SED with all except for

the highest recorded cheek exposure falling within 30% of the trail mean and therefore being close to the limit of measurement uncertainty determined at ± 24%.

No significant variation in the facial ER received by the manikin headforms were recorded over the study period indicating variation in student facial exposure was likely due to changes in SZA, atmospheric conditions and head position, with surface albedo contributions having minimum effect on the ambient UV. Manikin facial site exposures measured over the study period were recorded within the 30^{o} to 55^{o} SZA range on mid level cloud cover days (Table 2). From these results, maximum variation in manikin ER was recorded at protected forehead sites. This is due to the hat partially covering forehead dosimeters and hat placement varying slightly with brim tilt angle although attempts to minimise hat movement and placement on the manikin were implemented by using small velcro strips to secure the hat to the manikin headform.

Figure 9 lists the protected and unprotected facial UV_{ery} exposure received by students while playing both sports. The Figure is organised in decreasing order of mean unprotected UV_{ery} exposure. The median, *m* and number of facial site measurements, *n* are also provided. The influence of broad-brimmed hat protection when taken across the entire study period is greatest to the forehead reducing the mean UV_{ery} exposure to that site by an average of 1.2 SED, followed by the cheek (0.5 SED) then the chin (0.1 SED). As expected, these results confirm that most protection is provided by the hat for sites located closer to the brim. It is clear from the figure that the hats used in this study reduce the maximum exposure to each facial site except the nose and side sites. This may in part be due to narrow brim width

however, the sample size tested, particularly the protected student sample sizes were too small to show significant difference in the exposure to the nose compared with the unprotected student exposure sites. It should also be noted that where a direct nose site comparison could be made (trial 5 and trial 8) protected nose site exposures were less than or equal to the maximum unprotected exposure. Furthermore, where direct comparisons specific to each trial could be made, students protected by hats were found to have either the same or a reduced exposure to side sites (trial 1 and trial 3) although the global side median (Fig. 9) indicates exposures to protected students were higher. This is a direct result of averaging across the entire data set. If data were available in trials where low unprotected exposures were measured which for some cases, no protected exposures were measured, lower protected exposures, if available would reduce the global protected exposure mean altering the results presented in the figure. For this reason Figure 10 is provided and makes the same comparisons of the protective effectiveness measured at each facial site, but for only those trials where direct comparisons between the protected and unprotected exposure could be made. This reduces uncertainty in the comparison between protected and unprotected exposure when using data from the entire data set, however, sample size is directly affected as a result. Both Figure 9 and Figure 10 demonstrate the effectiveness of hat protection showing a reduction in UV_{ery} facial site exposure to forehead and cheek sites. The figures further demonstrate however, that the protective effectiveness of the hat worn by the students in this research is less clearly defined at the lower facial sites of the nose, side and chin.

For comparison, facial ERs are plotted against the different sports in Figure 11. These ERs were averaged over the entire data set. The side ER for protected soccer players was not

measured, therefore comparison between the protected side exposure for basketball and soccer players has been omitted from the figure. It can be observed however, that there is a general reduction in exposure (observed along the x-axis) for both protected and unprotected students with facial sites showing a reduction in exposure from dosimeters placed at the forehead to dosimeters placed at chin sites. If the trial 8 ER of 54% to the chin is omitted, a clear reduction in ER is shown for students using hat protection compared to those students not using hat protection. The figure also indicates a noticeable reduction in ER to the nose for students playing soccer compared to basketball for the unprotected case and a reduction to nose and chin sites for protected students.

Broad-brim hat Protection Factors

It is clearly evident from Table 2 that the broad-brimmed style of hat implemented in this study made a significant contribution to the reduction in UV_{ery} exposure relative to the ambient horizontal plane exposure. Averaging between both soccer and basketball manikin ERs, the broad-brimmed hats provided greatest protection to the forehead, cheek, nose, side, and chin respectively with respective ultraviolet protection factors (UPFs) of 5.4 ($1\sigma \pm 2.1$), 4.3 ($1\sigma \pm 0.6$), 3.5 ($1\sigma \pm 1.5$), 2.2 ($1\sigma \pm 1.0$), and 1.0 ($1\sigma \pm 0.2$). Here, UPF is calculated as the ratio of the mean unprotected site UV_{ery} exposure to mean protected site UV_{ery} exposure. Again due to the forehead and cheek sites being closer to the shade offered by the broad-brimmed hat, better protection is provided compared to the nose, side and chin sites. The order of increasing UV_{ery} exposure to specific facial sites are in agreement with broad-brimmed UPFs measured with manikin headforms by other researchers (30-32) with the exception of

cheek exposure for which the dosimeters vary in position relative to those used in this study. Significantly, ultraviolet protection factors measured using manikin headforms were greater than those measured using student UV_{ery} exposures for all sites except the chin. Calculation of UPFs to student facial sites were dependent on the availability of data representing protected and unprotected exposures to facial sites specific to each trial and calculated as the ratio of mean student unprotected exposure to mean student protected exposure. The UPFs calculated specifically to each facial site and further averaged across all trials listed in Table 1 provided UPFs of 1.6 ($1\sigma \pm 0.5$) to the cheek, 1.5 ($1\sigma \pm 0.8$) to the chin, 1.3 ($1\sigma \pm 0.2$) to the forehead, 1.2 ($1\sigma \pm 0.0$) to side facial sites and 1.0 ($1\sigma \pm 0.1$) to nose sites. The greatest UPF calculated from student data over the study was measured at the cheek with UPF 2.4 (trial 1).

Variation in student UV_{ery} exposure with SZA

Table 3 lists the unprotected and protected student facial UV_{ery} exposure with changing SZA, cloud cover and sport for the 2006-2007 study period. For Hervey Bay, the SZA ranges from between 3^o and 46^o over the summer months and between 67^o and 34^o over the winter months between the hours of 9:00 am and 3:00 pm (42). No measurements were taken over the study period for SZA ranges greater than 55^o or less than 9^o. For this research the SZA ranges listed in Table 3 were chosen as $0\text{-}30^o$ and $30\text{-}55^o$. The limiting division of 30^o was chosen as it isolates the winter SZA range. Furthermore, low solar elevation angles limited to a maximum SZA of 30^o make up the predominate maximum range that students need to be exposed to over the entire year provided outdoor activities are scheduled in either the first or last hour of the school day. Figure 12 shows the complete SZA range at Hervey Bay's latitude experienced

from 9:00 am to 3:00 pm and the SZA range experienced during the first and last hour of the 9:00 am to 3:00 pm range (42). Provided outdoor activities are scheduled to minimise exposure to low SZA (SZA 0^o-30^o), this research shows a potential reduction in the average received facial exposure with the unprotected mean falling from 1.6 to 1.3 SED and the protected mean falling from 1.1 to 1.0 SED (Table 3). Kimlin et al. (43) determined manikin facial exposures would shift from horizontally inclined facial regions to vertical regions from summer to winter, attributing this to increased diffuse UV at high SZA. Previous work using the same manikin headforms employed by Kimlin et al. (43) has indicated similar variation in facial ER with SZA (44-45). The mean human UV_{ery} facial exposure measured here is consistent with these findings, indicating a reduction in UV_{ery} facial exposure and corresponding increase in facial ER with increasing SZA (Fig. 13). Based on these results, it can reasonably be concluded that hat protection is particularly important at low (summer) SZA as increased ambient UV exposure can be more effectively reduced by the hat brim than at high (winter) SZA.

Variation in student UV_{ery} exposure with cloud cover

Variation in facial ER with changing cloud cover was determined for low, middle and high cloud cover cases. This division was based on ground observation of the total cloud cover estimated during each student trial and is divided to include the cases of low cloud (0-2 okta), middle cloud cover (2-6 okta) and high cloud cover (6-8 okta). To minimise the influence of SZA on the data, ERs are presented in Figure 14 rather than variation in SED. Figure ERs are presented as one of three levels 0-25%, 25-50% and 50-75%. In the figure, protected low and

middle cloud cover forehead and middle side sites have been omitted due to there being no data at these points. Unprotected low cloud cover nose and middle cloud cover side sites in the figure are also omitted due to no data being collected for these cases over the study period. ER to the middle cloud cover protected and unprotected cheek sites are based on trial 9 measurements (lowest variation in SED) and are therefore subject to greatest uncertainty. With the exception of the cheek site, it was generally noted however that increasing cloud cover increased student facial exposure ratio while reducing the total received UV_{ery} facial exposure. Using a manikin headform at a sub tropical site in south-east Queensland, Kimlin et al. (43) noted a similar increase in facial ER and a reduction in the total facial erythemal exposure correlated with an increase in cloud cover. For the results presented here in Table 3, mean unprotected facial exposure (not including the vertex site) for respective low, middle and high cloud cases varied from 1.8 SED, 1.2 SED and 1.2 SED while the mean protected facial exposure for the respective low middle and high cloud cases varied from 1.1 SED, 0.9 SED and 1.0 SED. A likely explanation for middle protected facial exposure not exceeding high cloud cover facial exposure is due to the middle cloud cover case being derived as the arithmetic average of three facial data points (Table 3), limiting the range of exposure likely to be measured with a larger data sample. Based on these results however, the use of hat protection under cloudy conditions does reduce variation in facial exposure with changing cloud conditions.

DISCUSSION

This research has provided quantitative data on facial UV_{ery} exposures to Queensland school children during their normal outdoor activities. The majority of previous research has employed manikin studies. The research presented in this paper has employed measurements on human subjects. Exposures to over 100 human facial and vertex sites have been measured to within a level of uncertainty of $\pm 24\%$. In addition, comparisons between student and manikin facial exposure have also been made. The results clearly indicate that the use of broad-brimmed hats can reduce cumulative facial exposure to UV_{ery}. However, variation in human exposure, most likely to be attributed to variation in head movement while playing sport, variation in cloud cover, and SZA indicate that the measured facial sites are not consistently protected, and hats should be used in conjunction with other forms of protection including sunscreens, provision of shade and appropriate outdoor activity time scheduling.

When broad brimmed hat protection was used, manikin headform exposures over estimated UPF to the forehead, cheek, nose and side facial sites. Ultraviolet protection factors (UPF) measured with manikin headforms indicate significantly better protection provided by the hats used in this study compared to UPF measured with the same hats on student subjects, with the respective facial mean UPF varying from 3.3 ± 1.1 (1σ) to 1.3 ± 0.3 (1σ) indicating that manikin measurements may not always be taken as suitable representations of human exposure, but rather a first order approximation that can be refined with further human measurements. Tilting headforms such that more of the face is exposed to direct UV, limiting the shade provided by the hat brim may better represent protected facial exposures received by human subjects. In another comparative study using humans and manikin headforms, Airey et al. (46) determined that headform tilt angles relative to the surrounding environment could be

used effectively to predict human postures of standing, sitting, bending and kneeling. This approach would seem plausible as human subjects do not remain in a position that keeps hat brims parallel to the ground as is the case for the manikin headforms operated in the manner used here. The measured protective effectiveness of the hats to specific manikin facial sites varied from UPFs of 5.4 to 1.0, with greatest respective protection being provided to the forehead, cheek, nose, side and chin, while human facial site UPFs varied from 1.6 to 1.0, with the greatest protection being provided to the respective cheek, chin, forehead, side and nose sites. These results indicate a less apparent site order in the protection provided by the hat when compared to manikin UPFs that clearly show greatest protection to sites located nearer the hat brim. It is possible however, that a greater student sample may be required to show a more consistent trend in UPF relative to the broad brimmed hat used as student UPFs were calculated from only 11 student samples. Furthermore it should be noted that variation in comparisons made between manikin and human facial site exposures were recorded within the specified $\pm 24\%$ level of dosimeter uncertainty and may therefore be considered as a reasonable approximation of human UV_{ery} exposure. However, variation in the facial exposures recorded by human subjects measured here indicate that hats which provide the greatest protection to the greatest area of the face should be used by students involved in outdoor sporting activities. While one style of hat may prove to be effective at protecting facial regions at most risk on a manikin, that same hat may not be as effective when used by a human subject. As a generalisation, the results presented here show that exposures to lower protected facial regions can be higher than upper regions, meaning that hats which offer best protection to the lower face should similarly provide better total protection. Although only one type of hat was tested here, better protection could be provided by larger hat sizes with wider brims.

Student UV_{ery} exposures as high as 9.0 SED to the vertex were measured over a 1 hour period with the highest received facial exposure recorded over the 2006-2007 study being 4.8 SED measured at the forehead. The study average, not including vertex sites is estimated at 1.4 SED, $1\sigma \pm 0.8$ SED for unprotected facial sites and 1.0 SED, $1\sigma \pm 0.3$ SED for protected facial sites. Both of these facial exposure averages exceed the daily Australian occupational safe limit of 0.3 SED specified by the National Health and Medical Research Council (47). Provided students were expected to play outdoor sport for 60 minutes per school day, the resulting unprotected yearly accumulated facial exposure has the potential to reach 29 kJm^{-2}, $1\sigma \pm 16$ kJm^{-2}. The use of broad-brimmed hats similar to those employed for this research indicates that the yearly accumulated exposure could be reduced to 21 kJm^{-2}, $1\sigma \pm 6$ kJm^{-2} although other sun safe strategies would need to be implemented to reduce the figure to an acceptable occupational annual exposure limit of 6 kJm^{-2}. For this research, it has been determined that the unprotected facial regions at maximum risk are the forehead, nose, and cheek sites. However, forehead, cheek and chin sites were found to receive the greatest protection from the broad-brimmed hat used in this study, though this was not directly correlated to manikin protected exposures, manikin exposure to the forehead and cheek sites were also significantly reduced when hat protection was used. Based on these results, the active use of broad-brimmed hats in schools could significantly reduce exposure to facial sites most at risk.

The variation in the received facial UV_{ery} exposure to students measured between both basketball and soccer players was determined to be the result of variation in head position,

atmospheric conditions and SZA. The significant variation in facial exposure of both the protected and unprotected basketball and soccer players was not influenced by small variations in surface albedo. Differences in exposure between protected and unprotected soccer and basketball players were found to be greatest at the nose, cheek and chin sites. The application of other forms of sun protection, including the application of sunscreens during sport is required in order to reduce the greater exposure level received by these sites. Application of sunscreen to the nose, cheek and chin site in addition to hat protection would significantly benefit basketball players. Though not directly measured in this study, head tilt is likely to be a significant contributor to measured increases in facial exposure received by basketball players as could be expected with players spending more time looking in an upward direction than soccer players more likely to be following the ball along the ground surface.

Increasing cloud cover and SZA resulted in an increase in facial ER at this location in sub-tropical Queensland with a corresponding decrease in the mean facial exposure. Increased scattering of the diffuse UV_{ery} with increasing levels of cloud cover and lower solar elevations was indicated by the redistribution of UV_{ery} to lower proximities of the face. Hat designs that provide greatest protection to lower facial proximities are likely to be the most effective with seasonal solar variation and changes in cloud cover. Based on the calculated daily variation in SZA over a full year, is was found that outdoor activities run during the first and last hour of the school day could result in a maximum SZA limit of 30^o for most of the year at 25.3^o S with the limit increasing for schools located further south and decreasing for more northerly latitudes. From the results detailed here, this has the potential to reduce the average unprotected student facial UV_{ery} exposure from a low SZA range of 0^o-30^o to a higher SZA

range of 30^{o}-55^{o} reducing the mean hourly unprotected facial UV_{ery} exposure from 1.6 SED, $1\sigma \pm 0.5$ SED to 1.3 SED, $1\sigma \pm 0.2$ SED, resulting in a reduction in the yearly accumulated exposure of 33 ± 10 kJm^{-2} to 27 ± 4 kJm^{-2} taken over a 205 day school year and assuming an exposure interval of at least 1 hour per day. Again this outcome clearly illustrates that although hat protection does reduce facial exposure to students, it cannot be considered as the sole or primary measure aimed at reducing sun exposure risk and should not therefore be relied upon as the only basis for school sun safe policy.

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FIGURE LEGENDS

Figure 1. Calibration curve of PS film badges expressed in SED (100 Jm^{-2}).

Figure 2. UV_{ery} uncertainty in spectroradiometer measurement determined as variation from the mean irradiance (error bars show the full range of cumulative measurements recorded over a 100 minute test interval and include spectroradiometer uncertainty of 6.3%).

Figure 3. UV_{ery} uncertainty due to variation in PS badge ΔA_{330} measurement (variance $\pm$ 1σ).

Figure 4. Total estimated uncertainty expressed as a percentage of the measured UV_{ery}, including variation due to atmospheric conditions and spectroradiometer uncertainty (Fig. 2) and variation in PS badge ΔA_{330} (Fig. 3).

Figure 5. Dosimeter facial site locations for the protected and unprotected manikin headforms.

Figure 6. Student volunteers playing basketball (trial 3). Vertex dosimeters were placed on top of hats.

Figure 7. Basketball trial location. (Top left clockwise: Facing North, East, South, West).

Figure 8. Soccer trial location. (Top left clockwise: Facing North, East, South, West).

Figure 9. Facial site exposure median (vertical line), box (interquartile range) and whisker (whole range) representation of variation in unprotected and protected UV_{ery} exposure (SED) determined as the arithmetic mean of site measurements from every trial (Table 1).

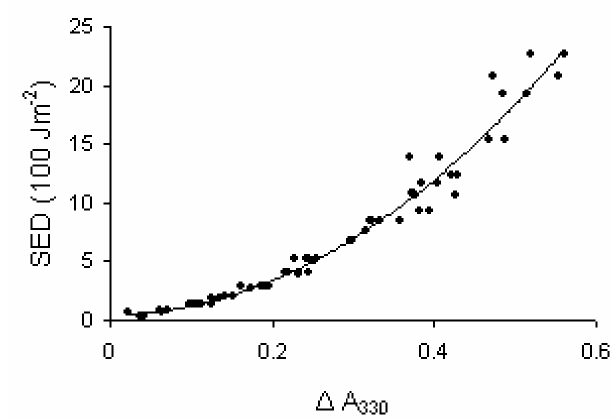
Figure 10. Facial site exposure median (vertical line), box (interquartile range) and whisker (whole range) representation of variation in unprotected and protected UV_{ery} exposure (SED) for trial 8 (forehead), trials1,4,6,7,9 (cheek), trials 5,8 (nose), trials 1,3 (side) and trials 5,8 (chin).

Figure 11. Contour plot of variation in facial ER (%) with sport. a) Unprotected. b) Protected.

Figure 12. Daily variation in SZA plotted between 9:00 am and 3:00 pm (light curve) and between 9:00 am to 10:00 am and 2:00 pm to 3:00 pm (dark curve) at latitude 25.3^{o} S.

Figure 13. Contour plot of variation in facial ER (%) with SZA. a) Unprotected. b) Protected (Protected cheek and forehead site data was not available in the 0^{o}-30^{o} range).

Figure 14. Contour plot of variation in facial ER (%) with cloud cover. a) Unprotected. b) Protected.



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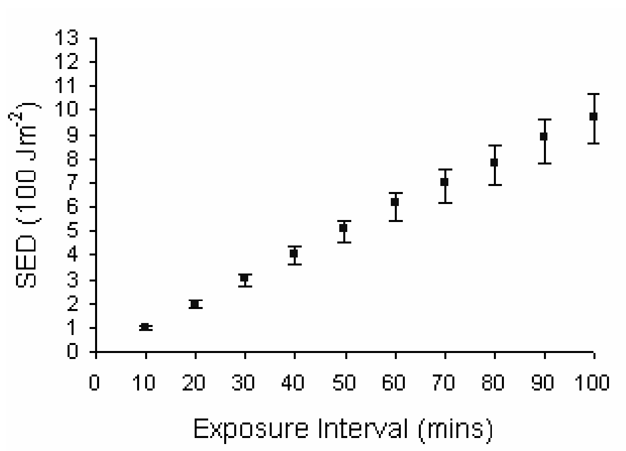

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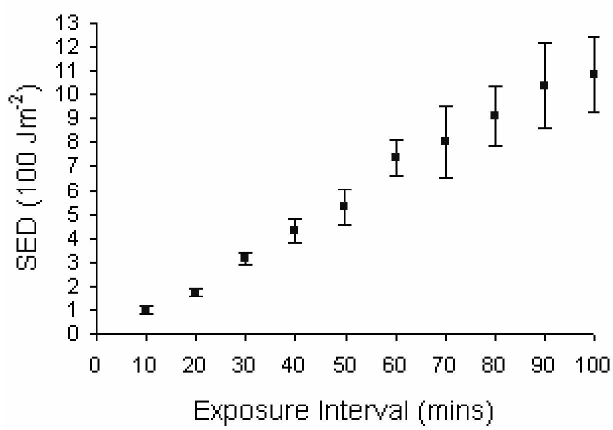

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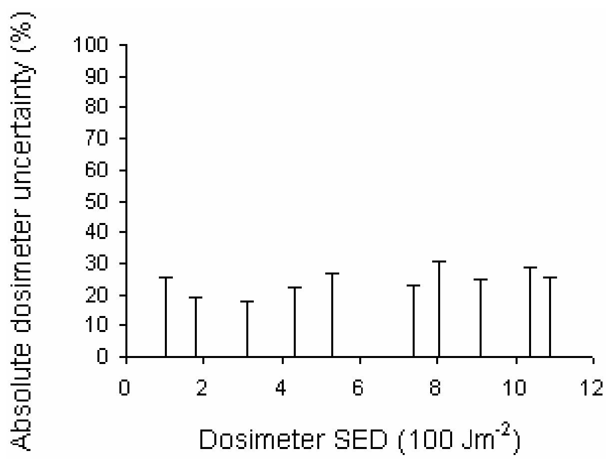
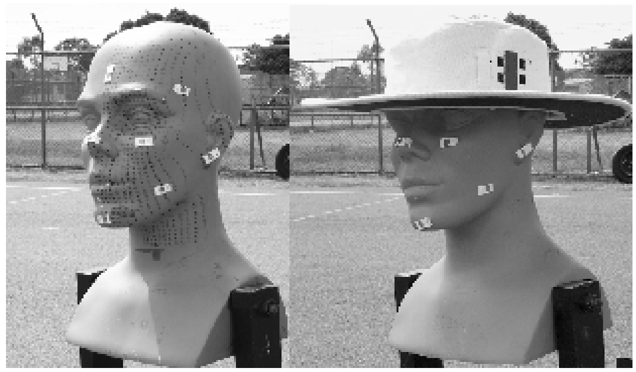


Figure 4. Total estimated uncertainty expressed as a percentage of the measured UV_{ery}, including variation due to atmospheric conditions and spectroradiometer uncertainty (Fig. 2) and variation in PS badge ΔA_{330} (Fig. 3).



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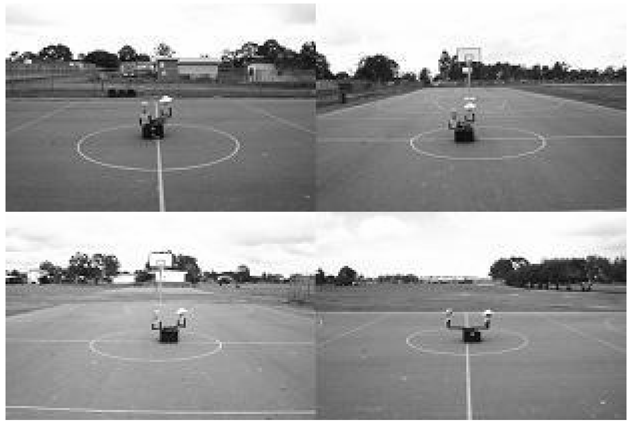

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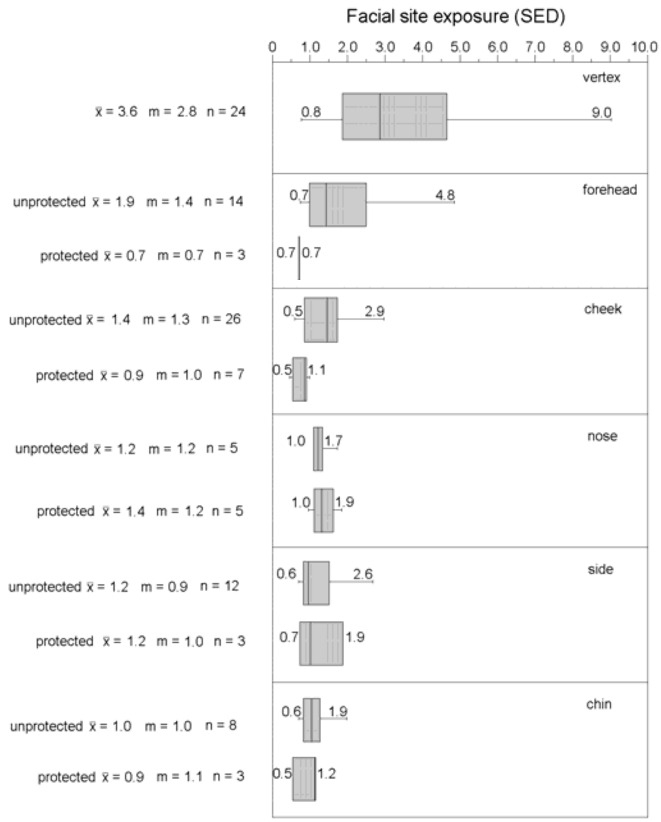

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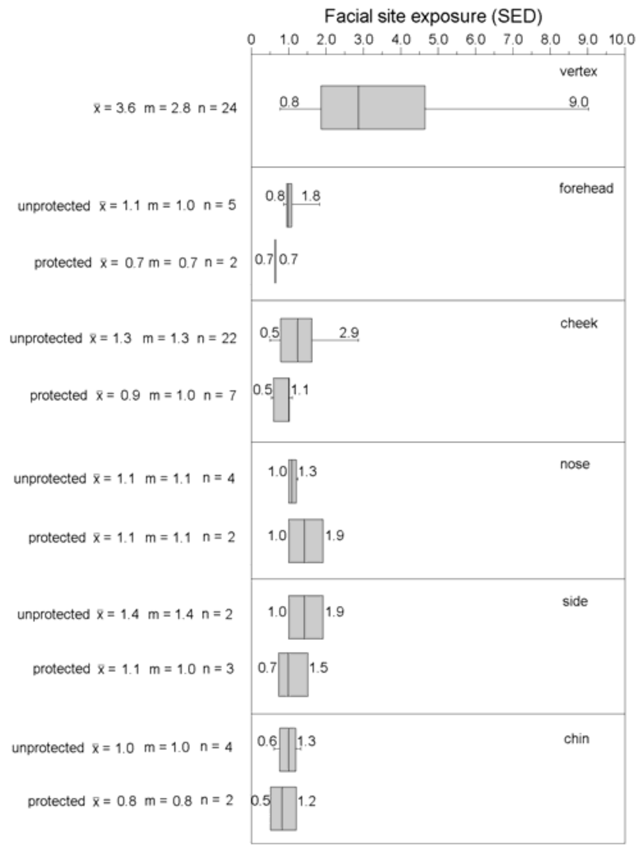

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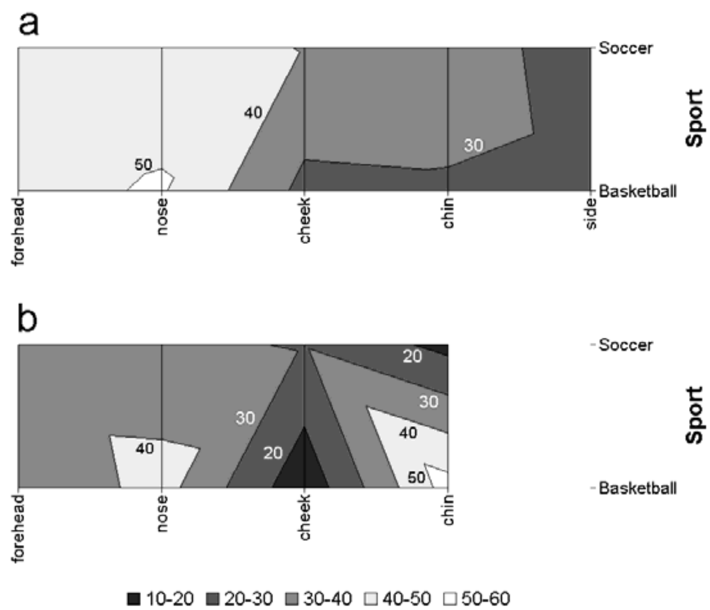

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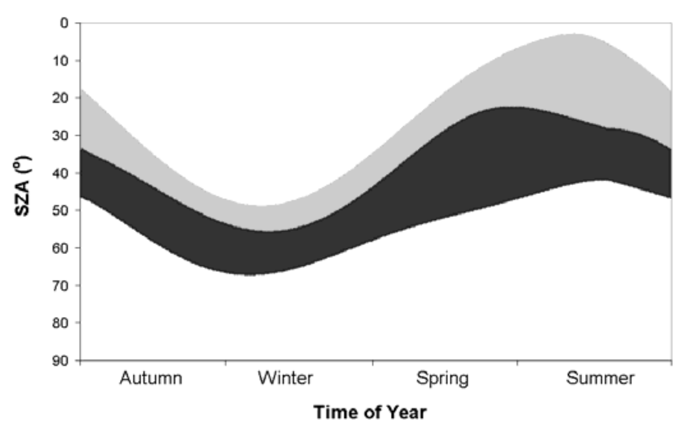

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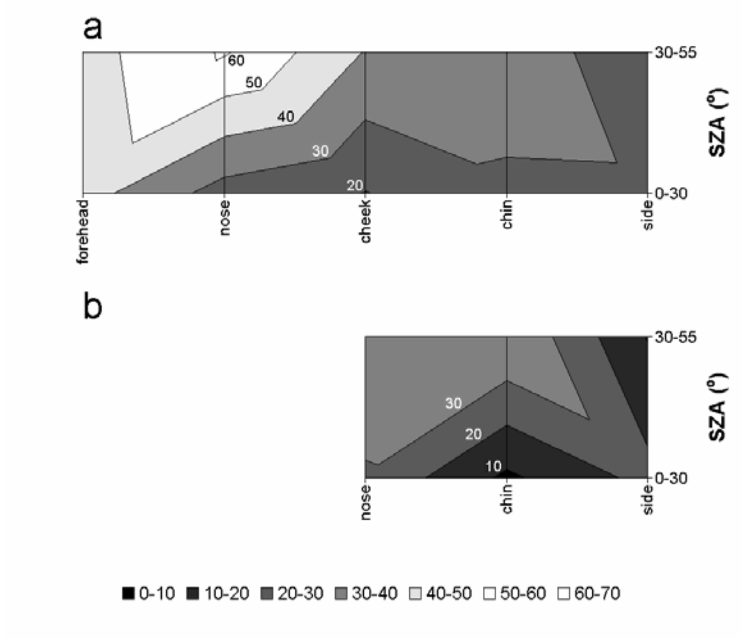

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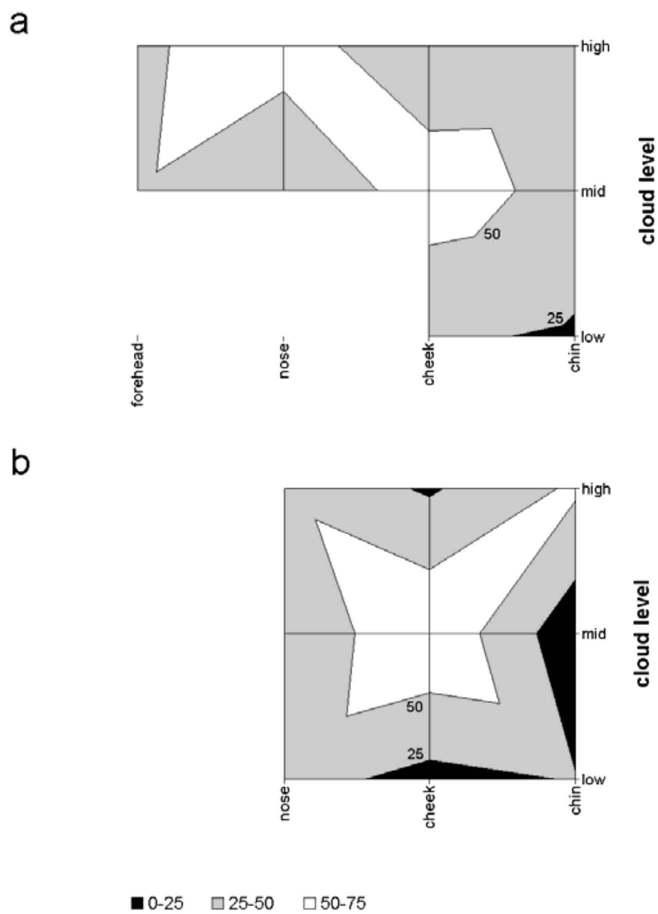

Figure 14. Contour plot of variation in facial ER (%) with cloud cover. a) Unprotected. b) Protected.

Table1. Facial UV_{ery} (SED) and ER (%) recorded over the study period 2006-2007.

Trial 1 - 29.03.2007, SZA 29-35º, 253 DU, Clear, Basketball

	Protected		$\bar{x}$	± t	ER	Unprotected								$\bar{x}$	± t	ER
Vertex						9.0	6.5							**7.8**	**11.2**	**85**
Forehead						4.4								**4.4**		**47**
Cheek	1.1		**1.1**		**13**	2.4	2.9							**2.7**	**2.2**	**30**
Chin						1.9								**1.9**		**22**
Side	1.0	0.7	**0.9**	**1.3**	**10**	1.0								**1.0**		**11**

Trial 2 - 30.03.2007, SZA 30-36º, 257 DU, Clear, Basketball

	Protected		$\bar{x}$	± t	ER	Unprotected								$\bar{x}$	± t	ER
Vertex						7.8								**7.8**		**100**
Cheek						2.4								**2.4**		**31**
Side						2.6								**2.6**		**34**

Trial 3 - 10.11.2006, SZA 9-17º, 300 DU, 6-7/8 Cumulonimbus, Basketball

	Protected		$\bar{x}$	± t	ER	Unprotected								$\bar{x}$	± t	ER
Vertex						7.1								**7.1**		**100**
Forehead						1.5	4.8	1.9						**2.7**	**3.7**	**40**
Cheek						1.5	1.6							**1.6**	**0.4**	**24**
Side	1.5		**1.5**		**23**	1.9								**1.9**		**28**

Trail 4 - 15.08.2006, SZA 40-45º, 269 DU, Clear, Soccer

	Protected		$\bar{x}$	± t	ER	Unprotected								$\bar{x}$	± t	ER
Vertex						5.6	4.3							**5.0**	**5.8**	**89**
Forehead						2.4	1.2							**1.8**	**5.4**	**34**
Nose	1.9		**1.9**		**35**											
Cheek	1.0	0.9	**1.0**	**0.4**	**19**	2.2	0.7	0.5	1.4	1.3	1.7	1.0	1.2	**1.2**	**0.4**	**23**
Side						1.3	1.3	0.7	0.7	0.7				**0.8**	**0.3**	**17**

Trail 5 - 23.02.2007, SZA 17-27º, 255 DU, 5-7/8 Cumulus, Soccer

	Protected		$\bar{x}$	± t	ER	Unprotected								$\bar{x}$	± t	ER
Vertex						3.1	4.3	4.6						**4.0**	**1.6**	**87**
Forehead						3.2	1.3							**2.3**	**8.5**	**51**
Nose	1.3		**1.3**		**29**	1.0	1.3							**1.1**	**1.3**	**26**
Cheek						0.6								**0.6**		**12**
Chin	0.5		**0.5**		**8**	1.1	1.3							**1.2**	**0.9**	**28**

Trial 6 - 29.03.2007, SZA 43-55º, 253 DU, Clear, Soccer

	Protected		$\bar{x}$	± t	ER	Unprotected								$\bar{x}$	± t	ER
Vertex						4.6	4.3	4.6						**4.5**	**0.4**	**98**
Nose	1.4		**1.4**		**32**											
Cheek	1.0		**1.0**		**22**	1.4	1.9	1.7	1.8					**1.7**	**0.4**	**39**
Chin	1.1		**1.1**		**26**											
Side						1.6	0.8							**1.2**	**3.6**	**28**

Trial 7 - 22.06.2006, SZA 50-53º, 264 DU, 7-8/8 Cumulonimbus, Soccer

	Protected		$\bar{x}$	± t	ER	Unprotected								$\bar{x}$	± t	ER
Vertex						1.9	2.1	1.4	2.1	2.5				**2.0**	**0.4**	**92**
Forehead	0.7		**0.7**		**33**											
Nose						1.7								**1.7**		**81**
Cheek	0.5	0.6	**0.6**	**0.4**	**22**	0.7	1.0	0.7						**0.8**	**0.4**	**37**
Chin						0.6	0.9							**0.8**	**1.3**	**35**
Side						0.6	0.7							**0.7**	**0.4**	**30**

Trial 8 - 19.06.2006, SZA 49-52º, 262 DU, 6-8/8 Cumulonimbus, Basketball

	Protected		$\bar{x}$	± t	ER	Unprotected								$\bar{x}$	± t	ER
Vertex						1.8	1.8	1.6	2.0	2.2				**1.9**	**0.2**	**85**
Forehead	0.7	0.7	**0.7**	**0**	**30**	1.0	1.8	0.8	1.1	0.9				**1.1**	**0.4**	**51**
Nose	1.0		**1.0**		**44**	1.2	1.0							**1.1**	**0.9**	**51**
Chin	1.2		**1.2**		**54**	0.9	0.6							**0.8**	**1.3**	**32**

Trial 9 - 10.11.2006, SZA 35-49º, 300 DU, 2-3/8 Cumulonimbus, Soccer

	Protected		$\bar{x}$	± t	ER	Unprotected								$\bar{x}$	± t	ER

Vertex				0.8	1.1				**0.9**	**1.3**	**65**
Forehead				0.7					**0.7**		**44**
Cheek	1.0	**1.0**	**72**	1.0	1.2	0.7	1.4	0.8	**1.0**	**0.3**	**73**
Chin				1.0					**1.0**		**69**

Table 2. Manikin ER (%) averaged over the study period 2006-2007. ERs are given relative to ambient UV_{ery} horizontal plane exposure.

	Basketball		Soccer	
	Protected	Unprotected	Protected	Unprotected
Vertex		88		86
Forehead	2	42	24	56
Nose	22	61	17	61
Cheek	10	56	14	46
Chin	23	33	24	35
Side	13	26	14	28

Table 3. Protected and unprotected student UV_{ery} exposure (SED ± t) shown for the t distribution 90% confidence interval measured at each facial site for variation in SZA, cloud cover and sport type.

	Unprotected						
	SZA		Cloud cover			Sport	
	0-30°	30-55°	low	mid	high	Basketball	Soccer
Forehead	2.5 ± 1.6	1.6 ± 0.8	2.7 ± 3.3	1.7 ± 2.7	1.7 ± 0.9	2.0 ± 1.0	1.8 ± 1.1
Nose	1.1 ± 1.1	1.3 ± 0.7		1.1 ± 1.1	1.3 ± 0.7	1.1 ± 0.5	1.3 ± 0.7
Cheek	1.3 ± 1.1	1.4 ± 0.2	1.6 ± 0.3	1.0 ± 0.3	1.1 ± 0.5	2.2 ± 0.6	1.2 ± 0.2
Chin	1.2 ± 1.0	1.0 ± 0.4	1.9	1.1 ± 0.4	0.8 ± 0.5	1.1 ± 1.4	1.0 ± 0.3
Side	1.9	1.1 ± 0.3	1.2 ± 0.4		1.1 ± 1.4	1.8 ± 1.7	0.9 ± 0.3
	Protected						
	SZA		Cloud cover			Sport	
	0-30°	30-55°	low	mid	high	Basketball	Soccer
Forehead		0.7 ± 0.0			0.7 ± 0.0	0.7 ± 0.1	0.7
Nose	1.3	1.4 ± 0.9	1.6 ± 2.2	1.3	1.0	1.0	1.5 ± 0.7
Cheek		0.9 ± 0.2	1.0 ± 0.1	1.0	0.6 ± 0.3	1.1	0.9 ± 0.2
Chin	0.5	1.4 ± 0.1	1.1	0.5	1.2	1.2	0.8 ± 2.7
Side	1.5	0.9 ± 1.1	0.9 ± 1.1		1.5	1.2 ± 1.2	