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Assessment of Biologically Effective Solar Ultraviolet Exposures for Court Staff and Competitors During a Major Australian Tennis Tournament

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Abstract

Sport is an integral and enduring part of many societies, such as Australia. Participation in outdoor sports, such as tennis, comes with a very real risk of dangerous solar ultraviolet exposure which can result in erythema (sunburn), serious conditions such as skin cancer, including melanoma, and eye conditions such as cataracts and pterygium. This study remotely assesses the effective ultraviolet exposures in response to the increased sun safety awareness at a major summertime tennis tournament in Australia. The assessment only uses

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publicly accessible data and information. It was found that tournament organisers have effectively adopted sun safe protocols into the uniform policy that the court officials (judges and ball kids) are mandated to follow. The combination of sun-participant geometry and the photoprotection provided by uniforms significantly reduced the ambient ultraviolet exposure, which was recorded to be as high as 9.9 SED/hr, to just 1.0 SED/hr and 0.5 SED/hr for ball kids and judges respectively, compared to up to 2.0 SED/hr for players. Even though caution is needed against complacency with sun safety, with the need for the court officials and the players to still apply sunscreen, the court officials provided persistent visual role modelling of sun safe behaviours.

INTRODUCTION

Australians have always had a long tradition with participation in sport. Sportspeople are frequently viewed as role models, particularly to younger members of the community (1). There are many drawcard sporting events throughout the calendar, one such event is the Australian Open Grand Slam tennis tournament held in Melbourne during the height of the Southern Hemisphere summer. As such, attendance at the tournament renders the officials, competitors and spectators prone to high temperature conditions coupled with the potential for overexposure to solar ultraviolet radiation (UVR) due to the often very high to extreme ultraviolet index (UVI) recorded during competition times (1-6). There is an opportunity for these kinds of events to highlight and role-model sun safety messages via the activities of all participants, an aspect that has been explored by several authors (1, 4, 7-9).

Proactive sun safety messages are necessary and critical as Australia has one of the highest rates of skin cancer prevalence in the world (3,4,6,10-13). Approximately two in every three Australians will be diagnosed with skin cancer before the age of 70 (4,14). Both long-term chronic and short-term and intermittent intensive exposure to UVR are primarily responsible for the development of non-melanoma skin cancers (NMSC) and melanoma in the Australian population (2,3,8,9,13-16). Additionally, repeated sub-erythematous UVR doses can cause cumulative mutational damage (6,17-19). UVR overexposure can also lead to eye conditions, such as cataracts and pterygium (9,19). Research also suggests that significant UVR exposure occurs in a person's younger years, before adulthood, which often leads to long term negative health effects (1-3,8,20,21). Despite the exceedingly high prevalence of Australians living with a type of skin cancer, the mortality rate after a positive diagnosis remains relatively low (11). In Australia the number of skin cancers treated yearly is greater than the combined total of all other cancer types (3,6,22). However, a grim reality is that skin cancer is a very common cancer endured by those in the ages of 15 to 39 in Australia (3) and is a major cause of mortality in the world (20).

Professional and amateur athletes competing in outdoor sports receive a substantial amount of solar UVR exposure due to their training and competition schedules generally taking place during periods of peak solar output (8). Sweating from physical exertion can also cause a greater risk of sunburn and skin damage as sweat increases the photosensitivity of the skin (23). Popular outdoor sports with extended play intervals such as tennis present a highly significant sun damage and future skin cancer diagnosis risk to players (24). Research by Jinna and Adams (8) identified that most tennis players reported experiencing at least sunburn, which is not unexpected as tennis is often played out in the open (7,25).

There is very little information available on skin cancer diagnosis rates amongst professional and amateur sportspeople both internationally and in Australia. European studies, such as those compiled by Serrano et al (26) and Serrano et al (27) have shown that median daily UVR exposure of tennis players can quickly exceed the levels that lead to extreme sunburn and sun damage. Most recently, Downs et al (28) has detailed how Olympic athletes participating in daytime sports events such as tennis are highly susceptible to damaging levels of solar UVR exposure. This study also found that the risk of long-term sun damage to these competitors is compounded due to very few of them choosing to use consistent and appropriate UVR protection strategies. In general, sun-protective behaviours utilised by people of all ages, particularly those participating in sporting events, are not always consistent with official sun protection recommendations (3,29).

As a result of the nature of outdoor recreational and competitive sporting activities, there is the potential for exposures that increase the risk of skin cancers and sun related eye diseases (9). This includes the risk to officials during competitive sporting activities. The requirement for the increase of UVR exposure reduction behaviours in adolescent and young adult sports competitors have been reported (7). For the tennis enthusiast, UVR exposure minimisation strategies such as wearing a hat, and clothing covering as much of the body as conditions permit alongside important UVR protection, such as applying sunscreen (21), and playing during times of lower UVR intensities before 10 am and after 4 pm have been recommended (30), though other logistical constraints can render the latter as being an impossibility.

Alongside being a major risk factor for skin cancer, solar UVR exposure, particularly in the UVB (280-320 nm), is essential for Vitamin D photosynthesis in the skin (19,31-33). Variations of vitamin D levels in humans are predominantly correlated to the amount of skin exposed, location (latitude) and season (33). Holick (34) concluded that exposing $\frac{1}{4}$ of the body (face, hands and arms) to $\frac{1}{4}$ minimal erythemal (sunburn) dose (MED) of solar radiation

satisfies the daily vitamin D requirement. The minimal erythemal dose is based on the minimal UVR exposure to produce a faint, but noticeable reddening of the skin (35-37).

In the Australian summer, when the UVI is usually higher than 3, the ¼ MED dose can be achieved after a few minutes of sun exposure (2,19,38). In general, MED and safe exposure times vary with age, skin type and global solar radiation, a factor that is a function of latitude, season, time of day and atmospheric conditions (19,31,39,40). It is necessary to optimize exposures to solar UVR to produce enough vitamin D while limiting sun-related damage (32). There is very little evidence that regular application of sunscreen, which is often applied unevenly and inconsistently (5), adversely restricts vitamin D production in the skin (41). Although there have been scarce trials concerning the effects of high sun protection factor sunscreen (41).

Consequently, the MED metric used in many studies is subject to considerable variability through aspects such as individual sensitivity, skin phototype, seasonal variation, anatomic test sites, previous UVR exposure, and is dependent on largely subjective observations (9,36). The geometry of the sun position to the person's position is also a major factor (35,42). Thus, this measure is not considered by many researchers as being suitable as a standard measurement tool (39).

The standard erythemal dose (SED) has subsequently been adopted by many researchers as an additional standard measurement tool, where 1 SED = 100 Jm⁻² erythemally effective radiation (35). The conversion between the commonly reported UVI to hourly erythemal dose (SED/hr) has been described by the ICNIRP (35) and Lucas et al. (19) as being:

$$\text{Hourly erythemal dose (SED/hr)} = 0.9 \times \text{UVI} \quad [1]$$

The ICNIRP standard for the maximum human biologically efficient UVR exposure for an 8-hour period is 30 Jm^{-2} , which is roughly equivalent to 1.0-1.3 SED, or roughly 0.5 MED for the fair skin phototype (35).

There has been a lack of UVR exposure measurements of tennis players and particularly, officials during either recreational or competitive tennis. UVR exposures are reported for different timeframes in previous research, mostly measured as SED/day – referring to a specific timeframe e.g. match duration, and SED/hr. For ease of calculations, UVR exposures for this research are presented in SED/hr.

One study has employed polysulphone dosimeters (43) attached to the anatomical sites of the cheek, hand, shoulder, back, chest, thigh and calf of recreational tennis players to establish the UVR exposures during a tennis match in summer in Hobart, the capital of the southern Australian state of Tasmania (42.8°S) (25). The average of the exposures to the anatomical sites during a match was over 8.7 SED for durations of up to approximately 2.6 hours. Similarly, dosimeters were used to determine median daily exposures of 7.5 SED reported for tennis players playing between 10:00 am and 2:00 pm during summer in Valencia, Spain (27). Further studies performed by Moehrle (23) have observed that tennis players can be exposed to up to 5.4 SED/hour. Some of the anatomical sites used for the locations of dosimeters in these previous studies were covered by clothing. Further research is required to consider the full protection provided by the garments worn by players and officials during a tennis match to provide a measure of the UVR exposures to the unprotected skin.

Tennis Australia imposes a stringent uniform policy for officials based on a commitment to sun safety (44). In general, the policy mandates that hats or caps, long sleeved uniform tops and full-length pants are to be worn. Additionally, the use of sunscreen, sun glasses and broad brimmed hats are recommended. This recommendation is extended to the players and

spectators, with some positive response in the latter group, with many spectators using personal UVR protection (45).

At this point in time, no investigations that we are aware of have been made detailing the short-term and long-term solar UVR exposure incident on officials at tennis matches. This research models and assesses the erythemally effective solar UVR exposures for court staff (chair and line umpires, and ball kids) compared to tennis players for each hour of the Australian Open Grand Slam as an example of a major summertime tennis tournament. This research employs a unique method of evaluation, quantifying the effective UVR exposure as a function of measured UVR with the clothing and participant-sun geometry.

MATERIALS AND METHODS

Location and times. The Australian Open Grand Slam tennis tournament was held at Melbourne Tennis Park in Melbourne, the capital of the southern Australian state of Victoria (37.82°S 144.97°E). The tournament took place during January 2019, which is at the height of local summer. Qualifying rounds were held from the 8th to 11th, competition starting at 10:00 am local time. The Main Draw was from the 14th to 27th, with competition generally starting at 11:00 am. As local Daylight Savings Time was in effect, all times are 1 hour ahead of the usual standard time for Melbourne, hence are UTC + 11.

Participants. Each match of the tournament had the same group of people present on the court. These people are the basis of the ‘participants’ whose UVR exposure is to be evaluated. There are two groups, ‘court staff’, comprising of chair and line umpires, and net and standing ball kids (sometimes referred to as ball boys and ball girls), and ‘players’

referring to the tennis players themselves, the latter being divided into two categories based on the observations of their sun protection clothing.

Despite the variable duration of matches that typically occur in a tennis tournament, coupled with the different duty times of the court staff, the erythemal UVR exposure is aggregated to each hour of competition. The participants are assumed to be standing upright relative to the horizontal plane for this assessment, except for net ball kids who crouch at either side of the centre net but have their faces in an upright position.

Data collection. Unlike previous studies carried out by Herlily et al. (25), Moehrle, (23) and Serrano et al. (27), it was not practically possible to use UVR dosimeters on tournament court staff and players. As such, for the purposes of this investigation, all data were extracted from official websites, specifically:

- Tournament match times, durations, uniform and sun protection rules were obtained from publicly accessible data and information available on the official Australian Open and Tennis Australia websites (44,46).
- Ambient solar erythemal UVR data for every minute from the start of competition to the late evening (8:00 pm), including both direct and diffuse UVR observations were obtained from the Australian Radiation Protection and Nuclear Science Agency (47).
- Weather condition data were collected from the Australian Bureau of Meteorology (48), using data from the Melbourne Olympic Park observation station.
- SZA for every minute were calculated using the National Oceanic and Atmospheric Administration (NOAA) *SolarCalc* website (49).

Data analysis. The median effective UVR that the court staff and players were exposed to, in SED/hr, for each hour of the tournament was determined using equation 2, adapted from Downs et al. (28):

$$E_{SED/hr} = \sum_{i=60}^i (1 - NCF) \times GCF \times E_{SED/min} \quad [2]$$

Where NCF is the Normalised Clothing Factor, developed by Downs et al. (28). This factor determines a normalised relative proportion of sun protection based on body sites covered by clothing, especially the head and face where the risk of skin cancer is greatest (5,50), and other areas such as the torso, arms and shins (5,28). The standard body sites described by Downs et al. (28) were adopted for this assessment: head/scalp, face, torso, arms and lower legs (shins).

The GCF is the Geometric Conversion Factor, developed by Pope and Godar, (42). Specifically, the GCF is a cylindrical simplification of the human form in various positions, prone to upright relative to the horizontal plane, corresponding to tilt angles between 0° to 90° respectively, the latter tilt being used for this assessment. The GCF is calculated from the SZA relative to the tilt and orientation of the subject.

$E_{SED/min}$ is the ambient erythemal exposure per minute based on the UVI recorded at ARPANSA's observation point in Melbourne within the vicinity of the tournament site. This is multiplied by the NCF and GCF for every minute, the sum for each hour was then taken to calculate the hourly effective erythemal UVR exposure expected for court staff and players.

For the purposes of this assessment, the following assumptions were made:

- The calculations were made for participants orientated with their faces towards the sun.
- The diffuse component of UVR was assumed to include all diffuse sources.
- The albedo of the blue tennis court surfaces used for the tournament (Plexicushion) was assumed to be a negligible contributor to total ambient UVR exposure. This was based on

prior research reported in Turner and Parisi (51) based on research by Blumthaler and Ambach (52) of green tennis courts having a relatively low UV reflectance. A review of the possible material making up the court surface (53) suggests the material may produce only a low UVR albedo (51).

RESULTS AND DISCUSSION

The 866 matches of the Australian Open Grand Slam were played in warm sunny conditions, with mostly clear skies (average = 2 okta) for the duration of the tournament. Most matches were played in bright sunlight with the median duration being 86 minutes.

Ambient UVR Exposure

The ambient erythemal UVR exposure was extremely high on most days of the tournament, corresponding to the elevated UVI typical for a Melbourne summer. The highest values occurred during the typical peak times of the day. The distribution of the median and the ranges of ambient erythemal UVR exposure for each hour between 10.00 am and 7.00 pm are shown in Figure 1. Each of the hourly values are the median of the values starting at that time over the days of the tournament.

Most of the tennis matches were played in the open sun during the times of the day that peak solar UVR exposure is expected and occurred on most days of the tournament. The peak UVI values were typically above 10, reaching the “extreme” category with 11.1, on 13 out of the 18 days, corresponding to ambient UVR exposures of up to 9.9 SED/hr. Despite inclement weather on the remaining 5 days, the peak UVI still reached close to the “very high” category at 7.4; however, the ambient UVR exposure dropped as low as 0.95 SED/hr.

The ambient erythemal UVR exposure for each hour during much of the tournament (Figure 1) far exceeded the ICNIRP occupational exposure limit of the equivalent of 1.0 to 1.3 SED within an 8-hour period (35,54). These exposures share some consistency with observations exceeding 8.7 SED for up to 2.6 hours for tennis players made by Herlily et al. (25) in Tasmania, 7.5 SED between 10:00 am and 2:00 pm recorded on players in summertime tennis matches in Valencia, Spain (27), and the maximum of 5.4 SED/hour observed by Moehrle (23). In addition, the ambient UVR exceeded many outdoor occupational UVR exposures as detailed by Gies and Wright (2).

The elevated ambient UVR exposures, which are typical for the Melbourne summer and between peak UVI times of 10:00 am to 4:00 pm strongly prompts those working or doing any activity outdoors, in any capacity, to use adequate personal protective equipment (35).

The exposure is not just from direct sunlight, but also from diffuse sources (24), such as reflections from air molecules, moisture from humidity and the surrounding structures, which are all assumed to be included in the ambient UVR exposure observations used. Another source of exposure is from UVR enhancement from clouds (9,55), which is relevant as several days during the tournament had at least 2 okta of cloud cover.

The length of time that skin is exposed to ambient UVR is a critical factor, particularly if the exposure is repeated (2,6,35). Days with UVI observations of 3 or less are often not associated with sun protection messages (6,18,19,50), but over an extended period of time, for example an hour of duty or play on the tennis court, a UVI of 3 equates to an ambient UVR exposure of 2.7 SED, approximately double the daily occupational exposure limit, and potentially sufficient to result in visible sunburn (35). The lowest hourly ambient UVR exposure throughout the tournament was 0.95 SED/hour (Figure 1), corresponding to a UVI of approximately 1.1, during a cloudy day, which can still be cumulatively damaging despite

being at a sub-erythral level (6,30). Cooler temperature days sometimes lead people into a 'false sense of security' about UV exposure (5).

Normalised Clothing Factor

The officials at the Australian Open wore event-based specific uniforms (44). The judges wore long-sleeved shirts, full-length trousers and a broad brimmed hat. Additionally, chair judges were often seated in a sheltered position. Ball kids wore shorts, long-sleeved promotional shirts and a legionnaire's hat, which is a cap with fabric protecting the ears and the back of the neck. The 'players with hats' category include only those that wore hats that completely covered the top of their head, hence those wearing 'cap brims' or visors, with the top of their head/scalp exposed, are classified as 'players without hats'. The NCF was divided into 4 categories (Table 1) based on general UVR clothing protection areas (28).

>Table 1<

Court staff are required to abide by a strict sun safe dress code, contributing to the high NCF approximations of 0.6 and 0.8 for ball kids and umpires respectively (Table 1). As all members of the court staff wear hats, as required, they are afforded more protection from direct UVR irradiance to the head, scalp and face during times of extreme ambient UVR exposure; however, they are still exposed to diffuse sources (24), and their faces potentially become exposed to more direct exposure when the sun is lower on the horizon (higher SZA) during the evening. The players do not always have the same sun protection, having NCF ratings of typically 0.2 and 0.4, depending on whether they are wearing a hat (Table 1).

The use of broad brim and legionnaire's hats for court officials is an example of Tennis Australia's positive sun safe commitment and provide an example of organisational responsibility (3). These hats, mandated by the uniform policy (44), provide satisfactory to very good UVR protection, particularly to the head/scalp, ears, neck (21,56), and in the case of broad brim hats, the face (21). The players routinely wore caps, visors or no hat at all, which are considered to provide less UVR protection (3,21). Although human hair can provide some significant UVR protection, the level of protection is highly dependent upon the hair type, style, thickness and the SZA (57,58).

The clothing worn by the court officials were also, in a large part, sun-safe, with both the judges and ball kids having their torso and arms covered, and the judges have their shins protected. The necessity for the ball kids to be running and retrieving balls require them to wear non-restrictive leg wear (e.g. shorts). Players always have their arms and legs exposed to UVR. The recommendation from the Tennis Australia uniform policy (44) to use sunscreen fulfils the necessity of a broad range of photoprotective measures (3,21,32,56,59), with sunscreen needing to be employed by the players.

Geometric Conversion Factor

The SZA range, a necessary component for the calculation of the GCF, during the competition was between 15° and 85° . This range corresponds to GCF values from approximately 0.25 in the morning tournament hours to a maximum of 0.63, or 25% and 63% of the horizontal plane UVR dose (42). The highest GCF occurred late in the afternoon, corresponding to higher SZA values, the maximum occurring at a SZA of 75° according to the cylinder model developed by Pope and Godar (42). This occurs when the sun is lower on the horizon and closer to being in a direct 'line of sight' with exposed photosensitive areas

(e.g. the face and eyes). The GCF with respect to the SZA range in this study is shown in Figure 2.

The geometry of UVR exposure is deemed to be an important factor in determining the effective exposure on photosensitive areas of the human body (35,42). The GCF varied with SZA during the day (Figure 2), from a minimum of 0.25 at the starting hour of tournament play, reaching 0.5 at SZA values corresponding to the late afternoon and the maximum of 0.63 later in the evening. With daylight savings in effect, this maximum occurred later than usual when the ambient UVR was already lower.

Calculated Solar Ultraviolet Exposure

The erythemal UVR exposures of each category in Table 1 effectively becomes a multiple of each other using equation 2 as the GCF and minute-based UVR data remain the same for all 4 categories, with only the NCF changing due to the sun protective clothing worn. Figure 3 displays the calculated median and range of effective UVR exposure, measured in SED/hour for each hour of the competition.

The inverse relationship between the GCF and UVR exposure coupled with the sun safety policy-based dress code and corresponding high NCF for court staff, contributes to a significant reduction in effective UVR exposure (28) for umpires and ball kids, compared to those of competitors, whether they're wearing a hat or not (Figure 3). The greatest effective UVR exposure for ball kids and umpires was calculated to be approximately 1.0 SED/hr and 0.5 SED/hr respectively. Even though these exposures are relatively low, repeated duties within a day of competition can result in cumulative exposures (2-4,6,28) to the face and

possibly, highlighting the necessity of these personnel to employ sunscreen to any exposed areas of skin.

The appearance of the tennis court officials in UVR protective uniforms provides positive sun-safe role models for adults and adolescents alike. Their visual presence provides a latent but persistent advertisement, modelling sun-safe behaviours while engaged in physical activity (3,4,12,20,45,56,60). An analogy is the relatively recent change in the iconic and very visible Australian surf lifesaver uniforms to include broad brim 'bucket' hats, long sleeved shirts and visible sunscreen (45), particularly as they often appear in local advertising campaigns, which is an important aspect of modelling and endorsing sun safe behaviours (8,12,19,20,45,56,60). This persistent form of advertising of sun safe behaviours is a valuable tool in promoting the application and maintenance of sunscreen (59), and of wearing appropriate sun safe clothing such as hats, long-legged trousers, and especially long-sleeved shirts, which have been identified as a sun safe behaviour deficiency (45,59).

Limitations and future directions

- A significant limitation of this investigation is that the calculations of effective UVR exposure are based on indirect observations, as it was not possible to obtain direct UVR dosimetry from the participants. An interesting comparison would be to compare dosimetric results with those obtained from this investigation.
- Generalisations about the sun protective properties of the clothing worn by court staff and players. Further research can be performed on the UVR protective properties of the uniforms and promotional clothing used by court staff (61). This could be performed using the Garment Protection Factor (62) or body mesh model (17).

- The contribution of albedo of the court surface is assumed to be minor and included within the ambient UVR exposure. An avenue of research would be to compare the blue Plexicushion tennis courts used in the Melbourne arenas and courts to the green and red surfaces measured in previous research.
- The effect of different duty positions, additional shelters and shade were not taken into account, as this assessment looked at the maximum exposure scenario.

CONCLUSION

A unique assessment method with a focus on evaluating the effective UVR exposure experienced by on-court tennis tournament officials (judges and ball kids) is presented comparing this exposure to what the players experience, using data obtained from the Australian Open Grand Slam tournament held in Melbourne, Australia in January 2019, as an example. The combination of an adherence to a relatively strong sun safety based tournament uniform policy ranked the officials with a high normalised clothing factors, with optimal sun-participant geometry, as calculated by the GCF resulted in a marked reduction in the UVR exposure, from an ambient UVR exposure of 9.9 SED/hr to an effective maximum UVR exposure assessed to be 1.0 SED/hr and 0.5 SED/hr for ball kids and judges respectively, with players exposure reaching up to 2.0 SED/hr in comparison. Typically, the court officials were observed to be behaving in a more sun safe manner than the players, thus with the extensive media coverage of the events, provided a strong and persistent role modelling of positive sun safe behaviour to all adolescent and adult spectators and broadcast viewers. This study also provides a fast and accurate method for evaluating UVR exposures incident upon tennis tournament staff and officials. Consequently, results obtained from this method may be useful in the planning and application of UV exposure mitigation strategies at other sporting events in the future.

Conflict of Interest Statement: There are no conflict of interest to report. All authors have no affiliation to Tennis Australia in any way.

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Table 1. Clothing, protected areas and Normalised Clothing Factor (28) for those on court in the Australian Open. Note: Net ball kids crouch with their legs under their body, but their faces are forward, so are in the same category as the umpires.

Category		Clothing	Protected areas	NCF
1	Chair and line umpire	Long-sleeved shirt Long-pants, broad-rim hat	Head/scalp Torso Arms Shins	0.8
2	Ball kid*	Long-sleeved shirt Shorts Legionnaires style cap	Head/scalp Torso Arms	0.6
3	Player with hat	Short-sleeved shirt or singlet Shorts Cap (covering the scalp)	Head/scalp Torso	0.4
4	Player without hat	Short-sleeved shirt or singlet Shorts Visor	Torso	0.2

List of Figure captions

Figure 1. Distribution of the median over the 18 days starting at each hour and the associated ranges of ambient UVR exposure (in SED/hr) for each hour of the tournament (times are 24-hour format).

Figure 2. Geometric conversion factor for upright participants as a function of the range of SZA relevant to the tournament adapted from Pope and Godar, (42).

Figure 3. Median effective UV exposure for court staff and players in SED/hour. Error bars represent the maximum and minimum UV exposure calculated for matches starting at that time. Only 4 days of Qualifying rounds started at 10:00am (times are in 24-hour format).



