The simulated ocular and whole-body distribution of natural sunlight to Kiteboarders: A high risk case of UVR exposure for athletes utilizing water surfaces in sport

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Abstract

Kiteboarding is an aquatic sporting discipline that has not yet been considered in the literature to date in terms of solar ultraviolet radiation (UVR) measurement. Kiteboarders need to look upward and are placed obliquely relative to the horizon when towed behind an overhead kite over a reflective water surface. This research defines the typical body surface orientation of a kiteboarder in motion through video vector analysis and demonstrates the potential risk to ocular and skin surface damage through practical measurement of solar UVR using a manikin model. Video analysis of 51 kiteboarders were made to construct skeletal wireframes showing the surface orientation of the leg, thigh, spine, humerus, lower arm and head of a typical kiteboarder. Solar UVR dosimeter measurements made using a manikin model demonstrate that the vertex and anterior surfaces of the knee, lower leg, and lower humerus received 89%, 90%, 80% and 63% of the available ambient UVR respectively for a typical kiteboarder who is tilted back more than 15° from vertical while in motion. Ocular (periorbital) exposures ranged from 56 to 68% of ambient. These new findings show that the anterior skin surfaces of kiteboarders and the eye are at elevated risk of solar UVR damage.

Keywords: Kiteboarding, ultraviolet, skin cancer, sun-protection

1.0 Introduction

Kiteboarding (or kitesurfing) is one of several solo aquatic sports practiced by young adults (predominately male) that is growing in popularity and developing a competitive culture worldwide [1]. Competing among three primary disciplines, including Twin tip, Strapless and Formula Kite, the sport is scheduled for Olympic exhibition in Tokyo 2020 and will be included formally in the Paris 2024 Olympic Games. Along with surfing, windsurfing, water-skiing and sailing, the kiteboarder is restricted to competition or pursuing the sport for leisure during daylight hours, often for a significant proportion of the day on a reflective water surface [2]. Unlike many winter and team sports, which are played during cooler months, participants of aquatic ocean-going sports are likely to be engaged in outdoor activity during warm periods of the year where ambient levels of solar ultraviolet radiation (UVR) are at their highest [2].

De Castro et al. [3] recently examined the frequency of sunburn, exposure duration, and sun protection habits of 246 elite surfers, windsurfers and Olympic sailors taking part in World Championship events in Spain. Among this study cohort, participants reported high frequencies of sunburn during competition, limited use of sunglasses and hats (particularly among surfers and windsurfers) and were exposed daily to sunlight for approximately four hours [3]. Relative to self-selected populations of similar age, surfers experience a higher rate of Basal Cell Carcinoma (BCC) [4,5]. From the research data that has been presented to date, these cancers seem likely to be restricted to the upper body [5,6]. In 1348 Australian surfers facial (23.5%), back (16.4%) and arm (12.4%) incidence of skin cancer (including BCC and Melanoma Skin Cancer (MSC)) was much higher than the reported incidence of skin cancer occurring on the feet (0.4%), thigh (2.0%) and neck (2.9%) [5]. This finding was reciprocated by Meir et al. [6] in another Australian survey of 685 surfers showing 50% of all skin cancers occur on the upper body with the face being the location of highest incidence (21.9%). Exposure risks to

Australian kiteboarders may be similar, given Australia is one of the best countries in the world to practice the sport according to the International Kitesurfing Organization. Although a greater number of studies are needed to confirm elevated cancer risk to the upper bodies of a surfing (and kiteboarding) population, there remains compelling evidence that facial skin cancer incidence and ocular exposure to solar UVR is significant in human populations that spend extended periods of time near the water [7,8,9].

There is a significant body of evidence demonstrating a causal association between solar UVR exposure and ocular disease. Eyelid malignancies, cortical cataract, pterygium, and climatic droplet keratopathy are strongly associated with ocular exposure to UVR [10]. Though limited, there is also evidence that an association may exist between prolonged solar UVR exposure and the development of pinguecula, squamous cell carcinoma of the cornea, conjunctiva, and ocular melanoma [10,11,12]. Acute high energy exposure to artificial sources of UVR or exposure over highly reflective surfaces such as snow may lead to photokerititis (snow-blindness) and photconjunctivitis [13], painful conditions that usually fade within days following an exposure event. Of all these ailments however, pterygium of the eye is the most prevalent in worldwide populations followed by cataract [14]. Cortical cataract, which shows a distinct increase in incidence with age typically results in mild visual loss but can also lead to blindness and mortality due to disability associated with a loss of vision [14]. The WHO estimates that 20% of blindness worldwide from cataract can be attributed to sunlight exposure [11]. Pterygia are growths that often occur on the anterior (inside) eye. This may be attributable to peripherical focusing of light from behind or below an individual [12]. This is of potential concern for kiteboarders (and other populations) that make frequent use of reflective water surfaces. Pterygium is a common disease among surfers [15,16]. Although not often resulting in complete blindness, associated annual costs for treating Pterygium are estimated at $8.3

million in Australia with populations residing in environments of elevated ambient solar UVR experiencing the highest rates of incidence [17,18].

Epidemiological and physical measurement studies in sport have not yet examined the potential for kiteboarding to be a leading candidate for hazardous ocular and facial exposure to solar UVR. This research presents baseline body site exposure distribution information for kiteboarders, a population at high risk of cumulative ocular and skin surface sun damage. Data are presented from publicly accessible video records of individuals engaged in kiteboarding to determine the approximate skeletal orientation of major body-site vectors, including the head, spine, arms and legs providing a three-dimensional vector solution to the approximate whole-body orientation of a typical kiteboarder with respect to the horizon. A practical method for deriving the simulated body site UVR exposure distribution is also presented utilizing poysulphone dosimetry. Polysulphone exposure distribution analysis was conducted in a sunny sub-tropical climate at the University of Southern Queensland, Toowoomba, Australia (27.5°S 151.9°E) demonstrating high biologically damaging exposures to kiteboarders are likely to be received in similar climates compared to other land-based sports that have been studied previously.

2.0 Materials and Methods

A literature review was conducted to ascertain the total volume and type of research that has previously examined the relationship between UVR and sport. Studies included in the review are summarized in the Results (section 3.3). Studies included for review were found using online scholarly databases, including PubMed and Google Scholar (August 2019). Search terms included; 'UV' AND 'Sport' AND 'Skin Cancer'. The outcome of this review uncovered a total of 65 studies including both individual and team sports published between 1991 to 2019. Upon completing the review, studies were subdivided by type (Type A – cross-sectional sunscreen / behavior survey; Type B - personal dosimeter measurement; Type C – Environment modelling; and Type D – Vitamin D measurement). The outcomes of the review indicated that limited research has previously investigated the measurement of solar UVR radiation in aquatic sports. A method has therefore been developed in this research to: 1) derive the expected body orientation of a kiteboarder with respect to a horizontal plane, and 2) quantify the solar UVR exposure distribution to the body while placed over a reflective surface and positioned according to the typical orientation of a kiteboarder in motion.

2.1 Video analysis

Kiteboarding, compared to other sports places the participant in a unique position with respect to the sun and general UVR environment. Apart from exposures received due to the elevated albedo of a horizontal reflective water surface, the kiteboarder must orientate their body frame in a position that will counter the tension of an overhead kite to prevent toppling into the water while being pulled along by the action of the wind [19]. This places the body at an oblique angle with respect to the horizon and in a position such that the anterior surfaces of the head (face), trunk, leg and arm receive a greater proportion of the available direct solar radiation from above than respective posterior surfaces which are orientated toward the water (Figure 1). The expected body orientation of a typical kiteboarder with respect to a horizontal sea surface was derived through video analysis.

Videos taken of 51 individual kiteboarders were sourced from publicly accessible recordings on the internet (YouTube) using search terms ‘Kiteboarding’ AND ‘Kitesurfing’. A total of 102 videos were examined for shots that showed a kiteboarder passing in front a camera. Where a discernable image of a kiteboarder passing in front the camera was found, it was included in this study for vector analysis where each body vector for all study subjects was expressed relative to the visible ocean surface (a horizontal plane) in three-dimensional space.

FIGURE 1

A series of ten vectors were used to express the orientation of a simplified skeletal wireframe of a kiteboarder in motion. In this research, the angle/s of each individual body vector were defined with respect to the horizon for 1-*left lower leg*, 2-*left thigh*, 3-*right lower leg*, 4-*right thigh*, 5-*spine*, 6-*left humerus*, 7-*left lower arm*, 8-*right humerus*, 9-*right lower arm* and 10-*head.* Respective β angles represent the direction of each body vector projected onto the *y-z* plane as shown in Figure 1. Individual β angles were expressed positively in an anti-clockwise direction for each body vector from $\hat{\boldsymbol{j}}$, and were calculated from video image analysis of each kiteboarder imaged at a point where an individual passed directly in front of the camera. This point represents the back or rear view of a kiteboarder in motion (Figure 2). The angle of each numbered body vector with respect to the horizon and projected onto the *x-z* plane was also defined. This angle, shown in Figure 1, is termed the α angle and is measured anticlockwise from the -$\hat{\boldsymbol{\imath}}$ axis.

FIGURE 2

To calculate β, the relative length of each body vector representing the 1-*lower left leg* through to 10-*head* was measured for each respective back view and expressed relative to the length of the imaged kiteboard. When positioned directly in front of the camera and viewed from behind a kiteboarder, the image of a kiteboard represents its maximum physical length as no component of the board is orientated either away from or toward the camera. In this position, the kiteboard is orientated directly along the x-axis of a kiteboarder in motion and can be used to accurately scale the apparent length of each body vector provided the absolute length of the board is known.

Kiteboards are available to surfers in a range of lengths from 134 to 165 cm with the average being approximately 149.5 cm [21]. An idealized human frame was used to approximate the length of the average kiteboard in terms of 'head lengths'. Here, an average human when standing upright was assumed to stand 183 cm tall (approximately 6'). Ideally, this represents the equivalent of eight head lengths (two lengths for the lower leg, two lengths for the thigh, three lengths for the torso and one length for the head) (Figure 3).

The average kiteboard when orientated along the x-axis and placed orthogonally to the viewpoint of a kiteboarder in motion measures approximately 6.5 head lengths, hereafter defined as 6.5 h. This known dimension was used to scale each of the ten body vectors for kiteboarders in motion where any foreshortening from the idealized body vector dimensions was assumed to be due to the kiteboarder leaning back toward the camera. The idealized dimensions for body vectors placed vertically upright with respect to the camera (no foreshortening) and when viewed from behind were assumed to be 2 h (*lower left leg*), 2 h (*left thigh*), 2 h (*lower right leg*), 2 h (*right thigh*), 3 h (*spine*), 1.7 h (*right humerus*), 1.9 h (*right forearm*), 1.7 h (*left humerus*), 1.9 h (*right forearm*), and 1 h *(head*).

As an example, the β angle of the left lower leg, β_1 can be calculated for any apparent measured vector length, a_1 in head lengths imaged from directly behind a kiteboarder (*x-z* plane), where:

$$\beta_1 = \sin^{-1}\left(\frac{a_1}{2}\right). \qquad (1)$$

Thus, a kiteboarder's lower left leg would be orientated at an angle of 48.6° toward the water surface if the apparent vector length, a_1 measured 1.5 h from a viewpoint directly behind the kiteboarder. The left lower leg in this position therefore presents an obtuse angle of 131.4° with respect to the horizon (ocean surface) when leaning back toward the camera viewpoint resulting in the anterior leg surface being exposed to direct sunlight with the posterior surface receiving reflected solar radiation from the water.

FIGURE 3

2.2 Measuring the UVR exposure distribution

2.2.1 Polysulphone film dosimetry

The distribution of exposure to sunlight for a typical kiteboarder was expressed relative to the available ambient UVR received upon a horizontal plane. To measure the likely exposure distribution of a kiteboarder, body site measurements were made using polysulphone (PS) film dosimeters placed at 15 points upon a full sized manikin model. Dosimeters were fixed upon both arms and legs of the manikin model and included measurement sites located at the ankle, knee, hip, wrist, elbow, shoulder, coccyx, neck and scalp. Measurements of exposure were taken after the manikin was orientated in a position that matched the skeletal wireframe of a typical kiteboarder in motion (Results section 3.1). Two additional dosimeters were placed underneath the left and right eye (periorbital).

Periorbital and body site exposures were taken to represent the biologically damaging solar UVR that has the potential to cause erythema in human skin [23]. PS dosimeters were preferred for this research application as they are small and lightweight and can be fixed or molded to match the surface topography of the human form. This type of dosimeter has been used extensively in research applications since the 1970's [24] and were manufactured from thin PS sheets cast at the University of Southern Queensland. The PS dosimeters were assembled from film strips (40 μm) adhered over flexible polymer frames measuring 10 x 15 mm with a clear circular aperture of 6 mm. Measurements of body site exposures were expressed relative to the biologically damaging UVR exposure measured simultaneously by a set of three PS dosimeters placed upon the ground surface and adjacent to the manikin model. Body site exposures are therefore presented as the fraction of available ambient UVR. This fraction is termed the Exposure Ratio (*ER*).

To calculate the *ER*, the biologically damaging exposure, *E* was first derived for each field dosimeter. Here, *E* is expressed as a function of the change in dosimeter absorbance measured pre- and post-exposure to solar UVR [25], where:

$$E = K(9\Delta A^3 + \Delta A^2 + \Delta A), \qquad (2)$$

ΔA is the change in PS film absorbance measured at 330 nm and *K* is a constant. The constant is eliminated in the exposure ratio, *ER* when expressed relative to the dosimeter absorbance measured simultaneously on a horizontal plane, ΔA_{hor}. That is, the exposure at each of the 15 body sites and each periorbital site of the kiteboarder manikin model may be expressed as:

$$ER = \frac{9\Delta A^3 + \Delta A^2 + \Delta A}{9\Delta A_{hor}^3 + \Delta A_{hor}^2 + \Delta A_{hor}}. \qquad (3)$$

The change in absorbance for each field dosimeter, ΔA was measured using a laboratory spectrophotometer (model 1601, Shimadzu Co, Japan). The uncertainty of PS film dosimeters estimated as the expected variance in PS film has been determined previously at 7% [26]. Thus, the total uncertainly of each body site measurement expressed as an *ER* in this research is estimated to be 14%.

2.2.2 Manikin exposure measurements

To simulate the potential for an ocean surface to reflect incident solar UVR back onto the kiteboarder, the manikin was exposed in an open land environment after being placed upon a surface of reflective insulation blankets. This surface consisted of four individual blankets pinned to the ground surface covering a total area of 4.2 x 2.5 m. The blankets were only weighted at the edges, allowing movement of the reflective surface with the breeze, thus simulating the movement of waves on the ocean.

On the day of the field exposure measurements, moderate breezes were blowing from a southerly direction. The manikin was therefore positioned on the simulated water surface facing north – the expected principle direction a kiteboarder would likely face if being pulled by a kite under the action of a southerly wind. The field exposure was taken under cloud-free conditions between 10:30 am and 12:00 pm, 19 August 2019 at the University of Southern

Queensland, Toowoomba campus (151.9° E, 27.5° S). At this Southern Hemisphere latitude, the kiteboarding manikin was facing the sun for the 1.5-hour duration of the field trial.

3.0 Results

3.1 Vector solutions

Table 1 presents the apparent vector lengths derived from video analysis of the 51 kiteboarders considered in this study when viewed from directly behind. The α angles (Figure 1) measured with respect to the x-z plane for all kiteboarders are also listed. Where body vectors were not visible from a respective rear view, this information was omitted from the table. Measured apparent vector lengths longer than the expected maximum for an upright kiteboarder were set at the idealized allowable length of respective upright vectors. These are shown in bold font in the table.

The arithmetic average of each apparent vector length and α angle is summarized at the end of Table 1. These averages were used to derive the body orientation of a typical kiteboarder which is shown in vector form in Figure 4. The figure indicates that there is a high degree of symmetry in both the leg and arm vectors on both the left and right sides and shows that the typical kiteboarder orientated according to the rear image of all 51 video frames leans backward by more than 15° from a vertically upright position while in motion. Respective β angles for the lower leg, thigh, spine and head calculated according the average apparent vector lengths are included in Figure 4.

TABLE 1

FIGURE 4

3.2 The exposure distribution of a kiteboarder

The manikin, with movable knee, hip, shoulder and elbow joints was orientated according to the approximated typical skeletal wireframe position shown in Figure 4. The correct α angles for the manikin shoulder, knee and hip joints could not be set according to Figure 4(b) due to the physical limitation of the manikin pivot points at these sites (x-z plane). However, an accurate depiction of the typical kiteboarder could be set according to the y-z plane. Here, the correct angle for the spine was set by pivoting the manikin so that the horizonal distance from the shoulder joint to the ankle represented a distance just greater than 3 h as shown in Figure 4(c). For the manikin model, this distance was 675 mm, given the manikin head length was 225 mm. Arms, elbow and knee joints were set to approximate the resultant positions shown in Figure 4(c).

Field exposure results for each of the 15 dosimeter sites measured using the manikin orientated with respect to the typical kiteboarder are given in Table 2. To measure both the anterior (frontal) and posterior (rear) site exposure, dosimeters were placed on the underside of the left leg and arm appendages, while dosimeters placed on the right manikin leg and arm appendages were fixed to upper manikin surfaces (Figure 5).

At the time of exposure between 10:30 am and 12:00 pm 19 August 2019, the Solar Elevation angle (SE angle – the angle from the horizon to the apparent solar position) varied from 44.5°

to 49.6° and was positioned on average at 47.9° above the horizon [27]. Site dosimeters exposed at close to normal incidence to the sun during field measurements received among the highest exposures. These dosimeters received the greatest component of incident direct solar UVR and include anterior dosimeters placed at the ankle, knee and periorbital sites. The approximate difference from normal direct solar incidence for dosimeters fixed at the anterior ankle, anterior knee and periorbital (eye) sites varied from 18°, 7° and 32° respectively in the period 10:30 am to 12:00 pm (assuming the manikin model and fixed dosimeters lie in the lower leg, thigh and spine planes shown in Figure 4(c)).

TABLE 2

FIGURE 5

3.3 Kiteboarding versus UVR in other sports

Between 1991 and 2019, our literature search showed that the highest number of sport and UVR studies were conducted in athletics or running disciplines (Type A [28,29,30,31,32,33,34,35,36,37,38], Type B [39,40,41]; Type C [42]; Type D [43,44,45]). This was followed by studies that examined snow skiing / snowboarding (Type A [46,47,48,49,50,51,52,53,54,55], Type B [56,57,58], Type C [48,59] Type D [57]; Golf (Type A [28,31,60,61,62,63], Type B [64,65,66,67,68], Type C [42,59,66,69], Type D [64]); Team field sports (Type A [28,31,70,71,72,73,74], Type B [75], Type C [42,73,76], Type D [44,45,74,77]); Tennis (Type A [28,31,63,70,72], Type B [39,66], Type C [66,42,78], Type D [44]); Sailing / rowing (Type A [3,28,31,74,79], Type B [66], Type C [12,42], Type D [44,74]); Cycling (Type A [80], Type B [81,82,83], Type C [42], Type D [44]); Beach Sports (Type A

[63,70,72,84], Type B [66], Type C [59,66]); Surfing (Type A [3,4,5,6], Type C [42]); Triathlon (Type B [85], Type C [42]); Skateboarding (Type A [86], Type C [42]); Hiking (Type B [39]); Snorkeling (Type B [87]); Fishing (Type A [88]); Horse Riding (Type D [77]); and Kiteboarding (Type A [89]).

Of all 65 studies included in the literature search, most were cross-sectional Type A survey studies (60%), aimed at resolving the behaviors and attitudes of participants of sport toward sun-protection, sunscreen use and the measurement of population skin cancer incidence. A total of 26% of studies were Type B studies that measured solar UVR directly using personal dosimeters, with Type C and Type D studies representing 12% and 9% of the literature sample respectively. A high proportion (89%) of the studies reviewed considered individual sports that take place on land compared to 28% of sports that are contested over or near the water (including sailing, beach sports, triathlon, surfing, snorkeling, fishing and kiteboarding).

One-quarter of the selected studies considered multiple sports as opposed to studies that examined a single sporting discipline (25% versus 75%). Of the studies that considered sports that take place on the ocean or over water surfaces, most considered sailing [3,28,42,44,66,79], followed by windsurfing and surfing [3,4,5,6]. Only one Type A study considered kiteboarding as a sporting discipline in terms of exposure risk to solar UVR [89].

Table 3 compares the measured *ER* of all Type B studies considered in the literature sample. Of all disciplines, UVR exposures measured upon surfaces approximating a horizontal plane during the sporting activity are the highest. These include the vertex and the top surface of the shoulder for sports where participants are standing upright, such as golf or tennis. Where participants are prone or lying in a plane close to the horizontal, exposures to the back and posterior neck can also be very high. These cases include sports such as swimming and snorkeling.

Across all Type B sports considered in the literature sample for which personal solar UVR dosimetry data are available, vertex, shoulder, back and neck sites stand out as body sites that receive a high proportion of the available ambient UVR. These sites will often exceed an *ER* of 50% but may be protected to some extent by clothing, helmets and other forms of hat wear [53,90]. Other body sites including the anterior and posterior leg do not often exceed an *ER* of 40% when exposed during sporting activity. Similarly, wrist sites do not often exceed an *ER* of 50%.

TABLE 3

Type B studies that have provided personal measurement of facial site UVR show that exposures measured to this site are often lower than the available ambient. In summer sports including golf, tennis, sailing and swimming where the face is not protected by clothing or goggles UVR exposure ratios listed in the literature range from 13 to 26% of the available ambient. These previously measured ratios are less than the periorbital *ER* determined here for the manikin kiteboarder at 56% and 68% for the left and right eye respectively.

The exposure risk to kiteboarders may be similar to that determined for participants of snow sports where the solar UVR albedo is greater than 76% [91]. Personal UVR exposures measured to snow skiers at a forehead site by Siani et al. [58] ranged from 19 to 175% of the available ambient (Table 3). These were the highest *ER* values found in the current literature search of Type B UVR dosimetry measurements in sport.

4.0 Discussion

Kiteboarding participation is relatively new and growing in popularity. Worldwide, approximately 1.5 million individuals participate in the sport with 60 000 participants taking it up on an annual basis [92]. Despite many studies being published about potential musculo-skeletal injuries [1,19] only one recent study has surveyed sunburn incidence within the sport [89] constituting a significant gap in the literature about the solar UVR risks that participants are exposed to. Results reported in this research for a model kiteboarder show the anterior leg, eye and vertex (scalp) to be the locations of the body at highest risk of solar UVR exposure. Consequently, exposure mitigation to the eye using sunglasses; and face, by using hat wear and high SPF sunscreens will be of high importance to kiteboarders.

For kiteboarders, facial site UVR exposure is also significant as the typical kiteboarder will lean back by more than 15^{o} from the vertical and be in a position where the face is orientated toward the sun. It is reasonable to suppose that the distribution of solar UVR to kiteboarders could be as significant as the measured facial exposures of snowboarders (and snow skiers) who are often positioned such that the face is orientated toward a highly reflective snow surface. Biologically damaging UVR exposure measured at anterior body sites in this research at the ankle, knee, thigh, shoulder, periorbital and lower humerus all exceed an *ER* of 50% (Table 2). The facial *ER* measured here between 56 and 68% at the left and right periorbital sites are approximately three times greater than the facial *ER* measured using personal dosimetry in all other sports, excluding snow sports. The potential biologically damaging skin and eye exposure is very high for a kiteboarder actively participating in the sport in a warm climate where active protection from hats, clothing or sunglasses may be less than applied in other sports that take place over land surfaces. For a typical kiteboarder, measurement at the anterior knee and ankle sites exceed an *ER* of 80% and are approximately double the *ER* presented in published research studies that have measured the anterior leg site exposure in other sports.

While the measurement of UVR exposure relative to the available ambient is greater at lower body sites of the manikin, the incidence of skin cancer for surfing populations has been reported to be higher to the upper body [4,5,6]. A likely explanation for the difference in expected exposure to a kiteboarder compared with the measured cancer incidence in surfing populations may be due to the legs of recreational (and competition surfers) being protected when the surfer is not engaged in their sport. Compared to the upper body and face which continue to be exposed to UVR on a day to day basis the legs of surfers (and the general population) are often protected by long trousers. An upright surfer will also receive a lower proportion of the available direct solar UVR incident from above than a kiteboarder placed obliquely relative to the ocean surface. Given the *ER* to the lower body (knee and anterior lower leg) is high for the kiteboarding manikin, renewed survey studies that specifically examine the incidence of skin cancer to the legs of kiteboarders could yield new information on potential differences in cancer incidence observed between surfers and kiteboarders. To date no survey evidence targeting kiteboarders has been completed. This has the potential to be an interesting avenue for future research.

In the current research the expected *ER* received at 15 individual body sites and two periorbital sites was simulated by using a manikin model orientated with respect to the expected position of a kiteboarder in motion. Preliminary measurements indicate the potential for the anterior surfaces of the kiteboarder to be at elevated risk of sun exposure and sunburn. The total incident solar radiation received at any one body site is made up of both direct (shadow causing) solar radiation and solar UVR scattered by the atmosphere. Therefore, dosimeters placed on or close to a horizontal plane that are not shaded by the manikin model also received a high proportion of the available ambient direct and diffuse UVR. Conversely, dosimeters placed upon posterior manikin body sites were shaded from exposure to direct sunlight. In the 1.5 hours of the exposure field trial, during which the manikin was placed in a fixed position facing north (Southern Hemisphere) no measurable difference in absorbance was found in any posterior dosimeter site.

The results presented are only indicative, being measured on a simulated water surface using a manikin model. The measured exposure potential of a kiteboarder facing different directions as may be expected when actively moving across the ocean surface will likely vary from the simulated measurements provided here. This research does however highlight a novel methodology that may be used in future research to investigate the biologically damaging sun exposure through simulation across a range of expected SE angles and for a variety of different manikin facings. Future research that implements the use of PS dosimeters, which can be applied in a kiteboarding population in all weather conditions [93] has the potential to verify the likelihood of increased exposure risk to the upper surfaces and ocular regions of the kiteboarder's body. Exposures measured using PS dosimetry, expressed here as an *ER* may also be expressed as a measured absolute erythemally effective dose [94]. This may be of particular interest when comparing kiteboarding populations from different regions, especially tropical regions where kiteboarding is popular and global UVR levels are often greater than in regions located at higher latitudes.

Reported sunburn rates in kiteboarders visiting tropical regions are high irrespective of the time of year. Villard et al. [89] showed that sunburn rates in 92 kiteboarders surveyed from Martinique (14.6°N, 61.0°W) exceeded 70%. This study also showed that kiteboarders had a good knowledge of sun-protection but experienced the most severe sunburn to the face when compared to the trunk, scalp and limbs [89]. This in part may be due to the nature of the sporting activity. Unlike sports conducted in cool climates, the kiteboarder may be restricted in the choice of suitable hat wear and may suffer visibility loss when wearing sunglasses that frequently encounter ocean water and sea spray. Kiteboarders are also more likely to be wearing short-sleeved shirts and shorts than full length sun-protective garments [89]. Compared to other sports, the frontal surfaces of body, face and eyes of the kiteboarder are often orientated toward a powerful overhead kite. These regions of the body are therefore at risk of receiving high doses of direct solar UVR.

Previous research has shown sunscreen to be the most popular sun exposure mitigation strategy employed by kiteboarders. Villard et. al [89] reported that 67% of kiteboarders applied sunscreen between 90 and 100% of the time they were on the water. Another Australian study confirmed competitors of surf-sports (associated with volunteer surf-lifesaving) practiced the highest use of sunscreen compared with sports practiced over artificial and field environments such as soccer, tennis and hockey [70]. This may be indicative of increased sun-exposure awareness in populations that experience high levels of ambient sun exposure. Villard et al. [89] found approximately one third of their tropical population of kiteboarders used some form of headwear while 55% used sunglasses. The number of kiteboarders in the current study filmed in a tropical location (where personal experience to UV exposure in an elevated UV climate is likely to be high) versus the number of kiteboarders filmed in temperate locations (where personal experience to sun exposure of high intensity is likely to be less) is unknown.

Personal sun protection in tropical climates, especially in terms of sunscreen (not visible in our video analysis), and also use of sun-protective clothing is likely to vary depending on location and local climate [95]. In France, sun protection campaigns have previously focused on kiteboarding and surfing [73]. An examination of sun-protection attitudes and practices of kiteboarders in temperate versus tropical regions remains an avenue for future research.

A unique methodology has been developed in this research for presenting the approximate position of ten individual body vectors for a typical kiteboarder with respect to the horizon (ocean surface), allowing the evaluation of the biologically damaging UVR exposure. Thus, the methodology developed here may also be applied to approximate the general body orientation of participants engaged in other aquatic sports where individual body vectors can be measured with respect to the visible ocean surface. This will enable the determination of the biologically damaging UVR exposure received by participants of other aquatic sports not yet examined in detail.

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6.0 Disclosure of interest

The authors report no conflict of interest.

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8.0 List of Tables

Table 1: Body vector apparent lengths when viewed from behind (*x-z* plane) and scaled with reference to an average kiteboard of 6.5 h.

	1–left leg		2–left thigh		3-right leg		4-right thigh		5-spine		6–left humerus		7-left arm		8-right humerus		9-right arm		10-head	
Kiteboarder	h	α	h	α	h	α	h	α	h	α	h	α	h	α	h	α	h	α	h	α
1	2.0	72°	1.6	65°	1.9	98°	1.3	94°	3.0	87°	1.1	194°	0.6	141°					1	75°
2	1.7	75°			1.9	95°	1.3	170°	2.8	71°					1.7	-60°	0.9	155°	1	80°
3									3.0	72°									1	65°
4	2.0	82°	1.7	60°	2.0	99°	1.6	95°	3.0	81°	1.6	220°	1.5	142°					1	90°
5	2.0	90°	1.8	50°	2.0	90°	1.3	112°	2.7	85°	1.3	205°							1	88°
6	2.0	95°	1.1	58°	1.7	100°	1.5	113°	3.0	96°					1.5	-70°			1	92°
7	1.9	90°	1.3	30°	1.3	90°	0.9	92°	2.7	95°									1	93°
8	2.0	100°	1.3	53°	**2**	102°	1.2	117°	**3**	90°					1.6	-11°	1.2	-113°	**1**	97°
9	1.8	92°	1.6	72°	2.0	114°	1.9	119°	2.7	100°					1.6	-48°	0.7	-68°	0.5	70°
10	1.7	50°	1.5	14°	1.5	90°	0.5	50°	3.0	97°	1.7	260°	1.6	204°					1	100°
11	1.9	45°	1.9	14°	**2**	90°			2.8	84°	1.2	202°							0.9	94°
12					**2**	132°	1.6	178°	**3**	84°										
13		110°			**2**	150°	**2**	160°	**3**	80°		334°	1.2	303°	**1.7**	-113°	**1.9**	-117°		80°
14	**2**	60°	**2**	50°	1.8	100°	1.7	60°	2.3	80°	0.8	260°	1.2	240°					1	90°
15	**2**	80°	1.4	60°	1.9	100°	1.4	110°	2.8	90°	1.5	250°							**1**	90°
16	**2**	112°	0.9	103°	**2**	137°	**2**	139°	**3**	96°				20°	0.8	-43°	0.7	38°	**1**	85°
17					1.5	109°	**2**	252°	**3**	101°					0.6	90°	1.2	101°	**1**	89°
18	1.7	99°	**2**	90°	1.8	96°	1.9	95°	**3**	66°	1.7	216°			**1.7**	-105°	1.4	-28°		50°
19	1.8	62°			1.7	103°			**3**	86°	1.3	233°			1.4	86°		153°	**1**	90°
20	1.9	46°	1.5	23°	1.6	84°	1.3	56°	**3**	89°	1.6	207°	1.2	222°		0°			**1**	89°
21	1.7	94°	1.7	90°	2.0	126°	2.0	123°	**3**	104°					1.4	-2°	1.6	2°	**1**	99°
22	1.6	78°	1.8	54°	1.4	96°	1.4	104°	**3**	89°	1.5	192°	1.4	104°					**1**	86°
23	0.8	66°	0.6	-15°	1.9	90°	1.0	48°	**3**	103°										
24	**2**	74°	**2**	69°	1.9	109°	1.7	89°	**3**	51°	**1.7**	177°	0.4	227°	**1.7**	-85°			0.8	61°
25	1.5	80°	1.6	68°	1.4	87°	1.4	115°	**3**	86°									**1**	87°
26	1.6	99°			1.9	137°	**2**	157°	2.6	98°									**1**	95°

27	1.1	82°			1.4	129°	1.6	160°	2.9	100°					1.2	-20°	1.4	81°	**1**	89°
28									2.4	95°									**1**	97°
29	1.9	73°	**2**	28°	**2**	98°	1.3	82°	**3**	89°	**1.7**	187°	0.4	123°					**1**	92°
30	1.9	88°	1.0	36°	1.5	99°	1.2	107°	3.0	92°									**1**	82°
31	1.8	98°	1.7	83°	**2**	118°	**2**	125°	**3**	101°					1.6	-59°	1.4	58°	**1**	83°
32					**2**	102°	1.8	183°	**3**	100°									**1**	89°
33	1.9	77°	1.4	73°	1.8	108°	1.1	103°	**3**	97°	1.2	270°	1.5	250°					**1**	99°
34	1.3	75°	1.2	86°	**2**	103°	1.2	116°	**3**	89°	1.1	255°			1.3	-77°			**1**	90°
35					**2**	92°	1.5	229°	**3**	119°										
36							**2**	233°	**3**	96°					**1.7**	-22°	**1.9**	146°	**1**	87°
37	**2**	78°	0.9	37°	**2**	86°	1.0	231°	**3**	79°	**1.7**	249°			**1.7**	-110°			**1**	98°
38	1.7	107°			1.8	132°	**2**	162°	**3**	104°					1.7	-18°	1.1	120°	**1**	100°
39					1.3	143°	2.0	168°	2.6	88°									**1**	64°
40	1.6	98°	1.0	64°	1.3	113°	1.3	124°	2.9	99°									0.8	97°
41	1.9	53°	1.4	52°	1.7	68°	1.1	93°	2.8	80°	1.5	163°	0.9	113°					0.8	68°
42	**2**	42°	**2**	22°	1.9	71°	1.9	44°	**3**	85°	1.4	209°	1.4	168°					0.8	100°
43					1.4	112°	**2**	224°	**3**	91°	0.8	238°			0.9	2°	0.9	139°	**1**	91°
44	2.0	54°	1.6	48°	1.7	68°	1.3	66°	3.0	64°	1.5	214°	1.1	69°					**1**	95°
45	1.5	91°	1.3	119°	2.0	137°	2.0	132°	**3**	112°					**1.7**	-23°			1	94°
46	1.8	66°	1.6	39°	1.6	75°	1.4	89°	**3**	73°	1.3	191°	0.8	130°					**1**	86°
47	1.8	81°	0.8	86°	1.4	106°	1.3	116°	2.4	101°					1.5	-50°	1.3	123°	**1**	95°
48	1.5	67°	1.0	23°	1.9	102°	0.6	211°	2.8	85°	1.5	218°	0.4	133°					**1**	89°
49	1.3	96°	1.3	91°	1.7	100°	1.6	108°	2.5	90°	0.5	66°	0.7	59°	0.8	25°	1.1	138°	1	91°
50	1.4	69°	1.6	8°	1.1	103°			2.7	99°	1.5	227°	1.2	110°					**1**	102°
51	1.5	63°	1.1	0°	1.6	103°			2.8	90°	1.7	227°	0.5	169°					**1**	99°
Average	1.7	79°	1.5	53°	1.7	104°	1.5	127°	2.9	90°	1.4	218°	1.0	155°	1.4	-34°	1.2	58°	1	88°

Table 2: Exposure ratio (*ER*) received by anterior and posterior body sites between 10:30 am and 12:00 pm 19 August 2019 at the University of Southern Queensland (27.5°S 151.9°E). *ER* is expressed as a percentage.

Body Site	Dosimeter Label	Surface location	ER
Left ankle	A	Posterior	0%
Left knee	K	Posterior	0%
Left thigh (buttock)	T	Posterior	0%
Left wrist	W	Posterior	0%
Left elbow	E	Posterior	0%
Left shoulder	H	Posterior	0%
Right ankle	a	Anterior	80%
Right knee	k	Anterior	90%
Right thigh	t	Anterior	50%
Right wrist	w	Anterior	35%
Right lower humerus	e	Anterior	63%
Right shoulder	h	Anterior	54%
coccyx	c	Posterior	0%
neck	n	Posterior	0%
Vertex	v	Anterior	89%
Left Periorbital	eye 1	Anterior	56%
Right Periorbital	eye 2	Anterior	68%

Table 3: Measured exposure ratio (*ER* – expressed as a percentage) in sporting disciplines considered in the literature to date for UVR exposure measurements published between 1991 and 2019. Snow sports include both snowskiing and snowboarding.

	Golf	Snow sports	Athletics	Cycling	Tennis	Sailing	Snorkeling	Hiking	Swimming	Baseball
Anterior body sites										
Vertex	15-123%			34-45%						
Face	13%	19-175%			23-26%	21%			23%	
shoulder / arm	2-74%	35%	0-33%		58-65%	59%		9-34%	74%	28-33%
Wrist	3-54%		1-14%	*71%	4-26.6%	49%			59%	
Leg	36%			*52%	31-36%	40%			39%	
Posterior body sites										
Neck							38-76%			
Back	5-130%				44-50%	49%	19-59%		54%	
legs	33%				39-46%	22%			30%	
Studies	[64,65,66,68]	[56,58]	[39,40]	[81,83]	[66,39]	[66]	[87]	[39]	[66]	[75]

*fractions expressed relative to the top of the cyclist's head [83].

9.0 List of Figures

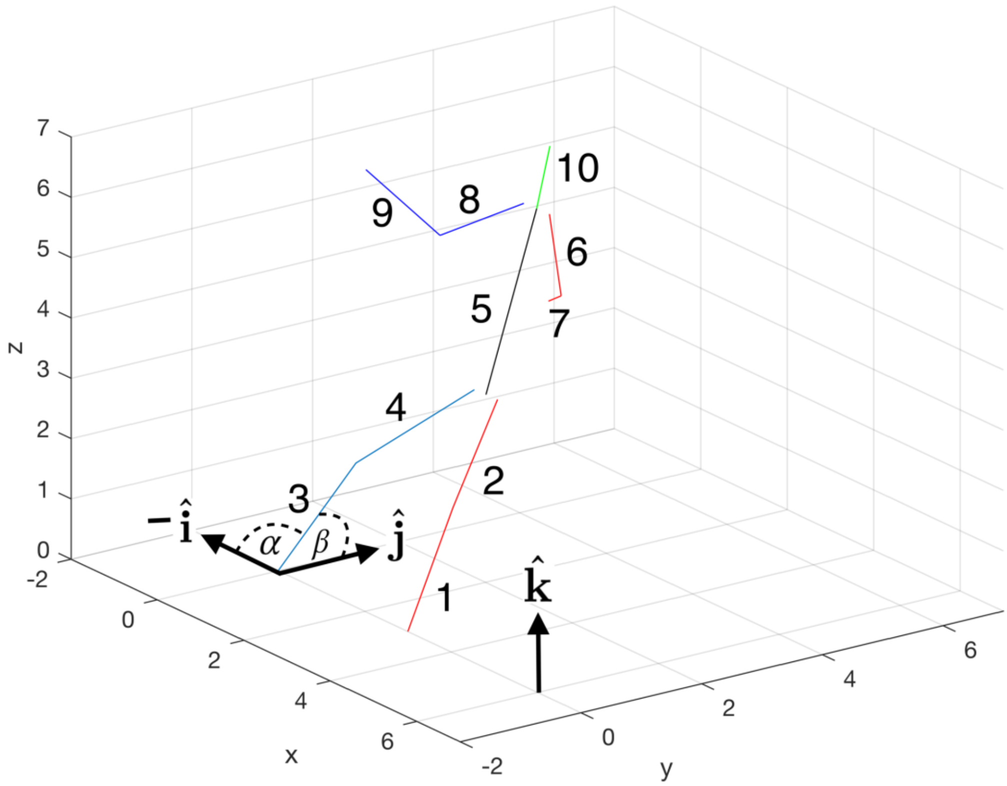
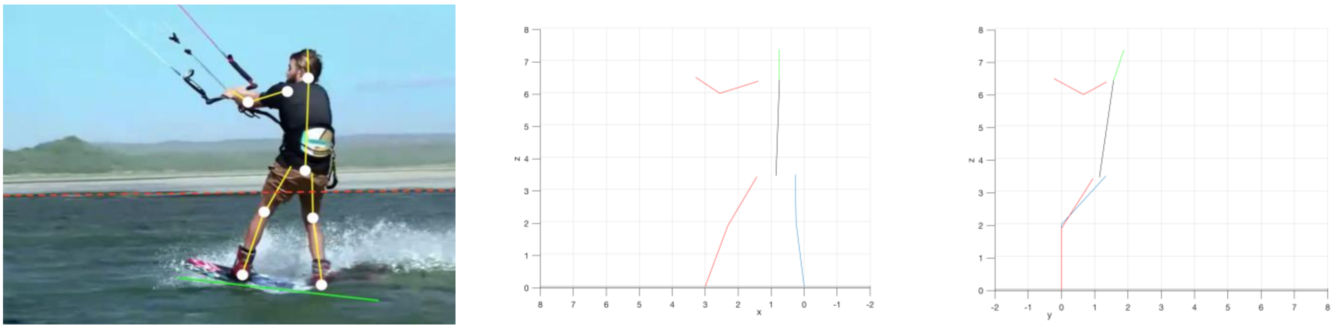


Figure 1: General body-frame orientation of a kiteboarder leaning back is placed at an oblique angle with respect to the horizon (*x-y* plane) in order to counter the tension of an overhead kite. Body wireframe vectors are labelled 1 through 10 (see text). Unit vectors, $-\hat{\imath}$, $\hat{\jmath}$ and $\hat{k}$ indicate reference directions used to determine three-dimensional body frame vector models for individual kiteboarders. The position of (0,0,0) represents the position of a kiteboarder's right foot. Axis units are given in 'head lengths'.

]).



(a) (b) (c)

Figure 2: (a) The back view of a kiteboarder in motion (sourced with permission from UniversKite.com [20]) presents the orientation of eight simplified body vectors with respect to the *x-z* plane. Green line – board length used to scale body vectors at 6.5 head lengths; red dotted line – horizon; yellow lines – body vectors 1- *lower left leg* to 10- *head* (vectors 8 and 9 not imaged). White circles represent vector reference points from which α angles are measured relative to the horizon. (b) Vector model viewed from behind (*x-z* plane). (c) Vector model viewed from in front of the kiteboarder after calculation of respective β angles (*y-z* plane).

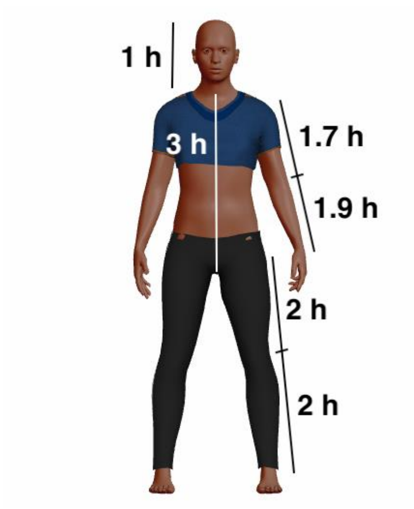
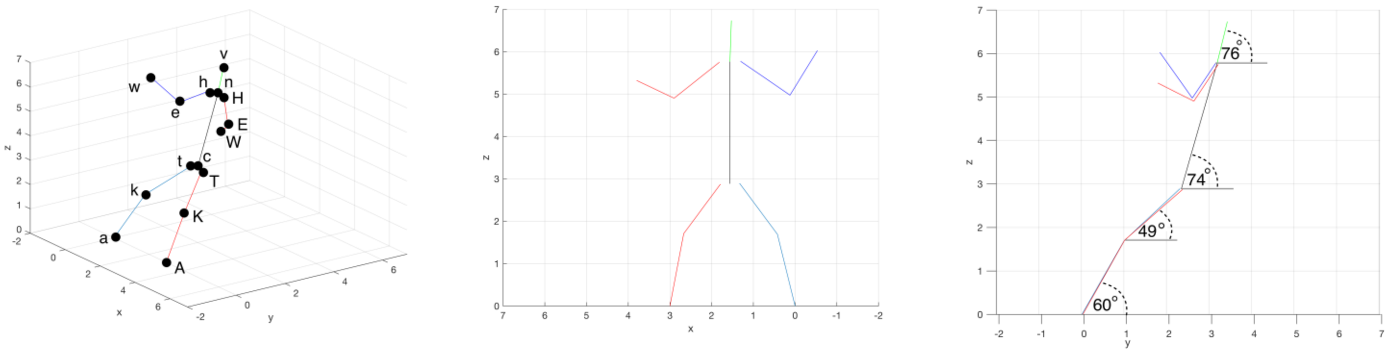
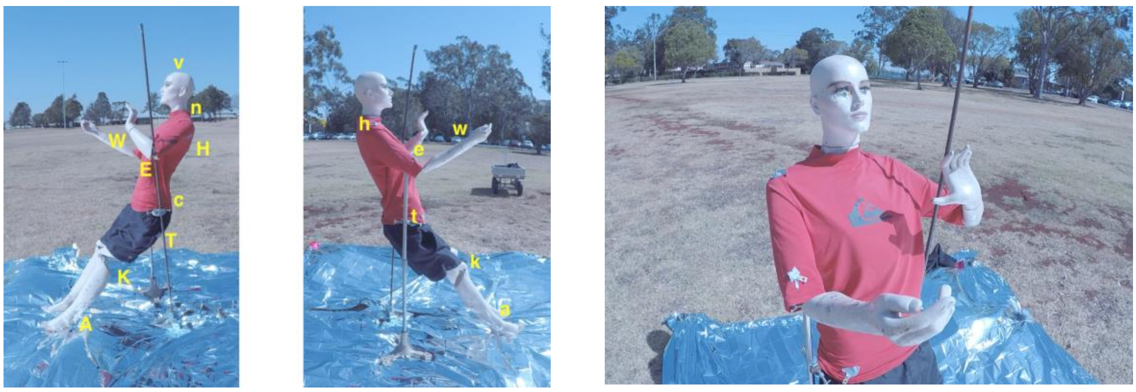


Figure 3: An approximate idealized human model standing 183 cm tall and vertically upright represents eight head lengths. At this scale, a kiteboard of 149.5 cm measures approximately 6.5 heads (MakeHuman version 1.1.1 [22]).



(a) (b) (c)

Figure 4: Averaged vector length and orientation of 51 kiteboarders in motion shown in three dimensions (Polysulphone dosimeter measurement sites are also marked as circles – refer to Table 2 for label descriptions). (b) Rear view (*x-z* plane). (c) Front view (*y-z* plane) including derived β angles for the lower leg, thigh, spine and head.



(a) (b)

Figure 5: (a) Left and right-side view of the manikin model placed upon a reflective surface (feet resting in the center of a 4.2 x 2.5 m reflective blanket). Locations of polysulphone dosimeters during the field exposure are also indicated – dosimeter descriptions included in Table 2. (b) An oblique frontal view of the manikin model showing the location of ocular dosimeters (eye 1 –manikin's left periorbital and eye 2 – right periorbital) and anterior dosimeters exposed on the manikin's right side.