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Ultraviolet Radiation Exposure, Risk, and Protection in Military and Outdoor Athletes

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Abstract

Over-exposure to ultraviolet radiation (UVR) from the sun is associated with deleterious health effects including, but not limited to, increased risk of skin cancers. Military personnel and those who participate in outdoor exercise or sports represent two potential populations at elevated risk of negative health consequences of UVR exposure, due to large amounts of time spent outdoors, often in harsh UVR environments. Despite exposure to high and/or frequent doses of UVR in recreational and tactical athletes, adequate sun-protection practices are often disregarded or not well understood by many within these at-risk populations, resulting in heightened risk of negative UVR effects. The focus of this review is to examine the available literature regarding UVR exposure, risk of adverse health effects of UVR exposure, and sun protection practices in outdoor exercisers, athletes, and military personnel.

Summary Statement

Outdoor athletes and military personnel may be at elevated risk of ultraviolet radiation-related health issues from persistent sun exposure.

Keywords

Ultraviolet radiation; athletes; military; sun protection; skin cancer

Introduction

Over-exposure to ultraviolet radiation (UVR) from the sun is associated with multiple health risks including DNA damage, immune suppression, premature skin aging, skin vascular dysfunction, and skin cancer (1–5). Those who regularly exercise or compete outdoors are at particularly high risk of experiencing these deleterious effects of UVR (6). Similarly, tactical athletes such as military personnel frequently spend extended periods of time outdoors, often

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in high-UVR environments, putting them at elevated risk of experiencing these same potentially harmful effects. Thus, it is crucial to understand the impact of repeated and/or long-term exposures to UVR, as well as sun-safety behaviors and perceptions, in these populations.

The purpose of this review is to examine how UVR exposure experienced by outdoor athletes, regular exercisers, and military personnel elevate UVR-related health risks. The magnitude of UVR exposure in athletes/exercisers and military personnel will be discussed, along with the health risks imposed by such exposures. Lastly, we will address the current state of sun protection practices and barriers to adequate sun protection in these active populations.

Measuring and Reporting Ultraviolet Radiation Exposure

Personal UVR exposures are typically expressed in a variety of ways, including *multiples of minimal erythema dose* (MED) or *standard erythema dose* (SED). One MED is defined as the minimal UVR dose necessary to elicit a visible erythema (reddening) response with well-defined skin borders 24 hours after exposure (7). MED is highly variable and dependent upon individual factors such as skin pigmentation and regular sun exposure practices.

One SED, on the other hand, is equivalent to an effective erythemogenic radiation exposure of 100 $J \cdot m^{-2}$ (8). SED eliminates individual skin differences in erythema responses and provides a more consistent measure of UVR exposure that can be generalized between individuals and among populations. For individuals with mild to moderate skin pigmentation (Fitzpatrick skin types I-IV), the MED falls within the range of 1.5 – 6 SED (7). Table 1 describes skin sensitivity to UVR exposure for different skin types.

The UV Index provides an easy-to-use indicator of biologically effective UVR exposure using the time-weighted average effective UV irradiance ($W \cdot m^2$) (9). A UV Index of 0 indicates a low risk of harm from unprotected UVR exposure, whereas an index of 11 or above is associated with extreme risk. One UV Index-hour corresponds to 90 $J \cdot m^{-2}$ (10); thus, at a moderate UV Index of 5, one hour of exposure is equivalent to 450 $J \cdot m^{-2}$ or 4.5 SED. As such, one hour of continuous sun exposure with a UV Index of 5 is likely to elicit a skin-reddening response in those with skin types I – III, and potentially skin type IV, if the skin is unprotected.

Outdoor Athletes and Ultraviolet Radiation Exposure

Those who participate in regular outdoor exercise or sport competition experience high daily doses of UVR exposure. The International Commission on Non-ionizing Radiation Protection (ICNIRP) has established guidelines for protection of outdoor workers against UVR exposure that are equally applicable to exercise occasions (11). According to those guidelines, maximum biologically effective UVR exposure over an eight-hour period should be limited to 30 $J \cdot m^{-2}$, a dose equivalent to approximately 1.0 – 1.3 SED or 0.5 MED for fair skin (11).

Studies using personal UVR dosimetry have allowed for quantification of the magnitude of UVR exposure experienced by those who work, exercise, or compete outdoors. Six professional cyclists competing in the Tour de Suisse wore personal UVR dosimeters attached to the back of their jerseys over the first eight stages of the race, demonstrating daily UVR doses as high as 17.2 MED and average daily UVR exposures of 8.1 MED (12). Three ironman triathletes competing at the World Championships in Kona, Hawaii were exposed to a total of 6.9 to 9.7 MED during the cycling and running portions of the race (13). Alpine ski instructors who wore UVR dosimetry for 26 days were exposed to daily UV-B exposures ranging from 0.5 to 7.6 MED, with more than two-thirds of the ski instructors exposed to greater than 2 MED of UV-B daily for the entire study period (14). Further, 10% of the ski instructors in that study were exposed to more than 1 MED per hour during peak exposure times. In marathon runners competing in the Barcelona and Madrid marathons, UVR exposures of 10 and 4.5 MED were experienced, respectively. These exposures far exceed the ICNIRP guidelines (11), and are likely to result in repeated sun damage and increased risk of UVR-related health issues.

High personal UVR exposures have also been reported in SED for hikers, tennis players, and runners during the summer and autumn months (15). On average, the hiking group spent 6.4 hours per day outdoors and experienced daily UVR exposures ranging from 1.8 to 19.5 SED, with a median daily exposure of 8.1 SED. Daily UVR exposures in tennis players who spent 4 hours per day outdoors ranged from 2.0 to 13.8 SED, and the median daily exposure was 7.5 SED. Runners who wore UVR dosimeters during races and spent 18 hours per day outdoors on average were exposed to 9.3 to 23.8 SED per day, with median exposure of 14.6 SED per day. Importantly, in that study hikers, tennis players, and runners *all* exceeded the UVR dose exposure limit recommended by the ICNIRP (11) by up to 8-fold, and in many cases the UVR exposure limit was reached in less than 20 minutes.

Risk of Adverse Effects from Ultraviolet Radiation Exposure in Athletes and Exercisers

Large doses of UVR exposure in those who exercise and/or compete outdoors may increase their risk of experiencing deleterious health effects. Indeed, the incidence of sunburn was significantly greater in those who self-reported *any* amount of physical activity outdoors compared to those who were inactive (6). Further, for every hour increase in outdoor physical activity there was a 2–4% increase in the likelihood of a sunburn. In a cohort of 290 NCAA athletes across 13 different sports, 84% had experienced one or more sunburns in the previous year and 28% had experienced at least four sunburns (16). These findings support the fact that those who participate in outdoor sports or exercise represent a population that is particularly vulnerable to the deleterious health effects of UVR exposure.

Regular exercisers and athletes who participate in outdoor sports are at increased risk of developing skin cancer. Sun exposure and sunburn may promote skin cancer via DNA damage in the skin, particularly damage to the tumor-suppressor gene *p53* (17, 18), resulting in cellular arrest, apoptosis, and tumorigenesis. The fact that regular physical activity is associated with a reduced risk of most cancers is well established. The exceptions to this relation are prostate and skin cancer. Examining the relation between physical activity and hazard ratio for 26 types of cancer in 1.44 million participants, those who were in the 90th

percentile of physical activity participation demonstrated reduced risk or no change compared to those in the 10th percentile for all types of cancer except prostate cancer and malignant melanoma (19). For malignant melanoma and prostate cancer, however, those in the 90th percentile of physical activity demonstrated *increased* hazard ratios compared to those in the 10th percentile. Furthermore, the association between malignant melanoma and physical activity was strengthened in high-UVR areas, suggesting that physically active people are, indeed, at an elevated risk for malignant melanoma compared to their less-active counterparts. Although that study did not characterize the relative risk of developing malignant melanoma for those who participated in outdoor compared to indoor physical activity, the increased hazard ratio in those who were most physically active can likely be explained by increased time spent outdoors rather than physical activity, per se. Of note, increased risk for prostate cancer was suggested to be a result of screening bias.

Common and atypical melanocytic nevi (moles) and actinic lentigines (lesions on sun exposed skin; also known as liver spots or age spots) are associated with nonmelanoma skin cancer, and may precede the development of malignant melanoma (20). Atypical melanocytic nevi and actinic lentigines are more common in marathon runners compared to control subjects (21). Further, higher training heart rates, training velocity, and physical strain indices were associated with significantly more melanocytic nevi on the left shoulder of marathon runners (22). Thus, development of nevi and lentigines are exaggerated in endurance athletes not only because of increased sun exposure, but also potentially due to immunosuppression during long training bouts. Endurance exercise-induced immune suppression may occur in response to large training loads (23) and diminish DNA repair in the skin after prolonged sun exposures, resulting in gene mutations and tumorigenesis.

Several studies have demonstrated increased incidence of skin cancer development in athletes within a variety of competitive outdoor sports. In a large sample of Swiss residents, the risk of basal cell carcinoma was two-fold greater in those who participated in outdoor sports compared to those who did not (24). Studies examining skin cancer prevalence in surfers in the Texas Gulf Coast (25) and Australia (26) documented non-melanoma and/or melanoma skin cancer in 18% and 14% of subjects, respectively, and the prevalence of skin cancer was greater in competitive surfers (17%) compared to recreational surfers (11%) (26). Precancerous lentigines were significantly more prevalent in a cohort of 283 mountain guides (25%) in Germany, Switzerland, and Austria compared to age-matched controls (7%) (27). Squamous cell carcinoma, basal cell carcinoma, and/or melanoma were diagnosed in approximately 12% of mountain guides, but no skin cancers were found in any of the control subjects. Two of the most important risk factors found in that study were lifetime number of heavy sunburns and lifetime days working as a guide. Taken together, these studies clearly demonstrate an elevated risk of skin cancer for those who regularly participate in outdoor sports or exercise, highlighting the importance of sun-protection strategies in those populations.

Sun Protection in Athletes and Exercisers

Despite being at increased risk for deleterious health effects of sun exposure, regular outdoor exercisers and athletes often do not adhere to adequate sun protection behaviors and practices. In a sample of 290 NCAA collegiate athletes, less than 25% reported regular use of sunscreen despite averaging 4 hours per day training outdoors over 10 months out of the year (16). Similar results were demonstrated in 186 collegiate soccer and cross-country athletes, 85% of whom reported no use of sunscreen over the previous 7 days of practice (28). An analysis of young adult (ages 18 to 30 years) men and women competing in field hockey, soccer, tennis, and surfing suggested that there are differences among sports and between men and women in sun protection behavior, with female participants engaging in far greater sunscreen use (Table 2) (29). Similarly, in a cohort of 970 runners in Switzerland, sex and age were predictive of sun-protective behaviors, such that women and adults older than 35 years were more likely to protect themselves from the sun (30). Only 5% of *adolescent* athletes in Buenos Aires reported regular use of sunscreen during training (31); this is particularly important in light of the fact that sun exposure in adolescence is positively associated with risk of melanoma in adulthood (32, 33).

Recommended sun safety strategies include: (1) avoiding sun exposure during peak UVR exposure hours, (2) staying in the shade while outdoors, (3) applying sunscreen with sun protection factor (SPF) ≥30 and reapplying sunscreen when sweating or swimming, (4) wearing hats and sunglasses, and (5) wearing protective clothing with long pants or sleeves that are black, navy blue, or green (34). Sunscreen should be properly applied at 2 mg/cm^2 (35) to ensure that the sunscreen is effective at its reported SPF, and reapplied every two hours when spending prolonged periods outdoors. Reasons for inadequate sun safety behavior in athletes include:

- rules of competition (i.e., equipment guidelines),
- lack of sunscreen availability,
- forgetting to apply sunscreen, and
- the belief that using sunscreen will impair their performance (34).

Although the most commonly reported barriers to optimal sun protection are lack of sunscreen availability or forgetting to apply sunscreen (16, 28), many athletes choose not to apply sunscreen, believing that sunscreen might impair performance by making their hands slippery, causing eye irritation (16, 36), or negatively impacting heat dissipation by reducing sweat production and/or evaporation, although studies examining these effects of sunscreen on thermoregulation are equivocal (37–41). Competition guidelines may also pose a substantial barrier to sun protection in many sports. In Ironman triathletes, sunscreen is not allowed on the shoulders or thighs where numbers are marked on the skin (13). Field hockey and soccer players are not permitted to wear hats or sunglasses due to equipment guidelines (29), and volleyball players are required to wear jerseys and shorts that leave a large skin surface area uncovered and exposed to the sun (42). Similarly, traditional sportswear in cycling and running leave large areas of the skin exposed to the sun (21, 43), usually to enhance heat dissipation. Such clothing guidelines and restriction within sport further highlight the importance of sunscreen use for these athlete populations.

Military Population and Ultraviolet Radiation Exposure

In addition to those who participate in outdoor recreational exercise or sport, military personnel represent an often-overlooked group with unique exposures to UVR, that likewise place these tactical athletes at higher risk for melanoma. Although rather sparse data are available regarding UVR exposure in the military compared to outdoor exercisers and athletes, active duty personnel are frequently required to be outdoors for prolonged periods of time, often with strict regulations on equipment and clothing coverage. Further, military personnel are often faced with other immediate safety concerns that may take priority over preventive care such as protection against UVR exposure and associated risks.

Although it is well-known that military personnel, particularly in the deployed environment, may experience large amounts of UVR exposure, no studies have yet been conducted to specifically assess daily doses of UVR in the military population. More than 3 million soldiers were deployed from 2001 to 2014 in support of Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) in Afghanistan and Iraq, respectively. Due to the relatively equatorial latitudes of these austere deployed environments, UVR exposure is often severe, with minimal seasonal variation, and thus may increase risk of melanoma (44). During deployment in support of OEF and OIF, 84% of respondents worked in a desert climate, with 64% spending three-quarters of their day in bright sun. 77% of respondents reported spending at least four hours per day in bright sun (45). Thus, military personnel deployed in such environments are at increased risk of experiencing deleterious health effects of UVR exposure.

Risks of Adverse Effects from Ultraviolet Radiation Exposure in the Military Population

Several studies have compared the incidence of melanoma in the general population versus specific military populations, with varied conclusions depending upon the specific subpopulation within the military. Increased rates of melanoma and non-melanoma skin cancers have been observed among United States veterans who operated in equatorial climates such as southwest Asia and the Western Pacific (46, 47). Rates of malignant melanoma in active duty personnel compared to the U.S. general population are 62% greater in the military, with the highest incidence observed in the Air Force (48).

Opposing findings, however, have also been reported, showing no differences in the incidence of melanoma between the general U.S. population and the Navy or Air Force branches of the U.S. military (49, 50). A comparison of melanoma incidence rates between active duty and general U.S populations within the age range of 20 to 59 years revealed *lower* age-adjusted incidence rates in the military (51). However, military age-specific rates were significantly higher in older individuals, with an age-dependent reversal of the incidence rate ratio (IRR) around age 45. Thus, the incidence rates for melanoma are lower in the military compared to the general population among those age 45 or younger, but higher in the military for those older than 45.

These differential skin cancer rates within the military population may be explained, at least in part, by improved education regarding sun safety and better preventative practices in recent years. Incidence rates (per 100,000 person-years) in the military compared to the general U.S. population were 34 vs. 27 among 45 to 49 year-olds, 50 vs. 32 among 50 to 54 year-olds, and 178 vs. 39 among 55 to 59 year-olds. Further, when comparing annual relative increases in the incidence of melanoma, the incidence among men rose by 36% in the military compared to only 7% in the general population from 1990–1994 and 2000 to 2004, with the greatest rise in incidence occurring in young men (40% in those aged 20 to 44 compared to 19% in those aged 45 to 59) in the military. In summary, melanoma rates rose over this decade in both military and civilian populations, but the greatest relative increase in incidence occurred among younger men in the military (51). Although the results of these studies vary, they suggest that the military population represent an at-risk population for adverse health effects of UVR and highlight the need to promote sun-safety behaviors in that population.

Sun Protection in the Military Population

With specific regulations on uniform attire that often requiring soldiers to wear proper long pants and a long-sleeved blouse, sun protection may be an afterthought for most military personnel (52). Though the uniform regulations are strictly enforced for wear in garrison, soldiers are permitted to make uniform adjustments such as rolling shirt sleeves above the elbow or de-blousing during times of high environmental heat loads, as determined by wet-bulb globe temperature (WBGT) (53). Although such adjustments to military uniform wear allow enhanced evaporative and convective cooling to mitigate heat injury, they also result in additional UVR exposures that may go unnoticed. During deployment, military personnel reported that their exposed skin was unprotected at least 70% of the time and fewer than 30% of surveyed soldiers reported regular sunscreen use (54).

The U.S. Army acknowledges the need for sun-safety education and provides sun-specific guidelines as part of their overall environmental casualty prevention guidance (55). The Army also includes written recommendations for sunscreen use with SPF rating of at least 15, and for unit commanders to ensure soldiers maintain their supply and apply when needed (52, 55). However, despite reporting long hours in bright sun, only 13% of military personnel reported routine sunscreen use and less than 30% had routine access to sunscreen while working (45). Thus, although regulations exist to promote sun-safety, further efforts may be warranted to enhance implementation of sun-safety behaviors in the military population.

Conclusions

Military personnel and outdoor athletes and exercisers represent two populations at elevated risk of over-exposure to UVR from the sun, and consequent negative health impacts from UVR exposure. As such, promoting healthy sun-protection behaviors in these populations is crucial. Risks associated with UVR exposures can be directly mitigated by wearing UVR protective clothing and sunscreen. However, inadequate sun-protection still often occurs in these athletes due to equipment regulations, lack of readily-available sunscreen, or forgetting to (or consciously choosing not to) apply sunscreen. Some competitive athletes choose not to use sunscreen due to the belief that sunscreen may impair performance or thermoregulatory capacity, although there is not strong evidence to support any impairment. These observations highlight the need for improved education about the negative health consequences of over-exposure to UVR, as well as the importance of practicing appropriate sun-protection behaviors, in outdoor athletes and military populations. Improved efforts should also be made to improve availability and accessibility to sunscreen when no other sun-protection strategies are feasible.

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Table 1.

Fitzpatrick skin types and sensitivity to ultraviolet radiation (UVR) exposure.

Skin Type	Skin Color	Tanning Ability	UVR Sensitivity	Continuous UVR Exposure Resulting in Erythema (SED)
I	Pale white	Always burns, does not tan	Extremely sensitive	2 – 3
II	Fair white	Burns very readily	Very sensitive	2.5 – 3
III	Darker white	May burn with no protection	Moderately sensitive	3 – 5
IV	Light brown	Burns rarely	Relatively tolerant	4.5 – 6
V	Brown	Despite pigmentation, may burn without protection	Very variable	6 – 20
VI	Dark brown or black	Rarely burns, although sunburn is difficult to detect	Relatively insensitive	6 – 20

Table 2.

Prevalence of sunscreen use in men and women competing in four different sports[29].

Sunscreen Use During Competition (%)		
Sport	**Men**	**Women**
Field Hockey	18	67
Soccer	24	82
Tennis	63	76
Surfing	93	100