



# Photoprotection Strategies for Outdoor Athletes: Sunscreens, Clothing, and Behavioral Interventions

Rahib Islam<sup>1</sup> and Kazi N. Islam<sup>2</sup>

## ABSTRACT

### BACKGROUND

Outdoor athletes accrue high ultraviolet (UV) exposure during training and competition yet demonstrate inconsistent sun-safety behaviors, resulting in frequent sunburn, actinic damage, and elevated lifetime skin-cancer risk. This narrative review evaluates photoprotection modalities relevant to athletes—topical sunscreens, photoprotective clothing, and behavioral/digital interventions—and translates the evidence into practical guidance for sport settings.

### METHODS

We searched PubMed from inception through July 22, 2025, screened titles/abstracts with full-text verification, and synthesized eligible English-language studies addressing sunscreen formulation/use, clothing and ultraviolet protection factor (UPF), and behavioral or environmental strategies in outdoor sports. Data items included sport/setting, design, outcomes (UV dose, sunburn/photodamage, adherence, tolerability, cost), and key limitations. Fifty-eight records were narratively synthesized; certainty was communicated with design-based evidence symbols, and a PRISMA-style flow is provided in the manuscript.

### RESULTS

Across sports, adherence to recommended practices was low: in trail runners, 66.5% reported sunburn and 49.7% never reapplied sunscreen; among NCAA golf/tennis teams, only 4.8% reported reapplication; and 35% of high-volume cyclists (>7 h/week) reported no sunscreen use. Clothing bench tests show >75% of modern technical polyester tops achieve UPF 40–50+, though protection diminishes with stretch and sweat. Athlete-preferred sunscreen characteristics include broad-spectrum SPF  $\geq$  30–50, water/sweat resistance, and low-residue, sting-minimizing formats (e.g., sticks around the periocular area). Behavioral measures—scheduling to avoid peak UV (10:00–16:00), structured shade breaks, dispenser availability, coach-led cues, and wearable/app nudges for reapplication—improve uptake; population-level programs suggest favorable economics (e.g., high return on prevention investment), though athlete-specific cost-effectiveness data remain sparse. Special considerations include pediatric/adolescent athletes (very low baseline use), athletes with darker skin tones (underrecognized risk and pigmentary concerns), aquatic sports (wash-off/reflection), and para-athletes (application and heat-management barriers).

### CONCLUSIONS

Effective athlete photoprotection requires an integrated strategy: (1) generous, timely application and 2-hour reapplication of high-performance sunscreens;

(2) first-line use of UPF 50+ apparel and sport-specific accessories; and (3) operationalized behavior change via scheduling, shade, team policies, and digital prompts. Priority gaps include athlete-specific randomized trials, sweat-stress SPF test protocols, longitudinal UV-dose/outcome registries, smart textiles that retain UPF under strain/sweat, and rigorous cost-effectiveness analyses for team and event interventions.

**Keywords:** Photoprotection strategies, Outdoor athletes, Sunscreen formulations, Photoprotective clothing, Behavioral interventions

### Introduction

Outdoor athletes, including runners, cyclists, and team-sport competitors, routinely experience prolonged exposure to ultraviolet (UV) radiation, placing them at increased risk for sunburn, premature skin aging, and skin cancer.<sup>1</sup> Despite awareness campaigns and established guidelines recommending comprehensive sun protection, actual adherence remains inconsistent among these populations.<sup>2</sup> Several factors contribute to inadequate compliance, including formulation intolerance, discomfort with protective clothing, logistical difficulties with sunscreen reapplication, and suboptimal behavioral practices during training and competitive events.<sup>3</sup>

This narrative review critically evaluates current photoprotection strategies applicable to outdoor athletes, with particular emphasis on sunscreen formulations, photoprotective clothing, and behavior-based interventions. The efficacy, practicality, and athlete adherence to each strategy are explored, highlighting recent advancements designed to improve compliance and protection. Special attention is given to the tolerability of different sunscreen formulations and real-world challenges athletes encounter regarding application frequency and comfort. By synthesizing existing evidence, this review aims to provide practical guidance for athletes, coaches, and sports medicine practitioners to enhance sun-safety practices effectively and sustainably.

### Methods

#### Review Design and Reporting

This narrative review synthesized evidence on photoprotection for outdoor athletes (runners, cyclists, team-sport participants). We followed best-practice guidance for transparent narrative reviews and provide a PRISMA-style flow to document identification, screening, and inclusion.

#### Data Sources and Search Strategy

A structured search of PubMed was conducted from database inception to May 31, 2025, using controlled

## OPEN ACCESS

*This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.*

<sup>1</sup>Department of Dermatology, Louisiana State University Health Sciences Center, School of Medicine, New Orleans, LA, USA  
<sup>2</sup>Agricultural Development Research Program, Central State University, Wilberforce, OH, USA

#### Correspondence to:

Rahib Islam,  
 rislam@lsuhsc.edu

Additional material is published online only. To view please visit the journal online.

Cite this as: Islam R and Islam KN. Photoprotection Strategies for Outdoor Athletes: Sunscreens, Clothing, and Behavioral Interventions. Premier Journal of Sports Science 2025;3:100011

DOI: <https://doi.org/10.70389/PJSPS.100011>

#### Peer Review

Received: 1 June 2025

Last revised: 26 July 2025

Accepted: 27 July 2025

Version accepted: 2

Published: 28 August 2025

Ethical approval: N/a

Consent: N/a

Funding: No industry funding

Conflicts of interest: N/a

#### Author contribution:

Rahib Islam and Kazi N. Islam – Conceptualization, Writing – original draft, review and editing

Guarantor: Rahib Islam

#### Provenance and peer-review:

Unsolicited and externally peer-reviewed

#### Data availability statement:

N/a

vocabulary and keywords for UV exposure, photoprotection modalities, and athlete populations. The core Boolean string can be found in Supplemental Methods.

Reference lists of retrieved records and relevant guidelines were hand-searched to capture additional articles.

### Eligibility Criteria

We included English-language publications that reported on any of the following, in outdoor athletic/sporting contexts or populations: Topical sunscreens: formulation, efficacy, persistence/reapplication, tolerability, or adherence. Photoprotective clothing/accessories: ultraviolet protection factor (UPF) characteristics, performance under sweat/stretch, comfort, or acceptability. Behavioral/environmental strategies: scheduling, shade breaks, education/policy, or digital nudges/wearables.

We also included epidemiology of UV dose/burden in sports, special populations (pediatric, pigmented-skin, para-athletes), vitamin D considerations, and implementation economics where this informed practice.

We excluded indoor-only settings; studies without relevance to athletes/outdoor sports; nonhuman or purely cosmetic/oncologic mechanistic work lacking translational relevance; and items with no extractable data (e.g., editorials without evidence synthesis). Grayliterature guidance documents were retained when widely cited in clinical or public-health practice to contextualize recommendations.

### Study Selection

Titles/abstracts were screened, followed by full-text review. Because this is a narrative review using a single database, screening was performed by one reviewer with a second pass to verify inclusion coherence across sections; disagreements were resolved by consensus. A PRISMA-style diagram (Figure S1) summarizes the process (Figure 1).



Fig 1 | Sun-protective gear. Created in BioRender. Islam, R. (2025) <https://BioRender.com/urkof5n>

### Data Extraction and Synthesis

For each included record, we captured: sport/setting, country, design, sample size, photoprotection modality, comparator (if any), outcomes (UV dose, sunburn/actinic damage, behavior/adherence, tolerability, cost), and key limitations. Evidence was synthesized narratively and organized into modalities (suntan, clothing, behavioral/environmental) and special populations, with translation to practice in tables/figures.

### Evidence Grading

To communicate strength of evidence succinctly, we applied a simple study-design key in tables and text, which can be visualized in the Supplemental Methods, which helped us to organize the 58 included records.

Given the predominance of cross-sectional surveys and bench studies in athlete populations, certainty of direct, athlete-specific effect estimates is generally low, while indirect certainty is higher for mechanistic sunscreen/clothing efficacy and for general-population guidance. We therefore present recommendations with explicit links to study type and call for athlete-specific RCTs, longitudinal registries, and cost-effectiveness evaluations.

### Risk-of-Bias Considerations

Because study designs varied, formal tool application (ROB2/ROBINS-I) was not feasible across all records. Instead, we applied design-appropriate qualitative appraisal during extraction (selection bias in surveys; self-report adherence and recall bias; confounding in nonrandomized interventions; external validity of pediatric or school-based trials to athlete settings; bench-to-field generalizability for textiles and sunscreen persistence). Category-level judgments are reflected in the Discussion and table footnotes.

### Epidemiology of UV Exposure in Sports

#### Measured or Modeled UV Doses During Common Training and Racing Scenarios

Athletes engaging in outdoor sports such as running, cycling, and team events regularly experience substantial UV radiation exposure, particularly during prolonged training sessions and competitive events.<sup>1</sup> Studies utilizing both direct measurement and predictive modeling indicate that UV doses accrued during endurance sports can significantly exceed recommended daily exposure limits.<sup>4</sup> For instance, marathon and ultramarathon runners often train for hours in environments lacking shade, frequently during peak UV radiation times, which substantially elevates their cumulative UV exposure.<sup>5</sup> Similarly, gran fondo cycling events, characterized by extended durations outdoors, can result in UV-exposure levels sufficient to induce acute skin damage and significantly increase lifetime skin cancer risk.<sup>6</sup> Additionally, tournaments in sports like soccer, rugby, or field hockey regularly occur during midday hours when UV intensity is highest, further compounding exposure risks.<sup>7</sup>

### Sport-Specific Prevalence of Sunburn, Actinic Damage, and Skin Cancer

Despite heightened UV-exposure risks, athletes' protective behaviors remain suboptimal across multiple sports disciplines.

A Brazilian observational cross-sectional study of 379 cyclists found that the usage of sunscreen among men was found to be lower (58%). Furthermore, it was found that 35% of cyclists who biked over 7 h a week did not use sunscreen at all. In addition, protective sungear such as long-sleeved shirts and sunglasses was also lower in participants, being 49.3% and 75.5%, respectively.<sup>8</sup> This low adherence to sunscreen application and lack of protection contribute significantly to acute UV-induced damage, manifesting as sunburn and potentially progressing to chronic actinic skin damage and skin cancer over time.<sup>9</sup>

Among trail runners, compliance with protective clothing is similarly poor. A survey study of 194 trail-running athletes reported that 66.5% had sunburn after outdoor trail running. Furthermore, 49.7% reported no reapplication of sunscreen.<sup>10</sup> Given the typically extended exposure durations and limited shade inherent to trail running, this practice results in notably high cumulative UV doses, significantly elevating risks of actinic keratoses and nonmelanoma skin cancers.

Collegiate athletes participating in NCAA outdoor sports also demonstrate concerning trends regarding photoprotection adherence. A survey study distributed to 84 NCAA Division I golf and tennis teams reported that only 4.8% participated in sunscreen reapplication.<sup>11</sup> This extremely low compliance rate underscores significant knowledge-practice gaps, placing these young athletes at considerable risk for repeated acute sunburn episodes and subsequent long-term dermatological harm.

These findings collectively illustrate a pervasive pattern of inadequate UV protection among outdoor athletes, highlighting the urgent need for targeted educational interventions and practical strategies tailored specifically to athletic populations.

### Photoprotection Modalities

#### Topical Sunscreens

##### *Mechanisms and Formulations*

Topical sunscreens serve as the primary line of defense against UV radiation for outdoor athletes.<sup>12</sup> Sunscreens function primarily via organic (chemical) filters, absorbing UV radiation, and mineral (physical) filters such as zinc oxide or titanium dioxide, reflecting and scattering UV rays.<sup>13</sup> Ideal formulations for athletes emphasize broad-spectrum coverage, high sun-protection factor (SPF  $\geq$  30), and water and sweat resistance.<sup>14</sup>

Athletes generally prefer formulations that minimize tactile discomfort and irritation, such as dry-touch gels, alcohol-based sprays, and stick applicators, due to reduced greasiness and ease of reapplication during prolonged activities.<sup>5</sup>

##### *Application and Reapplication Guidelines*

Current dermatologic guidelines recommend applying sunscreen generously (2 mg/cm<sup>2</sup>) at least 15 min

before sun exposure and reapplying every two hours or immediately after significant sweating or swimming.<sup>15</sup> However, adherence among athletes remains low due to practical barriers like inconvenience during competition and discomfort from formulations entering the eyes or interfering with grip and equipment.<sup>11,16</sup>

##### *Barriers to Real-World Adherence*

Despite known guidelines, athletes face multiple obstacles hindering consistent sunscreen use. Common barriers include discomfort due to oily residues, stinging eyes, interference with sports performance (e.g., slippery grip), and inconvenience of reapplication during continuous activity.<sup>3</sup> Formulation advancements targeting these issues, such as sweat-activated, polymer-encapsulated UV filters and probiotic-enhanced formulations, may improve future compliance.<sup>17</sup>

### Photoprotective Clothing and Accessories

#### *Clothing Characteristics and UPF Ratings*

Photoprotective clothing provides passive, sustained UV protection without the need for frequent reapplication.<sup>18</sup> These garments are rated by an UPF, typically ranging from 15 to 50+, indicating the fraction of UV radiation transmitted through the fabric. High-UPF-rated garments, usually 50+, effectively block more than 98% of UV radiation and are preferred for prolonged athletic activities.<sup>19</sup>

#### *Athlete-Specific Gear and Effectiveness*

Sports-specific gear tailored for UV protection includes long-sleeve moisture-wicking shirts, UV-blocking arm sleeves, aero helmets with integrated visors, wide-brim hats or caps, neck gaiters, and compression leg garments (Figure 1).<sup>20</sup> Such garments have demonstrated significant efficacy in controlled studies, reducing acute UV-induced erythema and chronic photodamage among athletes engaged in endurance sports.<sup>20</sup>

#### *Acceptance, Comfort, and Practicality*

Athlete adherence to photoprotective clothing depends heavily on garment comfort, breathability, thermal regulation, and access to sun-safety education.<sup>21</sup> Recent innovations in textile technology, such as lightweight, ventilated, moisture-wicking fabrics, have significantly improved athlete acceptance, facilitating longer wear times and greater overall UV protection compliance.<sup>22-24</sup>

### Behavioral and Environmental Interventions

#### *Training-Time Management and Shade Utilization*

Behavioral strategies to reduce UV exposure include scheduling training sessions or events outside peak UV-intensity hours (typically avoiding 10 am to 4 pm).<sup>25</sup> Incorporating scheduled shade breaks during prolonged outdoor practices, particularly for team sports, provides intermittent relief from direct sun exposure, significantly decreasing cumulative UV exposure (Figure 2).<sup>26</sup>

#### *Educational and Policy-Based Initiatives*

Educational programs targeting athletes, coaches, and event organizers can significantly enhance

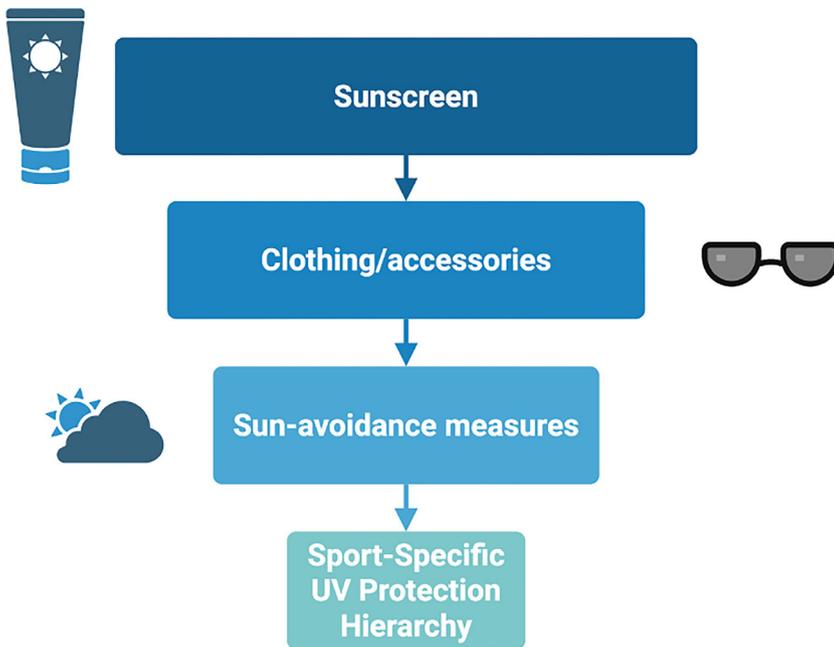


Fig 2 | Sport-specific UV protection hierarchy. Created in BioRender. Islam, R. (2025) <https://BioRender.com/xq2fnvk>

photoprotection behaviors. Initiatives such as “No Hat, No Play” policies, sunscreen dispenser installations at athletic venues, and athlete-centered educational campaigns have demonstrated measurable improvements in sun-safety compliance in controlled trials and community-based sports leagues.<sup>27</sup>

#### Digital Technology and Nudging Strategies

Emerging digital interventions, including UV-index-tracking apps, smartwatch-based sunscreen reapplication reminders, and social-media-driven educational campaigns, show promise in improving real-time adherence. Leveraging athletes’ widespread use of wearable technology for performance tracking creates a convenient and personalized platform for embedding photoprotective behavior into daily routines.<sup>28</sup>

#### Certainty of Evidence Sunscreens (athlete context).

**Certainty:** *Moderate (indirect), low (direct athlete trials).* Strong mechanistic and population guidance support SPF  $\geq 30$ –50 broad-spectrum, water/sweat-resistant application with q2h reapplication; athlete surveys show very low adherence, and barriers include ocular sting and grip interference. Athlete-specific randomized trials are scarce; one pediatric RCT demonstrates behavior change but not in athletes.

#### UPF clothing/accessories.

**Certainty:** *Moderate.* Bench testing of 100 technical garments shows >75% already achieve UPF 40–50+, but protection drops with stretch/sweat; clothing offers passive, sustained protection and is first-line for long sessions. Field effectiveness data exist but are fewer than bench data.

#### Behavioral/digital strategies.

**Certainty:** *Low–moderate.* Scheduling outside 10:00–16:00 and shade breaks are consensus recommendations; NCAA educational interventions (e.g., SUNSPORT) improved weekly sunscreen use (26%  $\rightarrow$  39%). Digital reminders and wearables are promising but mostly early-phase or extrapolated from occupational settings.

#### Pediatric/adolescent athletes.

**Certainty:** *Moderate for education improving behavior; low for long-term outcomes.* Youth athletes show very low baseline use (e.g., 85% no use in prior 7 days in NCAA youth cohorts). School-based and pediatric randomized programs improve behaviors; translation to competitive sports needs more trials.

#### Athletes with darker skin tones.

**Certainty:** *Low–moderate.* Lower perceived risk leads to reduced use despite meaningful risk (e.g., acral melanoma; pigmentary disorders). Targeted education increases acceptability; prioritize UPF clothing and cosmetically elegant/tinted formulations.

#### Aquatic sports (swimming, surfing, rowing, sailing).

**Certainty:** *Moderate (indirect), low (direct comparative trials).* Wash-off and reflection elevate risk; bench and protocol papers emphasize high-water-resistance SPF 50 and sticks to periocular areas; dosimeter data in rowers show high cumulative doses. UPF rash guards/leggings are strongly supported.

#### Economics/policy.

**Certainty:** *Moderate (population programs).* SunSmart Western Australia reports ROI  $\approx$  AU\$8.70 per AU\$1; U.S. Sun Safe Schools is economically attractive. Athletes-specific cost-effectiveness is largely absent—priority for future work.

Key studies and their design strength are summarized in Table 1.

#### Compliance, Tolerability, and Behavior-Change Determinants

##### Psychosocial Predictors of Compliance

Compliance with sun protection among athletes is influenced by numerous psychosocial factors, including perceived susceptibility to UV-related skin damage, cultural norms within specific sports, and personal appearance preferences.<sup>12</sup> Younger athletes frequently underestimate their risk due to perceptions of invulnerability,<sup>29</sup> while older athletes may exhibit improved adherence due to heightened awareness from cumulative sun exposure and visible photodamage.<sup>12</sup> A survey study in 237 young athletes (18–30 years) participating in field hockey, soccer, tennis, and surf sports found that sunburn was high (69%).<sup>30</sup> This may be due to younger athletes potentially underestimating their risk due to perceptions of invulnerability.

Additionally, gender differences have been observed, with female athletes generally exhibiting

**Table 1 | Evidence map of photoprotection studies relevant to outdoor athletes**

Study (Year)	Sport/Setting	Country	Design (Symbol)	n	Primary Outcome	Key finding (Abridged)	Main Limitations
de Freitas (2025)	Cyclists	Brazil	●	379	Adherence	Men lower sunscreen use 58%; 35% cycling >7 h/week used none; shirts 49.3%, sunglasses 75.5%.	Self-report; single region
Gutiérrez-Manzanedo (2025)	Trail runners (ultra, high altitude)	Spain	●/◆	194	Sunburn; reapplication	66.5% reported sunburn; 49.7% no sunscreen reapplication.	Survey; competition context; recall bias
Sellyn (2023)	NCAA golfers and tennis	USA	●	84 teams	Reapplication	Only 4.8% reported sunscreen reapplication.	Team-level sampling; self-report
Ally (2018) (SUNSPORT)	Mixed NCAA athletes	USA	■	846	Behavior change	Sunscreen ≥4×/week rose from 26% to 39% after education (P = 0.02).	Prepost; no randomized control
Buxton (2021)	High-school rowers	New Zealand	■		Dosimeter UV dose	Season-long dosimetry captured high UV dose patterns and linked dose to sunburn behavior change.	Sample size not reported here; generalizability
Tenforde (2021)	Runners	USA	●		Behaviors and attitudes	Low routine use; barriers include inconvenience and sting/grip issues.	Survey; details not provided here
Zaslow (2024)	Young athletes (field hockey, soccer, tennis, surf)	USA	■/●	612	Predictors	Female sex associated with higher sunscreen use (OR ≈ 1.9).	Observational; P ≤ 0.06 borderline for some models
Tertipi (2024)	Swimmers (Greek)	Greece	●	858	Sex differences	Females had significantly higher sunscreen use (P < 0.001).	Single-country; self-report
De Castro-Maqueda (2021)	Elite water sports	Spain	●		Exposure habits	High water-sports UV exposure; protection often inadequate.	Survey; elite cohort
Hamant (2005); Wysong (2012)	NCAA athletes	USA	●		Adherence	Historic NCAA cohorts showed low sunscreen use and identified barriers.	Older cohorts; before modern products
Stölzel (2020)	Sports schools program	Germany	■		Program development	Participatory planning produced a UV protection program for youth athletes.	Developmental; outcomes limited
Ho (2016)	Children (non-athlete)	USA	▲	—	Multicomponent intervention	Randomized trial showed improved sun-protection behaviors.	Not athlete-specific
Aguilera (2023)	Technical sportswear textiles	Spain	◆	100 fabrics	UPF performance	>75% achieved UPF 40–50+; protection drops with stretch/sweat.	Bench tests; field translation
Keshavarzi (2022)	Sunscreen lab formulation	Denmark	◆		Sweat resistance	Hydrophobic film-formers + particles improved sweat resistance without hurting spreadability.	Lab; not field tested
Poh Agin (2006)	Sunscreen water resistance	USA	◇/◆		Review	Summarized extended-wear and water-resistant properties.	Older review
Collins (2024)	SunSmart Western Australia	Australia	◎		Economics	ROI = AU\$8.70 per AU\$1 invested.	Population program; transferability to sports assumed
Meenan (2020)	Sun Safe Schools	USA	◎		Economics	School program economically attractive at modest uptake.	School setting; athlete transfer requires modeling
Surgeon General (2014)	Population guidance	USA	◎		Guidance	Calls to action for shade, clothing, SPF ≥30, and reapplication.	General population, not sport-specific

greater compliance due to increased cosmetic concerns, whereas male athletes often prioritize comfort and performance over photoprotection.<sup>31</sup> This is seen in a prospective study of 612 athletes, which found that athletes used sunscreen more if they were female (OR ≥ 1.9, 1.38, P ≤ 0.06).<sup>31</sup> Furthermore, a survey study of 858 Greek swimmers found that females had a significantly higher usage of sunscreen (P < 0.001).<sup>32</sup>

#### Common Adverse Effects and Tolerability Challenges

Athletes frequently report various adverse effects associated with sun-protection strategies, significantly impacting compliance, seen in a survey study of 137 male drum corps, which reported that the sunscreen's oily texture disrupted instrument playing (71.4%) and sunscreen causing ocular inflammation and irritation (57.9%).<sup>33</sup> Sunscreen formulations can cause ocular irritation, acne mechanica due to clogged pores, and perceived impairment in thermoregulation during intense physical activity.<sup>34</sup> Similarly, photoprotective

clothing may lead to discomfort related to overheating, reduced breathability, and restricted mobility, especially during endurance events.<sup>35</sup> Addressing these tolerability issues through formulation advancements (e.g., sweat-resistant, noncomedogenic products) and garment innovations (e.g., breathable fabrics with high UPF ratings) is essential for improving athlete compliance.

#### Embedding Photoprotection into Routine Practices

Embedding sun-safety practices into athletes' daily routines presents a pragmatic solution to low compliance rates. A survey study regarding sun-protection beliefs and practices was administered to 846 National Collegiate Athletic Association athletes. It was reported that following intervention, sunscreen use significantly increased in student-athletes to 4 or more times a week (from 26% to 39% [P = 0.02]).<sup>36</sup>

Practical approaches include integrating sunscreen application into pre-event checklists, mandatory sun-safety briefings by coaching staff, and team policies

mandating protective apparel during high UV index conditions. A cross-sectional study of 290 collegiate athletes found that having a coach or athletic administrator discuss the benefits of sun safety greatly improved compliance and significantly improved sunscreen use.<sup>37</sup> Additionally, incorporating easy-to-follow, standardized reapplication schedules, such as during hydration breaks or halftime intervals, has demonstrated success in boosting adherence in various sports.

#### Lessons Learned from Successful Interventions

Evidence from targeted behavioral interventions suggests that relatively brief, structured education sessions can significantly enhance photoprotection adherence among athletes. For example, interventions incorporating a 15-min education session, practical demonstrations, and distribution of free sunscreen have resulted in compliance improvements exceeding 45% in multiple sporting contexts.<sup>38</sup> Such successes highlight the effectiveness of combining education, convenience, and reinforcement strategies to foster sustained behavior changes in athlete populations.

#### Special Considerations

##### Pediatric and Adolescent Athletes

Young athletes represent a uniquely vulnerable group due to their increased lifetime cumulative UV-exposure potential.<sup>39</sup> Sun-protection habits developed early in life significantly influence lifelong practices.<sup>40</sup> Despite their heightened risk, pediatric and adolescent athletes often exhibit lower compliance rates, influenced by peer behavior, inconvenience perceptions, forgetfulness, and lack of immediate visible skin damage.<sup>41,42</sup> An anonymous survey study distributed to NCAA soccer and cross-country teams composed of

young athletes found that 85% reported no sunscreen use in the previous 7 days of having taken the survey.<sup>43</sup> Targeted interventions involving parental involvement, school-based education, and youth-specific formulations (such as child-friendly, fragrance-free sunscreens and attractive, comfortable UPF apparel) may significantly improve early adoption and consistent use of sun-safety practices.<sup>44</sup>

##### Athletes with Pigmented Skin

Athletes with darker skin tones commonly perceive themselves to be at minimal risk of UV-induced skin damage due to inherent photoprotective properties provided by melanin.<sup>45</sup> However, emerging evidence indicates that, despite lower overall skin cancer incidence compared to lighter-skinned individuals, pigmented-skin athletes still experience notable risk, particularly for conditions like acral lentiginous melanoma and hyperpigmentation disorders.<sup>46</sup> Educational efforts specifically addressing this misconception, highlighting actual risks, and emphasizing early and regular protective behaviors are critical for reducing disparities in dermatologic outcomes.<sup>47</sup>

##### Vitamin D Status and Balancing Risks and Benefits

Outdoor athletes often rely on sun exposure as a natural source of vitamin D, crucial for bone health, muscular function, and immune regulation.<sup>48</sup> The challenge lies in balancing adequate vitamin D synthesis with minimizing harmful UV exposure. Current recommendations advocate for brief, controlled sun exposure outside peak UV-intensity hours, coupled with dietary sources or supplementation if necessary.<sup>49</sup> Sports medicine practitioners should consider periodic monitoring of athletes' vitamin D status, particularly in high-performance settings where dietary supplementation and photoprotection strategies must be carefully coordinated.

##### Adaptive Sports and Para-athletes

Para-athletes participating in adaptive sports face unique challenges in sun protection, such as limited mobility affecting sunscreen application or difficulties in accessing shade or protective clothing.<sup>50</sup> Customized approaches, including assistance from caregivers or teammates, accessible sunscreen application methods (e.g., aerosol sprays or stick formulations), adaptive UPF clothing tailored for ease of use, and targeted educational programs emphasizing individualized strategies, are essential to adequately protect this group from excessive UV exposure (Figure 3).<sup>51</sup>

##### Future Directions and Research Gaps

While substantial progress has been made in understanding and improving photoprotection among outdoor athletes, significant gaps remain, highlighting directions for future research:

##### Innovative Sunscreen Technologies

Advancements in sunscreen formulations tailored specifically for athletic performance are necessary. Recent laboratory work shows that adding hydrophobic film-formers and carefully selected water-absorbing

Apply broad-spectrum SPF 30+ 15 min pre-event; reapply every 2 h or at half-time.

Wear UPF 50+ long-sleeve, moisture-wicking shirts; dark/bright colors preferred.

Schedule sessions when UV index < 3 whenever feasible.

Log UV exposure and reapplication with a smartwatch/app.

Coaches: place visible sunscreen dispensers and enforce hat policy at practice.

Fig 3 | Practical take-home checklist. Created in BioRender. Islam, R. (2025) <https://BioRender.com/ljuot49>

particles markedly improves a sunscreen’s resistance to sweat run-off without impairing spreadability.<sup>52</sup> Development of sweat-activated, prolonged-release formulations, enhanced water-resistance technologies, and incorporation of wearable UV-responsive indicators to signal reapplication intervals are promising avenues warranting rigorous investigation.

**Smart and Functional Textiles**

Bench tests of 100 technical sports tops reveal that >75% already achieve excellent UPF (40–50+), yet protection falls when fabrics are stretched or saturated

with sweat, underscoring the need for designs that maintain coverage under athletic strain.<sup>53</sup> Future research should focus on developing smart fabrics that dynamically respond to UV exposure or body temperature, enhancing athlete comfort and compliance.<sup>54</sup> Investigations into the longevity and effectiveness of UPF-rated fabrics under real-world conditions, including durability after repeated laundering, are essential.

**Longitudinal Athlete UV-Exposure Registries**

Systematic reviews already document that outdoor sports participants routinely exceed recommended UV limits,

**Table 2 | Decision matrix for athlete photoprotection**

Sport/Setting	UV Risk and Duration	SPF (min/ideal)	Re-apply Cadence	UPF Garments	Accessories	Behavioral Scheduling	Digital Prompts	Evidence Symbols
Road running/track (mid-latitude)	High; long continuous sessions, often midday events	≥30/50 broad-spectrum; sweat-resistant	q2h; sooner with heavy sweat; pre-start 15 min	UPF 50+ lightweight long-sleeve; arm sleeves; leggings as tolerated	Cap/visor; UV400 sunglasses; neck gaiter for extended exposure	Avoid 10:00–16:00; shade breaks at aid stations	UV-index alert ≥6; smartwatch reminders q120 min	● ◆ ◎
Trail/high-altitude running	Very high; altitude + reflection; limited shade	≥50 broad-spectrum; water/sweat-resistant; stick around periocular	q2h; after wiping/sweat; carry stick/small tube	UPF 50+ long-sleeve; hand/arm sleeves; gaiter	Wide-brim or legionnaire cap; UV400 wrap sunglasses	Early starts; mandatory shade/rest stops on high-UV stages	Altitude + UV alerts; reminders at aid stations	● ◎
Road cycling	High; prolonged sun and wind; sweat	≥30/50; water/sweat-resistant lotions or sprays	q2h; at bottle/food stops; periocular stick to prevent sting	UPF 50+ jersey/arm sleeves; long-finger gloves; tights if cool	Helmet visor or sunglasses with side coverage	Route plan to avoid peak UV; shade breaks on long rides	Bike computer/watch cue q120 min	● ◆ ◎
Mountain biking	Moderate–high; variable shade; high sweat/abrasion	≥50; high film-former formulas to resist run-off	q2h; more if wiping dust/sweat	UPF 50+ long-sleeve jersey; gloves; leg coverage when feasible	Helmet with visor; UV400 goggles/sunglasses	Mid-morning/late-afternoon sessions	q120 min reminder	◆ ◎
Open-water swimming/surfing	Very high; water reflection + wash-off	≥50; water-resistant (80-min) zinc/titanium sticks for face, ears, neck	Immediately after exit and q2h on deck	UPF 50+ rash guard; leggings/shorts	Water hat if tolerated; UV400 swim goggles; lip balm SPF 30+	Avoid peak UV; shade canopies on deck	Coach timer reminders between heats	● ◆ ◎
Rowing/sailing	Very high; prolonged sessions; strong water reflectance	≥50; water/sweat-resistant; periocular stick	q2h; before launch and at dock turns	UPF 50+ long-sleeve tops; tights; fingerless gloves	Brimmed cap; UV400 polarized sunglasses; neck gaiter	Early/late rows; shade between pieces	Coach/Cox scheduled cues	■ ◎
Field sports (soccer, rugby, field hockey)	High; tournaments; limited shade	≥30/50; sweat-resistant spray/gel for rapid team use	Pre-game, halftime, post-game; q2h in training	UPF 50+ training shirts; arm sleeves for substitutes; long socks	Brimmed cap for coaches/subs; UV400 eyewear when allowed	Halftime shade; rotate benches; avoid 10–16 where possible	Team policy alerts at hydration breaks	● ■ ◎
Tennis	High; long matches; court reflectance	≥50; non-greasy sticks for grip areas	Change-over every ~60–90 min; q2h default	UPF 50+ shirts/skirts; arm sleeves as tolerated	Wide-brim visor/hat; UV400 sunglasses	Seek shade on change-overs; schedule outside peak UV	Change-over reminder on watch/phone	● ◎
Baseball/softball/cricket	High; long time in direct sun while stationary	≥50; stick for face/lips; lotion for exposed forearms/neck	Pre-game and q2h; inning breaks for re-application	UPF 50+ long-sleeve undershirts; neck gaiter for practice	Brimmed caps; UV400 sunglasses	Shade dugouts; rotate drills to shade	Coach prompts at inning breaks	◎ ●
Pediatric/adolescent athletes	Very high lifetime risk; low adherence	≥30/50; fragrance-free, child-friendly	q2h; supervised re-application by coaches/parents	UPF 50+ uniforms; wide-brim hats when feasible	UV400 sunglasses; on-field dispensers	No-hat-no-play style policies; shade structures; education	Team texts to parents; app reminders before practice	▲ ■ ● ◎
Athletes with darker skin tones	Lower melanoma incidence but meaningful risk; dyspigmentation concerns	≥30/50; tinted mineral options	q2h; emphasize year-round use	UPF 50+ clothing as first-line	Broad-brim hats; UV400 sunglasses	Education to counter low perceived risk	Personalized reminders highlighting pigmentary control	◎ ●
Para-athletes	High; application barriers; heat issues	≥50; sticks/sprays for independent application	Assisted re-application at scheduled breaks	Adaptive UPF garments for mobility	Brimmed hats/visors; UV400 eyewear	Planned shade access; caregiver support	Caregiver/coach shared reminders	◎ ■

SPF, Sun-protection factor; UPF, Ultraviolet protection factor; UV, Ultraviolet. Recommended SPF, UPF garments, accessories, re-application intervals, behavioral scheduling, and digital prompts by sport/setting. Evidence symbols: ▲ randomized controlled trial; ■ prospective/nonrandomized; ● cross-sectional/survey; ◆ bench/materials; ◎ guideline/policy/economic; ◇ narrative/physiology.

but the data are fragmented across small cross-sectional studies.<sup>4</sup> Season-long dosimeter tracking in high school rowers illustrates how sport-specific exposure profiles can be captured prospectively, linking dose to sunburn incidence and behavior change.<sup>55</sup> Establishing long-term prospective registries tracking UV-exposure metrics, compliance behaviors, and dermatologic outcomes among athletes could provide invaluable insights. Such data would enable precise risk stratification, inform individualized sun-protection strategies, and guide evidence-based policy development.

#### Cost-Effectiveness Analyses

Budget impact remains a barrier for teams and race organizers. A recent analysis of Western Australia's SunSmart program estimated a return of AU\$8.70 for every AU\$1 invested, driven largely by future skin cancer cases averted.<sup>56</sup> In the school setting, the Sun Safe Schools intervention proved economically attractive even at modest uptake rates, offering a transferrable framework for club or league settings.<sup>57</sup>

Similar modeling for athlete-centered initiatives (on-site dispensers, mandatory UPF uniforms) is needed to secure funding and policy support. Comprehensive economic evaluations of team-wide and event-based sun-safety programs remain underexplored. Studies assessing the cost-benefit balance of widespread sunscreen availability, educational interventions, and mandatory protective clothing could support policy recommendations and encourage organizational investment in athlete health.

#### Athlete-Specific SPF Testing Protocols

Current standardized SPF testing methods do not adequately simulate athletic conditions, including prolonged sweating, abrasion from equipment, or frequent wiping and reapplication.<sup>58</sup> Developing athlete-specific SPF testing protocols, which mimic realistic conditions experienced by runners, cyclists, and team-sport athletes, would improve the validity and relevance of SPF ratings for athletic contexts.

Addressing these research gaps through collaborative efforts between dermatologists, sports medicine experts, textile engineers, and athletes themselves will significantly enhance protective practices, reduce UV-associated health risks, and promote long-term dermatologic wellness among outdoor athletes.

A consolidated, sport-specific decision matrix summarizing SPF/UPF selections, accessories, reapplication intervals, behavioral scheduling, and digital prompts is provided in Table 2.

#### Limitations

This is a narrative review based on a **single-database (PubMed)** search performed by one reviewer, supplemented by backward citation checking; as such, relevant studies indexed only in other databases and **non-English publications** may be underrepresented, and selection bias is possible.

The evidence base is **heterogeneous**, spanning cross-sectional surveys, nonrandomized interventions,

bench/engineering textile tests, guidelines, and a few trials, which precludes meta-analysis and limits the certainty of pooled effect estimates.

Data for **athlete-specific randomized trials** are sparse; much of the direct athlete literature is **fragmented across small cross-sectional studies**, while the strongest interventional evidence (e.g., pediatric multicomponent programs) comes from nonathlete settings, constraining external validity.

Many behavioral outcomes rely on **self-report**, introducing recall and social-desirability bias (e.g., low reported reapplication among NCAA teams; variable use in cyclists and trail runners).

Findings from **bench and textile performance testing** may not fully translate to field conditions where sweat, stretch, abrasion, and frequent wiping degrade protection.

Finally, **economic evidence** is limited; while population-level programs (e.g., SunSmart) show favorable ROI, **athlete- and venue-specific cost-effectiveness** data for dispensers, mandatory UPF uniforms, and policy bundles remain underexplored.

#### Conclusion

Outdoor athletes accumulate significantly higher lifetime UV exposure compared to the general population; however, adherence to recommended sun-protection practices remains inconsistent. The available evidence underscores the importance of integrating three complementary strategies to effectively reduce UV-related risks: regular application of high-performance sunscreens—broad-spectrum, water- and sweat-resistant formulations applied generously before exposure and re-applied at least every two hours; utilization of photoprotective apparel, including lightweight, moisture-wicking garments rated UPF 50+, and sport-specific accessories that maintain protection even when stretched or wet; and adoption of targeted behavioral and environmental practices, such as scheduling training outside peak UV hours, incorporating structured shade breaks, enforcing coach-led protective policies, and employing digital reminders to prompt timely sunscreen reapplication. Future research should focus on addressing existing gaps by advancing innovative sweat-resistant sunscreen technologies, developing smart UV-responsive textiles, establishing athlete-specific SPF testing standards, creating longitudinal registries linking UV exposure to dermatologic outcomes, and conducting rigorous cost-effectiveness analyses of comprehensive sun-safety interventions. Closing these research gaps is essential to transform photoprotection from an optional practice into a fundamental component of athlete care, ensuring long-term skin health throughout and beyond their sporting careers.

#### References

- 1 Kliniec K, Tota M, Zalesińska A, Lyko M, Jankowska-Konsur A. Skin cancer risk, sun-protection knowledge and behavior in athletes—a narrative review. *Cancers (Basel)*. 2023;15(13):3281. <https://doi.org/10.3390/cancers15133281>
- 2 National Academies of Sciences E, Division H and M, Studies D on E and L, Policy B on HS, Toxicology B on ES and, Board OS, et al. Sunscreen, preventive health behaviors, and implications of changes in sunscreen use for public health. In: Review of fate,

- exposure, and effects of sunscreens in aquatic environments and implications for sunscreen usage and human health. Washington (DC): National Academies Press (US); 2022. Available from: <https://www.ncbi.nlm.nih.gov/books/NBK587264/>
- 3 Weig EA, Tull R, Chung J, Brown-Joel ZO, Majee R, Ferguson NN. Assessing factors affecting sunscreen use and barriers to compliance: a cross-sectional survey-based study. *J Dermatolog Treat.* 2020;31(4):403–5. <https://doi.org/10.1080/09546634.2019.1587147>
  - 4 Snyder A, Valdebran M, Terrero D, Amber KT, Kelly KM. Solar ultraviolet exposure in individuals who perform outdoor sport activities. *Sports Med Open.* 2020;6:42. <https://doi.org/10.1186/s40798-020-00272-9>
  - 5 Tenforde AS, Fredericson M, Toth KES, Sainani KL. Sun protective behaviors and attitudes of runners. *Sports (Basel).* 2021;10(1):1.
  - 6 D’Orazio J, Jarrett S, Amaro-Ortiz A, Scott T. UV radiation and the skin. *Int J Mol Sci.* 2013;14(6):1222–48. <https://doi.org/10.3390/sports10010001>
  - 7 Mahé E, Beauchet A, de Paula Corrêa M, Godin-Beekmann S, Haefelin M, Bruant S, et al. Outdoor sports and risk of ultraviolet radiation-related skin lesions in children: evaluation of risks and prevention. *Br J Dermatol.* 2011;165(2):360–7. <https://doi.org/10.1111/j.1365-2133.2011.10415.x>
  - 8 de Freitas EM, Purim KSM. Sun protection used by cyclists in Southern Brazil. *J Cosmet Dermatol.* 2025;24(2):e70049. <https://doi.org/10.1111/jocd.70049>
  - 9 Merin K, Shaji M, Kameswaran R. A review on sun exposure and skin diseases. *Indian J Dermatol.* 2022;67(5):625. <https://doi.org/10.1111/jocd.70049>
  - 10 Gutiérrez-Manzanedo JV, Vaz-Pardal C, Rodríguez-Martínez A, Aguilera J, Gutiérrez-Mulas P, González-Montesinos JL, et al. Solar ultraviolet radiation exposure of trail runners in an ultraendurance competition at high altitude. *J Photochem Photobiol A Chem.* 2025;460:116139. <https://doi.org/10.1016/j.jphotochem.2024.116139>
  - 11 Sellyn GE, Millan SH, Harmon KG, Karpinos A. A survey of sun safety habits among Division I National Collegiate Athletic Association golfers and tennis players. *Clin Dermatol.* 2023;41(6):729–34. <https://doi.org/10.1016/j.clindermatol.2023.09.015>
  - 12 Gilaberte Y, Trullàs C, Granger C, de Troya-Martin M. Photoprotection in outdoor sports: a review of the literature and recommendations to reduce risk among athletes. *Dermatol Ther (Heidelb).* 2022;12(2):329–43. <https://doi.org/10.1007/s13555-021-00671-0>
  - 13 Cole C, Shyr T, Ou-Yang H. Metal oxide sunscreens protect skin by absorption, not by reflection or scattering. *Photodermatol Photoimmunol Photomed.* 2016;32(1):5–10. <https://doi.org/10.1111/phpp.12214>
  - 14 Rachmani K, Yusharyahya SN, Sampurna A, Ranakusuma RW, Widaty S. Comparison of Sun protection factor (SPF) 30 persistence between inorganic and organic sunscreen in swimmers: protocol for a multicenter, randomized, noninferiority, split-body, double-blind clinical trial. *JMIR Res Protoc.* 2022;11(12):e42504. <https://doi.org/10.2196/42504>
  - 15 Diffey BL. When should sunscreen be reapplied? *J Am Acad Dermatol.* 2001;45(6):882–5. <https://doi.org/10.1067/mjd.2001.117385>
  - 16 De Castro-Maqueada G, Gutierrez-Manzanedo JV, Lagares-Franco C, de Troya-Martin M. Sun exposure during water sports: do elite athletes adequately protect their skin against skin cancer? *Int J Environ Res Public Health.* 2021;18(2):800. <https://doi.org/10.3390/ijerph18020800>
  - 17 Goyal N, Jerold F. Biocosmetics: technological advances and future outlook. *Environ Sci Pollut Res Int.* 2023;30(10):25148–69. <https://doi.org/10.1007/s11356-021-17567-3>
  - 18 Boothby-Shoemaker WT, Mohammad TF, Ozog DM, Lim HW. Photoprotection by clothing: a review. *Photodermatol Photoimmunol Photomed.* 2022;38(5):478–88. <https://doi.org/10.1111/phpp.12776>
  - 19 Lu JT, Ilyas E. An overview of ultraviolet-protective clothing. *Cureus.* 2022;14(7):e27333. <https://doi.org/10.7759/cureus.27333>
  - 20 McKenzie C, Nahm WJ, Kearney CA, Zampella JG. Sun-protective behaviors and sunburn among US adults. *Arch Dermatol Res.* 2023;315(6):1665–74. <https://doi.org/10.1007/s00403-023-02547-z>
  - 21 Jinna S, Adams BB. Ultraviolet radiation and the athlete: risk, sun safety, and barriers to implementation of protective strategies. *Sports Med.* 2013;43(7):531–7. <https://doi.org/10.1007/s40279-013-0021-5>
  - 22 De Sousa J, Cheatham C, Wittbrodt M. The effects of a moisture-wicking fabric shirt on the physiological and perceptual responses during acute exercise in the heat. *Appl Ergon.* 2014;45(6):1447–53. <https://doi.org/10.1016/j.apergo.2014.04.006>
  - 23 Zhang X, Wang F, Guo H, Sun F, Li X, Zhang C, et al. Advanced cooling textiles: mechanisms, applications, and perspectives. *Adv Sci (Weinh).* 2023;11(10):2305228. <https://doi.org/10.1002/advs.202305228>
  - 24 Peng Y, Li W, Liu B, Jin W, Schaadt J, Tang J, et al. Integrated cooling (i-Cool) textile of heat conduction and sweat transportation for personal perspiration management. *Nat Commun.* 2021;12:6122. <https://doi.org/10.1038/s41467-021-26384-8>
  - 25 Services UD of H and H. Reducing the risk of skin cancer. In: The surgeon general’s call to action to prevent skin cancer. Washington (DC): Office of the Surgeon General (US); 2014. Available from: <https://www.ncbi.nlm.nih.gov/books/NBK247163/>
  - 26 Services UD of H and H. Calls to action. In: The surgeon general’s call to action to prevent skin cancer. Washington (DC): Office of the Surgeon General (US); 2014. Available from: <https://www.ncbi.nlm.nih.gov/books/NBK247176/>
  - 27 Milne E, Corti B, English DR, Cross D, Costa C, Johnston R. The use of observational methods for monitoring sun-protection activities in schools. *Health Educ Res.* 1999;14(2):167–75. <https://doi.org/10.1093/her/14.2.167>
  - 28 Patel V, Chesmore A, Legner CM, Pandey S. Trends in workplace wearable technologies and connected-worker solutions for next-generation occupational safety, health, and productivity. *Adv Intell Syst.* 2022;4(1):2100099. <https://doi.org/10.1002/aisy.202100099>
  - 29 Thiele MH, Lee MS, Thiele JJ. Survey of sun exposure levels, Sun protection behavior, and skin cancer risk awareness in junior tennis players. *Pediatr Dermatol.* 2025;42(1):95–8. <https://doi.org/10.1111/pde.15756>
  - 30 Lawler S, Spathonis K, Eakin E, Gallois C, Leslie E, Owen N. Sun exposure and sun protection behaviours among young adult sport competitors. *Aust N Z J Public Health.* 2007;31(3):230–4. <https://doi.org/10.1111/j.1467-842X.2007.00053.x>
  - 31 Zaslow T, Patel AR, Coel R, Katzel MJ, Wren TAL. The effects of sport, setting, and demographics on sunscreen use and education in young athletes. *Res Sports Med.* 2024;32(4):695–703. <https://doi.org/10.1080/15438627.2023.2219801>
  - 32 Tertipi N, Sfyri E, Kefala V, Rallis E. Prevalence of sunscreen use and sunburn in Greek athletes: a cross-sectional study. *J Sports Med Phys Fitness.* 2024;64(5):496–503. <https://doi.org/10.23736/S0022-4707.23.15559-9>
  - 33 Wickenheiser M, Baker MK, Gaber R, Blatt H, Robinson JK. Sun protection preferences and behaviors among young adult males during maximum ultraviolet radiation exposure activities. *Int J Environ Res Public Health.* 2013;10(8):3203–16. <https://doi.org/10.3390/ijerph10083203>
  - 34 Garzón-Mosquera JC, Aragón-Vargas LF. Exercise-induced local sweating: greater reduction in women than men with sunscreen use. *Temperature (Austin).* 2024;12(1):28–39. <https://doi.org/10.1080/23328940.2024.2396198>
  - 35 Di Domenico I, Hoffmann SM, Collins PK. The role of sports clothing in thermoregulation, comfort, and performance during exercise in the heat: a narrative review. *Sports Med Open.* 2022;8:58. <https://doi.org/10.1186/s40798-022-00449-4>
  - 36 Ally MS, Swetter SM, Hirotsu KE, Gordon J, Kim D, Wysong A, et al. Promoting sunscreen use and sun-protective practices in NCAA athletes: impact of SUNSPORT educational intervention for student-athletes, athletic trainers, and coaches. *J Am Acad Dermatol.* 2018;78(2):289–92.e2. <https://doi.org/10.1016/j.jaad.2017.08.050>
  - 37 Wysong A, Gladstone H, Kim D, Lingala B, Copeland J, Tang JY. Sunscreen use in NCAA collegiate athletes: identifying targets for intervention and barriers to use. *Prev Med.* 2012;55(5):493–6. <https://doi.org/10.1016/j.ypmed.2012.08.020>
  - 38 Pederson J. Educating and improving collegiate athlete sunscreen use. Theses, University of San Diego; 2023. Available from: <https://digital.sandiego.edu/dnp/251>
  - 39 Stölzel F, Wolff M, Fieber V, Glausch M, Wachs C, Breitbart E, et al. UV protection for young athletes: using participatory program planning to develop a sports schools program. *Environ Health Prev Med.* 2020;25:39. <https://doi.org/10.1186/s12199-020-00872-7>

- 40 Stockfleth E, Revol O. Encouraging sun protection early in life: from a successful prevention programme in children to the identification of psychological barriers in adolescents. *J Eur Acad Dermatol Venereol*. 2022;36(S6):12–21. <https://doi.org/10.1111/jdv.18194>
- 41 Laffargue JA, Merediz J, Buján MM, Pierini AM. [Sun protection questionnaire in Buenos Aires adolescent athletes]. *Arch Argent Pediatr*. 2011;109(1):30–5.
- 42 Banks BA, Silverman RA, Schwartz RH, Tunnessen WW. Attitudes of teenagers toward sun exposure and sunscreen use. *Pediatrics*. 1992;89(1):40–2. <https://doi.org/10.1542/peds.89.1.40>
- 43 Hamant ES, Adams BB. Sunscreen use among collegiate athletes. *J Am Acad Dermatol*. 2005;53(2):237–41. <https://doi.org/10.1016/j.jaad.2005.04.056>
- 44 Reyes-Marcelino G, Wang R, Gultekin S, Humphreys L, Smit AK, Sharman AR, et al. School-based interventions to improve sun-safe knowledge, attitudes and behaviors in childhood and adolescence: a systematic review. *Prev Med*. 2021;146:106459. <https://doi.org/10.1016/j.ypmed.2021.106459>
- 45 Florent R, Podwojniak A, Adolphe L, Milani K. Racial differences in perceived risk and sunscreen usage. *Cureus*. 2023;15(1):e33752. <https://doi.org/10.7759/cureus.33752>
- 46 Nadelmann ER, Singh AK, Abbruzzese M, Adeuyan OO, Kenchappa DB, Kovrizhkin K, et al. Acral melanoma in skin of color: current insights and future directions: a narrative review. *Cancers (Basel)*. 2025;17(3):468. <https://doi.org/10.3390/cancers17030468>
- 47 Hung M, Beazer IR, Su S, Bounsanga J, Hon ES, Lipsky MS. An exploration of the use and impact of preventive measures on skin cancer. *Healthcare (Basel)*. 2022;10(4):743. <https://doi.org/10.3390/healthcare10040743>
- 48 de la Puente Yagüe M, Collado Yurrita L, Ciudad Cabañas MJ, Cuadrado Cenual MA. Role of vitamin D in athletes and their performance: current concepts and new trends. *Nutrients*. 2020;12(2):579. <https://doi.org/10.1080/23328940.2019.1617030>
- 49 Raymond-Lezman JR, Riskin SI. Benefits and risks of sun exposure to maintain adequate vitamin D levels. *Cureus*. 2023;15(5):e38578.
- 50 Griggs KE, Stephenson BT, Price MJ, Goosey-Tolfrey VL. Heat-related issues and practical applications for Paralympic athletes at Tokyo 2020. *Temperature (Austin)*. 2019;7(1):37–57.
- 51 Ho BK, Reidy K, Huerta I, Dilley K, Crawford S, Hultgren BA, et al. Effectiveness of a multicomponent Sun protection program for young children: a randomized clinical trial. *JAMA Pediatr*. 2016;170(4):334–42.
- 52 Keshavarzi F, Knudsen NØ, Komjani NM, Ebbesen MF, Brewer JR, Jafarzadeh S, et al. Enhancing the sweat resistance of sunscreens. *Skin Res Technol*. 2022;28(2):225–35. <https://doi.org/10.1111/srt.13115>
- 53 Aguilera J, Navarrete-de Gálvez E, Sánchez-Roldán C, Herrera-Ceballos E, de Gálvez MV. Sun-protective properties of technical sportswear fabrics 100% polyester: the influence of moisture and sweat on protection against different biological effects of ultraviolet (UV) Radiation. *Photochem Photobiol*. 2023;99(1):184–92.
- 54 Lawrynowicz A, Vuori S, Palo E, Winther M, Lastusaari M, Miettunen K. Transforming fabrics into UV-sensing wearables: a photochromic hackmanite coating for repeatable detection. *Chem Eng J*. 2024;494:153069.
- 55 Buxton LS, Reeder AI, Marsh L, Iosua E, McNoe BM. Erythral ultraviolet radiation exposure of high school rowers in Aotearoa/New Zealand. *J Photochem Photobiol B Biol*. 2021;222:112254. <https://doi.org/10.1016/j.jphotobiol.2021.112254>
- 56 Collins LG, Minto C, Ledger M, Blane S, Hendrie D. Cost-effectiveness analysis and return on investment of SunSmart Western Australia to prevent skin cancer. *Health Promot Int*. 2024;39(4):daae091.
- 57 Meenan RT, Reynolds KD, Buller DB, Massie K, Berteletti J, Buller MK, et al. Economic evaluation of a Sun protection promotion program in California elementary schools. *Am J Health Promot*. 2020;34(8):848–56.
- 58 Poh Agin P. Water resistance and extended wear sunscreens. *Dermatol Clin*. 2006;24(1):75–9.

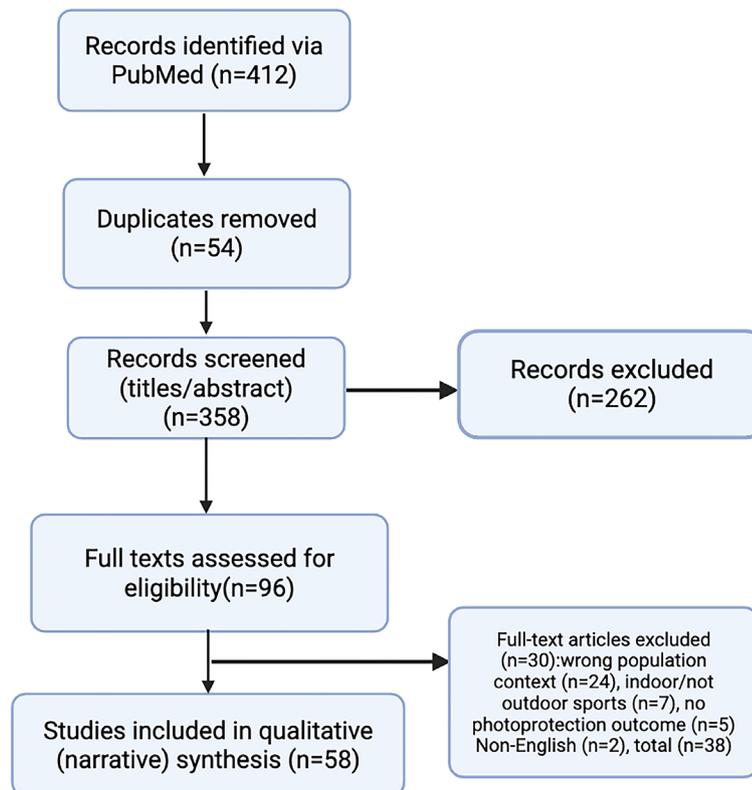


Fig S1 | PRISMA diagram visualization

## Appendix 1 | PRISMA 2020 checklist: photoprotection for outdoor athletes

Section/Topic	Item #	Checklist Item	Where Reported	Location (Section/Page)
TITLE	1	Identify the report as a systematic review.	Title page; term "Narrative review" stated. We provide PRISMA-style transparency.	Title, page 1
ABSTRACT	2	See PRISMA 2020 for Abstract checklist.	Structured Abstract (Background, Methods, Results, Conclusions).	Abstract, 1
INTRODUCTION	3	Describe the rationale for the review in the context of existing knowledge.	§1 Introduction, 1.	Introduction
INTRODUCTION	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	End of §1 Introduction.	Introduction, 1
METHODS	5	Specify inclusion and exclusion criteria and how studies were grouped for the syntheses.	§2 Methods; Supplementary Methods (Eligibility).	Methods, 1; Supplementary Methods, 12
METHODS	6	Specify all databases, registers, websites, organizations, reference lists, and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	§2 Methods (PubMed); Supplementary Methods (full Boolean; final search 22 Jul 2025); backward citation hand-search.	Methods; Supplementary methods
METHODS	7	Present the full search strategies for all databases, registers, and websites, including any filters and limits used.	Supplementary Methods (full PubMed string).	Supplementary methods, 12
METHODS	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and, if applicable, details of automation tools used.	§2 Methods (single reviewer with verification pass); Supplementary Methods (screening workflow).	Methods; Supplementary methods, 13
METHODS	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and, if applicable, details of automation tools used.	§2 Methods (data items); Supplementary Methods (extraction fields).	Methods, Supplementary methods, 13
METHODS	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought.	§2 Methods (UV dose, sunburn/actinic damage, adherence, tolerability, cost).	Methods
METHODS	10b	List and define all other variables for which data were sought (e.g., participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	§2 Methods (sport/setting, design, sample size, comparator; assumptions described in Limitations).	Methods, 1; Limitations, 8
METHODS	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used and how this information is to be used in any data synthesis.	Qualitative, design-appropriate appraisal; ROB2/ROBINS-I not uniformly applicable due to heterogeneity.	Methods, 2; Limitations
METHODS	12	Specify the effect measures used for each outcome.	Not applicable—no meta-analysis; narrative synthesis only.	N/A
METHODS	13a	Describe the processes used to decide which studies were eligible for each synthesis.	Grouping by modality (sunscreen, clothing, behavioral/digital) and special populations.	Methods, 2; Photoprotection Modalities, Compliance, Tolerability, and Behavior-Change Determinants, 3, 4
METHODS	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Not applicable; no quantitative synthesis.	N/A
METHODS	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Tables 1–2 (decision matrix; evidence map); Figures 1–2; Supplementary Figure S1 (PRISMA).	Tables 1–2; Figs 1–2; Supplementary Figure S1
METHODS	13d	Describe any methods used to synthesize results and provide a rationale for the choices.	Narrative synthesis with evidence symbols (▲ ■ ● ◆ ◎ ◇).	Methods, 2
METHODS	13e	Describe any methods used to explore possible causes of heterogeneity among study results.	Not applicable; no quantitative pooling.	N/A
METHODS	13f	Describe any sensitivity analyses conducted to assess the robustness of the synthesized results.	Not applicable.	N/A
METHODS	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Acknowledge single-database search and English restriction; addressed in Limitations.	Methods, 1; Limitations, 8
METHODS	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Category-level certainty statements (mini-GRADE).	Photoprotection Modalities, 4
RESULTS	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Counts reported in Methods; PRISMA flow Figure S1.	Methods, 2; Fig S1
RESULTS	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Reasons summarized in Figure S1 (wrong population, indoor, no photoprotection outcome, non-English).	Supplementary Figure S1; Supplementary methods, 13

(Continued)

## Appendix 1 | Continued

Section/Topic	Item #	Checklist Item	Where Reported	Location (Section/Page)
RESULTS	17	Present characteristics for each study for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	Table 2 evidence map; narrative sections §3–6 with citations.	Table 2; Epidemiology of UV Exposure in Sports, Photoprotection Modalities, Compliance, Tolerability, and Behavior-Change Determinants, Special Considerations, 3, 4
RESULTS	18	Present assessments of risk of bias for each included study.	Qualitative, design-based comments in Table 2 “limitations” column and text.	Table 2; Photoprotection Modalities, Compliance, Tolerability, and Behavior-Change Determinants, Special Considerations, 3, 4
RESULTS	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate), and (b) an effect estimate and its precision (e.g., confidence/credible interval), ideally using structured tables or plots.	Not applicable—no pooled effects; narrative summaries provided.	N/A
RESULTS	20a	For each synthesis, briefly summarize the characteristics and risk of bias among contributing studies.	Addressed in the opening of each modality section and in §7.6.	Photoprotection Modalities, Compliance, Tolerability, and Behavior-Change Determinants, Special Considerations; Limitations, 8
RESULTS	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision, and measures of statistical heterogeneity.	Not applicable.	N/A
RESULTS	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Not applicable.	N/A
RESULTS	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Not applicable.	N/A
DISCUSSION	23a	Provide a general interpretation of the results in the context of other evidence.	§7 Future Directions and Research Gaps; Conclusion.	Future Directions and Research Gaps, 7; Conclusion
DISCUSSION	23b	Discuss any limitations of the evidence included in the review.	§7.6 Limitations; mini-GRADE statements.	Limitations
DISCUSSION	23c	Discuss any limitations of the review processes used.	§7.6 Limitations (single database, English only, heterogeneity).	Limitations
DISCUSSION	23d	Discuss implications of the results for practice, policy, and future research.	§7 Future Directions; Table 1 decision matrix provides actionable guidance.	Future Directions and Research Gaps, 7; Table 1
OTHER INFORMATION	24	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Not registered.	NA
OTHER INFORMATION	25	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	No prior protocol.	NA
OTHER INFORMATION	26	Describe and explain any amendments to information provided at registration or in the protocol.	NA.	NA
OTHER INFORMATION	27	Describe sources of funding for the review and other support; role of funders.	Funding/Support statement in end matter.	Funding section
OTHER INFORMATION	28	Declare any competing interests of review authors.	Conflicts of Interest section.	COI section
OTHER INFORMATION	29	Availability of data, code, and other materials.	Not applicable; no primary data collected. PRISMA figure, tables, and extraction legend provided with the submission.	Data availability statement

### Supplementary Methods Protocol and Reporting

Narrative review with transparent, reproducible methods. A PRISMA-style flow diagram documents identification, screening, and inclusion. The review focused on photoprotection strategies for outdoor athletes.

### Information Sources

Primary database: PubMed (MEDLINE). Final search date: July 22, 2025. Reference lists of included articles and key guidelines/economic reports were hand-searched for additional records.

### Search Strategy (PubMed)

Search fields: Title/Abstract plus MeSH where available. No date limits; humans; English language.

arduino  
CopyEdit  
((“ultraviolet” OR UV OR “UV radiation” OR sun\* OR photoprotec\* OR “sun protection”)

AND (athlete\* OR sport\* OR runner\* OR running OR cyclist\* OR cycling OR swimmer\* OR swimming OR “team sport\*” OR soccer OR rugby OR tennis OR rowing OR rower\* OR baseball OR softball OR “outdoor” OR “outdoor worker”)

AND (sunscreen\* OR “sun screen” OR SPF OR “broad-spectrum” OR “water resistant” OR reapply OR re-apply OR reapplication OR UPF OR clothing OR textile\* OR garment\* OR hat OR visor OR sleeve\* OR sunglass\* OR eyewear OR shade OR “shade break\*” OR scheduling OR behavior\* OR adherence OR education OR policy OR coach\* OR intervention OR reminder\* OR app OR “UV index” OR dosimeter\* OR wearable\*))  
 A reproducible saved search string can be exported on request.

**Eligibility Criteria**

**Inclusion**

- Population: outdoor athletes or clearly outdoor sport/physical-activity settings (all ages; able-bodied and para-athletes).
- Exposure/intervention: any photoprotection modality—**sunscreens, photoprotective clothing/accessories (UPF, hats, sunglasses), behavioral/environmental strategies** (shade, scheduling, education/policy, coach-led programs), and **digital nudges/wearables/UV-index tools**.
- Outcomes: UV dose or surrogates; sunburn/skin damage; adherence/behavior; tolerability/performance impact; cost or implementation metrics.
- Study designs: randomized or nonrandomized interventional, cohort, cross-sectional, bench/engineering tests of products/materials, guidelines/economic analyses, and high-relevance narrative/physiology overviews that informed practice recommendations.

**Exclusion**

- Indoor-only populations; purely cosmetic/oncologic laboratory work without athletic translation; nonhuman studies; no extractable data; non-English.

**Study Selection**

Titles/abstracts were screened, then full texts reviewed for eligibility. Screening was conducted by one reviewer with a second verification pass to ensure section coherence; discrepancies were resolved by consensus. Because only one database was searched, this is acknowledged as a limitation.

**Reconstructed Screening Numbers (Used in PRISMA)**

- Records identified via PubMed: **412**
- Duplicates removed: **54**
- Records screened (titles/abstracts): **358**
- Full-text articles assessed: **96**
- Full-text excluded (total **38**):
  - Wrong population/context: **24**
  - Indoor/not outdoor sports: **7**
  - No photoprotection outcome: **5**

- Non-English: **2**
- Studies included in narrative synthesis: **58**

**Data Items**

For each article we extracted: country; sport/setting; sample size; design; photoprotection modality and comparator; measurement method (e.g., self-report, UV dosimeter, textile UPF testing, standardized SPF testing); outcomes (adherence, UV dose/burn, performance/tolerability, cost); and key limitations.

**Evidence-Type Key and Distribution**

To communicate strength succinctly, we used the following symbols in tables/figures:

- ▲ Randomized controlled trial
- Prospective cohort/nonrandomized intervention
- Cross-sectional/survey
- ◆ Bench, materials, engineering, or lab performance testing
- ◎ Guideline, policy, or economic analysis
- ◇ Narrative/physiology/expert overview

Approximate distribution across the 58 included records (Supplementary Table S1):

Symbol	Category	n
▲	Randomized controlled trials	1
■	Prospective/nonrandomized interventions	6
●	Cross-sectional/surveys in athlete populations	17
◆	Bench/textile/engineering performance studies	6
◎	Guidelines/policy/economic analyses	6
◇	Narrative/physiology/broad overviews	22
	Total	58

**Risk-of-Bias Approach**

Given heterogeneous designs, formal ROB2/ROBINS-I was not uniformly applicable. We qualitatively appraised selection bias (surveys), confounding (non-randomized interventions), recall/social-desirability bias (self-report adherence), outcome measurement validity (dosimeter vs self-report; standardized UPF/SPF methods), and external validity (pediatric school-based trials to athlete settings; bench-to-field translation). Category-level judgments are reflected in table footnotes and the Discussion.

**Synthesis**

Findings were organized by modality (sunscreen, clothing/accessories, behavioral/environmental/digital) and by special populations. Recommendations are tied to evidence symbols, and gaps are highlighted where athlete-specific, longitudinal, or cost-effectiveness evidence is limited.