Sunscreen Use and Sweat Production in Men and Women

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Context: Sunscreen lotions are important to protect the skin during outdoor exercise, but they may interfere with sweating.

Objective: To measure the effect of 2 water-resistant sunscreens on local sweat production in men and women exercising in the heat and to compare those effects with the expected inhibition resulting from the use of an antiperspirant.

Design: Randomized crossover study.

Setting: Exercise in the heat (ambient temperature = 30.2°C ± 0.4°C dry bulb and 58% ± 4.3% relative humidity) in a controlled-environment laboratory.

Patients or Other Participants: Twenty physically active, apparently healthy college students, 10 men (age = 22.5 ± 2.8 years, height = 1.771 ± 0.069 m, mass = 70.2 ± 11.0 kg) and 10 women (age = 22.2 ± 3.2 years, height = 1.625 ± 0.075 m, mass = 57.7 ± 7.9 kg).

Intervention(s): With sweat-collection patches applied to their right and left scapular regions, the participants performed 2 exercise sessions on consecutive days. We assigned skin treatments (antiperspirant; organic chemical sun filter, sunscreen A; inorganic physical sun block, sunscreen B; no lotion)

randomly to side and session. Participants pedaled at 79% ± 1% of maximum heart rate for 20 minutes in the heat.

Main Outcome Measure(s): Scapular localized sweat rate.

Results: No baseline, environmental, or exercise condition was different among skin treatments. Scapular localized sweat rate was lower for the antiperspirant treatment (88.3 μL/min·dm²; 95% confidence interval [CI] = 82.0, 94.7 μL/min·dm²) and the inorganic physical sun block (sunscreen B) treatment (99.3 μL/min·dm²; 95% CI = 93.1, 105.5 μL/min·dm²) than for the organic chemical sun filter (sunscreen A) treatment (114.8 μL/min·dm²; 95% CI = 108.8, 120.6 μL/min·dm²) or the no-lotion treatment (122.6 μL/min·dm²; 95% CI = 116.2, 129.0 μL/min·dm²; *P* < .01).

Conclusions: The inorganic physical sun block, sunscreen B, hindered effective sweating to the same extent as the antiperspirant, whereas the treatment with the organic chemical sun filter, sunscreen A, was not different from the control treatment. At this stage, it is not possible to identify the specific ingredient responsible for the effect.

Key Words: sweat rate, thermoregulation, exercise, hyperthermia, skin care

Key Points

- We identified 1 sunscreen formulation that reduced effective sweating.
- Athletes should use a sunscreen that provides a good balance between effective sweating and skin protection during outdoor exercise in the heat.

When humans exercise, the increase in metabolic heat production should be matched by a greater heat transfer to the environment to maintain core temperature within safe limits and prevent deterioration of performance or the extreme of exertional heat stroke.^{1,2} However, when protective clothing and equipment are worn during sport training and competition, convective, conductive, and evaporative heat losses are limited.³

During outdoor physical activity, particularly in hot and humid environments, humans need protection from solar radiation without compromising sweat production and evaporation, a major path for heat dissipation. A few studies^{4,5} have shown that clothing does indeed limit convection and evaporation. With this in mind, authors^{6–9} have investigated sweat-production patterns in males and females, and several manufacturers have claimed to design clothing that facilitates thermoregulation by improving sweat evaporation from the skin. The use of sunscreen lotions, however, has not received much attention in association with a potential limitation of sweat production. These products are widely used and aggressively promoted to protect unclothed skin from ultraviolet rays, but they

may interfere with effective sweat production and, if used over large skin areas, they may impair thermoregulation.

The objective of our study was to measure the possible effects of 2 water-resistant sunscreen products on local sweat production in men and women exercising in the heat and to compare these effects with the expected inhibition resulting from the use of an antiperspirant (AP). We hypothesized that the latter would significantly reduce sweat rates when compared with a no-lotion condition, whereas the 2 sunscreens would have either significant but smaller effects or nonsignificant, undetectable effects.

METHODS

After undergoing basic screening (Physical Activity Readiness Questionnaire¹⁰ and questioning about known skin allergies), 20 physically active, apparently healthy college students volunteered for the study: 10 men (age = 22.5 ± 2.8 years, height = 1.771 ± 0.069 m, mass = 70.2 ± 11.0 kg) and 10 women (age = 22.2 ± 3.2 years, height = 1.625 ± 0.075 m, mass = 57.7 ± 7.9 kg). We obtained written informed consent from all participants before the

Table 1. Main Skin Lotion Characteristics (as Reported by the Manufacturers)

	Antiperspirant	Sunscreen A	Sunscreen B
Base	Water	Water	Water
Sun protection factor	Not applicable	50	50
Type	Antiperspirant	Organic chemical sun filter	Inorganic physical sun block
Major active ingredient	Aluminum chloride	Oxybenzone	Titanium dioxide
Other ingredients	Estereat-2, helianthus annuus oil, sunflower seed oil, geraniol, dipentene, linalol	Octocrylene, hydrogenated polyisobutene, lauryl PEG-8 dimethicone, benzophenone-3 (oxybenzone), butyloctyl salicylate, ethylhexyl palmitate, butyl methoxydibenzoylmethane, hydrated silica, cyclopentasiloxane, cyclohexasiloxane, acrylates/C12-22 alkyl methacrylene copolymer, sodium chloride, benzyl alcohol, cera alba, microcristallina cera, polyethylene caprylyl glycol, disodium EDTA, stearoxy dimethicone, PEG-8 dimethicone, aloe barbadensis leaf juice powder, octyldodecanol, retinyl palmitate, silica, tocopheryl acetate, ascorbic acid, sodium propoxyhydroxypropyl thiosulfate silica, methylparaben, propylparaben	Denatured ethanol, C12-15 alkyl benzoate, octyldodecanol, titanium dioxide, bis-ethylhexyloxyphenol methoxyphenyl triazine, butylene glycol dicaprylate, cetyl alcohol, phenylbenzimidazole sodium sulfonate, cetylaryl alcohol, myristyl myristate, diethylhexyl butamide triazine, ethylhexyl methoxycinnamate, tocopheryl glycol acetate (vitamin E), tapioca starch, SE glyceryl stearate, PEG-40 resin oil, sodium cetylarylsulfate, sodium acrylate cross polymer, C10-30 alkyl acrylate, xanthan gum, trimethoxycaprylylsilane, trisodium EDTA, phenoxyethanol, methylparaben, perfume

study, and the University of Costa Rica Science and Ethics Committee approved all procedures in advance.

Procedures

Using a repeated-measures design (randomized crossover design), we tested each participant under all 4 skin treatments: sunscreen A (SA; [organic chemical sun filter] Banana Boat Sport Performance Sun Filter 50; Edgewell Personal Care Company, St Louis, MO), sunscreen B (SB; [inorganic physical sun block] Nivea Sun Solar Protection 50; Beiersdorf, Hamburg, Germany), AP (Rexona V8 Tuning Roll-On; Unilever, London, UK), or control (C, no treatment; Table 1). We used both the left and right subscapular regions, allowing 2 treatments to be tested on each participant in each session. We assigned treatments in random order to the left or right subscapular region and the first or second day of testing.

Testing procedures have been previously described¹¹ but are detailed here in English. We instructed all participants to avoid diuretics 24 hours before the tests and to drink at least 1 L of water the night before testing. To allow us free access to the scapular region, women dressed in a comfortable top covering the upper body and men were shirtless.

Each participant reported to the laboratory on 2 consecutive days, at the same time of day. Upon arrival, participants voided their urine, and we measured urine specific gravity (USG) using a refractometer (model URC/Ne; ATAGO Co Ltd, Tokyo, Japan). We obtained their nude and dry body mass to the nearest 20 g on a scale (model e-Accura SB710-120; Bright Advance Corporation, Shanghai, China). Both subscapular regions were wiped clean with gauze and distilled water and marked with a waterproof eyeliner (model ColorStyle; Revlon, Inc, New York, NY) according to the International Society for the Advancement of Kinanthropometry international standards for anthropometric assessment.¹²

We applied the assigned lotion to the marked area (0.162 g or 10 mg/cm² of skin) with the help of a stencil and left it to dry for 60 minutes while the participant rested in a climate-controlled chamber. Then we measured body temperature in triplicate using a tympanic thermometer (model ThermoScan Pro 4000; Braun GmbH, Kronberg, Germany). Excess sunscreen or AP was removed with dry gauze before a sweat patch (model MSX-6446; 3M, Brookings, SD) was placed over each marked region.

Participants exercised on stationary bicycles for 20 minutes in the chamber at a dry-bulb temperature of 30.2°C ± 0.4°C and relative humidity of 58% ± 4.3%. Exercise intensity was maintained between 78% and 80% of maximum heart rate, which we estimated according to the formula of Gellis et al¹³: maximum heart rate = (207 – [0.7 × age]). On completion of the exercise period, we removed the sweat patches, weighed them, and recorded sweat-collection time and obtained nude and dry body mass to the nearest 20 g for each participant.

We calculated local sweat rate (LSR) according to the method used by Maughan et al,¹⁴ Smith and Havenith,¹⁵ and Morris et al¹⁶ and refined in our laboratory.¹¹ We placed each new patch in a labeled, hermetically sealed plastic bag and weighed it on a precision scale (model GX-200; A&D Company, Limited, Tokyo, Japan) to the nearest 1 mg. Then we removed the patch from the bag, peeled the backing off, and applied it to the skin. Once the test was completed, we placed the patch in the same bag with all its parts and sealed it until it was weighed. Weight gain corresponded to sweat absorbed during testing; 1 g was considered to be equivalent to 1 mL. We divided sweat volume by testing time (recorded to the nearest second) and by the area covered by the patch (0.1617 dm²), to obtain µL/min·dm².

We rescheduled testing for any participant who arrived hypohydrated (as assessed by USG with a cutoff point of ≥1.020)¹⁷ and any female participant in transition between 2 menstrual-cycle phases; the latter was to avoid extraneous body temperature differences.^{18,19}

Table 2. Reference Values

Variable	Treatment, Mean (95% Confidence Interval)				Analysis of Covariance	
	Antiperspirant	Sunscreen A	Sunscreen B	Control	F Value	P Value
Working heart rate, beats/min	151.9 (150.7, 153.1)	151.9 (150.6, 153.2)	151.8 (150.5, 153.0)	151.7 (150.4, 152.9)	0.645	.426
Urine specific gravity	1.012 (1.009, 1.015)	1.011 (1.009, 1.015)	1.011 (1.008, 1.015)	1.012 (1.009, 1.015)	0.156	.695
Pre-exercise tympanic temperature, °C	37.0 (36.8, 37.1)	36.9 (36.8, 37.1)	37.0 (36.8, 37.1)	37.0 (36.8, 37.1)	0.458	.502
Baseline body mass, kg	63.99 (58.52, 69.46)	63.99 (58.49, 69.48)	63.99 (58.69, 69.29)	63.89 (58.56, 69.21)	0.206	.655
Body mass change, kg	0.44 (0.30, 0.58)	0.38 (0.31, 0.45)	0.39 (0.26, 0.52)	0.35 (0.29, 0.40)	1.267	.266
Room temperature, °C	30.3 (30.1, 30.4)	30.2 (30.1, 30.4)	30.2 (30.0, 30.3)	30.2 (30.1, 30.3)	0.036	.850
Room relative humidity, %	59.8 (58.3, 61.4)	59.7 (57.8, 61.5)	59.0 (57.4, 60.7)	59.7 (57.9, 61.5)	1.547	.220

Statistical Analysis

To characterize the sample, we calculated descriptive statistics for age, height, baseline body mass, and total body sweat rate. We performed a mixed, 2-way sex-by-treatment (2×4) analysis of covariance with LSR as the dependent variable and working heart rate, USG, pre-exercise body temperature, baseline body mass, change in body mass, room temperature, and relative humidity as covariates. In addition, we performed two 1-way, repeated-measures analyses of variance (left side versus right side and session 1 versus session 2) with LSR as the dependent variable. For a power of .90, we calculated that a sample of 10 men could identify differences as small as $16.4 \mu\text{L}/\text{min}\cdot\text{dm}^2$ and a sample of 10 women could identify differences as small as $1.73 \mu\text{L}/\text{min}\cdot\text{dm}^2$: that is, one-half and one-tenth, respectively, of the difference in average sweat rates for men and women ($32.8 \mu\text{L}/\text{min}\cdot\text{dm}^2$ and $17.3 \mu\text{L}/\text{min}\cdot\text{dm}^2$, respectively) found when participants used AP in a previous study.¹¹

RESULTS

Descriptive data are shown as mean $\pm$ SD. Men and women were the same age (22.5 ± 2.8 and 22.2 ± 3.2 years, respectively), but men were taller (height = 1.771 ± 0.069 m versus 1.625 ± 0.075 m, respectively; $P = .001$)

and heavier (mass = 70.2 ± 11.0 kg versus 57.7 ± 7.9 kg, respectively; $P = .001$) and had a greater total body sweat rate estimated from body mass loss (1454 ± 759 mL/h versus 876 ± 438 mL/h, respectively; $P = .001$).

As shown in Table 2, no baseline, environmental, or exercise condition was different among skin treatments ($P > .05$).

Local sweat rates are shown in Figure 1. The mixed 2-way analysis of covariance demonstrated no significant interaction between sex and treatment ($P = .439$). A main effect was noted for sex, with a greater mean sweat rate in men ($115.6 \mu\text{L}/\text{min}\cdot\text{dm}^2$; 95% confidence interval [CI] = $109.6, 121.5 \mu\text{L}/\text{min}\cdot\text{dm}^2$) than in women ($97.0 \mu\text{L}/\text{min}\cdot\text{dm}^2$; 95% CI = $91.0, 102.9 \mu\text{L}/\text{min}\cdot\text{dm}^2$; $P = .0007$).

There was also a main effect of skin treatment ($P = .001$). Post hoc analysis indicated that LSR was lower for the SB ($99.3 \mu\text{L}/\text{min}\cdot\text{dm}^2$; 95% CI = $93.1, 105.5 \mu\text{L}/\text{min}\cdot\text{dm}^2$) and AP ($88.3 \mu\text{L}/\text{min}\cdot\text{dm}^2$; 95% CI = $82.0, 94.7 \mu\text{L}/\text{min}\cdot\text{dm}^2$) treatments than for the SA ($114.8 \mu\text{L}/\text{min}\cdot\text{dm}^2$; 95% CI = $108.8, 120.6 \mu\text{L}/\text{min}\cdot\text{dm}^2$) or C ($122.6 \mu\text{L}/\text{min}\cdot\text{dm}^2$; 95% CI = $116.2, 129.0 \mu\text{L}/\text{min}\cdot\text{dm}^2$; $P < .01$) treatments. No differences were found between the SB and AP ($P = .10$) or between the SA and C ($P = .48$) treatments.

The LSR did not differ between the left and right sides ($P = .654$; Figure 2A). Mean sweat rates were $103.4 \mu\text{L}/\text{min}\cdot\text{dm}^2$ (95% CI = $85.4, 121.4 \mu\text{L}/\text{min}\cdot\text{dm}^2$) for the left

Figure 1. Scapular localized sweat rate. Columns represent mean values; error bars, 95% confidence intervals. ^a The sunscreen A and control treatments were not different ($P = .48$). ^b The antiperspirant and sunscreen B treatments were not different ($P = .10$).

Figure 2. Scapular localized sweat rate by **A**, side, and **B**, session. Columns represent mean values; error bars, 95% confidence intervals. Mean differences were not significant between sides ($P = .654$) or sessions ($P = .397$).

and $109.1 \mu\text{L}/\text{min}\cdot\text{dm}^2$ (95% CI = $91.1, 127.1 \mu\text{L}/\text{min}\cdot\text{dm}^2$) for the right. Finally, LSR was not different between sessions ($P = .397$), with $104.5 \mu\text{L}/\text{min}\cdot\text{dm}^2$ (95% CI = $91.5, 117.5 \mu\text{L}/\text{min}\cdot\text{dm}^2$) for session 1 and $108.2 \mu\text{L}/\text{min}\cdot\text{dm}^2$ (95% CI = $94.6, 121.8 \mu\text{L}/\text{min}\cdot\text{dm}^2$) for session 2 (Figure 2B).

DISCUSSION

Our main result was that the application of SB to the skin hindered sweat production to the same extent as an AP. This was not the case for SA, which had no measurable effect on LSR when compared with the C treatment. The effect of the lotions was not differentiated by sex.

The SB reduced LSR by 17.2% compared with C and 12.5% compared with SA. At this point, it is not possible to explain the major differences between the sunscreens. We tested 2 commercially available products with the same SPF but many different specific ingredients. The major active ingredients were different: oxybenzone for SA and titanium dioxide for SB. Also, we can speculate that phenylbenzimidazole sodium sulfonate, a secondary ingredient consisting of very small particles and used in combination with titanium dioxide in SB, may penetrate the skin and physically interfere with sweating; there may be a chemical inhibition of sweat gland activity as well. Future researchers should identify those ingredients that interfere with effective sweating.

In previous studies^{20,21} of sunscreen, no differences in sweat rate, core temperature, or exercise performance have been observed. Connolly and Wilcox²⁰ evaluated the physiological responses of 22 men who exercised at 50% to 60% $\dot{V}\text{O}_2\text{max}$ in the heat (temperature = 32°C , relative humidity = 54%) for 45 minutes with or without sunscreen (30 mL sunscreen/ m^2 of bare skin). No differences were found for rectal temperature, blood lactate, plasma volume changes, oxygen consumption, heart rate, perceived exertion, or total body sweat loss during exercise. However, because they provided no details about the brand or type of sunscreen tested, it is possible that they used a product similar to our SA, which had no effect on LSR. House and Breed²¹ compared thermoregulation during 60 minutes of stepping exercise in dry heat (temperature = 40°C , relative

humidity = 20%) for 8 males and 4 females under 3 conditions: after the application of 20 g/ m^2 of alcohol-based sunscreen, oil-based sunscreen, or no sunscreen (C). No differences were noted in sweat output ($P = .939$), heart rate, core temperature, or skin temperature (all P values $>.05$). However, the initial conditions (ie, body temperature, hydration status) and exercise intensity were not carefully controlled in the study, limiting the strength of the conclusions. No ingredients in the sunscreens used were reported, so it is also possible that they were similar to SA in our study. The physiological relevance of the LSR reductions we observed with SB remains to be tested; thermoregulatory effects will likely depend on the ratio of the clothed skin area to the bare skin area treated with sunscreen.

The AP had the expected effect on LSR, which was 25.5% less than for the C condition, consistent with a previously reported 24% reduction (90.3 versus $118.7 \mu\text{L}/\text{min}\cdot\text{dm}^2$ for AP and C, respectively; $P = .001$).¹¹ This reduction in sweat output is far from the 50% claimed by some manufacturers. Nevertheless, we consider it high enough to advise physically active people and athletes against the use of AP over wide skin areas when effective sweating is important for thermoregulation.

In summary, this study showed a potential conflict between thermoregulation (the need for effective sweat production to promote evaporation) and the need for skin protection during outdoor exercise in the heat.²² Future authors should aim to identify the specific ingredients in sunscreens that interfere with effective sweating and their physiological mechanisms, as well as the thermoregulatory implications. Meanwhile, we advise athletes and physically active people to limit the use of AP and SB if they are concerned about reducing sweat rates during exercise in the heat.

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REFERENCES

- Hadad E, Rav-Acha M, Heled Y, Epstein Y, Moran DS. Heat stroke: a review of cooling methods. *Sports Med.* 2004;34(8):501–511.
- Hosokawa Y, Adams WM, Stearns RL, Casa DJ. Heat stroke in physical activity and sports. *Pensar Mov.* 2014;12(2):1–21.
- McCullough EA, Kenney WL. Thermal insulation and evaporative resistance of football uniforms. *Med Sci Sports Exerc.* 2003;35(5):832–837.
- Zhang XH, Li J, Wang YY. Effects of clothing ventilation openings on thermoregulatory responses during exercise. *Indian J Fibre Text Res.* 2012;37(2):162–171.
- Davis JK, Bishop PA. Impact of clothing on exercise in the heat. *Sports Med.* 2013;43(8):695–706.
- Havenith G. Interaction of clothing and thermoregulation. *Exog Dermatol.* 2002;1(5):221–230.
- Gavin TP. Clothing and thermoregulation during exercise. *Sports Med.* 2003;33(13):941–947.
- Ueda H, Inoue Y, Matsudaira M, Araki T, Havenith G. Regional microclimate humidity of clothing during light work as a result of the interaction between local sweat production and ventilation. *Int J Cloth Sci Technol.* 2006;18(4):225–234.
- Kwon J, Choi J. Clothing insulation and temperature, layer and mass of clothing under comfortable environmental conditions. *J Physiol Anthropol.* 2013;32(11):1–8.
- Adams R. Revised Physical Activity Readiness Questionnaire. *Can Fam Physician.* 1999;45(992.995):1004–1005.
- Aburto-Corona JA, Aragón-Vargas LF. Capacidad del método de parches de sudoración para detectar el efecto de un antitranspirante [Capacity of a sweat patch method to detect the effect of an antiperspirant]. *Pensar Mov.* 2015;13(1):1–10.
- Marfell-Jones M, Olds T, Stewart A, Carter L. International standards for anthropometric assessment. The International Society for the Advancement of Kinanthropometry Web site. <http://www.isakonline.com/publications>. Accessed April 6, 2015.
- Gellis RL, Goslin BR, Olson RE, McDonald A, Russi GD, Moudgil VK. Longitudinal modeling on the relationship between age and maximal heart rate. *Med Sci Sports Exerc.* 2007;39(5):822–829.
- Maughan RJ, Merson SJ, Broad NP, Shirreffs SM. Fluid and electrolyte intake and loss in elite soccer players during training. *Int J Sport Nutr Exerc Metab.* 2004;14(3):333–346.
- Smith CJ, Havenith G. Body mapping of sweating patterns in male athletes in mild exercise-induced hyperthermia. *Eur J Appl Physiol.* 2011;111(7):1391–1404.
- Morris NB, Cramer MN, Hodder SG, Havenith G, Jay O. A comparison between the technical absorbent and ventilated capsule methods for measuring local sweat rate. *J Appl Physiol.* 2013;114(6):816–823.
- Armstrong LE, Pumerantz AC, Fiala KA, et al. Human hydration indices: acute and longitudinal reference values. *Int J Sport Nutr Exerc Metab.* 2010;20(2):145–153.
- Moran VH, Leathard HL, Coley J. Cardiovascular functioning during the menstrual cycle. *Clin Physiol.* 2000;20(6):496–504.
- Lacerda MG, García AM, Cruz C, Calcagno JC, Reis FM, Silami-Garcia E. Effects of menstrual cycle on sweating during exercise performed in hot and dry environment. *Biochem Physiol.* 2013;2:1–5.
- Connolly DA, Wilcox AR. The effects of an application of sunscreen on selected physiological variables during exercise in the heat. *J Sports Med Phys Fitness.* 2000;40(1):35–40.
- House JR, Breed M. Sunscreen use reduces sweat evaporation but not production. Presented at: 15th International Conference on Environmental Ergonomics; February 11–15, 2013; Queenstown, New Zealand.
- Adams BB. *Sports Dermatology*. New York, NY: Springer; 2006: 106–123.

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