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Incidence and public health burden of sunburn among beachgoers in the United States

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ABSTRACT

The beach environment creates many barriers to effective sun protection, putting beachgoers at risk for sunburn, a well-established risk factor for skin cancer. Our objective was to estimate incidence of sunburn among beachgoers and evaluate the relationship between sunburn incidence and sun-protective behaviors. A secondary analysis, of prospective cohorts at 12 locations within the U.S. from 2003 to 2009 (n = 75,614), were pooled to evaluate sunburn incidence 10–12 days after the beach visit. Behavioral and environmental conditions were cross-tabulated with sunburn incidence. Multivariable logistic regression was used to estimate the association between new sunburn and sun-protective behaviors. Overall, 13.1% of beachgoers reported sunburn. Those aged 13–18 years (16.5%), whites (16.0%), and those at beach locations along the Eastern Seaboard (16.1%), had the highest incidence of sunburn. For those spending ≥5 h in the sun, the use of multiple types of sun protection reduced odds of sunburn by 55% relative to those who used no sun protection (Odds Ratio = 0.45 (95% Confidence Interval:0.27–0.77)) after adjusting for skin type, age, and race. Acute health effects of sunburn tend to be mild and self-limiting, but potential long-term health consequences are more serious and costly. Efforts to encourage and support proper sun-protective behaviors, and increase access to shade, protective clothing, and sunscreen, can help prevent sunburn and reduce skin cancer risk among beachgoers.

1. Introduction

The number of U.S. adults treated for skin cancer each year has increased rapidly (Guy et al., 2015). Between 2007 and 2011, almost 5 million adults were treated annually for skin cancer, at an estimated cost of over $8 billion (Guy et al., 2015). Skin cancer is a growing, but preventable, public health concern (U.S. Department of Health and Human Services, 2014). Identifying factors associated with the development of sunburn, an important risk factor for skin cancer (U.S. Department of Health and Human Services, 2014; Dennis et al., 2008), can help to inform sun-safety interventions, which may aid in reducing the incidence of skin cancer.

Sunburn is a biologic indicator of skin damage from ultraviolet radiation (UVR) exposure and is influenced by the intensity of a person's UVR exposure and their sensitivity to such exposure (Wu et al., 2016; International Agency for Research on Cancer, 2012). Each year, approximately one-third of U.S. adults (Holman et al., 2018) and over half of U.S. high school students (Kann et al., 2018) get at least one sunburn. In 2013, almost 34,000 people in the U.S. had sunburn severe enough to seek treatment in an emergency department (ED), resulting in an estimated cost of $11.2 million (Guy et al., 2017).

Beach visitation is a prominent mechanism for incurring sunburn, with one study estimating that 15% of beachgoers report sunburn in a single beach visit (Marion et al., 2018). Approximately 43% of

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Americans aged 16 years and older visited a beach for an average of 11 days each year during 2005–2009 (Cordell, 2012). Using a combination of sun protection strategies when spending time outdoors, including staying in the shade, wearing protective clothing, a wide-brimmed hat, sunglasses, and using sunscreen, can minimize skin damage from the sun (U.S. Department of Health and Human Services, 2014; Centers for Disease Control and Prevention, 2018). However, sun protection adequate to avoid sunburn can be challenging in beach settings. Beaches are often visited during times when the UV Index is high (U.S. Environmental Protection Agency, 2017), and beachgoers frequently engage in activities that can create additional barriers to adequate protection. For example, sand and water reflect UVR, potentially increasing exposure and reducing the amount of protection conferred by shade structures (Holman et al., in press), and water-related activities can often cause sunscreen to wash off (Wright et al., 2001).

The primary aim of this study was to quantify the incidence of new sunburn over a 10–12 day period among beachgoers in 12 large prospective cohorts (n = 75,614) and compare incidence across demographic characteristics and other factors. These studies were conducted using similar methodology (Wade et al., 2008; Yau et al., 2014; Arnold et al., 2013; Colford et al., 2012; Wade et al., 2006, 2010) and were combined, as has been described previously (Arnold et al., 2016). The secondary aim of this study was to evaluate the relationship between the odds of incident sunburn and sun protective behaviors.

2. Methods

The current study, involved a secondary analysis of data from prospective cohort studies at 12 locations within the U.S. from 2003 to 2009, which have been previously described (Arnold et al., 2016) (Fig. S1). Four cohorts were at freshwater beaches in the Midwest (n = 21,015), two were along the Eastern Seaboard (n = 14,136), two were in the Gulf Coast (n = 3373), three were in Southern California (n = 8797), and one was at tropical beach in Puerto Rico (n = 15,726). The primary purpose of these prospective cohort studies was to examine swimming-associated gastrointestinal illness among beachgoers. However, beachgoers also answered questions about sunburn and sun protection behaviors.

All studies followed similar protocols and questionnaires. Eligible household members who agreed to participate provided informed consent and were enrolled between May and September during the study years. Institutional Review Board approval was obtained from the University of North Carolina-Chapel Hill; the University of California, Berkeley; and the Centers for Disease Control and Prevention. One adult member of each household responded to questions for the entire household 10–12 days after the beach interview. Procedures for recruitment and survey administration have been described previously (Arnold et al., 2016).

One member of each participating household answered questions for themselves and all other household members. The baseline interview was conducted at the beach and included a question regarding whether any of the household members had been sunburned in the past three days. Those who had been sunburned at the time of the baseline interview were excluded from the analyses. A follow-up interview was conducted by phone 10–12 days after the baseline interview. Participants were asked, “has anyone in the household had a sunburn since the interview at {BEACH} on {beach interview date}.” If answered in the affirmative, the question was followed with questions about which household members had a sunburn and where on their body the sunburn occurred. As a sensitivity analysis, we also incorporated the reported date of sunburn symptom onset, which was reported only among beachgoers in Southern California.

We focused on assessing certain participant characteristics and behaviors at the beach that might impact the incidence of sunburn using cross-tabulation and chi-square analyses comparing those with and without sunburn. First, we evaluated age, sex, and race. We collapsed ages ≥55 into one category because of small sample sizes at older ages. A subset of participants at beaches in the Eastern Seaboard, Gulf Coast, and Puerto Rico were asked to describe what typically occurs when they are exposed to the sun in the absence of sunscreen or protective clothing/equipment (dark tan, some tanning, freckles, repeat sunburns, other, and never go in the sun). Participants were asked to estimate the amount of time spent in the sun and total time spent in the water and indicate whether they had contact with the water. We also examined sun protective behaviors such as sunscreen use, if sunscreen was reapplied, if any protective clothing was worn, or if any time was spent in the shade (under a canopy or an umbrella). We stratified our analyses by sex and race to understand any differences among males versus females or whites versus non-whites.

Cloud coverage, air temperature, and solar radiation were recorded daily at 8:00 am, 11:00 am, and 3:00 pm at all beaches except California. Cloud coverage was assessed via consensus with the field research team at each beach. Air temperature (°C) was measured at a fixed location using a thermometer. Portable meters (Silicon Pyranometer Sensor in 2003 and UVX Radiometers 2004–2009) were used to measure solar power per unit area in $\mu W/m^2$ and were calibrated once per season prior to use. We assessed sunburn frequency with median daily cloud cover, average daily temperature, and solar radiation measurements taken at 11:00 am, when UVR is often at its highest (Vanicek et al., 2000).

Among those with information available on skin type (as described above in terms of what typically occurs when exposed to the sun) the association between sun protective behaviors and sunburn incidence, was evaluated using multivariable logistic regression models where recent sunburn (Yes/No) was the outcome and the number (0–3) of sun protective behaviors (sunscreen, protective hat, and shade) was the primary exposure. Models were adjusted for age, race, beach site, water contact, skin type and hours spent in the sun. Cluster- robust standard errors were used in regression models to account for clustering at the household level (Williams, 2000). Hours spent in the sun were also considered an effect modifier of the association between protective behaviors and sunburn. Adjusted average probabilities following regression were estimated using the *margins* command in Stata 14 (Stata Statistical Software, 2015).

Beachgoers participating at all locations except California were asked to provide information relating to the burden of their illness. Participants reported over-the-counter (OTC) and prescription medication use, visits with a healthcare provider (in person or by phone), visits to an ED, and the number of workdays lost due to sunburn. These questions were asked for skin symptoms in general, which could have included sunburn, rash, or cuts, but were only analyzed among those reporting sunburn and no other skin symptoms.

3. Results

During the study period, 75,614 beachgoers participated and 9882 (13.1%) reported sunburn symptoms after the beach visit (Table 1). Sunburn incidence varied by beach location ($p < 0.001$), with the lowest incidence (9.9%) in Puerto Rico and the highest (16.1%) along the Eastern Seaboard. At all beaches, 5.1% of those ≤3 years old experienced sunburn. Among those < 35 years old, sunburn incidence increased with age ($p < 0.001$), peaking at 18.3% for those 19–34. Sunburn incidence decreased with age among adults ≥35. Whites were more likely to be sunburned (16.0%) compared to non-whites (blacks = 4.3%, other races = 11.0%, $p < 0.001$). There was little difference in sunburn incidence between males (13.8%) and females (14.2%) ($p = 0.17$). When examining the skin's reaction to sun exposure, the highest incidence of sunburn (16.5%) was among those reporting that they get ‘repeat sunburns’, and the lowest (11.3%) was among those indicating they get a ‘dark tan’ when out in the sun ($p < 0.001$). Approximately 5.3% of those indicating they ‘never go out in the sun’, developed sunburn.

Table 1
Demographics by beach location for those with and without sunburn.

Sunburn (no. (%))	All locations		Midwest		Eastern seaboard		Gulf Coast		Southern California		Puerto Rico	
	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
No. (%)	65,732 (86.9%)	9882 (13.1%)	16,941 (85.0%)	2982 (15.0%)	11,129 (83.9%)	2137 (16.1%)	2895 (89.4%)	342 (10.6%)	16,231 (84.7%)	2920 (15.3%)	13,603 (90.1%)	1501 (9.9%)
Age categories												
3 and under	3899 (94.9%)	208 (5.1%)	1143 (94.5%)	67 (5.6%)	631 (95.6%)	29 (4.4%)	231 (96.4%)	8 (3.6%)	1251 (94.2%)	77 (5.8%)	643 (96.0%)	27 (4.0%)
4–7	5069 (90.6%)	528 (9.4%)	1518 (91.1%)	149 (8.9%)	757 (89.6%)	88 (10.4%)	290 (94.5%)	17 (5.6%)	1734 (89.5%)	203 (10.5%)	770 (91.6%)	71 (8.4%)
8–12	6274 (87.7%)	879 (12.3%)	1813 (89.0%)	224 (11.0%)	947 (86.3%)	151 (13.7%)	316 (91.9%)	28 (8.1%)	1967 (85.6%)	332 (14.4%)	1222 (89.5%)	144 (10.5%)
13–18	5327 (83.5%)	1054 (16.5%)	1318 (80.8%)	328 (19.2%)	885 (79.2%)	233 (20.8%)	226 (84.6%)	41 (15.4%)	1290 (81.6%)	291 (18.4%)	1545 (90.6%)	161 (9.4%)
19–34	13,832 (81.7%)	3108 (18.3%)	4017 (79.1%)	1062 (20.9%)	2360 (79.1%)	622 (20.9%)	785 (85.6%)	132 (14.4%)	2865 (80.2%)	707 (19.8%)	3805 (86.7%)	585 (13.3%)
35–54	19,284 (85.4%)	3306 (14.6%)	5325 (84.7%)	958 (15.3%)	3641 (82.5%)	772 (17.5%)	760 (88.2%)	102 (11.8%)	5525 (83.8%)	1071 (16.2%)	4033 (90.9%)	403 (9.1%)
55 and over	6281 (90.3%)	674 (9.7%)	1310 (90.6%)	136 (9.4%)	1760 (89.2%)	214 (10.8%)	262 (95.3%)	13 (4.7%)	1543 (86.9%)	232 (13.1%)	1406 (94.7%)	79 (5.3%)
χ^2, p-value	801.2783, 0.000		356.1341, 0.000		206.8901, 0.000		55.3733, 0.000		207.9073, 0.000		125.2392, 0.000	
Sex												
Females	27,163 (85.8%)	4489 (14.2%)	9462 (84.8%)	1292 (15.2%)	6237 (84.8%)	1120 (15.2%)	1593 (90.1%)	175 (9.9%)	8747 (84.9%)	1553 (15.1%)	7479 (89.9%)	838 (10.8%)
Males	33,518 (86.2%)	5376 (13.8%)	7461 (85.2%)	1690 (14.8%)	4854 (82.8%)	1006 (17.2%)	1293 (88.6%)	167 (11.4%)	7445 (84.5%)	1366 (15.5%)	6110 (90.3%)	658 (9.7%)
χ^2, p-value	1.8821, 0.170		0.5964, 0.440		9.1291, 0.003		2.0025, 0.157		0.6649, 0.415		0.5220, 0.470	
Race												
White	36,947 (84.0%)	7061 (16.0%)	14,086 (84.2%)	2652 (15.8%)	9592 (82.7%)	2002 (17.3%)	1728 (86.4%)	272 (13.6%)	11,499 (84.4%)	2128 (15.6%)	42 (85.7%)	7 (14.3%)
Black	2096 (95.7%)	94 (4.3%)	563 (96.7%)	19 (3.3%)	353 (93.4%)	25 (6.6%)	882 (96.7%)	30 (3.3%)	290 (93.6%)	20 (6.5%)	8 (100.0%)	0 (0.0%)
Other	21,271 (89.0%)	2641 (11.0%)	2229 (88.2%)	298 (11.8%)	1153 (91.6%)	105 (8.4%)	284 (87.7%)	40 (12.4%)	4062 (85.2%)	706 (14.8%)	13,543 (90.1%)	1492 (9.9%)
χ^2, p value	498.4908, 0.000		92.7904, 0.000		92.7969, 0.000		71.6541, 0.000		20.6946, 0.000		1.9216, 0.383	
What typically happens when exposed to sun?[a]												
Dark tan	7870 (88.7%)	1001 (11.3%)			3461 (86.6%)	537 (13.4%)	1050 (91.1%)	103 (8.9%)			3359 (90.3%)	361 (9.7%)
Some tanning	11,783 (87.7%)	1647 (12.3%)			4406 (84.0%)	842 (16.0%)	1019 (87.9%)	(12.1%)			6358 (90.5%)	665 (9.5%)
No tan, freckles	1254 (86.7%)	193 (13.3%)			546 (83.6%)	107 (16.4%)	191 (90.9%)	19 (9.1%)			517 (88.5%)	67 (11.5%)
Repeat sunburns	4963 (83.5%)	979 (16.5%)			2222 (79.2%)	585 (20.8%)	392 (84.7%)	71 (15.3%)			2322 (87.8%)	323 (12.2%)
Other	659 (88.2%)	88 (11.8%)			239 (84.5%)	44 (15.5%)	102 (95.3%)	5 (4.7%)			318 (89.1%)	39 (10.9%)
Never go out in sun	945 (94.7%)	53 (5.3%)			204 (92.7%)	16 (7.3%)	129 (97.7%)	3 (2.3%)			612 (94.7%)	34 (5.3%)
χ^2, p-value	148.3906, 0.000				80.4389, 0.000		31.2279, 0.000				34.9128, 0.000	

[a] Skin's reaction to sun was not asked at Midwestern or California beaches.

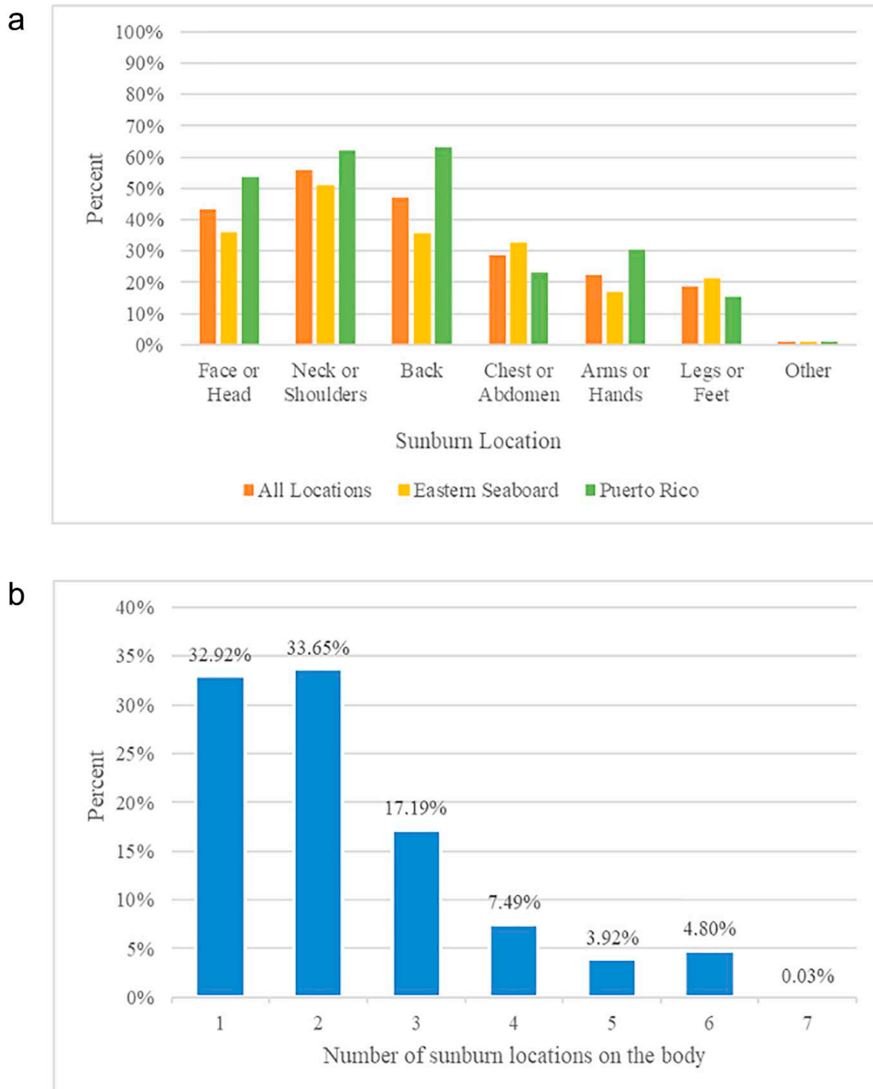

Fig. 1. Parts of the body sunburned (a) and number of sunburn locations on the body (b) among those with incident sunburn. Contains only participants at Eastern Seaboard and Puerto Rico beaches.

The neck/shoulders (55.7%) and the back (46.9%) were the two most frequently reported sunburn locations among those with incident sunburn (Fig. 1a). The proportion reporting incident sunburn on the back differed by beach location (35.4% along the Eastern Seaboard versus 63.2% in Puerto Rico). Approximately 43.2% were sunburned on their face/head, and < 30% were sunburned on their chest/abdomen, arms/hands, or legs/feet. Almost 33% were sunburned in ≥3 body locations (Fig. 1b).

Table 2 shows the association between sunburn and behaviors possibly putting beachgoers at greater risk for sunburn. Sunburn was more likely to occur the longer a person spent in the sun (> 6 h = 19.9%, < 1 h = 8.0%, $p < 0.001$). Any water contact (15.2%) was associated with a higher probability of sunburn relative to those with no water contact (11.0%) ($p < 0.001$). When examining date of sunburn onset among Southern California residence, no differences in the associations between sunburn and beach behaviors, were observed among sunburns reported within 0–3 days of the beach visit (Table S1).

Environmental factors also affected sunburn incidence (Table 2). On sunny days, 13.4% of beachgoers experienced sunburn, compared to 9.2% on overcast days ($p < 0.001$). Cloud coverage (Sunny = 13.4%, Overcast 9.2%, $p < 0.001$) was also strongly associated with sunburn incidence. Some locations show a greater incidence of sunburn on "mostly sunny" days compared to "sunny" days but was only significantly different ($p < 0.001$) along the Eastern Seaboard. There also was an increased incidence of sunburn for each 500 μW/m^2 increase in solar radiation at most beach locations (10.1% on days when solar radiation at 11 am was < 500 μW/m^2 versus 14.9% when solar radiation at 11 am was > 1500 μW/m^2 ($p < 0.001$).

No differences in risk factors by sex (Tables S2 and S3) were observed. While blacks had the lowest incidence of sunburn (4.3%) (Table 1), the same risk factors for sunburn among whites applied to other races. (Tables S4 and S5).

Many beachgoers indicated some form of sun protection behavior (Table 3). Overall, 66.4% used sunscreen, but varied by age, ranging from about 60% among those aged 19–34 and ≥55 to over 77% among those < 7 years old ($p < 0.001$). Of those who applied sunscreen, 50.4% reported reapplying sunscreen. Additionally, 28.5% indicated wearing a hat and/or protective clothing, and 26.8% stayed in the shade. Use of hats and/or protective clothing was significantly more common among those ≤3 years (25.1%) and those ≥55 years (51.2%), compared to 12.6% of those 8–12 ($p < 0.001$).

Without adjustment for other factors, use of sunscreen and shade were associated with an increased incidence of sunburn (Odds Ratio

Table 2
Behavioral and environmental risk factors by beach location[a] among those with and without sunburn.

Sunburn (no. (%))	All locations		Midwest		Eastern seaboard		Gulf Coast		Southern California		Puerto Rico	
	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Time in the sun												
< 1 h	6182 (92.0%)	534 (8.0%)	1488 (92.8%)	113 (7.2%)	1303 (90.2%)	141 (9.7%)	593 (93.4%)	42 (6.6%)	1325 (89.9%)	149 (10.1%)	1513 (94.4%)	89 (5.6%)
1–2 h	25,891 (87.7%)	3620 (12.3%)	7811 (87.6%)	1104 (12.4%)	5520 (85.6%)	928 (14.4%)	1484 (89.6%)	172 (10.4%)	6112 (86.5%)	951 (13.5%)	4964 (91.4%)	465 (8.6%)
2–4 h	20,797 (83.9%)	3979 (16.1%)	6179 (82.5%)	1310 (17.5%)	3382 (80.3%)	832 (19.7%)	656 (97.0%)	98 (13.0%)	5435 (83.1%)	1106 (16.9%)	5145 (89.0%)	633 (11.0%)
5–6 h	6201 (81.7%)	1387 (18.3%)	1204 (75.4%)	393 (24.6%)	760 (79.3%)	198 (20.7%)	120 (83.3%)	24 (16.7%)	2471 (82.7%)	518 (17.3%)	1646 (86.6%)	254 (13.4%)
> 6 h	1301 (80.1%)	324 (19.9%)	169 (78.6%)	46 (21.4%)	103 (76.9%)	31 (23.1%)	24 (82.8%)	5 (17.2%)	815 (81.2%)	189 (18.8%)	190 (78.2%)	53 (21.8%)
χ^2, p-value	527.3986, 0.000		280.6776, 0.000		117.7149, 0.000		22.2467, 0.000		81.3125, 0.000		115.1370, 0.000	
Any contact with water												
Yes	18,257 (89.0%)	2259 (11.0%)	11,155 (83.6%)	2188 (16.4%)	8233 (81.8%)	1832 (18.2%)	1806 (88.4%)	237 (11.6%)	10,572 (83.8%)	2050 (16.2%)	10,776 (89.1%)	1316 (10.9%)
No	42,542 (84.8%)	7623 (15.2%)	5786 (87.9%)	794 (12.1%)	2896 (90.5%)	305 (9.5%)	1089 (91.2%)	105 (8.8%)	5659 (86.7%)	870 (13.3%)	2827 (93.9%)	185 (6.1%)
χ^2, p-value	212.0471, 0.000		64.9550, 0.000		135.1946, 0.000		6.2821, 0.012		28.3210, 0.000		60.5611, 0.000	
Body immersed in water												
Yes	25,913 (87.7%)	3623 (12.3%)	8223 (83.3%)	1651 (16.7%)	6935 (81.0%)	1624 (19.0%)	1329 (88.1%)	179 (11.9%)	8056 (84.0%)	1534 (16.0%)	10,343 (89.1%)	1271 (10.9%)
No	34,886 (84.8%)	6259 (15.2%)	8718 (86.7%)	1331 (13.3%)	4194 (89.1%)	513 (10.9%)	1566 (90.6%)	163 (9.4%)	8175 (85.5%)	1386 (14.5%)	3260 (93.4%)	230 (6.6%)
χ^2, p-value	124.0503, 0.000		47.2693, 0.000		146.5505, 0.000		5.0860, 0.024		8.3299, 0.004		56.8260, 0.000	
Time in the water												
< 30 min	16,143 (84.7%)	2920 (15.3%)	5915 (83.6%)	1157 (16.4%)	3716 (84.7%)	674 (15.4%)	671 (88.1%)	91 (11.9%)	4227 (83.2%)	851 (16.8%)	1614 (91.7%)	147 (8.3%)
30 min–1 h	10,394 (85.4%)	1780 (14.6%)	2693 (84.0%)	513 (16.0%)	2183 (80.9%)	516 (19.1%)	461 (89.9%)	52 (10.1%)	2660 (85.6%)	448 (14.4%)	2397 (90.5%)	251 (9.5%)
1–3 h	12,769 (84.6%)	2320 (15.4%)	2251 (83.6%)	443 (16.4%)	2113 (78.7%)	571 (21.3%)	586 (88.0%)	80 (12.0%)	2875 (83.1%)	583 (16.9%)	4944 (88.5%)	643 (11.5%)
> 3 h	3134 (84.3%)	583 (15.7%)	258 (78.7%)	70 (21.3%)	213 (75.0%)	71 (25.0%)	88 (86.3%)	14 (13.7%)	759 (83.0%)	155 (17.0%)	1816 (86.9%)	273 (13.1%)
χ^2, p-value	4.4049, 0.221		6.2195, 0.101		51.2501, 0.000		1.7182, 0.633		9.9471, 0.019		29.6224, 0.000	
How often do you come to this beach yearly												
Never	5671 (84.4%)	1049 (15.6%)	1223 (85.3%)	211 (14.7%)	275 (88.1%)	37 (11.9%)	34 (91.9%)	3 (8.1%)	3966 (83.5%)	782 (16.5%)	173 (91.5%)	16 (8.5%)
1–5 times	37,326 (85.7%)	6251 (14.3%)	10,802 (84.4%)	1999 (15.6%)	6517 (81.7%)	1456 (18.3%)	1890 (89.1%)	232 (10.9%)	7805 (84.6%)	1417 (15.4%)	10,312 (90.0%)	1147 (10.0%)
6–10 times	8651 (87.0%)	1298 (13.0%)	2320 (86.9%)	349 (13.1%)	2056 (84.8%)	368 (15.2%)	330 (90.9%)	33 (9.1%)	2279 (86.5%)	355 (13.5%)	1666 (89.6%)	193 (10.4%)
> 10 times	9151 (87.7%)	1284 (12.3%)	2596 (86.0%)	423 (14.0%)	2281 (89.2%)	276 (10.8%)	641 (89.7%)	74 (10.4%)	2181 (85.6%)	366 (14.4%)	1452 (90.9%)	145 (9.1%)
χ^2, p-value	51.2276, 0.000		13.9731, 0.003		86.5052, 0.000		1.4105, 0.703		13.4945, 0.004		2.2478, 0.523	
Miles traveled to beach												
< 20 miles	21,009 (86.4%)	3316 (13.6%)	7187 (87.2%)	1058 (12.8%)	8603 (83.4%)	1717 (16.6%)	1201 (89.9%)	135 (10.1%)			4018 (90.8%)	406 (9.2%)
20–50 miles	9105 (87.2%)	1338 (12.8%)	4352 (83.5%)	857 (16.5%)	1018 (91.6%)	93 (8.4%)	771 (92.3%)	64 (7.7%)			2964 (90.2%)	324 (9.8%)
50–100 miles	7951 (87.1%)	1174 (12.9%)	3024 (84.0%)	576 (16.0%)	315 (87.0%)	47 (13.0%)	239 (88.2%)	32 (11.8%)			4373 (89.4%)	519 (10.6%)
> 100 miles	5319 (84.4%)	985 (15.6%)	2200 (85.0%)	459 (17.3%)	1102 (79.9%)	277 (20.1%)	684 (86.0%)	111 (14.0%)			1333 (90.6%)	138 (9.4%)
χ^2, p-value	31.7421, 0.000		52.5893, 0.000		69.7218, 0.000		17.8865, 0.000				5.7914, 0.122	
Cloud coverage												
Sunny	13,132 (86.6%)	2028 (13.4%)	6675 (84.8%)	1198 (15.2%)	2772 (85.7%)	464 (14.3%)	961 (89.6%)	111 (10.4%)			2724 (91.4%)	255 (8.6%)
Mostly sunny	21,428 (86.1%)	3449 (13.9%)	3675 (84.7%)	664 (15.3%)	7020 (82.4%)	1495 (17.6%)	1363 (89.4%)	162 (10.6%)			9370 (89.3%)	1128 (10.7%)
Cloudy	5827 (86.1%)	938 (13.9%)	3475 (84.1%)	658 (15.9%)	1175 (87.7%)	165 (12.3%)	357 (89.3%)	43 (10.8%)			820 (91.9%)	72 (8.1%)
Mostly cloudy	3125 (88.4%)	409 (11.6%)	2149 (86.6%)	333 (13.4%)	162 (92.6%)	13 (7.4%)	125 (88.0%)	17 (12.0%)			689 (93.7%)	46 (6.3%)

(*continued on next page*)

Table 2 (*continued*)

Sunburn (no. (%))	All locations		Midwest		Eastern seaboard		Gulf Coast		Southern California		Puerto Rico	
	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Overcast	890 (90.8%)	90 (9.2%)	801 (90.8%)	81 (9.2%)			89 (90.8%)	9 (9.2%)				
χ^2, p-value	30.6848, 0.000		31.6309, 0.000		44.7628, 0.000		0.5655, 0.967				28.5473, 0.000	
Mean air temperature (C)												
< 25 °C	15,693 (85.9%)	2567 (14.1%)	13,103 (85.4%)	2240 (14.6%)	2286 (88.3%)	303 (11.7%)	304 (92.7%)	24 (7.3%)				
23–30 °C	16,163 (84.7%)	2924 (15.3%)	3838 (83.8%)	742 (16.2%)	8843 (82.8%)	1834 (17.2%)	1716 (88.6%)	221 (11.4%)			1766 (93.3%)	127 (6.7%)
> 30 °C	12,712 (89.6%)	1471 (10.4%)					875 (90.0%)	97 (10.0%)			11,837 (89.6%)	1374 (10.4%)
χ^2, p-value	177.7183, 0.000		7.1068, 0.008		46.1988, 0.000		5.4762, 0.065				25.2097, 0.000	
Solar radiation at 11 am												
< 500 μW/m^2	3278 (89.9%)	367 (10.1%)	1253 (83.9%)	240 (16.1%)			689 (94.4%)	41 (5.6%)			1336 (94.0%)	86 (6.0%)
500–1000 μW/m^2	5310 (87.4%)	764 (12.6%)	3430 (85.9%)	562 (14.1%)	1157 (90.7%)	118 (9.3%)	162 (86.6%)	25 (13.4%)			561 (90.5%)	59 (9.5%)
1000–1500 μW/m^2	12,675 (86.7%)	1949 (13.3%)	6090 (84.1%)	1152 (15.9%)	3270 (88.5%)	424 (11.5%)	1254 (87.7%)	176 (12.3%)			2061 (91.3%)	197 (8.7%)
> 1500 μW/m^2	17,279 (85.1%)	3029 (14.9%)	878 (78.9%)	235 (21.1%)	6702 (80.8%)	1595 (19.2%)	711 (89.4%)	84 (10.6%)			8988 (89.0%)	1115 (11.0%)
χ^2, p-value	74.277, 0.000		32.6391, 0.000		162.5109, 0.000		25.3540, 0.000				40.3475, 0.000	

[a] Environmental risk factors not collected in California.

(OR) = 1.30(95% Confidence Interval (95% CI): 1.23–1.37); OR 1.27(95% CI: 1.19–1.35)), respectively). However, following adjustment for race, skin type, and other factors described above, sun protective behaviors were associated with a reduced odds of sunburn. The odds of sunburn among those using at least one form of protection were reduced by about 13% compared to those who used no protection (OR = 0.88 (95% CI: 0.78–0.98)), whereas the odds were reduced by about 23% among those using three forms of protection (OR = 0.77(95% CI: 0.65–0.91)), compared to those who used no protection. The protective effects were stronger with increased time spent in the sun, and a test of this interaction was statistically significant (p = 0.007). Among those spending ≥5 h in the sun, use of 1, 2, and 3 forms of protection were associated with a 46%, 47%, and 55% reduced odds of sunburn, respectively, compared to those using no protection (OR = 0.54 (95% CI: 0.39–0.77), 0.54 (95% CI: 0.37–0.79), and 0.45 (95% CI: 0.27–0.77)). For those spending ≥5 h in the sun and using no protection, the adjusted estimated probability of sunburn was 25%, compared to 16%, 16% and 14% for those using 1, 2 and 3 forms of protection, respectively.

Among those with sunburn (excluding those with rash and cuts) in the Midwest, Gulf Coast, and Eastern Seaboard (n = 5071), 34.3% used OTC and 0.3% used prescription medication to treat symptoms. Additionally, 0.3% visited a healthcare provider, 0.04% visited an ED, and 0.03% reported missing work for an average of 1.3 days.

4. Discussion

This analysis used a large cohort of beachgoers (n = 75,614) to assess the incidence of new sunburn (13.1%) over 10–12 days following a single event. Sunburn incidence varied by age, race, and location, among other factors, with the highest incidence among those 13–18 (16.5%) and whites (16.0%). After control for skin type, age, and race, we demonstrated that for those spending ≥5 h in the sun, the use of multiple types of sun protection reduced reported the odds of sunburn incidence by over half. The large sample size allowed us to evaluate demographic, behavioral, and environmental factors at several beaches throughout the U.S. Additionally, we were able to evaluate the burden of illness for a typical sunburn following a day at the beach, among a subset of participants. Similar to other analyses (Marion et al., 2018), we found that sunburn was positively associated with certain beach behaviors, such as water contact, beach visit frequency, and time spent in the sun. While behaviors appear to be important, environmental factors such as weather conditions and solar radiation also influence sunburn incidence.

Reported sunburns tended to be relatively mild and treatable at home. Most sunburn occurred on the neck/shoulders and back, but this pattern varied according to beach location. Approximately 34.3% of those with sunburn used OTC medications, while < 1% used prescriptions, visited a healthcare provider or ED, or missed time from work. In addition to the initial cost-savings and morbidity reduction, reducing sunburn prevalence in the U.S. could, in the long-term, reduce the incidence of skin cancer which is much more expensive and can sometimes be fatal (Guy et al., 2015).

After adjusting for race, age, and skin type, we found that those who used sunscreen and other protective behaviors were less likely to report getting sunburned, compared to those engaging no sun protective behaviors. This protective effect increased as the amount of time spent in the sun increased. Although these results are consistent with experimental trials showing that sunscreen use protects against UV damage (Green et al., 2011; van der Pols et al., 2006), some previous observational studies have found a positive association between sunscreen use and sunburn risk (Holman et al., 2018). Individuals who have sun-sensitive skin or spend long periods of time outdoors may be more likely to get sunburned and more likely to use sunscreen, which may partially explain the lack of protective effect for sunscreen found in some studies. By adjusting for race and skin type and limiting

Table 3
Sun-protection behaviors.

No. (%)	Sunscreen use	Reapply sunscreen	Protective hat/clothing	Shade
All	55,715 (66.4%)	16,042 (50.4%)	17,936 (28.5%)	22,492 (26.8%)
Age categories				
3 and under	3787 (77.1%)	1086 (54.0%)	923 (25.1%)	1765 (36.0%)
4–7	5621 (77.0%)	1399 (53.6%)	757 (14.8%)	1843 (27.0%)
8–12	6265 (70.4%)	1688 (51.4%)	852 (12.6%)	2221 (25.0%)
13–18	4934 (64.9%)	1597 (54.4%)	745 (13.0%)	1775 (23.4%)
19–34	12,565 (60.6%)	3597 (47.6%)	3612 (23.7%)	4703 (22.7%)
35–54	17,522 (67.1%)	5101 (51.3%)	7718 (39.4%)	7393 (28.3%)
55 and over	4630 (60.5%)	1280 (43.8%)	3.161 (51.2%)	2539 (33.2%)
χ^2, p-value	1100, p < 0.001	119.8, p < 0.001	4900 p < 0.001	636.3, p < 0.001
Sex				
Females	31,107 (68.7%)	9316 (50.8%)	8922 (26.6%)	11,916 (26.3%)
Males	24,449 (63.8%)	6681 (49.9%)	8966 (30.7%)	10,501 (27.4%)
χ^2, p-value	224.1, p < 0.001	2.4, p = 0.12	132.0, p < 0.001	12.4, p < 0.001
Race				
White	34,196 (68.6%)	8997 (49.2%)	10,857 (33.6%)	13,503 (27.1%)
Black	770 (29.8%)	167 (37.0%)	387 (19.5%)	837 (32.3%)
Other	20,220 (65.8%)	6836 (52.5%)	6530 (23.3%)	7888 (25.7%)
χ^2, p value	1700, p < 0.001	66.0, p < 0.001	876.6, p < 0.001	60.5, p < 0.001

participants to those at the beach (a context in which most participants were spending extended periods of time in the sun), we were able to account for these potential confounders in our analyses.

Given the protective effect demonstrated for sunscreen use in beach settings, there may be value in ensuring easy access to sunscreen in these settings and educating consumers on proper sunscreen use. For example, it is estimated that beachgoers take a median of 51 min to apply sunscreen after arriving at the beach (Robinson and Rademaker, 1998). Additionally, sunscreen application is often considerably less than the amount recommended (2 mg/cm^2) by the U.S. Food and Drug Administration (FDA) (U.S. Food and Drug Administration, 2012). A study among beachgoers (Lademann et al., 2004) found that volunteers typically applied only 10% of the recommended amounts, with the ears and top of the feet mostly remaining unprotected and a recent study (Young et al., 2018) found that sunscreen applied at 0.75 mg/cm^2, was not effective in reducing DNA damage from UVR exposure. Currently, the FDA requires sunscreen labeling stating that sunscreen should be used in combination with other sun protective measures, such as the use of shade or protective clothing (U.S. Food and Drug Administration, 2012). Improving these aspects of sunscreen use would likely increase sun-protective benefits.

In the current study, use of multiple forms of sun protection was associated with lower sunburn odds. This is consistent with previous research findings that suggest seeking shade or wearing protective clothing is associated with a greater reduction in sunburn risk compared to the use of sunscreen alone (Linos et al., 2011; Morris and Perna, 2018). The Community Preventive Services Task Force (Community Guide) recommends interventions in outdoor recreational and tourism settings that include skin cancer prevention messages or educational activities for visitors, and may also provide free sunscreen of SPF 15 or greater (The Community Guide, 2014). This recommendation is based on strong evidence of effectiveness for increasing sunscreen use and avoidance of sun exposure, and decreasing prevalence of sunburns. Such interventions would likely reduce the prevalence of sunburn among those in beach settings.

While evaluating sun protective behaviors, we chose to evaluate a composite index (number of sun protective behaviors: sunscreen, protective hat, and shade) rather than considering individual effects. We decided against evaluating individual effects since these protective behaviors are highly correlated with one another, making it difficult to accurately assess the independent effects while holding the others constant, and the associations are affected both by strong confounding and effect modification. Although we made efforts to account for these there may have been residual confounding not likely completely accounted for, which could affect interpretation of the independent effects. Additionally, while the sample size is large, the analysis of the effects of the protective behaviors was limited to the beach sites that asked about skin tone (~30,000), and then the more pronounced effects were among those spending 5 or more hours in the sun, reducing the size further. As a result we could not adequately tease out the individual effects in a meaningful way.

This study relied on self-reported assessment of behaviors and symptoms and results may be subject to bias from issues such as inaccurate recall and socially desirable responses. Because one household member answered questions for the rest of the members of the household, exposures or symptoms could have been over-or underestimated. The follow-up interview occurred 10–12 days following the initial exposure, which may increase the likelihood of potential exposure misclassification since no data were collected regarding outdoor recreational activities between the initial beach interview and follow-up. However, a subset of beachgoers included in this analysis (from Southern California beaches), provided the date in which sunburn erupted following the beach visit. In a sensitivity analysis (Table S1), we found no differences in the conclusions drawn from the associations between beach behaviors and sunburn, which suggests that exposure misclassification may be minimal. In addition, our solar radiation measurements estimated total flux, but did not incorporate erythema (skin reddening), like the UV Index (World Health Organization, 2002). However, we still found it to be a reliable predictive variable, with incidence increasing with increased solar radiation. While the study data were collected during 2003–2009, these findings are likely still relevant given sunburn prevalence remains high in the U.S., and barriers to sun-safety in beach settings likely have not changed much since these data were collected.

5. Conclusion

In a large pooled analysis of beachgoers at 12 beaches, we found that approximately 13.1% of beachgoers experienced sunburn following the beach visit. Several factors were associated with increased sunburn incidence, including time in the sun, and water contact, whereas use of sunscreen, protective clothing and shade reduced the odds of sunburn by at least half. Although the acute health effects of a sunburn tend to be mild and self-limiting the potential long-term health consequences are more serious and costly (U.S. Department of Health and Human Services, 2014). Efforts to encourage and support proper sun-protective behaviors, and increase access to shade, protective clothing, and sunscreen among beach patrons (The Community Guide, 2014), could help prevent sunburn and reduce skin cancer risk among beachgoers.

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Disclaimers

The views expressed in this manuscript are those of the individual authors and do not necessarily reflect the views and policies of the U.S. Environmental Protection Agency.

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Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

CRediT authorship contribution statement

Stephanie DeFlorio-Barker: Conceptualization, Methodology, Formal analysis, Writing - original draft.**Dawn Holman:**Conceptualization, Writing - review & editing.**Robert Landolfi:**Conceptualization.**Benjamin F. Arnold:**Data curation, Investigation, Resources.**John M. Colford:**Investigation, Resources.**Stephen B. Weisberg:**Investigation, Resources.**Kenneth C. Schiff:**Investigation, Resources.**Elizabeth A. Sams:**Investigation, Resources, Project administration.**Timothy J. Wade:**Conceptualization, Methodology, Formal analysis, Writing - review & editing, Supervision.

Declaration of competing interest

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Appendix A. Supplementary data

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