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Assessment of temperature and ultraviolet radiation effects on sunburn incidence at an inland U.S. Beach: A cohort study

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ABSTRACT

Background: Increases in outdoor temperature may lead to increases in sunburn, outdoor exposure, and skin cancer in human populations.
Objective: This study aimed to quantify sunburn incidence and risk for Ohio beachgoers exposed to varying outdoor conditions.
Methods: Sunburn incidence data were obtained through a prospective cohort study at East Fork Lake (Cincinnati, Ohio, USA). Recruitment occurred over 26 weekend days. Beach interviews and follow-up telephone interviews obtained exposure and health information. New sunburns were self-reported 8–9 days post-enrollment. Survey data were paired with ultraviolet radiation (UVR) index and temperature data for statistical analysis.
Results: Among 947 beachgoers, new sunburns were reported in 18% of swimmers. Sunburn incidence was associated with temperature (odds ratio = 1.2; 95% CI: 1.1 – 1.4) and UVR index (odds ratio = 1.6; 95% CI: 1.0 – 2.5) in models adjusted for water exposure, arrival time, and beach visit frequency. Some evidence of a temperature + UVR interaction was observed.
Limitations: Exposure and sunburn data were self-reported without clinical diagnosis and date of onset. The follow-up period enabled sunburns to be reported from a variety of days rather than only the beach visit day thereby limiting interpretation. Sun protection behaviors were not evaluated.
Conclusions: Temperature and UVR influence sunburn frequency. Temperature, however was more strongly associated with sunburn in beachgoers than the nearest measured UVR index, suggesting future investigations are needed to better understand how temperature effects on sunburn development. Interventions for decreasing sunburn are needed.

1. Introduction

Sunburn remains a significant public health concern due to strong associations between sunburn and a variety of skin cancers, including melanoma (Hartman et al., 2012). The most recent U.S. data indicate sunburn rates are increasing among non-hispanic whites (Buller et al., 2011). The effects of sunburn translate into U.S. sunburn treatment costs exceeding $11 million annually (Guy et al., 2016). Given relationships between outdoor sunburn history and skin cancer development (Lazovich et al., 2010; Wu et al., 2016) costs attributable to downstream cancer effects are greater. As sunburns increase, so do U.S. rates of malignant melanoma skin cancer (MMSC) (Guy et al., 2015). For MMSCs there are an estimated 87,110 new cases and 9730 deaths annually (Siegel et al., 2017). There are also an estimated 5.4 million new cases of non-melanoma skin cancers (NMSCs) each year in the U.S., of which 3.3 million result in treatment (Rogers et al., 2015). Accordingly, enhanced research and education remain vital for sunburn and skin cancer prevention efforts. Such research on populations exposed to recreational water activities is also of importance, as total lifetime ex-

Abbreviation and acronyms: aOR, adjusted odds ratio; cOR, crude odds ratio; IR, infrared radiation; UVR, ultraviolet radiation.

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posure to beach and waterside activities have been linked to melanoma in multi-country European research (Kricker et al., 2007)

Overexposure to ultraviolet radiation (UVR) causes sunburn, tissue injury, DNA damage, and pain (Moore et al., 2013). For this reason, the UVR index is used for communicating sunburn risk (Italia and Rehfuess, 2012).[4] The UVR index is forecasted and provided by 58 U.S. monitoring locations by the National Oceanic and Atmospheric Administration (NOAA) and U.S. Environmental Protection Agency (National Oceanic and Atmospheric Administration, 2016). These stations provide national UVR index coverage, but interpretation is subject to public misunderstanding (Italia and Rehfuess, 2012; Wong et al., 2015). Internationally, temperature as a metric for communicating sunburn risk has been suggested, at least as an addendum to UVR messaging (Dobbinson et al., 2008). Temperatures are understood nationwide and may supplement, not supplant, UVR communication since warmer temperatures promote more outdoor activities and less clothing use (Dobbinson et al., 2008). Elevated skin temperatures related to visible light and infrared radiation may enhance inflammatory processes (Liebel et al., 2012), and potentially promote carcinogenesis at sites of sunburnt skin (Boukamp et al., 1999; Calapre et al., 2016).

To date, few epidemiological studies have evaluated sunburn frequency in the U.S. following typical outdoor recreational exposure. Multiple studies have occurred with respect to seasonal frequencies of sunburns, attitudes, and skin protection practices of U.S. lifeguards (Hiemstra et al., 2011; Hall et al., 2009), and more general populations in Australia (Xiang et al., 2015). These studies, along with a recent study on North American vacationers (Andersen et al., 2016) demonstrate poor adherence to recommended sun protection behaviors even when UV exposure potential is great. Overall, U.S. swimmers represent a large population at risk for sunburn with over 41 million swimming at inland lakes (U.S. Army Corps of Engineers, 2013). Millions more visit outdoor pools and coastal beaches.

Improving understanding of temperature and UVR impacts on sunburn frequency remains timely as global climate change may enhance exposure through increased outdoor activities and decreases in clothing coverage (Thomas et al., 2012). Among vacationers, as temperature increases clothing coverage decreases (Andersen et al., 2016). Additionally, little is known regarding sunburn prevalence in the U.S., with the more current U.S. data coming from a three-state sunburn prevalence study from 1999, 2003, and 2004 (Buller et al., 2011).

Quantifying relationships between temperature, UVR, and sunburn have global application in the midst of a changing climate. In this study, a prospective study design enabled estimation of sunburn risks attributable to several environmental risk factors. This study was part of a larger study evaluating recreational water-associated gastrointestinal illnesses and water quality at East Fork State Park (Cincinnati, Ohio, USA) (Marion et al., 2010, 2012). Here, we (1) characterize sunburn frequency among Ohio beach users and (2) estimate sunburn risks among swimmers and non-swimmers exposed to varying outdoor temperature and UVR over one weekend day and one proceeding week, with enrollment occurring over 13 summer weekends.

2. Materials and methods

2.1. Study design and location

The East Fork Beach Study utilized a prospective cohort design for evaluating exposures associated with changes in health status following visitation to the 365 m public beach near Cincinnati, Ohio, U.S.A (39°1′11.2″; 84°1′2.8″W) during the 2009 outdoor swimming season. Sunburn data were collected as part of our studies on beach water quality and gastrointestinal illness (Cincinnati, Ohio, USA) (Marion et al., 2010, 2012)

The beach is located along the 8.7 km^2 Harsha Lake, a flood-control reservoir operated by the U.S. Army Corps of Engineers. The approach used for collecting health and exposure data was adapted from studies performed by the U.S. Environmental Protection Agency and the Centers for Disease Control and Prevention as part of their National Epidemiological and Environmental Assessment of Recreational Water (NEEAR) (Wade et al., 2006, 2008, 2010).

In brief, beach water samples (not used in this study) were obtained and paired with data obtained from a beach user/exposure data questionnaire for examining relationships with a variety of self-reported conditions including sunburn and gastrointestinal illness. On the enrollment day before beach users left the beach for the day, a household spokesperson over 18 years of age was identified. The speaker provided responses to an oral questionnaire that ascertained beach arrival times, swimming durations, and more among all members of the household present at the beach. First names of household participants and a spokesperson telephone number were obtained for follow-up. After eight to nine days, participants were contacted (or attempted to be contacted three times) to provide information on self-reported health conditions observed since their beach visit. All follow-up data (health effects data) and exposure data from the enrollment day were paired for each individual along with environmental data pertaining to UVR and temperature."

2.2. Study participants

Participants were enrolled at the beach. Specifically, households with a spokesperson over 18 years of age were recruited during their beach visit. Recruitment/enrollment occurred over 13 weeks, which resulted in participants being enrolled into the study over 26 weekend days; using signage, a script, and modest incentives (gifts under \$3). Participants completed an oral survey at enrollment, an exit survey when leaving the beach, and a follow-up telephone-based survey 8–9 days post-enrollment. The study was approved by the Chief of the Ohio Department of Natural Resources, Division of Parks and Recreation and the Institutional Review Board at The Ohio State University (IRB Protocol #2009H0107).

2.3. Survey instruments

Questionnaires were administered orally and were shortened versions of the U.S. EPA NEEAR questionnaire (Wade et al., 2006). The enrollment questionnaire ascertained beach arrival time and demographic information (e.g. age, gender, ethnicity) from household members at the beach. The questionnaire gathered information on existing health conditions including sunburn, skin problems, and other conditions (e.g. fever, diarrhea) related to our waterborne disease studies (Marion et al., 2010). The beach exit interview gathered exposure information (e.g. time spent at the beach, extent of water exposure, etc.). The exit interview did not ascertain sun/UVR protection behaviors. The final interview occurred by telephone 8–9 days post-enrollment and ascertained incidence of health conditions, including sunburn.

2.4. Environmental exposure assessment

Temperature and UVR data were obtained from the National Weather Service station at the Cincinnati Municipal Airport, Lunken Field, Cincinnati, Ohio (Station ID: GHCND: USW00093812) located 32 km west of the beach (National Oceanic and Atmospheric Administration, 2017). Average daily temperature, highest temperature of the day, and cloud coverage were recorded from daily summaries issued by NOAA (National Oceanic and Atmospheric Administration, 2017). Temperature and UVR data were recorded for the beach visit day and six days following the visit. Daily UVR indices (with cloud effects) were obtained from the most proximal NOAA UV monitor (National Oceanic and Atmospheric Administration, 2016) located at Standiford Field - Louisville International Airport, Louisville, Kentucky (Station ID: SDF1) 160 km southwest of the beach. UVR index values were obtained for each beach visit day and for the following six days to calculate a 7-day mean UVR exposure.

2.5. Sunburn characterization

During telephone follow-up, the presence or absence of sunburn was self-reported by household spokespersons after being prompted: "Since the interview at the East Fork Beach, have you or any of your household members at the beach experienced any sunburn?" If the spokesperson answered "yes", the interviewer ascertained which individual(s) in the household experienced sunburn. Persons were then dichotomously coded as "0" and "1" for either no reported sunburn or reported sunburn, respectively. Sunburn severity and clinical diagnoses were not ascertained.

2.6. Statistical analysis

Logistic regression models were generated in Stata 14.1 (StataCorp., College Station, TX, USA). Since data were obtained from one to several individuals through a household-based survey design that utilized a household spokesperson, data were analyzed as complex survey data to account for clustering by households. Models were developed using backward selection procedures to develop parsimonious models and evaluated for goodness-of-fit and model discrimination.

During model development, age, gender, and race were evaluated as potential confounders. Age was evaluated as a continuous, categorical, and binary variable (teenager coded as "1" versus non-adolescent/teenager coded as "0"). Teenager, defined as beachgoers 12–18 years of age, was considered in model development since this group has a higher risk for sunburn than other age groups (Pettigrew et al., 2016).

Water exposure variables were considered in models. Each person was dichotomously coded for having or not having any water contact. Similarly, dichotomous coding was done for persons who submersed or did not submerse their head in water. Swim duration (recorded in minutes) was evaluated continuously and categorically. Categorical determinations of swim duration, beach arrival time, and beach visit frequency (number of visits per year) were made, as these terms were not linear in the logit. Weather covariates (temperature, UVR index, etc.) were assessed as continuous and categorical covariates. Categorical determinations were made using the quartile approach (Hosmer and Lemeshow, 2013).

For consideration of potential interaction effects between maximum daily temperature and UVR on sunburn frequency, a sunburn risk index was constructed based upon median daily values for maximum temperature and UVR index. Four sunburn risk index values were constructed (low temperature and low UVR index; low temperature and high UVR index; high temperature and low UVR index; and high temperature and high UVR index). When evaluating associations between incident sunburn and this categorical sunburn risk index in the final model, the reference was set as the group in which the UVR index and maximum daily temperature were the lowest in the study period.

3. Results

3.1. Study population characteristics and sunburn frequency

In total, 682 households were recruited into the study. At the time of telephone follow-up, 290 households representing 947 individuals provided complete health questionnaire data, representing 42.5% of all households enrolled. Approximately 15% of beachgoers reported sunburn at follow-up. Mean and median participant ages were 23.5 and 21 years, respectively. Teenagers represented 14.6% of participants. 56% of participants were female. The sample population was nearly all white (96.0% white, 2.4% Hispanic, and 1.6% other), which is comparable to the U.S. Census Bureau's value for Clermont County, Ohio in 2010 (95.9% white).

Most beach visitors had some water contact (83.4%) with 68% reporting head submersion in beach water (Table 1). Among swimmers, the median contact time with water was 90 min. Sunburn was more common for swimmers than non-swimmers. Specifically, 18% of persons reporting head submersion developed sunburn. Less sunburn (7%) was reported for beachgoers without head submersion. Sunburn incidence was highest among beachgoers who arrived early in the day (before 12:30) impacting 27% of this group (Table 1).

3.2. Crude associations between environmental exposures and sunburn

Maximum daily air temperatures ranged over the 26 weekend days from 21.1 to 31.7 °C with mean and median temperatures of 27.6 and 27.8 °C, respectively. UV indices ranged from 7.9 to 11.1 with mean and median UV indices of 9.7 and 9.9, respectively. Temperature and UVR were associated with elevated odds of sunburn (Table 2).

Sunburn risk was greatest for beach participants who enrolled on the highest temperature days. Compared to beachgoers in the lowest temperature quartile, the crude odds of sunburn on the highest temperature days were 8.7 times greater. Specifically, 28% of beach visitors who were at the beach and enrolled on these warmest days developed sunburn (Table 2). Among the eight days of follow-up for participants, the cOR for temperature most associated with incident sunburn was the date participants were enrolled at the beach (Suppl. Table 1). In simple logistic models exploring a potential UVR + temperature interaction, sunburn incidence was greatest among participants enrolled at the beach when the highest UV indices and temperatures were observed (Table 2; cOR = 4.5; 95% C.I.: 2.0 – 10).

3.3. Multivariable models for predicting sunburn

Multivariable logistic models showed significant associations between sunburn and both UVR index scores and maximum daily temperature after adjusting for potential confounding variables. Table 3 demonstrates that for each unit increase in the UVR index, a 60% increased odds of sunburn was observed (aOR = 1.6; 95% C.I.: 1.0 – 2.5). For temperature, each 1 °C increase in maximum daily temperature increased the odds of sunburn by 20% (aOR = 1.2; 95% C.I.: 1.1 – 1.4). Both models had acceptable model discrimination (Area under the receiver operating characteristic curve [AUC] of 0.77 and 0.78) for the UVR index-based model (Table 3) and the maximum daily temperature-based model (Table 4), respectively. Both models had acceptable model fit according to the Hosmer-Lemeshow Goodness-of-Fit test (H-L test). More specifically, the deciles of sunburn risk observed in the study were not significantly different than the model predicted deciles of risk according to H-L tests. The maximum daily temperature-based model had superior fit ($P = 0.68$) compared to the UVR index-based model ($P = 0.38$). When assessing relationships between sunburn with the maximum temperatures and UVR index values for all days during the follow-up period for each participant, the model accounting for the maximum temperature at enrollment and swimming exposure had the best fit and best discrimination when compared to the other models (Suppl. Table 2).

In adjusted models predicting sunburn using both temperature and UVR index terms, temperature was significant ($P = 0.02$) and UVR was not significant ($P = 0.42$). In multivariable models exploring a multiplicative interaction effect containing temperature, UVR, and a temperature x UVR term, none of the terms were significant ($P > 0.75$).

Table 1
Crude (unadjusted) associations between beach user characteristics and incident sunburn occurring during the 8- to 9-day follow-up period after the beach visit.

Category	Covariate	N	Cases (%)	cOR (95% CI)
All Beach Users	All Beach Users	947	137 (15)	N/A
Age Group	Missing	14	6 (43)	ND
	0.1 − 5 years	127	13 (10)	0.6 (0.3 − 1.2)
	6 − 11 years	170	25 (15)	0.9 (0.5 − 1.5)
	12 − 18 years	136	23 (17)	1.1 (0.7 − 1.7)
	19 − 30 years	169	20 (12)	0.7 (0.4 − 1.4)
	31 − 55 years	300	48 (16)	Referent
	56 − 79 years	31	2 (6.5)	0.4 (0.1 − 1.6)
Teenager	Missing Age	14	6 (43)	ND
	<12 years & >18 years	797	108 (14)	Referent
	12–18 years of age	136	23 (17)	1.3 (0.8 − 2.1)
Sex	Missing	4	0 (0)	ND
	Female	525	79 (15)	Referent
	Male	418	58 (14)	0.9 (0.6 − 1.3)
Water Contact	No Water Contact	157	11 (7.0)	Referent
	Any Water Contact	790	126 (16)	2.5 (1.3 − 4.8)
Water Exposure	Missing	8	3 (38)	ND
	No Head Immersion	301	21 (7.0)	Referent
	Immersed Head	638	113 (18)	2.9 (1.8 − 4.7)
Swim Duration	Missing	3	0 (0)	ND
	0 − 40 (min)	159	12 (7.6)	Referent
	> 40 − 90 (min.)	196	42 (21)	3.3 (1.3 − 8.3)
	> 90 min − 150 (min.)	140	26 (19)	2.8 (1.0 − 7.7)
	> 150 min − 360 (min.)	140	33 (24)	3.7 (1.4 − 9.7)
Arrival Time	Missing	10	0 (0.0)	ND
	09:00 − 12:30	276	74 (27)	16.0 (5.1 – 52.0)
	12:45 − 13:30	258	32 (12)	6.3 (1.8 – 22.0)
	13:45 − 14:30	176	26 (15)	7.7 (2.2 – 27.0)
	14:40 − 18:30	227	5 (2.2)	Referent
Food Consumption	Missing	10	3 (30)	ND
	Did not eat food at beach	373	35 (9.4)	Referent
	Consumed food at beach	564	99 (18)	2.1 (1.1 − 4.0)
Beach Visits	1 − 2 days per year	382	35 (9.2)	Referent
	3 − 7 days per year	271	36 (13)	1.5 (0.7 − 3.5)
	8 − 64 days per year	296	66 (22)	2.8 (1.4 − 5.9)

Abbreviations: cOR, crude odds ratio; CI, confidence interval; N/A, non-applicable; ND, not determined.

For further examining the relationship between sunburn frequency and a combined UVR-temperature effect, four exposure classifications were created as follows: (1) low UVR – low temperature; (2) high UVR – low temperature; (3) low UVR – high temperature; (4) high temperature – high UVR. In the adjusted model for this UVR-temperature index (Table 5), the only days with significant adjusted odds ratios were the two high temperature categories when compared to the reference group (low UVR – low temperature). The high UVR – low temperature category was not significant ($P = 0.25$). This model (Table 5) had acceptable discrimination (AUC = 0.77) and model fit ($P = 0.47$).

4. Discussion

Overall, 15% of all beachgoers were reported to have recent sunburn in our prospective study. In comparison, a summer cross-sectional Australian study (n = 5772), observed that 25% of adolescents and 18% of adults experienced recent weekend sunburn, which was associated with temperature and UVR in both populations (Dobbinson et al., 2008). The studies are different in that the East Fork study relied on household-based self-reporting using 8–9 day recall; whereas, the Australian study had a 1–3 day recall period with questions differentiating levels of reported sunburn (redness, red and tender, and red, tender, and blistered). In both the Australian and East Fork sunburn models, temperature was a more significant predictor of recent sunburn than UVR. In the East Fork model, when the two terms (UVR and temperature) are in the multivariable model simultaneously, UVR was not significant ($P = 0.42$) while temperature remained significant ($P = 0.02$).

Emphasizing temperature over UVR risk communication has been discouraged, as sunburn and DNA damage can occur when temperatures are cool and UVR is high (Wong et al., 2015), particularly in high elevation environments (Blumthaler et al., 1997), including skiing areas (Andersen et al., 2010). However, understanding more fully the role of temperature on sunburn and skin cancer is timely for public health since rising temperatures are linked to increased UV exposure. Specifically, rising temperatures are linked to persons spending more time outdoors and wearing less clothing (Thomas et al., 2012; Anderson et al., 2010). The Interagency Working Group on Climate Change and Health suspects climate change-related increases in skin cancer are plausible, but notes that temperature effects on UVR-induced cancers are not fully understood (Portier et al., 2010). Associations between non-melanoma skin cancer and temperature have been demonstrated (van der Leun et al., 2008); however, the biological basis for this association needs more exploration. A better understanding of temperature effects on melanoma also remains as the annual incidence of melanoma in the U.S. continues to rise while most other cancers are declining (Siegel et al., 2016).

Combined effects of temperature and UVR may act additively or synergistically in causing sunburn and skin cancer development according to animal and skin tissue models. Solar-related heat and infrared radiation (IR) may promote skin aging (Lan et al., 2013) and enhance epidermal cell survival following UVR-induced DNA damage (Calapre et al., 2016; Kimeswenger et al., 2016). Similar findings have been observed in animal studies where heat and/or IR may be harmful or protective to skin depending upon whether heat or IR are administered before or after UVR exposure (Haarmann-Stemmann et al., 2013; Gonzalez et al., 2015).

In nature, some DNA damage from UVR is prevented by DNA absorbing and converting radiation into heat energy through vibrational cooling (Pecourt et al., 2001). When damage occurs, one major DNA repair mechanism utilizes photolyases, which also perform repairs extending beyond UVR-induced damage. Photolyases perform DNA repair related to damage from the more holistic photocycle (Li et al., 2010). Therefore, sunbathing and other outdoor exposures can potentially in-

Table 2
Crude (unadjusted) associations between beach environmental conditions and incident sunburn occurring during the 8- to 9-day follow-up period after the beach visit.

Category	Covariate	N	Cases (%)	cOR (95% CI)
Continuous Data	Temperature (°C)	947	137 (15)	1.3 (1.1 − 1.4)
	UVR (UVR Index)	947	137 (15)	2.1 (1.4 − 3.0)
Temperature Quartile	21.1 − 25.0 °C	276	12 (4.4)	Referent
	>25.0 − 27.8 °C	220	27 (12)	3.1 (1.0 − 9.1)
	>27.8 − 30.6 °C	242	39 (16)	4.2 (1.5 − 12.0)
	>30.6 − 31.7 °C	209	59 (28)	8.7 (3.0 − 25.0)
Quartile (UVR Index)	7.9 − 9.0	252	13 (5.2)	Referent
	>9.0 − 9.9	373	58 (16)	3.4 (1.3 − 8.9)
	>9.9 − 10.5	113	24 (21)	5.0 (1.6 – 15.0)
	>10.5 − 11.05	209	42 (20)	4.6 (1.6 – 13.0)
UVR + Temperature Index	UVR < 9.9 & < 27.8 °C	406	24 (5.9)	Referent
	UVR > 9.9 & < 27.8 °C	90	15 (17)	3.2 (1.0 − 10.0)
	UVR < 9.9 & > 27.8 °C	219	47 (21)	4.3 (1.9–10.0)
	UVR > 9.9 & > 27.8 °C	232	51 (22)	4.5 (2.0 − 10.0)
Cloud Coverage	Overcast (100%)	194	18 (9.3)	Referent
	Broken (>62.5% & <100%)	304	52 (17)	2.0 (0.8 − 5.2)
	Scattered (>37.5% & <50%)	213	26 (12)	1.4 (0.5 − 4.0)
	Clear (0%)	236	41 (17)	2.1 (0.8 − 5.6)

Abbreviations: cOR, crude odds ratio; CI, confidence interval.

Table 3
Multivariable logistic regression model showing associations between UVR and incident sunburn occurring during the 8- to 9-day follow-up period with adjustment for potential confounding and modifying factors.

Covariate	ß	$SE_ß$	Adjusted OR (95% CI)
UVR (UV Index)	0.467	0.23	1.6 (1.0 − 2.5)
Head Immersion	0.757	0.28	2.1 (1.2 − 3.7)
Beach Visit Frequency			
1 − 2 days per year	Referent		Referent
3 − 7 days per year	0.372	0.43	1.5 (0.62 − 3.4)
8 − 64 days per year	0.706	0.39	2.0 (0.94 − 4.4)
Arrival Time			
09:00 − 12:30	2.466	0.62	12.0 (3.5 – 40.0)
12:45 − 13:30	1.636	0.65	5.1 (1.4 – 19.0)
13:45 − 14:30	1.736	0.64	5.7 (1.6 – 20.0)
14:40 − 18:30	Referent		Referent
Teenager	0.138	0.28	1.1 (0.7 − 2.0)
Male Gender	0.039	0.19	1.0 (0.7 − 1.5)
Constant Term	−9.180	2.31	

Abbreviations: ß, coefficient; $SE_ß$, standard error of coefficient; OR, odds ratio; CI, confidence interval.

Table 4
Multivariable logistic regression model showing associations between maximum daily temperature and incident sunburn occurring during the 8- to 9-day follow-up period with adjustment for covariates.

Covariate	ß	$SE_ß$	Adjusted OR (95% CI)
Max Temperature (°C)	0.18	0.06	1.2 (1.1 − 1.4)
Head Immersion	0.50	0.28	1.6 (1.0 − 2.8)
Beach Visit Frequency			
1 − 2 days per year	Referent		Referent
3 − 7 days per year	0.22	0.40	1.2 (0.6 − 2.7)
8 − 64 days per year	0.72	0.39	2.1 (0.9 − 4.5)
Arrival Time			
09:00 − 12:30	2.54	0.61	13 (3.8 – 42.0)
12:45 − 13:30	1.82	0.63	6.1 (1.8 – 21.0)
13:45 − 14:30	1.72	0.65	5.6 (1.5 – 20.0)
14:40 − 18:30	Referent		Referent
Teenager	0.17	0.28	1.2 (0.7 − 2.1)
Male Gender	0.08	0.19	1.1 (0.7 − 1.6)
Constant Term	−9.70	1.93	

Abbreviations: ß, coefficient; $SE_ß$, standard error of coefficient; OR, odds ratio; CI, confidence interval.

crease DNA damage since the high outdoor temperatures raise skin temperatures while in the presence of UVR (Petersen et al., 2014), which may exceed vibrational cooling functions thereby enhancing DNA damage. Furthermore, elevated skin temperatures can also impact

Table 5
Multivariable logistic regression model showing associations between a UVR-Temperature Index and incident sunburn occurring during the 8- to 9-day follow-up period with adjustment for listed covariates.

Covariate	ß	$SE_ß$	Adjusted OR (95% CI)
UVR-Temperature Index			
UVR < 9.9 & < 27.8 °C			
UVR > 9.9 & < 27.8 °C	0.744	0.65	2.1 (0.58 − 7.6)
UVR < 9.9 & > 27.8 °C	0.965	0.46	2.6 (1.1 − 6.4)
UVR > 9.9 & > 27.8 °C	1.104	0.42	3.0 (1.3 − 6.9)
Head Immersion	0.611	0.28	1.8 (1.1 − 3.2)
Beach Visit Frequency			
1 − 2 days per year	Referent		Referent
3 − 7 days per year	0.300	0.41	1.3 (0.61 − 3.0)
8 − 64 days per year	0.706	0.39	2.0 (0.94 − 4.4)
Arrival Time			
09:00 − 12:30	2.481	0.65	12.0 (3.6 − 40.0)
12:45 − 13:30	1.715	0.64	5.6 (1.6 − 20.0)
13:45 − 14:30	1.770	0.61	5.9 (1.6 − 21.0)
14:40 − 18:30	Referent		Referent
Teenager	0.143	0.27	1.2 (0.67 − 2.0)
Male Gender	0.045	0.19	1.0 (0.72 − 1.5)
Constant Term	−5.165	0.76	

Abbreviations: ß, coefficient; $SE_ß$, standard error of coefficient; OR, odds ratio; CI, confidence interval.

inflammatory and/or DNA repair processes leading to acute or chronic health effects (Petersen et al., 2014).

The study presented here has limitations. Most notably, data were not obtained on clothing, time spent in the shade, sunscreen use, or sunscreen quality as the initial study focused on waterborne disease (Marion et al., 2010). In the beach environment, the potential for sunscreen to fail is higher due to water exposure and sweating (Xu et al., 2016). Recent research on the highest consumer-rated sunscreens demonstrated that 40% of these sunscreens failed to meet the American Academy of Dermatology's criteria, with inadequate water resistance being the most frequent cause of failure (Xu et al., 2016). The impact of swimming as risk factor with this data set is speculative, as the health outcome follow-up survey did not ascertain the date of the sunburn for specifically linking to swimming on the particular beach visit date. It is noteworthy that upon adjusting for maximum temperature or UVR for each follow-up day in the eight day follow-up, in 31 of these

32 models, swimming exposure the day of the beach visit significantly ($p < 0.05$) increased the odds of sunburn with significant odds ratio estimates ranging from 1.9 to 2.4 (Suppl. Table 3).

Other study limitations relate to potential misclassification of exposure and sunburn among participants. Data were obtained from household spokespersons. Spokespersons may have not been fully aware of exposures and sunburns developed by other household members, especially throughout the entire follow-up period. Some spokespersons may have been reluctant reporting sunburnt children due to social desirability bias. Additionally, perceptions of sunburn likely varied by spokespersons as no specific definition of sunburn was provided during the questionnaire. The potential for misclassification of UVR exposure among participants was plausible as UV data were obtained from the nearest federal UVR monitor located in Louisville, Kentucky (160 km from the beach). Future studies could more accurately assign UVR exposure through wristwatch-style UVR dosimeters worn by participants (Thieden, 2008) or through using UV monitors brought to the site. The 8–9 day follow-up period also enabled opportunities for sunburn development to occur from activities not related to the beach visit. Our analysis did observe the strongest associations between sunburn and temperature on the beach visit day compared to any single day after or the weekly average values (Suppl. Table 1 and Suppl. Table 2).

Future epidemiological studies on sunburn and skin cancer are needed to clarify relationships between outdoor temperature and adverse skin-related health effects. Given biological mechanisms associated with sunburn and carcinogenesis likely extend beyond UVR exposure; greater understanding is needed with respect to infrared radiation and visible light, which can initiate inflammatory processes (Liebel et al., 2012). Since community-wide interventions for reducing UVR exposure and increasing sunscreen use have been successful where implemented (Sandhu et al., 2016), greater research on beach user exposures inclusive of and beyond UVR may be able to better inform interventions. Future studies with larger populations, greater variability in UVR and temperature exposures, and estimates of sun protection strategies, including clothing coverage, may further clarify the relative importance of temperature in regulating sunburn and other solar-related dermatological conditions.

In summary, temperature was more strongly associated with sunburn in beachgoers than the nearest measured UVR index, as demonstrated by 28% of all beachgoers experiencing sunburn following their beach visit when temperatures exceeded 30.6 °C. While the highest risk scenario for sunburn was associated with persons who were enrolled at the beach on days when both temperature and UVR were elevated. At this Ohio beach, approximately 20–24% of all swimmers who reported outdoor swimming lasting 40 min or longer developed sunburn. Among persons who arrived at the beach early in the day (before 12:30 p.m.), 27% reported sunburn. Overall, this research illustrates the importance of examining temperature and associated risk factors for potential impacts on sunburn in addition to UVR. Such future studies will be of particular importance as local and global temperatures increase. Future studies examining relationships between outdoor temperatures, solar radiation, sun protection efforts, and sunburn are encouraged.

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Human participants study approval

The study was approved by the Chief of the Ohio Department of Natural Resources, Division of Parks and Recreation and the Institutional Review Board at The Ohio State University [Ohio State University IRB Protocol #2009H0107].

COI statement

The authors have no conflict of interest to declare.

Uncited references

Marion et al., 2014; Portier et al., 2013.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envres.2017.11.036.

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