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Original Contribution

Contact With Beach Sand Among Beachgoers and Risk of Illness

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Recent studies of beach sand fecal contamination have triggered interest among scientists and in the media. Although evidence shows that beach sand can harbor high concentrations of fecal indicator organisms, as well as fecal pathogens, illness risk associated with beach sand contact is not well understood. Beach visitors at 7 US beaches were enrolled in the National Epidemiological and Environmental Assessment of Recreational Water (NEEAR) Study during 2003–2005 and 2007 and asked about sand contact on the day of their visit to the beach (digging in the sand, body buried in the sand). Then, 10–12 days after their visit, participants were telephoned to answer questions about any health symptoms experienced since the visit. The authors completed 27,365 interviews. Digging in the sand was positively associated with gastrointestinal illness (adjusted incidence proportion ratio (aIPR) = 1.13, 95% confidence interval (CI): 1.02, 1.25) and diarrhea (aIPR = 1.20, 95% CI: 1.05, 1.36). The association was stronger between those buried in the sand and gastrointestinal illness (aIPR = 1.23, 95% CI: 1.05, 1.43) and diarrhea (aIPR = 1.24, 95% CI: 1.01, 1.52). Nonenteric illnesses did not show a consistent association with sand contact activities. Sand contact activities were associated with enteric illness at beach sites. Variation in beach-specific results suggests that site-specific factors may be important in the risk of illness following sand exposure.

bathing beaches; diarrhea; disease transmission, infectious; environmental pollution; fomites; fresh water; oceans and seas; sewage

Abbreviations: aIPR, adjusted incidence proportion ratio; CI, confidence interval; NEEAR, National Epidemiological and Environmental Assessment of Recreational Water.

Recent studies of fecal contamination of beach sand have triggered interest among scientists, the media, and the general public regarding the safety of exposure to sand at the beach (1–19). There exists evidence that beach sand can harbor fecal indicator organisms (microbes whose presence indicates the potential presence of fecal pathogens), as well as pathogenic bacteria (*Pseudomonas aeruginosa*, *Salmonella*, *Shigella*, *Campylobacter jejuni*, *Staphylococcus aureus*, *Vibrio parahaemolyticus*, and *Vibrio harveyi*); viruses (adenovirus, norovirus, enterovirus, coxsackievirus types A16, B1, and B5, echovirus type 1, poliovirus type 2, hepatitis A virus); fungi (*Candida albicans* and dermatophytic fungi); and parasitic nematodes (*Toxocara canis*) (6, 8, 10, 14, 20–25).

The sources of high levels of fecal microbial pollution in beach sand are not clear. Some studies attributed the source of fecal pollution to municipal sewage treatment plant discharges in close proximity to beaches (26, 27); however, other studies attributed the source of fecal pollution to nonpoint sources, such as urban runoff and/or warm-blooded domestic and wild animals (2, 5, 6, 28). Numerous studies found that the conditions in foreshore, nearshore, and backshore sand can favor the persistence, survival, and regrowth of *Escherichia coli* and *Enterococcus*, suggesting that elevated levels of these fecal indicator bacteria in beach sand may represent autochthonous populations rather than impacts from sewage sources of contamination (2, 6, 8, 10, 16, 29). Conditions that favor the persistence, survival, and possible

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regrowth of autochthonous fecal indicator bacteria in sand include increased protection from sunlight, buffered temperatures, more nutrient availability, reduced osmotic stress, cover from predation by other microorganisms, a large surface area for biofilm development, and higher moisture and organic content from wave swash (2, 6, 8, 10, 14, 29, 30).

Despite the presence of fecal indicator organisms and pathogens in the sand, a consistent relation with health effects has not been demonstrated (16, 31). Little is known about the relation between specific sand contact activities and health effects, and few studies have examined whether specific beach sand contact activities are associated with an increased risk of illness among beachgoers (16, 31). Using data gathered from beachgoers participating in the 2003–2005 and 2007 trials of the National Epidemiological and Environmental Assessment of Recreational Water (NEEAR) Study (32, 33), we examined the relation between reported beach sand contact and the risk of enteric and nonenteric illnesses at beaches with a nearby sewage treatment plant outfall.

MATERIALS AND METHODS

Study design/participant sampling

The NEEAR Study evaluated microbial water quality and followed cohorts of visitors to freshwater and marine beaches. The data collection methods have been described previously (32, 33). In brief, we interviewed beachgoers as they arrived and as they were leaving the beach about their contact with beach sand, swimming behaviors, and other beach activities; 10–12 days later, one of the adults in the household was interviewed by telephone about symptoms experienced by participating household members. Because of the acute nature and short duration of the illnesses and infections considered during this study, participants could reenroll in the study 28 days after their previous enrollment.

Beach descriptions

Seven beaches with nearby sewage treatment plant discharges were chosen for the NEEAR studies (32, 33). In 2003, NEEAR studies were conducted at West Beach (on Lake Michigan in Indiana Dunes National Lakeshore in Porter, Indiana) and Huntington Beach (on Lake Erie in Bay Village, Ohio). In 2004, 2 Lake Michigan beaches were studied: Silver Beach in St. Joseph, Michigan, and Washington Park Beach in Michigan City, Indiana. In 2005, a marine water beach was studied: Edgewater Beach, on the Gulf of Mexico near Biloxi, Mississippi. In 2007, we studied 2 additional marine water beaches: Fairhope Beach, on Mobile Bay in Fairhope, Alabama, and Goddard Beach, on Greenwich Bay near Warwick, Rhode Island. All beaches participating in the Environmental Protection Agency's NEEAR Study had sewage treatment plant discharges within 7 miles (11.2 km) of the beach location.

Definition of sand contact

As they were leaving the beach, participants reported whether they had dug or been buried in the sand. Being buried in the sand was considered as a potential indicator of more intense sand exposure. In 2007, participants reported whether they got sand in their mouth, ate or drank after playing in the sand, and washed their hands before eating or drinking after playing in sand. In addition to sand exposures on the day of enrollment, participants reported other activities, such as whether they swam or ate raw meat, runny eggs, or shellfish, in the 3 days prior to enrollment.

Health assessments

In a telephone interview 10–12 days following the day of beach exposure, participants reported if they had experienced any of the following symptoms since their day of enrollment.

1. ''Gastrointestinal illness'' was defined as any of the following: diarrhea (3 or more loose stools in a 24-hour period); vomiting; nausea and stomach ache; and nausea or stomach ache and interference with regular activities (missed time from work or school or missed regular activities as a result of the illness).
2. ''Upper respiratory illness'' was defined as any 2 of the following: sore throat, cough, runny nose, cold, or fever.
3. ''Rash'' was defined as a rash or itchy skin.
4. ''Eye ailments'' were defined as either eye infection or watery eye.
5. ''Earache'' was defined as earache, ear infection, or runny ears.
6. ''Infected cut'' was defined as a cut or wound that became infected.

During the telephone follow-up interview, we also asked participants about activities since enrollment, including the number of times attending the same beach, swimming at another beach or pool, or eating raw or undercooked foods (e.g., red meat, fish, shellfish, eggs). Participants with prevalent illness (symptoms within 3 days of the beach visit) were excluded from the analysis for that outcome and were eligible to be included in analyses of other outcomes. We also examined a definition of gastrointestinal illness as diarrhea alone ($\geq$3 loose stools in a 24-hour period).

Statistical analysis

Participants with complete data for exposure, outcome, and critical covariates (age, sex, race/ethnicity, swimming status, and beach) were included in analyses. We used log-linear binomial regression models to estimate the crude and adjusted incidence proportion ratios and 95% confidence intervals for each outcome and its association with each beach sand contact activity. Observations that matched on birth date and other distinctive characteristics were considered potential reenrollees of the same household. Robust variance estimates were used to account for the nonindependence of observations within a household (34, 35).

We considered covariates strongly associated with beach sand contact and illness or those regarded by investigators to be potential confounding factors for inclusion in regression models: age, sex, race/ethnicity, swimming, beach, contact

Table 1. Characteristics of Those Who Did Not Dig in the Sand, Those Who Dug in the Sand, Those Who Did Not Have Their Body Buried in the Sand, and Those Who Did Have Their Body Buried in the Sand, NEEAR Study, 2003–2005, 2007[a]

	Digging in the Sand				Body Buried in the Sand			
	No (n = 15,833)[b]		Yes (n = 10,776)[b]		No (n = 24,128)[b]		Yes (n = 2,474)[b]	
	No.	%	No.	%	No.	%	No.	%
Age, years								
0–4	511	3	1,678	15	1,758	7	431	17
5–10	659	4	2,741	25	2,491	10	906	37
11–19	2,171	14	1,746	16	3,446	14	470	19
20–54	10,618	67	4,268	40	14,258	59	626	25
≥55	1,874	12	343	3	2,175	9	41	2
Sex								
Male	6,664	42	5,009	46	10,449	43	1,222	49
Female	9,169	58	5,767	54	13,679	57	1,252	51
Race/ethnicity								
White	12,747	81	8,498	80	19,364	81	1,874	77
Black	981	6	642	6	1,486	6	137	6
Asian	229	1	159	1	368	2	20	<1
American Indian	49	<1	26	<1	66	<1	9	<1
Hispanic/Latino	1,584	10	1,173	11	2,405	10	352	14
Multiethnic/other	148	1	122	1	231	<1	39	2
Miles traveled to the beach[c]								
0–5	3,889	25	2,462	23	5,906	25	441	18
6–20	4,351	28	2,458	23	6,228	26	580	24
21–50	3,925	25	2,845	27	6,044	25	724	30
≥51	3,498	22	2,883	27	5,685	24	696	28
Conditions in the 3 days prior to the beach visit								
Vomiting	169	1	108	1	250	1	27	1
Other gastrointestinal symptoms	366	2	230	2	549	2	47	2
Sore throat	834	5	651	6	1,339	6	146	6
Rash	352	2	267	2	546	2	73	3
Sunburn	844	5	444	4	1,192	5	95	4
Infected cut	854	5	844	8	1,499	6	199	8
Eye irritation	80	<1	53	<1	118	<1	15	<1
Earache	196	1	160	1	320	1	36	1

Table continues

with animals, contact with other persons with diarrhea, number of other visits to the beach, any other chronic illnesses (gastrointestinal, skin, asthma), presence of beach festivals, and eating any food or drink while at the beach. For upper respiratory illness, rash, infected cuts, and eye outcomes, use of insect repellent and sun block was also considered. At a minimum, age, sex, and beach were included in all models (for the pooled analysis). If there was a substantial difference between fully adjusted and reduced model results, we used a backwards elimination approach. For each analysis, the set of covariates was reduced through a change-in-estimate procedure (36). Adjusted incidence proportion ratio (full ($aIPR_{full}$) and reduced ($aIPR_{reduced}$)) values were compared by using the formula: $\ln|aIPR_{full}/aIPR_{reduced}| \times 100$. A criterion of a 5% change was used, and results from fully adjusted models were used if the reduced model resulted in a change in estimate of greater than 5%. The selection procedure generally reduced the number of covariates to 7 or less.

To model an observed age-sex crossover for the enteric outcomes more precisely, we used multiplicative interaction coding between the linear age regression spline and sex variables in log-linear binomial regression models. Nonenteric illnesses showed a linear trend of decline in the

Table 1. Continued

	Digging in the Sand				Body Buried in the Sand			
	No (n = 15,833)[b]		Yes (n = 10,776)[b]		No (n = 24,128)[b]		Yes (n = 2,474)[b]	
	No.	%	No.	%	No.	%	No.	%
History of chronic respiratory problems or asthma	1,041	7	728	7	1,611	7	157	6
History of allergies	3,093	20	1,938	18	4,613	19	416	17
History of chronic gastrointestinal illness	504	3	184	2	659	3	29	1
Any history of chronic gastrointestinal illness, asthma, or allergies	3,094	20	1,940	18	4,615	19	417	17
Water contact status								
No water contact	7,579	48	1,960	18	9,264	38	272	11
Water contact	8,254	52	8,816	82	14,864	62	2,202	89
Contact with animals 48 hours prior to or after the beach visit, or between the beach visit and phone interview	11,455	72	8,328	77	17,884	74	1,893	77
Consumption of red, raw, or undercooked meat 48 hours prior to the beach visit or between the beach visit and phone interview	1,772	11	891	8	2,479	10	183	7
Beach								
Goddard Beach	2,337	14	596	5	2,825	11	108	4
Fairhope Beach	1,249	8	766	7	1,905	8	110	5
Edgewater Beach	829	5	492	5	1,217	5	104	4
Washington Park Beach	2,200	14	1,994	18	3,534	15	658	27
Silver Beach	5,772	37	4,725	44	9,513	40	981	40
Huntington Beach	1,913	12	903	8	2,682	11	134	6
West Beach	1,533	10	1,300	12	2,452	10	379	16

Abbreviation: NEEAR, National Epidemiological and Environmental Assessment of Recreational Water.

[a] The beach locations, by state, are as follows: Goddard Beach, Rhode Island; Fairhope Beach, Alabama; Edgewater Beach, Mississippi; Washington Park Beach, Indiana; Silver Beach, Michigan; Huntington Beach, Ohio; and West Beach, Indiana.

[b] Excludes those with missing information on age, sex, race/ethnicity, water contact status, and beach.

[c] One mile = 1.6 km.

age-specific incidence proportions and no age-sex crossover. For the nonenteric illnesses (upper respiratory illness, skin rash, eye ailments, earache, infected cuts), linear age was used in regression models.

We generated separate risk estimates for the following age categories: 1) 0–10 years (children); 2) 11–54 years (older children and adults); and 3) 55–103 years (older adults). The age groups were selected on the basis of sample size considerations and previous research (16). All analyses were completed by using SAS, version 9, software (SAS Institute, Inc., Cary, North Carolina) and Stata, version 9, software (StataCorp LP, College Station, Texas).

RESULTS

A total of 29,100 beach exit interviews were completed. A total of 27,365 telephone interviews were completed 10–12 days later. Of these telephone interviews, 26,609 had complete information on the full set of key covariates and were retained for analysis.

Respondents at the 7 beaches differed by age, race/ethnicity, miles traveled to the beach, and proportion of individuals who reported digging in sand. Those who dug in the sand were younger than those who did not dig in the sand (median ages, 14 and 35 years, respectively) but were equally likely to report vomiting, other gastrointestinal symptoms, rash, eye irritation, earache, and a history of chronic respiratory problems or asthma at baseline (Table 1). Individuals who dug in the sand had a tendency to report less chronic gastrointestinal illness (2% vs. 3%), fewer chronic allergies (18% vs. 20%), and less consumption of red or raw meat prior to or immediately after the beach visit (8% vs. 11%). Individuals who dug in the sand reported more instances of infected cuts or wounds at baseline (8% vs. 5%), more contact with animals 48 hours prior to or immediately after the beach visit (77% vs. 72%), and more swimming, defined as any contact with the water (82% vs. 52%). Those who had their body buried in the sand showed a similar pattern of differences compared with those who did not have their body buried in sand (Table 1). Digging in sand and being buried in the sand were also strongly associated with any water

Table 2. Illness Incidence According to Sand Exposure and Adjusted Incidence Proportion Ratios Comparing Those With Sand Exposure With Those Without Sand Exposure, NEEAR Study, 2003–2005, 2007[a]

	Incidence by Status of Digging in Sand						
	No		Yes		No.	aIPR	95% Confidence Interval
	No.	%	No.	%			
Gastrointestinal illness	1,009	7	873	8	25,807	1.13	1.02, 1.25
Diarrhea	676	4	592	6	25,989	1.20	1.05, 1.36
Respiratory illness	719	5	660	7	25,121	1.05	0.93, 1.19
Rash	404	3	325	3	25,977	1.02	0.86, 1.22
Eye ailments	511	3	267	3	26,473	0.85	0.72, 1.02
Earache	210	1	182	2	26,267	1.06	0.84, 1.33
Infected cuts	74	<1	42	<1	26,598	0.71	0.46, 1.08
	Incidence by Status of Body Buried in Sand						
	No		Yes		No.	aIPR	95% Confidence Interval
	No.	%	No.	%			
Gastrointestinal illness	1,654	7	228	9	25,800	1.23	1.05, 1.43
Diarrhea	1,120	5	148	6	25,982	1.24	1.01, 1.52
Respiratory illness	1,248	5	141	6	25,114	0.85	0.70, 1.04
Rash	650	3	79	3	25,970	1.01	0.80, 1.30
Eye ailments	716	3	62	3	26,466	0.98	0.73, 1.31
Earache	362	2	30	1	26,260	0.66	0.45, 0.99
Infected cuts	103	<1	13	<1	26,591	1.15	0.62, 2.13

Abbreviations: aIPR, adjusted incidence proportion ratio; NEEAR, National Epidemiological and Environmental Assessment of Recreational Water.

[a] The numbers are those reporting new symptoms, among those without baseline symptoms. For gastrointestinal illness, participants reporting vomiting, diarrhea, or loose bowels in the past 3 days were excluded. The aIPR was estimated from log-risk binomial regression models adjusted for age, sex, race/ethnicity, beach, and swimming.

contact. Participants at Washington Park Beach reported digging in the sand (47%) and being buried in the sand (16%) most frequently, followed by West Beach participants digging in the sand (46%) and buried in the sand (13%).

Relation between sand contact activities and illness

The adjusted risk of gastrointestinal illness among those who dug in the sand was 1.13 (95% confidence interval (CI): 1.02, 1.25) times the risk of gastrointestinal illness among those who did not dig in the sand (Table 2). The adjusted risk of diarrhea among those who dug in the sand was 1.20 (95% CI: 1.05, 1.36) times the risk of diarrhea among those who did not dig in the sand (Table 2).

The crude incidence of upper respiratory illness was higher among those who dug in the sand compared with those who did not dig in the sand, but adjustment reduced the difference (aIPR = 1.05, 95% CI: 0.93, 1.19) (Table 2). Age was a strong confounder because younger respondents more often both dug in the sand and reported upper respiratory illness. The remaining nonenteric illnesses did not show a strong or consistent positive association with digging in the sand.

Generally, being buried in the sand was more strongly associated with enteric illness than was digging in the sand among all subjects. The aIPR of gastrointestinal illness among those who had their bodies buried in the sand was 1.23 (95% CI: 1.05, 1.43) (Table 2). The aIPR of diarrhea was 1.24 (95% CI: 1.01, 1.52) (Table 2). For the nonenteric illnesses, no consistent increase in risk was observed among those buried in the sand compared with those not buried in the sand (Table 2).

A slightly elevated risk of gastrointestinal illness was observed among children who dug in the sand (aIPR = 1.22, 95% CI: 0.93, 1.60) (Table 3). There was no evidence of increased gastrointestinal illness risk associated with digging in sand among adults 55 years of age or older (aIPR = 0.92, 95% CI: 0.55, 1.54) (Table 3). For diarrhea, the aIPR for digging in the sand was highest among children 10 years of age or younger (aIPR = 1.44, 95% CI: 1.00, 2.06) (Table 3). This observation was not consistent for all age groups, sand exposures, and enteric illness outcomes. The observed elevated enteric illness effect estimates among those 55 years of age or older were imprecise (Table 3) because of the low incidence of diarrhea (4%) and the low prevalence of exposure (2%) and should be interpreted with caution. The nonenteric illnesses did not show a strong or consistent positive association with either of the sand contact activities among the age subgroups.

The effect of sand exposure showed variation across the beaches studied. aIPR estimates ranged from 0.98 to 1.91

Table 3. Adjusted Incidence Proportion Ratios for Illness Comparing Those With Sand Exposure With Those Without Sand Exposure, by Age Group, NEEAR Study, 2003–2005, 2007[a]

	Age Group, years											
	0–10				11–54				≥55			
	Incidence		aIPR	95% Confidence Interval	Incidence		aIPR	95% Confidence Interval	Incidence		aIPR	95% Confidence Interval
	No.	%			No.	%			No.	%		
Digging in the sand												
Gastrointestinal illness	468	9	1.22	0.93, 1.60	1,311	7	1.10	0.98, 1.23	134	5	0.92	0.55, 1.54
Diarrhea	307	6	1.44	1.00, 2.06	884	5	1.13	0.97, 1.30	97	4	1.03	0.59, 1.82
Upper respiratory illness	428	8	1.12	0.84, 1.48	912	5	1.08	0.94, 1.24	73	3	1.12	0.53, 2.40
Rash	187	3	0.89	0.61, 1.30	505	3	1.09	0.90, 1.33	56	2	0.61	0.23, 1.64
Eye ailments	117	2	0.86	0.52, 1.45	580	3	0.84	0.69, 1.01	89	4	1.42	0.77, 2.63
Earache	99	2	0.80	0.47, 1.35	274	1	1.20	0.93, 1.55	24	<1	0.87	0.17, 4.46
Infected cuts	28	<1	0.68	0.27, 1.69	84	<1	0.75	0.46, 1.20	5	<1		
Body buried in the sand												
Gastrointestinal illness	468	9	1.21	0.98, 1.51	1,311	7	1.24	1.00, 1.52	134	5	1.46	0.44, 4.80
Diarrhea	307	6	1.27	0.97, 1.68	884	5	1.19	0.91, 1.56	97	4	1.24	0.29, 5.30
Upper respiratory illness	428	8	0.85	0.66, 1.09	912	5	1.00	0.75, 1.34	73	3		
Rash	187	3	0.86	0.60, 1.23	505	3	1.27	0.91, 1.78	56	2	2.97	0.83, 10.64
Eye ailments	117	2	1.34	0.87, 2.07	580	3	0.90	0.60, 1.34	89	4		
Earache	99	2	0.61	0.34, 1.08	274	1	0.80	0.46, 1.39	24	<1		
Infected cuts	28	<1	1.16	0.47, 2.90	84	<1	1.30	0.54, 3.13	5	<1		

Abbreviations: aIPR, adjusted incidence proportion ratio; NEEAR, National Epidemiological and Environmental Assessment of Recreational Water.

[a] The numbers are those reporting new symptoms, among those without baseline symptoms. The aIPR was estimated from log-risk binomial regression models. Covariates in models included age, sex, and beach, and selection was through a change-in-estimate procedure from the following: race/ethnicity, any contact swimming, contact with animals, contact with other persons with diarrhea, eating food while at the beach, eating raw or undercooked meat since the time of the beach interview, eating raw or undercooked eggs since the time of the beach interview, number of other visits to the beach, and any other chronic illnesses (gastrointestinal, skin, asthma). For upper respiratory illness and skin outcomes, insect repellent and sun block use were also considered.

among those digging in the sand (Table 4). The strongest associations were for gastrointestinal illness (aIPR = 1.48, 95% CI: 1.02, 2.16) and diarrhea (aIPR = 1.91, 95% CI: 1.27, 2.85) at Fairhope Beach (Table 4). The weakest associations were at Huntington Beach, where the aIPR was 0.98 (95% CI: 0.77, 1.26) for gastrointestinal illness and 1.01 (95% CI: 0.75, 1.35) for diarrhea. There was also variation by type of beach (marine vs. freshwater). At the marine beaches, the adjusted risk of diarrhea among those who dug in the sand was 1.43 (95% CI: 1.08, 1.90) times the risk of diarrhea among those who did not dig in the sand (Table 4). This association was also somewhat elevated for gastrointestinal illness at marine beaches (aIPR = 1.26, 95% CI: 0.98, 1.56) (Table 4). Similar variability was observed among participants buried in the sand (Table 4).

DISCUSSION

The results of our study suggest that, among beachgoers participating in a large prospective cohort study at beaches nearby sewage treatment discharges, reported contact with beach sand (defined as either digging in the sand or having one's body buried in the sand) was associated with an elevated risk of enteric illnesses (gastrointestinal illness and diarrhea). Being buried in the sand was more strongly associated with enteric illness than was digging in the sand. We also observed a higher proportion of people who got sand in their mouth among those buried in the sand (40%) compared with those who dug in the sand (20%).

This is one of the first studies to demonstrate an association with specific sand contact activities. One previous study demonstrated that time spent in the wet sand was associated with a dose-dependent increase in gastrointestinal illness (per 10-minute increase spent in contact with wet sand: adjusted odds ratio = 1.008, 95% CI: 1.001, 1.015) (16). The variability that we observed across beaches, however, indicates that risks may be site specific and may depend on the characteristics of each beach.

These results provide limited evidence that children aged 10 years or less may be at higher risk of gastrointestinal illness and diarrhea following digging in the sand, and we also observed that children had a much higher frequency of exposure to sand (80% reported digging in sand). Results from the 2007 beach sites also indicate that children aged 10 years or less had a higher frequency of getting sand in their mouth (20%) compared with older children and adults (11–54 years) (4%) and older adults (≥55 years) (2%).

Table 4. Adjusted Incidence Proportion Ratios for Illness Comparing Those with Sand Exposure With Those Without Sand Exposure, by Beach and by Marine Versus Fresh Water Beaches, NEEAR Study, 2003–2005, 2007[a,b]

	Illness							
	Gastrointestinal Illness				Diarrhea			
	Incidence		aIPR	95% Confidence Interval	Incidence		aIPR	95% Confidence Interval
	No.	%			No.	%		
Digging in the sand								
Beach								
Goddard Beach	138	5	1.17	0.74, 1.86	83	3	1.27	0.69, 2.34
Fairhope Beach	162	8	1.48	1.02, 2.16	117	6	1.91	1.27, 2.85
Edgewater Beach	121	9	1.05	0.69, 1.61	76	6	1.13	0.66, 1.95
Washington Park Beach	312	7	1.34	1.04, 1.73	209	5	1.28	0.94, 1.75
Silver Beach	675	6	1.09	0.91, 1.31	412	4	1.18	0.93, 1.50
Huntington Beach	274	10	0.98	0.77, 1.26	209	8	1.01	0.75, 1.35
West Beach	232	8	1.09	0.82, 1.46	179	6	1.04	0.73, 1.49
Marine water beaches								
Goddard, Fairhope, and Edgewater beaches	420	7	1.23	0.98, 1.56	276	5	1.43	1.08, 1.90
Fresh water beaches								
Washington Park, Silver, Huntington, and West beaches	1,493	7	1.11	0.99, 1.24	1,009	5	1.14	0.99, 1.32
Body buried in the sand								
Beach								
Goddard Beach	138	5	1.55	0.67, 3.56	83	3	1.66	0.52, 5.33
Fairhope Beach	162	8	1.26	0.53, 3.00	117	6	1.7	0.72, 4.00
Edgewater Beach	121	9	1.47	0.77, 2.78	76	6	1.65	0.69, 3.92
Washington Park Beach	312	7	0.92	0.64, 1.32	209	5	0.92	0.58, 1.46
Silver Beach	675	6	1.3	1.03, 1.66	412	4	1.17	0.84, 1.64
Huntington Beach	274	10	0.89	0.47, 1.66	209	8	0.83	0.39, 1.76
West Beach	232	8	1.82	1.30, 2.54	179	6	1.85	1.23, 2.78
Marine water beaches								
Goddard, Fairhope, and Edgewater beaches	420	7	1.32	0.87, 1.99	276	5	1.47	0.87, 2.47
Fresh water beaches								
Washington Park, Silver, Huntington, and West beaches	1,493	7	1.21	1.03, 1.44	1,009	5	1.21	0.97, 1.51

Abbreviations: aIPR, adjusted incidence proportion ratio; NEEAR, National Epidemiological and Environmental Assessment of Recreational Water.

[a] The beach locations, by state, are as follows: Goddard Beach, Rhode Island; Fairhope Beach, Alabama; Edgewater Beach, Mississippi; Washington Park Beach, Indiana; Silver Beach, Michigan; Huntington Beach, Ohio; and West Beach, Indiana.

[b] The numbers are those reporting new symptoms, among those without baseline symptoms. aIPR was estimated from log-risk binomial regression models. Covariates in models included age, sex, and beach, and selection was through a change-in-estimate procedure from the following: race/ethnicity, any contact swimming, contact with animals, contact with other persons with diarrhea, eating food while at the beach, eating raw or undercooked meat since the time of the interview, eating raw or undercooked eggs since the time of the interview, number of other visits to the beach, and any other chronic illnesses (gastrointestinal, skin, asthma). For upper respiratory illness and skin outcomes, insect repellent and sun block use were also considered.

We observed beach-specific variation in the enteric illness risk following beach sand contact. This could have been due to a number of site-specific differences at the beaches studied, including factors such as sand composition (e.g., clay, silt, loam), particle size, moisture and organic content, nutrient availability, osmotic pressure, tidal phenomena, wave action, currents, salinity, and algae/seaweed density that may impact the sand and survival/density of fecal indicator

organisms and pathogens (17, 37–41). Human factors, such as bather density and sand-grooming practices (such as daily tilling), may also impact beach sand quality (14, 38). The observed variation in enteric illness risks across beaches could also be explained by different levels of fecal pollution influencing recreational waters and sand from sources including sewage discharges from publicly owned treatment works, non-point source runoff (e.g., domestic and wild animals, urban storm water), and bathers.

The observed beach-specific variation in enteric illness risk and the stronger association between sand contact and enteric illness at marine beaches warrant further investigation. We examined potential effect measure modification by beach and by marine versus freshwater beaches by comparing a model with interaction terms with a model without using a likelihood ratio test. Despite the wide range of estimates presented in Table 4, there was little statistical evidence of heterogeneity across the 7 beaches ($\chi^2_{6df} = 2.60$, $P = 0.8575$). However, there was some evidence of heterogeneity by marine beaches versus freshwater beaches ($\chi^2_{1df} = 2.27$, $P = 0.1318$).

There was little evidence of effect measure modification by swimming status. Nonswimmers who dug in the sand had a similar risk of gastrointestinal illness (aIPR = 1.26, 95% CI: 1.03, 1.54) and diarrhea (aIPR = 1.26, 95% CI: 0.98, 1.62) compared with swimmers who dug in the sand for gastrointestinal illness (aIPR = 1.11, 95% CI: 0.99, 1.25) and diarrhea (aIPR = 1.19, 95% CI: 1.03, 1.37).

Some of the illnesses studied were nonspecific (e.g., gastrointestinal illness, eye irritation) and may have been affected by recall bias. However, the NEEAR Study's focus was swimmers' health, and it is unlikely that participants' recall of illness would have been influenced by their recall of sand exposure. We expected that participants' recall of illness would have been nondifferential with respect to sand exposure status. In our study, nondifferential recall of illness with respect to sand exposure would have resulted in unbiased estimates, although there could have been a loss of precision if there was underrecall (or underreporting) of illness among participants (36). The association between contact with sand and enteric illnesses was robust to varying definitions of sand contact (digging in the sand, being buried in the sand) and definitions of enteric illness (gastrointestinal illness, diarrhea). Strengths of our study include large sample size, ability to follow a cohort of people who reported no disease within the past 3 days, and a high level of follow-up. To the best of our knowledge, this is the most comprehensive investigation of the association between specific beach sand contact activities and risk of illness.

These findings suggest a need for future studies of relations between quantitative measures of beach sand quality (i.e., fecal indicator organism concentrations in beach sand) and measures of beach sand exposure and illness. Seasonal visitation of coastal beaches is a favored pastime in the United States. The National Survey on Recreation and the Environment found that, during 1999–2000, 43% of the civilian population, 16 years of age or older, participated in marine outdoor recreation activities, equivalent to 89 million individuals (42). Although the aIPRs in this study are modest in magnitude, suggesting an increased risk on the order of 20%–50% depending on the age range and type of sand exposure, the results are of public health importance because of the large numbers of people who recreate at beaches and who are exposed to sand. If the relation between sand exposure and enteric illness is causal, many cases of illness could be prevented by decreasing microbial burdens in beach sand.

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