Title

Child environmental exposures to water and sand at the beach: Findings from studies of over 68,000 subjects at 12 beaches

Journal
Journal of Exposure Science & Environmental Epidemiology, 28(2)

ISSN
1559-0631

Authors
DeFlorio-Barker, Stephanie
Arnold, Benjamin F
Sams, Elizabeth A
et al.

Publication Date
2018-03-01

DOI
10.1038/jes.2017.23

Peer reviewed

HHS Public Access
Author manuscript
J Expo Sci Environ Epidemiol. Author manuscript; available in PMC 2018 May 08.

Published in final edited form as:
J Expo Sci Environ Epidemiol. 2018 March ; 28(2): 93–100. doi:10.1038/jes.2017.23.

Child environmental exposures to water and sand at the beach: Findings from studies of over 68,000 subjects at 12 beaches

Stephanie DeFlorio-Barker, PhD, MPH,
National Health and Environmental Effects Research Laboratory, Office of Research and Development, US Environmental Protection Agency, 109 TW Alexander MC 58C, Research Triangle Park, NC

Benjamin F. Arnold, PhD, MPH,
Division of Epidemiology, School of Public Health, University of California, Berkley

Elizabeth A. Sams, MSHSA, CCPH,
National Health and Environmental Effects Research Laboratory, Office of Research and Development, US Environmental Protection Agency

Alfred P. Dufour, PhD,
National Exposure Research Laboratory, Office of Research and Development, US Environmental Protection Agency

John M. Colford Jr., MD, PhD, MPH,
Division of Epidemiology, School of Public Health, University of California, Berkley

Steven B. Weisberg, PhD,
Southern California Coastal Water Research Project

Kenneth C. Schiff, MA, and
Southern California Coastal Water Research Project

Timothy J. Wade, PhD, MPH
National Health and Environmental Effects Research Laboratory, Office of Research and Development, US Environmental Protection Agency

Abstract

Swimming and recreating in lakes, oceans, and rivers is common, yet the literature suggests children may be at greater risk of illness following such exposures. These effects might be due to differences in immunity or differing behavioral factors such as poorer hygiene, longer exposures to, and greater ingestion of potentially contaminated water and sand. We pooled data from 12 prospective cohorts (n=68,685) to examine exposures to potentially contaminated media such as beach water and sand, among children compared to adults, and conducted a simulation using self-reported time spent in the water and volume of water swallowed per minute by age, to estimate the

---

corresponding author: 919-843-6660, Deflorio-Barker.Stephanie@epa.gov.

Conflict of Interest
The authors declare no conflict of interest.

total volume of water swallowed per swimming event by age category. Children 4–7 and 8–12 had the highest exposures to water, sand, and algae compared to other age groups. Based on our simulation, we found that children (6–12) swallow a median of 36mL (90^{th} percentile= 150 mL), while adults 35 and over swallow 9 mL (90^{th} percentile=64 mL) per swimming event, with male children swallowing a greater amount of water compared to females. These estimates may help to reduce uncertainty surrounding routes and durations of recreational exposures and can support the development of chemical and microbial risk assessments.

Keywords

recreational water; children; QMRA; sand exposure; algae exposure

Introduction

Surface water recreation in the US is popular among both adults and children (1, 2), but close to one-third of all beachgoers are under the age of 20 (1). Because of their underdeveloped immune systems, children are often cited as being more vulnerable to enteric illnesses from pathogens encountered during such activity (2, 3). In particular, children age 10 and under are at greater risk of developing gastrointestinal illness compared to those over age 10 (4).

Children are also at greater risk because they spend a greater amount of time in the water compared to adults (4–6), and thus are more likely to swallow water while at the beach (1, 7, 8). Children are also more likely to participate in splashing behaviors that have been found to be associated with water ingestion while swimming (9). Swallowing water during recreation in water contaminated with feces is a risk factor for gastrointestinal illness (4, 10).

Moreover, surface water is often not the only source of fecal contamination at beaches. Beach sand has also been found to have high concentrations of fecal indicator organisms (11), yet is not always related to fecal contamination (12–14). However, exposure to beach sand affected by wastewater effluent, has been positively associated with gastrointestinal illness (15). Algae, particularly *Cladophora* algae, has been known to harbor fecal indicator organisms in some cases in higher concentrations than surrounding surface water (16), as the algal mat may provide an environment suitable for bacterial growth (17). However, evidence suggests that the fecal indicator organisms growing within the algal mat may (18) or may not (19) be related to human sources. Nonetheless, young children are more likely to play and have direct contact with sand, and possibly algae, compared to adults (1).

One key component of quantitative microbial risk assessments (QMRA), which are used to compare and assess the risk of illness due to exposures to recreational waters (20, 21), is the route and duration of exposure (22). In such studies, the volume of water ingested is a critical parameter required to estimate the risk of infection or illness due to enteric pathogen exposure in recreational water. Previous QMRAs have relied on a range of estimates for volumes swallowed (23–26), but little emphasis has been placed on estimating risk based on the differences in volume of recreational water swallowed according to age. Compared to adults, children often exhibit different exposure patterns due to their small physical size and differences in behavior (27). Evaluating exposures among different age groups of beach goers, especially the total volume of water swallowed, may be useful to characterize risk and inform QMRAs.

Our objective was to estimate exposure to water, sand and algae among different age groups recreating at US beaches by using a pooled analysis of 12 prospective cohorts of beachgoers in the contiguous United States (n=68,685). These studies used similar designs, and methodology, allowing the data to be combined into a single data set (2, 7, 28–33), as has been described by Arnold et al. (2016) (4).

Materials and Methods

Study Settings

All 12 cohorts were enrolled between 2003 and 2009 at temperate beaches within the contiguous United States, and have been previously described (4) (Figure 1). Four of these studies were at freshwater beaches (n=21,015) and 8 at marine beaches (n=47,670) (4). Because the focus of this study was on beaches in temperate climates, one site (Boqueron Beach in Puerto Rico) included in Arnold et al (2016) was excluded from this analysis due to the tropical setting.

Eligible household members attending the beach who provided informed consent were enrolled between May and September during the study years. Institutional Review Board (IRB) approval was obtained from the University of North Carolina–Chapel Hill, the Centers for Disease Control and Prevention, and the University of California, Berkeley. Enrolled beachgoers participated in a short survey as they left the beach for the day to assess exposures while at the beach. Children (under 18) were eligible when accompanied by an adult (18 years or older) while at the beach. Unaccompanied children were ineligible to participate. One adult (18 years or older) responded to exposure questions for the rest of the household. Details regarding recruitment and survey administration have been described previously (4).

Swimming and other Exposures

In this analysis, we focused on participant responses to survey questions regarding various exposures and behaviors while at the beach. Participants were asked about water exposures; if they had any contact (wading, swimming, or playing) with water, if they had body contact with the water (body was immersed in the water), if their head or face was submerged in the water, if they got any water in their mouth, and if they swallowed any water. Participants were also asked to estimate, in minutes, the total time they spent in the water. All participants were also asked if they dug into the sand or were buried in the sand, but additional details collected about sand exposure varied by beach. At marine beaches (Avalon, Doheny, Edgewater, Fairhope, Goddard, Malibu, and Surfside) participants were asked if they ingested any sand, whether the sand they played with was wet or dry, and if they washed their hands following sand contact. Participants at Fairhope, Goddard, and Surfside beaches were asked if they ate or drank following digging or playing in the sand. All participants were asked if they played with any algae or seaweed, while participants at

Avalon, Doheny, Malibu, and Surfside beaches were asked if they washed their hands after playing with algae or seaweed, and participants at Avalon, Doheny, Fairhope, Goddard, Malibu, and Surfside locations were asked if they got any algae or seaweed in their mouth.

We summarized beachgoer demographics, behaviors and exposures by age group and water type (freshwater and marine). We assessed exposure across the following age categories: children ≤1, ages 1–3, 4–7, 8–12, and 13–18; and adults 19–34, and ≥ 35. For the purposes of this analysis, we consider children to be 18 years or less, while adults are 19 and over. Due to the large data set, several age categories for those 18 and under were chosen to observe any potential exposure patterns among children at the beach. Since we did not anticipate any behavioral differences among adults 35 years and older, we included them as one age category. We also compared the total number of minutes spent in the water according to age group among subjects with body immersion using the *Kruskal-Wallis* test. Participants were asked to self-report their estimated total number of hours and minutes spent in the water, and not the total time spent at the beach. Self-reported swimming ≥10 hours were excluded (n=15) as possible errors, and those who swam but reported 0 minutes were recoded as 1 minute (n=16).

Simulation

Self-reported estimates of time spent in the water were combined with estimates provided by Dufour et al. (2017) (n=553) of the volume of water swallowed during 45–90 minutes of swimming. Dufour et al., measured the amount of cyanuric acid found in the urine of participants who to performed "normal swimming activities" in a treated swimming pool and recorded the time spent in the water, age and sex of the participants, which we used to provide an estimate of the rate of water swallowed per minute for those age 6 and older. Data for the 68,685 beachgoers from the 12 locations were used to develop estimates of total minutes spent in the water among those who had body contact with the water (n=35,176). Using bootstrap sampling with replacement from the original data set, we conducted a simulation study according to the following algorithm to integrate these two data sources.

1. Sample volumes per minute (mL/min) from Dufour et al (2017 (34)) and Evans et al (2006) The volume of water swallowed during the swimming pool study was divided by the self-reported total time spent in the pool, to yield an estimated rate of water swallowed (. Sampling was conditional on age and sex.
2. Sample time from the distribution of self-reported times (min/event) from the study locations from the subset who had body contact with the water. Sampling was conditional on age, sex, and beach type.
3. Estimate volume of water swallowed per swimming event: Volume (mL/min) x Time (min/event) = Volume (mL/event).
4. Repeat 10^6 times (sampling swimming times and ingested volumes with replacement).
5. Summarize the distribution of 10^6 volumes (mL) of water swallowed per event generated.

6. Conduct separately for all subjects, children ages 6–12, children 13–18, adults 19–34, and adults 35 and over.

This simulation was conducted for each age group using all participants, and for males and females separately, since evidence suggests males may swallow a greater volume compared to females (26, 34, 36–38). The simulation was also conducted separately based on beach water type (freshwater and marine), since behavior was expected to differ at different types of beaches (1). Also, to be consistent with age categories presented in the US EPA *Exposure Factors Handbook* (5, 6, 27) and other US EPA documentation (39), we chose to also assess the simulation for the following age categories; 6–10, 11–17, and 18 and over. In addition, a sensitivity analysis was conducted by restricting the time spent in the water at the beach to only those who reported head immersion, since head immersion behavior may more closely represent the behavior among participants in the Dufour et al. (2017) and Evans et al. (2006) study. All statistical analyses were conducted using Stata version 13 (40) and R version 3.2.1. (41). Statistical code available upon request.

Results

Beachgoer Characteristics

A total of 68,685 beachgoers participated in the 12 studies (Table 1), approximately 26% (n=17,801) of whom were under the age of 13. The majority of beachgoers at freshwater (84.2%) and marine (67.8%) beaches were white, and most beachgoers at these locations were non-Hispanic, 90.7% and 76.6%, respectively.

Beach Exposures

Overall, we observed that 67% of both freshwater and marine (Table 2) participants waded, swam, or played in the water (any water contact). In both fresh and marine waters children swam more frequently than adults. At all beach locations, approximately 90% of children aged 4–7 and those aged 8–12 waded, swam, or played in the water, compared to about 56% of adults aged 35 and older. In freshwater, 72% of children aged 8–12 immersed their head or face in the water, compared to approximately 19% of adults. Similarly, in marine water, 71% of children aged 8–12 immersed their head or face in the water, compared to 29% of adults over the age of 35. Among freshwater participants, 25% of children aged 1–3, 24% of children aged 4–7, and 20% of children aged 8–12 swallowed water while swimming, compared to only 2% of adults 35 and over. Twenty-two percent of children aged 1–3, 27% of children aged 4–7, and 28% of children aged 8–12 in marine waters swallowed water, compared to only 7% of adults. All types of water exposures were lower among children under 1 year of age, and gradually increased to age 12, with the highest exposures mostly among children aged 8–12, and then declining in older age groups. The lowest exposures were consistently among adults aged 35 and over. Males and females were observed to have similar behaviors while at the beach (Supplement Table S1 and Table S2).

Total time spent in the water varied by age (*Kruskal-Wallis p-value <0.001*) (Table 3), with children 8–12 at freshwater locations spending a mean of 93 minutes (SD=65 minutes) per event in the water compared to adults 35 and over, who spent a mean of 47 minutes (SD= 46 minutes). Children 8–12 at marine locations spent a mean of 121 minutes (SD=85 minutes) in the water compared to adults 35 and over, who spent a mean of 68 minutes (SD= 64 minutes). Those recreating in marine waters, typically spent more time in the water compared to freshwater swimmers (Freshwater: mean=63.7 minutes, Marine: mean=86.4 minutes, p-value >0.001) (Figure 2, Table 3). Males on average, spent a greater amount of time in the water compared to females (Males: mean=83.7 minutes, Females: mean=75.4 minutes, p-value >0.001) (Figure 2, Table 3). Data from Dufour et al (2017) and Evans et al (2006) show that children under age 18 swallow water at a faster rate compared to adults (Figure 3). Across almost all age groups, male participants in the Dufour et al. study swallow water at a faster rate compared to females in the same age group.

The simulation estimated the total volume swallowed per event. Overall, we estimated that children swallowed more water per swimming event compared to adults 19 and older (Figure 4a–b, Table 4). Children, aged 6–12 swallowed a median of 36.0 mL (90^{Th} percentile=150.0 mL), compared to adults 35 and older who swallowed a median of 9.0 mL (90^{th} percentile=64.0 mL). We also observed differences in volumes swallowed per event based on sex (Figure 4a, Table 4). Based on this analysis, we estimated that females ages 6–12 swallowed a median of 34.3 mL (90^{th} percentile=146.1 mL) per swimming event and females ages 13–18 swallowed median of 17.3 mL (90^{th} percentile=97.0 mL), while females 35 and over swallow a median of 6.6 mL (90^{th} percentile=44.3 mL). However, males 6–12 swallowed a median of 40.0 mL (90^{th} percentile=161.0 mL) per swimming event and males 13–18 swallowed a median 34.7 mL (90^{th} percentile=200.0 mL) per swimming event, while males 35 and over swallowed a median of 13.3 mL (90^{th} percentile=104.0 mL). These differences in volume of water swallowed according to sex, results from a combination of both the Dufour et al. (2017) data which observed males swallowing water at a higher rate (per minute), and from our data which indicate males spend a greater amount of time in the water compared to females (Table 3, Figure 2). Additionally, those recreating in marine water, tended to swallow more water compared to freshwater recreators (Figure 4b, Table 4), with all marine recreators swallowing a median of 18.0 mL (90^{th} percentile=116.0 mL) and freshwater recreators swallowing a median of 12.7 mL (90^{th} percentile=84.0 mL). Similar age differences were also noted between marine versus freshwater recreators.

The sensitivity analysis results, which only included times for those reporting head immersion, were similar to the simulation that included those with body contact. Overall, children aged 6–12 with head immersion swallowed a median of 42.7 mL (mean= 72.0 mL, 90^{th} percentile=172.0 mL), while adults 35 and over were estimated to swallowed a median of 13.0 mL (mean= 41.1 mL, 90^{th} percentile=88.0 mL) (Supplement Table S3).

To be consistent with age categories presented in the US EPA *Exposure Factors Handbook* (5, 6, 27) and other US EPA documentation (39), estimated exposure for the following age categories; 6–10, 11–17, and 18 and over. Overall, children aged 6–10 (median= 40.0, 90^{th} percentile=164.0) and children aged 11–17 (median=32.0, 90^{th} percentile= 170.7) swallowed more water than those aged 18 and over (median=9.3, 90^{th} percentile=64.0) (Supplement Figure S1, Table S4). Similar patterns were observed among males versus females and marine versus freshwater recreators as were observed with the narrower age categories (Supplement Figure S1, Table S4).

Author Manuscript

Author Manuscript

Author Manuscript

Beach sand and algae contact

Contact with beach sand was relatively common, with almost 44% of freshwater participants and 36% of marine participants (Table 5) indicating playing in or digging in the sand. At freshwater locations approximately 88% of children aged 4–7 reported digging or playing in sand, compared to 27% of adults 35 and over. At marine locations, 76% of children aged 4–7 reported digging in the sand compared to only 22% of adults over the age of 35.

In freshwater, 4% of children aged 4–7 and 5% of children aged 8–12 touched or had contact with algae or seaweed, compared with only 1% of adults 19 and older (Table 5). At marine beaches, 20% of children aged 4–7 and 18% of children 8–12 touched or had contact with algae or seaweed, compared to 8% of adults aged 19–34 and 7% of adults aged 35 and older (Table 5). Among participants at the marine beaches, 4% of children under 1 and 2% of children 1–12 reported getting seaweed or algae in their mouths, compared to less than 1% of those aged 35 and older.

Discussion

In this analysis, based on the largest assembled data set of recreational water exposure, we provided improved estimates of the volumes of water swallowed among beachgoers for a wide range of age groups. Based on the results of our simulation, we found that children tend to swallow more water per swimming event, and males swallow more water compared to females (Table 4, Figure 4a). This finding is a result of the fact that males were observed to swallow a greater volume of water in the Dufour et al. (2017) (Figure 3) study and that males spent more time in the water compared to females (Figure 2, Table 3). We also observed that marine water recreators swallow more water compared to freshwater recreators (Table 4, Figure 4b). This may be because marine recreators spent more time in the water compared to freshwater recreators (Figure 2b, Table 3), which may have been influenced by the warmer water at most of the marine sites (California and Gulf Coast) compared to the freshwater sites in the Great Lakes. We also found across the beaches studied that children have more exposure to sand and algae than adults--another potential route of exposure to fecal contamination. Using the same data, Arnold et al (2016) found significantly higher risk of diarrhea and gastrointestinal illness among young children (age 0–4 and 5–10) compared with adults (4). Our exposure estimates (Table 2) are consistent with the findings by Arnold et al. (2016), and the present effort to summarize exposure across a broad range of age, sex, and beach categories provides valuable additional information for future studies.

The results of the simulation, using self-reported time spent in the water (n=68,685) and estimated volume of water swallowed per minute (34), present a refined estimate of the volume of water swallowed per swimming event and decrease the uncertainty associated with recreational water ingestion estimates, especially among children, compared to previous studies. Other studies that have estimated the volume of water swallowed per swimming event, included subjective parameters, such as self-reported ordinal estimates of the volume of water swallowed (8, 42, 43), which may potentially be problematic as estimating the volume of water swallowed may be subjective and vary from person to person. In addition, the WHO guidelines for recreational water assume individuals swallow between 20–50 mL of water per hour of swimming and suggests that swimmers could swallow between 100–200 mL in a single swimming event. The WHO also indicates that this estimate could be larger for other types of water activities such as water skiing (44). In our analysis we found that children (6–12) swallow a median of 40 mL (75th percentile= 87 mL), while adults 35 and over swallow 10 mL (75th percentile=31 mL) per swimming event.

The simulation relied on several assumptions to estimate the total volume of water swallowed per swimming event. In this analysis, we assumed there is a linear relationship between the volume of water swallowed and total time spent in the water, and thus more time spent in the water suggests a greater volume of water swallowed. Therefore, the volume of water swallowed per unit time was multiplied by the total time in the water to yield the total volume of swallowed per swimming event. This approach has been used previously in QMRA studies to estimate the total volume swallowed based on exposure times and the volume of water swallowed per minute (25). In addition, the US EPA *Exposure Factors Handbook* (5, 27) and the *Child-Specific Exposure Factors Handbook* (27) provide values for the volume ingested per hour of swimming and the total number of hours swimming to yield total volume ingested per event. This approach has also been used to assess risk of ingested recreational surface water (39).

The analysis of exposures to sand and algae at the beach indicate that sand exposure is relatively common among beachgoers (Table 5), but occurs much more frequently among children, who are more likely to exhibit hand-to-mouth behavior (27). Previous analyses have indicated that beach sand can harbor fecal indicator bacteria (11), but that it is not necessarily always related to fecal contamination (12–14). However, sand exposure may be a potentially important pathway for ingestion of harmful pathogens (15) among children particularly at beaches affected by wastewater effluent. Algae exposure was less common compared to sand exposure, but occurred commonly among children under 12. Since certain types of algae have been known to harbor potentially more fecal indicator bacteria compared to surrounding recreational water (16), algae exposure may be another important pathway for children's exposure to pathogens associated with fecal contamination, since algae may (18) or may not (19) harbor harmful organisms.

This study relied on self-reported data of swimming and beach exposures and time spent in the water, which may be subject to recall bias. Study participants are also likely to have rounded their estimate of the amount of time spent in the water, which could have contributed some misclassification to the actual time spent swimming. In addition, parents/guardians were often responsible for answering survey questions on behalf of their young children. Despite the fact that the children were often present during follow-up and could also answer questions about their own exposure, it may be difficult for parents to be able to assess certain exposures, such as getting water in the mouth or swallowing water. Therefore, we could have underestimated or overestimated exposure among young children, if parents/guardians were unaware of these types of specific exposures.

Previously, children ≤ 6 have been identified to be at the highest risk of gastrointestinal illness due to exposure to recreational water (4). However, in our simulation, analysis of volume ingested per swimming event could only be assessed for those ≥ 6, since the Dufour et al (2017) and Evans et al (2006) studies only assessed volume swallowed per minute in participants ≥ 6. In addition, we conducted our simulation including all those who had any contact with the water, and again including only those who immersed their head in the water. Overall, our findings were very similar (children 6–12 full dataset: median=36.0, mean=63.2; children 6–12 head immersion only: median=42.7, mean=72.0), indicating consistency across the analysis.

This analysis aimed to assess exposures at the beach among adults and children and to estimate the total volume of water swallowed among beachgoers. Our findings indicate that children are more likely to engage in activities associated with greater exposure, such as spending more time in the water and having more contact with algae and sand compared to adults. The results of our bootstrap simulation suggest children, especially those aged 6–12, swallow a greater amount of water compared to adults over 35, and that male children swallow a greater amount of water compared to females. Given the previous observation by Arnold et al (2016) that more children are more likely to become ill following swimming in recreational water compared to adults, the results presented here suggest that behaviors among children may potentially put them at higher risk of becoming ill following swimming at beaches. In addition, by integrating the amount of time spent in the water with the rate of swallowing water, we were able to identify a significantly increased water ingestion rate among males, with male children potentially the highest exposed group based on volume of water swallowed per event. Therefore, future QMRA studies should consider these differences in exposure among adults and children when estimating risk among surface water recreators.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Funding: This study was funded in part by the National Institutes of Health (NIH; grant R03-HD076066)

The research described in this article has been reviewed by the National Health and Environmental Effects Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Agency, nor does the mention of trade names of commercial products constitute endorsement or recommendation for use.

References

1. Collier SA, Wade TJ, Sams EA, Hlavsa M, Dufour AP, Beach MJ. Swimming in the USA: Beachgoer characteristics and health outcomes at US marine and freshwater beaches. Journal of Water and Health. 2015; 13(2):531–43. [PubMed: 26042984]
2. Wade TJ, Calderon RL, Brenner KP, Sams E, Beach M, Haugland R, et al. High sensitivity of children to swimming-associated gastrointestinal illness: results using a rapid assay of recreational water quality. Epidemiology. 2008; 19(3):375–83. [PubMed: 18379427]
3. Nwachuku, N., Gerba, CP. Reviews of environmental contamination and toxicology. Springer; 2006. Health risks of enteric viral infections in children; p. 1-56.
4. Arnold BF, Wade TJ, Benjamin-Chung J, Schiff KC, Griffith JF, Dufour AP, et al. Acute Gastroenteritis and Recreational Water: Highest Burden Among Young US Children. American Journal of Public Health. 2016; 106(9):1690–7. [PubMed: 27459461]

5. US EPA. Assessment NCfE. Exposure Factors Handbook: 2011 Edition. Washington D.C: National Technical Information Service; 2011.
6. US EPA. Assessment NCfE. Exposure Factors Handbook (1997 Final Report). Washington D.C: National Technical Information Service; 1997.
7. Yau VM, Schiff KC, Arnold BF, Griffith JF, Gruber JS, Wright CC, et al. Effect of submarine groundwater discharge on bacterial indicators and swimmer health at Avalon Beach, CA, USA. Water Research. 2014; 59:23–36. [PubMed: 24776951]
8. Schets FM, Schijven JF, de Roda Husman AM. Exposure assessment for swimmers in bathing waters and swimming pools. Water Research. 2011; 45(7):2392–400. [PubMed: 21371734]
9. Suppes LM, Abrell L, Dufour AP, Reynolds KA. Assessment of swimmer behaviors on pool water ingestion. Journal of Water and Health. 2014; 12(2):269–79. [PubMed: 24937221]
10. Wade TJ, Pai N, Eisenberg JNS, Colford JM. Do U.S. Environmental Protection Agency water quality guidelines for recreational waters prevent gastrointestinal illness? A systematic review and meta-analysis. Environ Health Perspect. 2003; 111(8):1102–9. [PubMed: 12826481]
11. Alm EW, Burke J, Spain A. Fecal indicator bacteria are abundant in wet sand at freshwater beaches. Water Research. 2003; 37(16):3978–82. [PubMed: 12909116]
12. Byappanahalli MN, Whitman RL, Shively DA, Ting WE, Tseng CC, Nevers MB. Seasonal persistence and population characteristics of Escherichia coli and enterococci in deep backshore sand of two freshwater beaches. Journal of Water and Health. 2006; 4(3):313–20. [PubMed: 17036839]
13. Feng F, Goto D, Yan T. Effects of autochthonous microbial community on the die-off of fecal indicators in tropical beach sand. FEMS Microbiology Ecology. 2010; 74(1):214–25. [PubMed: 20629750]
14. Zhang Q, He X, Yan T. Differential decay of wastewater bacteria and change of microbial communities in beach sand and seawater microcosms. Environmental Science & Technology. 2015; 49(14):8531–40. [PubMed: 26125493]
15. Heaney CD, Sams E, Dufour AP, Brenner KP, Haugland RA, Chern E, et al. Fecal indicators in sand, sand contact, and risk of enteric illness among beachgoers. Epidemiology. 2012; 23(1):95. [PubMed: 22157306]
16. Nevers MB, Byappanahalli MN, Edge TA, Whitman RL. Beach science in the Great Lakes. Journal of Great Lakes Research. 2014; 40(1):1–14.
17. Byappanahalli MN, Shively DA, Nevers MB, Sadowsky MJ, Whitman RL. Growth and survival of Escherichia coli and enterococci populations in the macro-alga Cladophora (Chlorophyta). FEMS Microbiology Ecology. 2003; 46(2):203–11. [PubMed: 19719574]
18. Byappanahalli MN, Sawdey R, Ishii S, Shively DA, Ferguson JA, Whitman RL, et al. Seasonal stability of Cladophora-associated Salmonella in Lake Michigan watersheds. Water Research. 2009; 43(3):806–14. [PubMed: 19059626]
19. Byappanahalli MN, Whitman RL, Shively DA, Ferguson J, Ishii S, Sadowsky MJ. Population structure of Cladophora-borne Escherichia coli in nearshore water of Lake Michigan. Water Research. 2007; 41(16):3649–54. [PubMed: 17451778]
20. Schoen ME, Ashbolt NJ. Assessing Pathogen Risk to Swimmers at Non-Sewage Impacted Recreational Beaches. Environmental Science & Technology. 2010; 44(7):2286–91. [PubMed: 20201509]
21. Soller JA, Eftim S, Wade TJ, Ichida AM, Clancy JL, Johnson T, et al. Use of quantitative microbial risk assessment to improve interpretation of a recreational water epidemiological study. Microbial Risk Analysis. 2015
22. Haas, CNRJB., Gerba, CP. Quantitative Microbial Risk Assessment. John Wiley & Sons, Inc; 1999.
23. Ashbolt, N.Reidy, C., Haas, C., editors. Microbial health risk at Sydney's coastal bathing beaches. Proceedings of the 17th Australian Water and Wastewater Association Meeting; 1997;
24. Craig D, Fallowfield H, Cromar N. Effectiveness of guideline faecal indicator organism values in estimation of exposure risk at recreational coastal sites. Water Science & Technology. 2003; 47(3): 191–8.

25. Tseng LY, Jiang SC. Comparison of recreational health risks associated with surfing and swimming in dry weather and post-storm conditions at Southern California beaches using quantitative microbial risk assessment (QMRA). Marine pollution bulletin. 2012; 64(5):912–8. [PubMed: 22472787]
26. Evans, O., Wymer, L., Behymer, T., Dufour, A. An Observational Study: Determination of the Volume of Water Ingested During Recreational Swimming Activities. National Beaches Conference; Niagra Falls, NY. 2006;
27. US EPA. Development OoRa. Child-Specific Exposure Factors Handbook. Washington, DC: 2008.
28. Arnold BF, Schiff KC, Griffith JF, Gruber JS, Yau V, Wright CC, et al. Swimmer illness associated with marine water exposure and water quality indicators: Impact of widely used assumptions. Epidemiology. 2013; 24(6):845–53. [PubMed: 24045718]
29. Colford JM, Schiff KC, Griffith JF, Yau V, Arnold BF, Wright CC, et al. Using rapid indicators for Enterococcus to assess the risk ofA illness after exposure to urban runoff contaminated marine water. Water Research. 2012; 46(7):2176–86. [PubMed: 22356828]
30. Colford JM, Wade TJ, Schiff KC, Wright CC, Griffith JF, Sandhu SK, et al. Water quality indicators and the risk of illness at beaches with nonpoint sources of fecal contamination. Epidemiology. 2007; 18(1):27–35. [PubMed: 17149140]
31. Wade TJ, Calderon RL, Sams E, Beach M, Brenner KP, Williams AH, et al. Rapidly measured indicators of recreational water quality are predictive of swimming-associated gastrointestinal illness. Environ Health Perspect. 2006; 114(1):24–8. [PubMed: 16393653]
32. Wade TJ, Sams E, Brenner KP, Haugland R, Chern E, Beach M, et al. Rapidly measured indicators of recreational water quality and swimming-associated illness at marine beaches: a prospective cohort study. Environ Health. 2010a; 9:66. [PubMed: 21040526]
33. Wade TJ, Sams E, Haugland R, Brenner KP, Li Q, Wymer L, et al. Report on 2009 National Epidemiologic and Environmental Assessment of Recreational Water Epidemiology Studies. 2010b Contract No.: EPA/600/R-10/168.
34. Dufour A, Behymer T, Cantu R, Magnuson M, Wymer L. Ingestion of swimming pool water by recreational swimmers. Journal of water and health. 2017
35. Yoder JS, Hlavsa MC, Craun GF, Hill V, Roberts V, Yu PA, et al. Surveillance for waterborne disease and outbreaks associated with recreational water use and other aquatic facility-associated health events--United States, 2005–2006. MMWR Surveill Summ. 2008; 57(9)
36. Kim SI, Kang JH, Lee DI, Jo JR, Kim HJ, Lee JB, et al. Measurement of Volume of a Swallow for Liquid Swallowing in Healthy Young Adults. Journal of the Korean Society of Clinical Toxicology. 2013; 11(2):114–8.
37. Langille R, Wigmore J. The mouth alcohol effect after a “mouthful” of beer under social conditions. Canadian Society of Forensic Science Journal. 2000; 33(4):193–8.
38. Nilsson H, Ekberg O, Olsson R, Kjellin O, Hindfelt B. Quantitative assessment of swallowing in healthy adults. Dysphagia. 1996; 11(2):110–6. [PubMed: 8721069]
39. Water, Oo, editor. US EPA. Human Health Recreational Ambient Water Quality Criteria or Swimming Adviseries for Microcystins and Cylindrospermopsin. U.S. Environmental Protection Agency; 2016.
40. StataCorp. Stata Statistical Software: Release 13. College Station, TX: StataCorp LP; 2013.
41. R Core Team. R: A Language and environment for Statistical Computing. Vienna, Austria: R Foundation for Statstical Computing; 2014.
42. Schijven J, de Roda Husman AM. A survey of diving behavior and accidental water ingestion among Dutch occupational and sport divers to assess the risk of infection with waterborne pathogenic microorganisms. Environmental Health Perspectives. 2006:712–7. [PubMed: 16675425]
43. Stone DL, Harding AK, Hope BK, Slaughter-Mason S. Exposure assessment and risk of gastrointestinal illness among surfers. Journal of Toxicology and Environmental Health, Part A. 2008; 71(24):1603–15. [PubMed: 18850460]
44. WHO. Guidelines for safe recreational water environments: Coastal and fresh waters. World Health Organization; 2003.

Figure 1.
Beach study locations

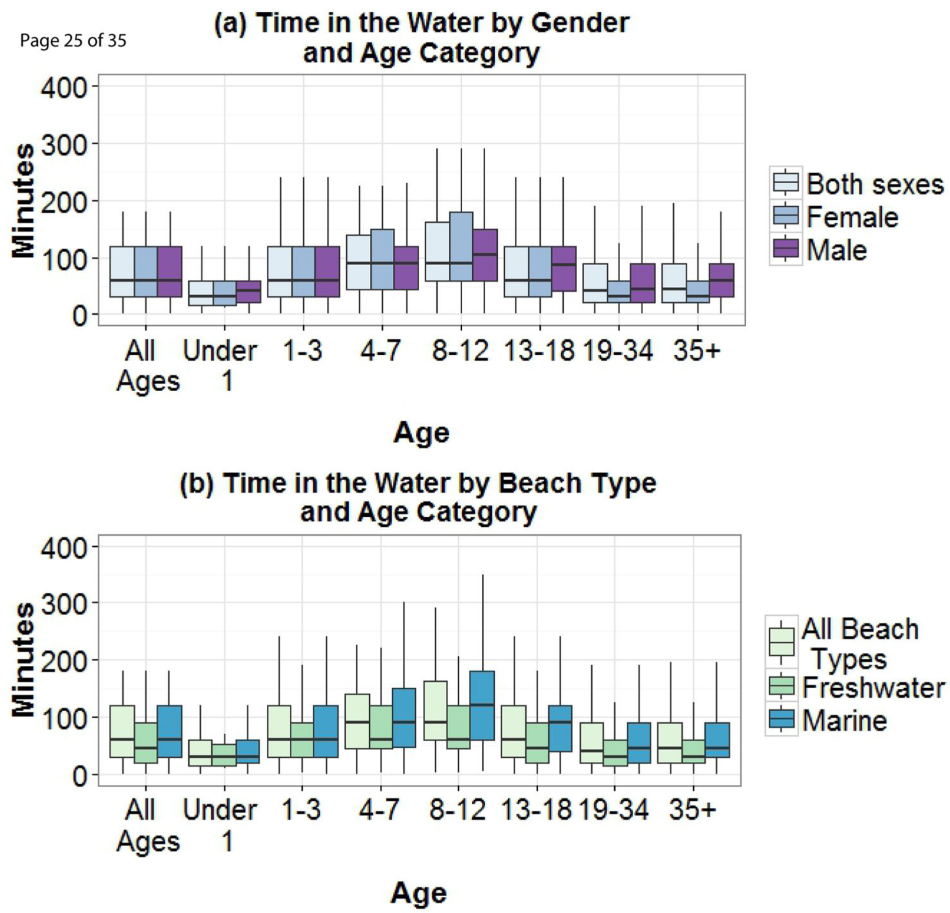

Figure 2.

Time in the water per minute for each age category by (a) sex and (b) water type (freshwater and marine

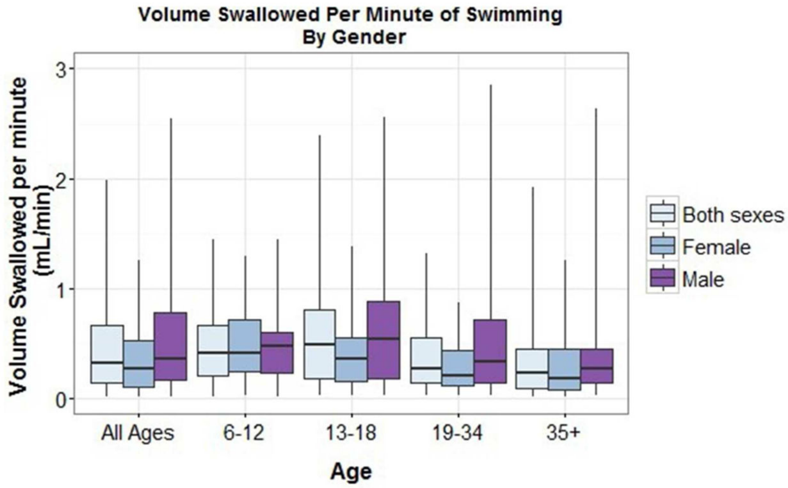

Figure 3.
Volume swallowed per minute (mL/min) (34)

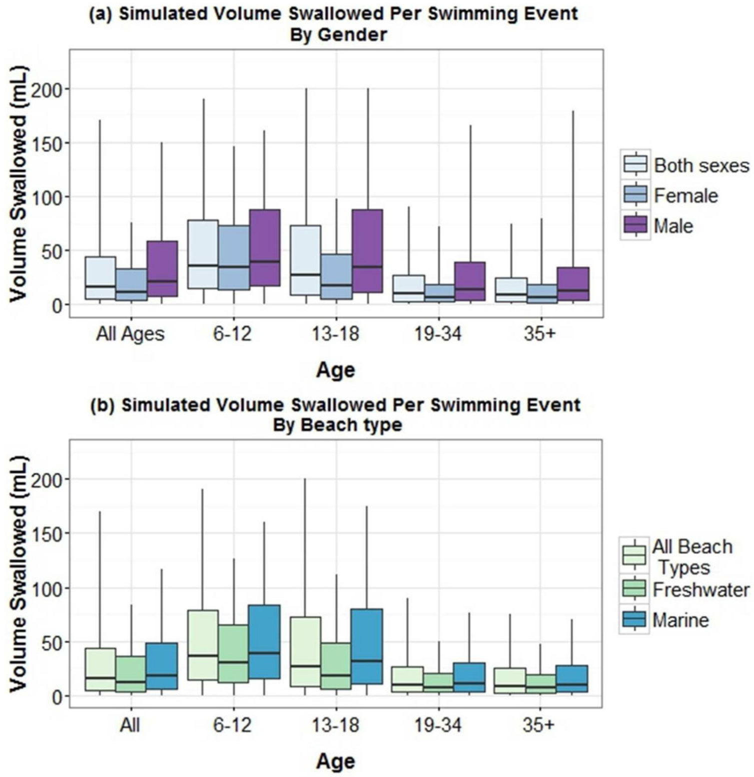

Figure 4.

Estimated volume (mL) of water swallowed for each age category per swimming event by (a) sex and (b) water type (freshwater and marine)

Table 1

Demographics by water type, all participants

	Freshwater[a] **n=21,015** ***n (%)***	**Marine**[b] **n=47,670** ***n (%)***
Age		
Under 1	171 (0.81%)	350 (0.73%)
1–3	1,061 (5.08%)	2,687 (5.64%)
4–7	1,738 (8.27%)	4,260 (8.94%)
8–12	2,136 (10.16%)	5,398 (11.32%)
13–18	1,855 (8.83%)	4,021 (8.44%)
19–34	5,478 (26.07%)	10,786 (22.63%)
35 and up	8,058 (38.34%)	19,745 (41.42%)
Missing	518 (2.46%)	423 (0.89%)
Race		
White	17,687 (84.16%)	32,339 (67.84%)
Black	596 (2.84%)	1,991 (4.18%)
Other	2,647 (12.60%)	12,750 (26.75%)
Missing	85 (0.40%)	590 (1.24%)
Ethnicity		
Hispanic	1,898 (9.03%)	11,137 (23.36%)
Non-Hispanic	19,056 (90.68%)	36,496 (76.56%)
Missing	61 (0.29%)	37 (0.08%)

[a]Huntington, Silver, Washington Park, and West

[b]Avalon, Doheny, Edgewater, Fairhope, Goddard, Malibu, Mission Bay, and Surfside

Table 2

Water exposure by age category

	Overall *n (%)*	Under 1 *n (%)*	1–3 *n (%)*	4–7 *n (%)*	8–12 *n (%)*	13–18 *n (%)*	19–34 *n (%)*	35 and Up *n (%)*	χ^2 p-value
Freshwater[a]									
Any water contact	13,568 (66.6)	55 (32.2)	857 (80.8)	1,562 (89.9)	1,901 (89.0)	1,342 (72.4)	3,427 (62.6)	4,514 (56.0)	<0.01
Body immersion	10,123 (49.4)	26 (15.2)	647 (61.0)	1,370 (78.8)	1,716 (80.3)	1,119 (60.3)	2,492 (45.5)	2,753 (34.2)	<0.01
Head immersion	7,142 (34.8)	15 (8.8)	418 (39.4)	1,127 (64.8)	1,540 (72.1)	882 (47.6)	1,635 (29.9)	1,525 (18.9)	<0.01
Water in mouth	4,036 (20.2)	11 (5.9)	411 (39.7)	849 (51.6)	985 (49.1)	468 (26.4)	704 (13.0)	609 (7.7)	<0.01
Swallow water	1,652 (8.1)	8 (4.7)	263 (24.8)	420 (24.2)	417 (19.5)	145 (7.8)	226 (4.1)	173 (2.2)	<0.01
Wear nose plugs	49 (0.24)	1 (0.6)	3 (0.3)	6 (0.4)	10 (0.5)	6 (0.3)	12 (0.2)	11 (0.1)	0.05[b]
Wear mask/goggles	753 (3.7)	1 (0.8)	20 (1.8)	204 (11.8)	323 (15.1)	61 (3.3)	55 (1.0)	89 (1.1)	<0.01
Marine Water[c]									
Any water contact	31,685 (67.1)	136 (38.9)	1,977 (73.6)	3,784 (88.8)	4,848 (89.8)	3,170 (78.8)	6,688 (62.0)	11,082 (56.1)	<0.01
Body immersion	24,516 (51.9)	77 (22.0)	1,411 (52.5)	3,122 (73.3)	4,292 (79.5)	2,749 (68.4)	5,016 (46.5)	7,849 (39.8)	<0.01
Head immersion	19,184 (40.6)	50 (14.3)	903 (33.6)	2,507 (58.9)	3,852 (71.4)	2,389 (59.4)	3,832 (35.5)	5,651 (28.6)	<0.01
Water in mouth	14,558 (31.0)	46 (13.2)	920 (34.6)	2,123 (50.2)	3,061 (57.2)	1,799 (45.1)	2,806 (26.2)	3,803 (19.3)	<0.01
Swallow water	6,458 (13.7)	34 (9.7)	594 (22.1)	1,167 (27.4)	1,532 (28.4)	764 (19.0)	1,069 (9.9)	1,298 (6.6)	<0.01
Wear nose plugs	136 (0.4)	0 (0.0)	6 (0.3)	15 (0.4)	28 (0.6)	20 (0.6)	28 (0.4)	39 (0.3)	0.06[b]
Wear mask/goggles	2,401 (6.7)	4 (1.8)	33 (1.6)	406 (10.6)	699 (14.3)	333 (9.8)	307 (3.9)	619 (4.5)	<0.01

[a] Huntington, Silver, Washington Park, West

[b] Fisher's exact test

[c] Avalon, Doheny, Edgewater, Fairhope, Goddard, Malibu, Mission Bay, and Surfside

Table 3

Distribution of time spent in the water (in minutes) among swimmers, by age

	Males	Females	Freshwater	Marine
Under 1				
Mean	64.4	51.8	56.0	60.5
Median	45.0	30	37.5	45.0
Standard Deviation	67.4	55.3	69.1	61.2
Minimum-Maximum	1–300	2–300	5–300	1–300
Age 1–3				
Mean	76.6	73.0	66.7	79.1
Median	60.0	60.0	60.0	60.0
Standard Deviation	67.7	62.5	56.0	69.3
Minimum-Maximum	2–420	1–480	2–300	1–480
Age 4–7				
Mean	102.7	100.9	88.5	107.8
Median	90.0	90.0	60.0	90.0
Standard Deviation	75.5	76.1	62.8	80.3
Minimum-Maximum	1–600	1–600	2–300	1–600
Age 8–12				
Mean	114.2	112.1	92.9	121.4
Median	102.5	90.0	60.0	120.0
Standard Deviation	80.0	81.7	64.7	85.4
Minimum-Maximum	1–600	2–600	2–360	1–600
Age 13–18				
Mean	100.3	82.2	64.0	102.0
Median	75.0	60.0	45.0	90.0
Standard Deviation	80.6	72.9	58.1	81.4
Minimum-Maximum	1–600	1–600	1–360	1–600
Adults 19–34				
Mean	65.5	56.2	45.4	68.2
Median	45.0	30	30.0	45.0
Standard Deviation	63.1	58.2	47.4	65.2
Minimum-Maximum	1–480	1–600	1–360	1–600
Adults 35 and over				
Mean	67.4	55.3	47.0	66.9
Median	60	30	30.0	45.0
Standard Deviation	62.1	57.4	45.6	64.0
Minimum-Maximum	1–600	1–600	1–360	1–600
Kruskal Wallis p-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

Table 4

Estimate volume (mL) of water swallowed per swimming event, by gender and beach type

	All	Females	Males	Freshwater	Marine
All Ages					
Mean	44.4	32.0	57.3	35.4	48.3
Median	16.0	12.0	21.3	12.7	18.0
Standard Deviation	93.1	69.5	110.0	74.6	99.3
5th percentile	1.0	0.7	1.4	0.8	1.2
10th percentile	2.0	1.3	2.7	1.3	2.0
90th percentile	104.7	76.0	140.0	84.0	116.0
95th percentile	174.0	121.3	232.0	140.0	186.7
Children 6–12					
Mean	63.2	61.1	67.3	53.0	67.7
Median	36.0	34.3	40.0	30.0	39.3
Standard Deviation	83.4	86.1	79.4	69.9	88.5
5th percentile	2.8	2.7	3.4	2.4	3.0
10th percentile	5.5	5.3	7.0	5.0	6.0
90th percentile	150.0	146.1	161.0	126.2	160.0
95th percentile	213.0	205.3	225.0	184.0	220.0
Ages 13–18					
Mean	63.7	39.3	77.3	45.0	71.4
Median	27.0	17.3	34.7	18.0	32.0
Standard Deviation	83.4	60.3	122.4	79.9	115.5
5th percentile	1.6	1.2	2.3	1.02	2.0
10th percentile	3.1	2.1	4.0	2.0	4.0
90th percentile	156.0	97.0	200.0	112.0	174.7
95th percentile	254.0	150.0	304.0	174.7	280.0
Adults 19–34					
Mean	29.0	19.8	40.1	21.9	32.8
Median	9.7	7.1	13.8	7.1	11.1
Standard Deviation	69.4	52.4	84.9	54.4	76.3

	All	Females	Males	Freshwater	Marine
5th percentile	0.7	0.4	1.0	0.4	0.7
10th percentile	1.3	0.9	1.8	0.9	1.3
90th percentile	66.0	42.9	95.7	50.0	76.0
95th percentile	116.0	72.0	165.3	85.3	126.0
Adults 35 and over					
Mean	29.9	21.0	42.9	22.6	32.3
Median	9.0	6.6	12.7	6.7	9.8
Standard Deviation	82.6	60.3	109.8	62.1	88.1
5th percentile	0.7	0.4	1.0	0.4	0.7
10th percentile	1.1	0.8	1.8	0.9	1.3
90th percentile	64.0	44.3	90.0	47.6	70.5
95th percentile	118.0	80.0	178.7	88.0	121.3

Table 5

Sand and algae exposure by age category

	Overall *n (%)*	Under 1 *n (%)*	1–3 *n (%)*	4–7 *n (%)*	8–12 *n (%)*	13–18 *n (%)*	19–34 *n (%)*	35 and Up *n (%)*	χ^2 p-value
Freshwater[a]									
Sand Exposure									
Digging in sand	8,975 (43.9)	56 (33.0)	915 (86.3)	1,523 (87.8)	1,641 (77.2)	764 (41.4)	1,891 (34.6)	2,185 (27.2)	<0.01
Body buried in sand	2,172 (10.6)	11 (6.4)	239 (22.6)	527 (30.4)	581 (27.3)	204 (11.0)	331 (6.1)	279 (3.5)	<0.01
Algae/Seaweed Exposure									
Touched or had contact with algae/seaweed	370 (1.8)	0 (0.0)	27 (2.6)	63 (3.7)	110 (5.2)	34 (1.8)	55 (1.0)	81 (1.0)	<0.01
Marine water[b]									
Sand Exposure									
Digging in sand	17,057 (36.4)	93 (26.8)	1,917 (71.8)	3,238 (76.4)	3,196 (59.6)	1,293 (32.4)	3,014 (28.2)	4,306 (22.0)	<0.01
Body buried in sand	2,390 (7.1)	8 (3.8)	291 (11.8)	634 (16.4)	611 (13.9)	233 (8.5)	301 (3.9)	312 (2.5)	<0.01
Sand in mouth [c]	4,693 (12.8)	83 (24.7)	867 (18.5)	886 (18.9)	732 (15.6)	345 (7.4)	781 (16.6)	999 (21.3)	<0.01
Was sand wet? [c]	6,640 (49.3)	37 (39.8)	712 (47.0)	1,430 (55.4)	1,369 (55.9)	502 (50.1)	874 (38.8)	1,716 (48.2)	<0.01
Eat/drink after playing in sand [d]	3,049 (57.2)	21 (51.2)	324 (60.1)	499 (57.0)	491 (56.8)	251 (58.8)	555 (54.2)	908 (58.1)	0.28
Wash hands after playing in sand [c]	4,437 (39.9)	31 (43.1)	524 (40.6)	885 (40.5)	790 (38.2)	338 (41.2)	689 (38.8)	1,180 (40.6)	0.50
Algae/Seaweed Exposure									
Touched or had contact with algae/seaweed	4,930 (10.5)	13 (3.8)	396 (14.9)	860 (20.4)	953 (17.8)	454 (11.4)	838 (7.9)	1,416 (7.3)	<0.01
Seaweed/algae in mouth [e]	246 (1.3)	6 (3.7)	23 (2.3)	38 (2.1)	43 (2.0)	23 (1.4)	45 (1.0)	68 (0.8)	<0.01
Wash hands after touching algae/seaweed [f]	1,257 (32.0)	3 (30.0)	107 (33.9)	255 (36.0)	250 (33.8)	100 (27.0)	178 (27.7)	364 (32.0)	0.01

[a] Huntington, Silver, Washington Park, West

[b] Avalon, Doheny, Edgewater, Fairhope, Goddard, Malibu, Mission Bay, and Surfside

[c] Only collected on a subset of samples from Avalon, Doheny, Edgewater, Fairhope, Goddard, Malibu, and Surfside

[d] Only collected on a subset of samples from Fairhope, Goddard, and Surfside

[e] Only collected on a subset of samples from Avalon, Doheny, Malibu, and Surfside

[f] Only collected on a subset of samples from Avalon, Doheny, Fairhope, Goddard, Malibu, and Surfside