The Health Effects of Swimming at Sydney Beaches

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ABSTRACT

Objectives. The purpose of the study was to determine the health risks of swimming at ocean beaches in Sydney, Australia.

Methods. From people attending 12 Sydney beaches in the period from December 5, 1989 to February 26, 1990, we recruited a cohort of 8413 adults who agreed to participate in this study. Of these, 4424 were excluded either because they had been swimming in the previous 5 days or because they reported a current illness. Of the remainder, 2839 successfully completed a follow-up telephone interview conducted within 10 days after recruitment. We recorded reported respiratory, gastrointestinal, eye, and ear symptoms and fever that occurred within the 10 days between initial interview on the beach and the follow-up interview.

Results. A total of 683 participants (24.0%) reported experiencing symptoms in the 10 days following initial interview. Of these, 435 (63.7%) reported respiratory symptoms. Swimmers were almost twice as likely as nonswimmers to report symptoms. There was a linear relationship between water pollution and all reported symptoms with the exception of gastrointestinal complaints.

Conclusions. Swimmers at Sydney ocean beaches are more likely to report respiratory, ear, and eye symptoms than beachgoers who do not swim. The incidence of these symptoms increases slightly with increasing levels of pollution. (*Am J Public Health.* 1993;83:1701–1706)

Introduction

The disposal of human sewage through ocean outfalls adjacent to recreational bathing areas and, before that, into Sydney Harbour has been a contentious issue since the early years of the colony in New South Wales.[1] Apart from the aesthetic objections, there is a long-standing concern that bathing in polluted waters poses a risk to the health of the estimated 3 million people who use these beaches annually.[2]

Seventy percent of Sydney's sewage is discharged through three ocean outfalls at North Head, Bondi, and Malabar. Each outfall releases primary treated sewage into coastal waters, 150 to 650 ML per day in dry weather and 700 to 2400 ML per day in wet weather.[3] The sewage system is designed to overflow into the storm-water system at times of high rainfall to cope with this large increase in volume in wet weather. Fecal contamination of swimming beaches can occur when the sewage plume from these outfalls, under the influence of winds or currents, moves onto the beach and via discharge from storm-water drains, many of which discharge directly onto beaches.

Studies at ocean and freshwater sites in the United States,[4–6] Canada,[7,8] Egypt,[9] and Israel[10] have shown a variable relationship between gastrointestinal, respiratory, ear, and skin symptoms and indices of sewage pollution of bathing water. The results of these studies are not necessarily applicable to Sydney's beaches because of differences in dilutive factors, water temperature, ocean currents, and method of sewage treatment and their potential effects on the survival of pathogenic organisms[11] in bathing waters.

In the summer of 1989, the New South Wales Health Department released the results of a survey of bathing water quality that showed that one third of all samples tested at many popular Sydney beaches failed to meet existing water quality criteria.[12] A wave of media and community protest followed. Bodies such as the Australian Surf Lifesaving Association, whose members are the very icons of Australian beach culture, added their voices to the call for an urgent review of bathing water quality in Sydney. Physicians practicing in beachside suburbs reported an increase in the incidence of ear infections, gastroenteritis, and other viral illnesses that could be attributed to ocean bathing.[13] The desertion of beaches that followed these reports had major economic implications for local businesses and for Sydney's reputation as an international tourist destination. Against this background the Sydney Beach Users Study was commissioned, with a brief to investigate the relationship between ocean swimming at Sydney's beaches and illness. An advisory committee comprising representatives from the state government and consumer groups was formed to oversee the planning and execution of the

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TABLE 1—Geometric Mean Bacterial Counts of Beach Water Samples, by Organism and Time of Collection, Sydney Beach Users Study, 1989/90

	Colony-Forming Units per 100 mL			No. Samples Passed[a]	No. Samples Failed[a]	Total No. Samples[b]
	Median	Maximum	Mean			
Fecal coliforms						
Morning	26.2	20000.0	591.4	191	42	233
Afternoon	15.9	25570.9	389.1	203	25	228
Fecal streptococci						
Morning	16.4	1356.5	65.9	...[a]	...[a]	229
Afternoon	11.5	1263.3	42.7	...[a]	...[a]	223

[a]For coliforms, a sample failed if the geometric mean count exceeded 300 colony-forming units per 100 mL or if any one reading was greater than 2000 colony-forming units per 100 mL. There is currently no recreational-water quality standard for fecal streptococci in New South Wales.
[b]A total of 482 samples were tested; 21 tests for fecal coliforms and 30 tests for fecal streptococci did not yield usable results.

study. This paper reports the results of this epidemiological study.

Methods

Subjects

Subjects for this cohort study were selected from persons attending 12 designated Sydney beaches on a total of 41 sampling days including weekends, public holidays, and one randomly selected weekday between December 5, 1989, and February 26, 1990. We selected the 12 most popular beaches in the metropolitan area, as assessed by the Surf Lifesaving Association, to recruit subjects.

On each of the study days, beachgoers at 6 of the 12 beaches were approached to obtain consent to participate in the study. The 6 beaches selected on any day included 2 each from the northern, eastern, and southern areas. We used a quota sampling technique for selection of subjects at individual beaches, setting equal quotas for each beach on each sampling day. Each beach was divided into three sectors, defined by the position of the swimming area flags erected by the lifesavers (lifeguards). The allotted quota for the beach was divided equally among the three sectors. Trained interviewers recruited subjects, starting at the center of each sector and moving in a clockwise fashion until the quota for that sector had been reached. To minimize the inclusion in the study of family or social groups, we specified that potential subjects be at least 3 m apart.

To quality for inclusion, a respondent had to be 15 years old or older and had to agree to both an initial beach interview and a follow-up telephone interview. We excluded children younger than 15 years of age because of the problems involved in obtaining consent from minors for biomedical research. At the beach interview the interviewer introduced the respondent to the survey, collected basic demographic data, and asked whether the respondent had swum anywhere in the previous 5 days or had any condition that precluded swimming on the day of the interview.

Subjects were excluded from the study if they reported having been swimming in the 5 days prior to the beach interview or having an illness that prevented them from swimming on the interview day.

Interviewers telephoned study participants 7 to 10 days after the initial interview to elicit details of symptoms of illness in the previous week, attendance at a doctor's office, absence from work, and whether the subject had been swimming at any time between the initial and follow-up interviews. Respondents were asked whether they had experienced vomiting; diarrhea; cough, cold, fever, or symptoms suggestive of flu; or ear or eye infections since the day of the beach interview.

Field interviewing, clerical checking, data entry, and initial computer editing were performed by AGB McNair, a division of AGB Research Australia Pty Ltd under contract to the New South Wales Health Department.

Exposure Assessment

We defined swimming as immersion of the face and head in water. At follow-up the interviewer asked whether the subject had swum on the day of the beach interview and asked the subject to estimate the amount of time spent in the water.

Water samples were taken on the same days and at the same beaches on which interviews were conducted. Health department surveyors collected morning and afternoon samples on each day from sites approximately at the midpoint of each sector of the beach. As nearly as could practicably be achieved, interviewing of respondents at selected beaches was done in the period in which water samples were taken. A standard protocol for the collection of 250 mL of water at a depth of 30 to 45 cm was used. Samples were refrigerated at 4°C and transported for analysis at the Division of Analytical Laboratories of the New South Wales Health Department. Recommended standard methods were used to count fecal coliforms[14,15] and fecal streptococci.[16]

We defined fecal contamination of beachwater as low if there was compliance with the current New South Wales Department of Health standard—geometric mean coliform count not exceeding 300 colony-forming units per 100 mL and no single sample exceeding 2000 colony-forming units per 100 mL—and high if these levels were exceeded.

Statistical Methods

We used the Statistical Analysis System (SAS)[17] for tabulations and subsequent statistical modeling. Unconditional logistic regression, using both the CATMOD procedure in SAS (Version 6.03) and the MULTLR program, was used to model the main effects and covariates on the probability of reporting symptoms.[18] Point and interval estimates in the presence of interaction were performed according to the methods of Kleinbaum et al.[19]

We assessed the health effects of swimming in polluted water by fitting a series of logistic regression models to the data to adjust—for age, sex, and a history of subsequent swimming—estimates of odds of reporting specific symptoms in swimmers compared with nonswimmers. Two variables denoted exposure to polluted water in these models: swimming duration and a measure of bacterial count in the water. The bacterial count was derived from the geometric or arithmetic mean organism count or from the maximum organism count of all water samples collected on that beach on the day of the beach interview.

These logistic regression models were fitted separately for each outcome, that is, (1) any reported symptoms, (2) respiratory symptoms, (3) fever, (4) eye symptoms, (5) ear symptoms, and (6) gastrointestinal symptoms.

Results

Water Sampling

Of 482 individual water samples tested, 461 yielded usable results. Of these, 67 (14.5%) failed to meet the water quality criteria set by the New South Wales Department of Health. Summary results of water testing for both fecal contamination indices measured, coliforms and fecal streptococci, are presented in Table 1. There was a strong correlation between a "pass" on the morning test and a "pass" in the afternoon test. (A water sample was categorized as a "pass" if the geometric mean fecal coliform count was below 300 colony-forming units per 100 mL.) On days when the water failed the morning test, there was a 50% chance of its also failing the afternoon test.

Exposure and Reported Symptoms

Of the 9650 persons who were approached on the selected beaches, 8413 (87.2%) agreed to participate. Of these, we excluded 325 (3.9%) because they had illnesses that prevented them from swimming on that day and 4099 (48.7%) because they reported that they had been swimming in the previous 5 days. Of the remaining 3989 persons, we were able to contact 2968 (74.4%) by telephone for a follow-up interview. Young males were the most likely not to respond at the follow-up interview. The age and sex of those refusing to participate, those excluded because of prior swimming or illness, and those enrolled in the study were similar (Table 2).

TABLE 2—Persons Approached to Participate in the Sydney Beach Users Survey, by Age, Sex, Area of Residence, and Study Status

	Initial Nonresponse	Excluded: Swam Previously	Excluded: Illness	Total Enrolled	Total Contacted at Follow-up
Age					
15–19 y	164	933	61	930	649
20–49 y	871	2734	217	2803	2109
50+ y	130	381	44	240	200
Unknown	72	51	3	16	10
Total	1237	4099	325	3989	2968
Sex					
Male	591	2455	140	2041	1436
Female	580	1608	182	1944	1529
Unknown	66	36	3	4	3
Total	1237	4099	325	3989	2968
Place of residence					
Sydney	...	...	...	3554	2672
Other NSW	...	...	...	254	188
Other	...	...	...	94	52
Unknown	...	...	...	87	56
Total	...	...	...	3989	2968

We excluded 12 subjects from the analysis because of missing age and sex data and a further 117 subjects because of missing data on pollution levels on the day of beach interview. This left 2839 subjects available for analysis. Of this group, 915 (32.2%) reported that they had not swum on the day of the beach interview. Only 303 (10.7%) of the subjects swam on days on which high pollution levels were recorded.

TABLE 3—Percentages[a] of Beachgoers Reporting Symptoms, by Swimming Status and Pollution Level, Sydney Beach Users Study, 1989/90

	Swimming Status/Pollution Level, %: Did Not Swim (n = 915)	Swam, Low Pollution[b] (n = 1770)	Swam, High Pollution[c] (n = 154)	Total Sample (n = 2839)
Vomiting	0.9	1.0	0.6	0.9
Diarrhea	2.2	3.7	3.2	3.2
Cough, cold, flu	10.2	17.3	23.4	15.3
Ear infection	1.3	3.9	5.8	3.2
Eye infection	1.0	2.4	3.9	2.0
Fever	1.1	1.8	5.2	1.7
Other conditions	4.7	8.0	13.0	7.2
Any condition reported	16.5	26.9	35.7	24.0
Attended a doctor (any condition)	3.5	4.3	8.4	4.3
Took time off work (any condition)	2.6	4.6	6.5	4.0

Note. Symptoms were self-reported; respondents could report multiple symptoms.
[a]Percentages are based on column totals.
[b]Geometric mean fecal coliform count of less than 300 colony-forming units per 100 mL recorded on the day of initial interview.
[c]Geometric mean fecal coliform count of more than 300 colony-forming units per 100 mL recorded on the day of initial interview.

A total of 683 subjects (24.0%) reported experiencing symptoms in the previous week; of these, 435 (63.7%) reported respiratory symptoms. The prevalence of reported fever and respiratory, eye, ear, and other symptoms increased with increasing bacterial counts measured on the day of initial interview. Gastrointestinal symptoms, which were reported by 4.1% of the subjects, did not increase with increasing counts of fecal bacteria (Table 3).

The prevalence of respiratory symptoms in young people aged 15 through 25 years was high, irrespective of swimming status or pollution level. Only in older people did the incidence of respiratory symptoms rise with increasing levels of pollution. The prevalence of other reported symptoms did not vary significantly across age groups (Table 4).

Swimmers were almost twice as likely as nonswimmers to report symptoms (odds ratio [OR] = 1.9; 95% confidence interval [CI] = 1.4, 2.4), after adjustments were made for age and sex. Symptoms were reported less frequently by people who swam between the original and follow-up interviews (Table 5). There was no evidence that swimmers were deterred from entering the water because it was or appeared to be contaminated.

We assessed the effect of increasing pollution levels by comparing the estimated odds ratios at different levels of pollution for swimmers vs nonswimmers. As the counts of fecal bacteria measured on the day of original interview rose, swimmers were more likely to report all symptoms except gastrointestinal symptoms

TABLE 4—Numbers and Percentages of Persons Who Reported Symptoms, by Age, Swimming Status, and Pollution Level, Sydney Beach Users Study, 1989/90

	Swimming Status/Pollution Level															
	Did Not Swim (n = 915)				Swam, Low Pollution[a] (n = 1770)				Swam, High Pollution[b] (n = 154)				Total Sample (n = 2839)			
	15–24 y	25–39 y	40+ y	All Ages	15–24 y	25–39 y	40+ y	All Ages	15–24 y	25–39 y	40+ y	All Ages	15–24 y	25–39 y	40+ y	All Ages
Gastrointestinal symptoms	11 (3.4)	6 (1.6)	7 (3.1)	24 (2.6)	35 (4.5)	30 (4.7)	13 (3.7)	78 (4.4)	1 (1.4)	3 (5.9)	1 (3.2)	5 (3.2)	47 (4.0)	39 (3.6)	20 (3.3)	107 (3.8)
Cough, cold, flu	56 (17.2)	23 (6.3)	14 (6.2)	93 (10.1)	161 (20.9)	113 (17.6)	32 (9.0)	306 (17.3)	17 (23.3)	12 (23.5)	7 (22.6)	36 (23.2)	234 (20.0)	148 (13.6)	53 (8.7)	435 (15.3)
Ear infection	5 (1.5)	3 (0.8)	4 (1.8)	12 (1.3)	38 (4.9)	18 (2.7)	13 (3.7)	69 (3.9)	5 (6.9)	2 (3.9)	2 (6.5)	9 (5.8)	48 (4.1)	23 (2.1)	19 (3.1)	57 (2.0)
Eye infection	5 (1.5)	4 (1.1)	0 ...	9 (1.0)	15 (1.9)	22 (3.3)	5 (1.4)	42 (2.4)	1 (1.4)	5 (9.8)	0 ...	6 (3.9)	31 (2.6)	31 (2.8)	5 (0.8)	90 (3.2)
Fever	5 (1.5)	1 (0.3)	4 (1.8)	10 (1.1)	15 (1.9)	12 (1.8)	4 (1.1)	31 (1.8)	3 (4.1)	3 (5.8)	2 (6.7)	8 (5.2)	16 (1.4)	16 (1.5)	10 (1.7)	49 (1.7)

Note. Numbers in parentheses are percentages of total n's in the relevant age group and swimming/pollution category (n's for age groups not shown).
[a]Geometric mean fecal coliform count of less than 300 colony-forming units per 100 mL recorded on the day of initial interview.
[b]Geometric mean fecal coliform count of more than 300 colony-forming units per 100 mL recorded on the day of initial interview.

TABLE 5—Odds Ratios (ORs)[a] of Swimmers' Reporting Health Problems, Sydney Beach Users Study, 1989/90

	Swam Once Only		Swam More Than Once		All Swimmers	
	OR	95% CI	OR	95% CI	OR	95% CI
Any symptom	2.6	1.8, 3.8	1.6	1.2, 2.2	1.9	1.4, 2.4
Cough	2.4	1.6, 3.8	1.6	1.1, 2.3	1.9	1.4, 2.6
Ear symptoms	6.1	1.7, 21.8	2.8	1.3, 6.2	3.6	1.8, 7.2
Eye symptoms	4.4	0.9, 21.3	1.1	0.4, 2.9	1.7	0.7, 4.3
Fever	1.8	0.5, 6.0	1.1	0.4, 3.2	1.4	0.5, 3.7
Any gastrointestinal symptom	1.8	0.7, 4.6	1.3	0.7, 2.6	1.5	0.8, 2.7

Note. CI = confidence interval.
[a]Adjusted for age, sex, swimming duration, and geometric mean fecal coliform count; the reference category is nonswimmers.

TABLE 6—Odds Ratios (ORs)[a] of Swimmers' Reporting Health Problems, by Specific Symptom and Pollution Level, Sydney Beach Users Study, 1989/90

	Pollution Level							
	10–300 cfu/100 mL		300–1000 cfu/100 mL		1000–3000 cfu/100 mL		>3000 cfu/100 mL	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Any symptom	2.9	1.7, 5.1	3.8	2.1, 7.1	5.2	1.7, 16.0	5.9	3.0, 11.5
Cough	2.4	1.5, 3.8	2.0	0.9, 4.4	4.2	1.2, 14.6	6.9	3.3, 14.1
Ear symptoms	4.3	1.1, 16.2	8.6	1.7, 43.2	8.5	0.8, 97.6	7.4	1.3, 43.3
Eye symptoms	6.3	1.3, 30.8	9.7	1.5, 63.7	8.7	1.0, 72.8		...[b]
Fever	2.1	0.6, 7.0	4.7	1.0, 22.5	9.0	1.9, 43.5		...[b]
Any gastrointestinal symptom	4.6	1.9, 4.9	3.1	0.7, 13.0	3.4	0.7, 18.0		...[b]

Note. Results are for swimmers who swam only on the day of the original interview and who swam for longer than 30 minutes. CI = confidence interval; cfu = colony-forming units of fecal coliforms.
[a]Adjusted for age, sex, and swimming duration; the reference category is nonswimmers.
[b]Highest category > 1000 cfu/100 mL.

(Table 6). We plotted the estimated odds ratios of swimmers' reporting symptoms (within the group of swimmers only, using the lowest pollution level as the reference group) against pollution level (Figure 1). The linear relationship between pollution level and the odds of reporting symptoms can be expressed mathematically by the formula $OR = 1 + 0.0000921 \ln$ (Geometric Mean Coliform Count).

Substituting the arithmetic mean for the geometric mean coliform count in the logistic model slightly improved the fit of this model to the data ($\chi^2 = 2.18$, $P < .25$). Counts of fecal streptococci were worse predictors of the odds of reporting symptoms than were counts of fecal coliforms.

We assessed the effect of swimming duration on health by comparing information on those who swam for less than 30 minutes and those who swam for more than 30 minutes, but only in those subjects who did not swim between interviews. Those who swam for longer than 30 minutes were 4.6 times more likely to develop gastrointestinal symptoms than were nonswimmers or those who swam for less than 30 minutes (Table 7).

Discussion

The cohort design used in this study is an adaptation of that used in similar studies in other countries.[6–9] The design has the explicit aim of isolating exposure to a particular day so that the measurements of beach pollution on that day can be used as a proxy measure of the dose of potentially pathogenic microorganisms. We attempted to improve on this design by increasing the frequency of pollution measurement on study days and by including data on swimming duration in the follow-up questionnaire. The exclusion of children, done primarily for ethical reasons, reduces reporter bias but limits the applicability of our results to people younger than 15 years.

There are at least two explanations for the lower prevalence of reported symptoms in those who swam between interviews. In some people, illness may have prevented swimming between the day of the original interview and the follow-up call. Conversely, those people who did swim subsequently may have included regular swimmers who have some immunity to pathogenic microorganisms in ocean water.

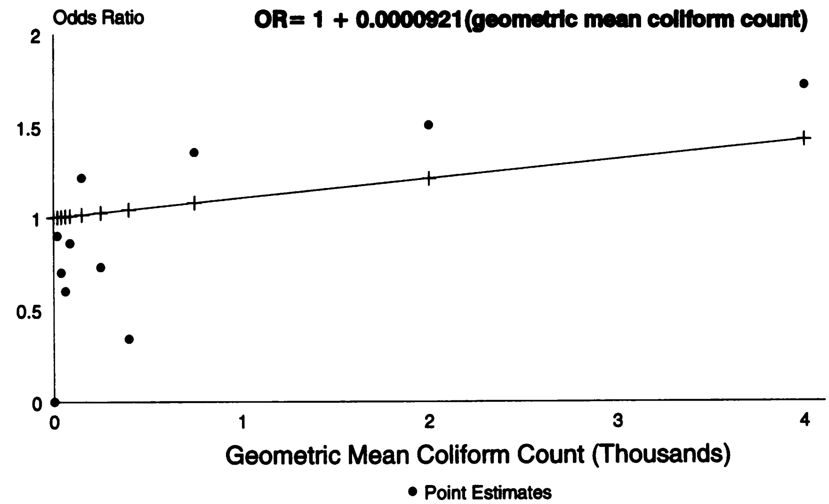
Our results provide evidence that the risk of swimming-related illness increases with increasing pollution levels. The estimates of the magnitude of the slope of the relationship between pollution levels and all symptoms are similar to those obtained elsewhere.[8] The assumption of a linear relationship between illness and pollution levels may have overestimated the risk of illness at lower pollution levels. If a minimum infective dose of microorganisms acquired while swimming is required to cause illness then we should see a threshold pollution level below which illness did not occur. Our data suggest that such a threshold may in fact be present (see Figure 1).

The increases in risk of respiratory, ear, and eye symptoms account wholly for the increases in illness observed. Enteroviruses, the commonest viruses present in sewage effluent, can cause respiratory symptoms.[20] They also persist in marine sediments and water for many months.[21] In a pilot study of viruses and pathogenic bacteria in waters at two Sydney beaches,[22] 2 of 10 samples taken from bathing areas contained enteroviruses; both vaccine-strain polioviruses. However, enteroviruses were isolated in 63% of samples collected from sewage effluent or the sewage plume. All counts of fecal indicator organisms in bathing areas in this study were below the current New South Wales standard, and it may therefore have underestimated the numbers of viruses present in polluted conditions.

Over the 41 days of data collection the beaches were cleaner than usual, thereby limiting the precision of our estimates of the odds of pollution-related symptoms at high levels of pollution. Of the water samples tested in our study, 14% exceeded the current New South Wales standard. Daily surveillance of ocean water quality at seven Sydney beaches between 1983 and 1987[3] showed that five of these beaches exceeded the current standard on more than 30% of occasions in dry weather. In wet weather, six beaches failed more than 50% of the tests.

Our data do not support the contention that minor barotrauma associated with surf swimming is the cause of an increase in reported respiratory symptoms in bathers. If this were true, we would expect an increase in reported respiratory symptoms with increasing swimming duration. We found no such increase.

Reported gastrointestinal symptoms showed no increase with increasing pollution levels. The prevalence of gastrointestinal symptoms (4.1%) was similar to that reported in other studies.[6–9] A dose–response relationship between indices of bacterial pollution and gastrointestinal symptoms has been an inconsistent finding and has been most clearly demonstrated in children, who were excluded from our study. Some of these studies did not fully adjust for confounders such as age and reporter and interviewer bias, and they may have overestimated the magnitude of the dose–response effect.[23] In the study design we used self-reporting of symptoms and exclusion of children to minimize reporter bias. We did not use



Note. ORs are adjusted for age, sex, and swimming duration; swimmers in water with 10 colony-forming units of fecal coliforms per 100 mL were the reference category.

FIGURE 1—Odds ratio (OR) of swimmers' reporting health problems, by geometric mean coliform count, Sydney Beach Users Study, 1989/90.

TABLE 7—Odds Ratios (ORs)[a] of Swimmers' Reporting Health Problems, by Specific Symptom and Swimming Duration, Sydney Beach Users Study, 1989/90

	Swimming Duration			
	< 30 min		> 30 min	
	OR	95% CI	OR	95% CI
Any symptom	1.9	1.3, 2.8	2.9	1.7, 5.1
Cough	1.8	1.1, 2.8	2.4	1.5, 3.8
Ear symptoms	3.7	1.0, 13.5	4.3	1.1, 16.4
Eye symptoms	6.9	1.5, 31.4	6.3	1.3, 30.8
Fever	2.5	0.8, 7.4	2.1	0.6, 7.0
Any gastrointestinal symptom	1.0	0.4, 3.0	4.6	1.9, 10.9

Note. Results are for swimmers who swam only on the day of the original interview and who were exposed to pollution levels of 10–300 colony-forming units of fecal coliforms per mL.
[a]Adjusted for age and sex; the reference category is nonswimmers.

any clinical confirmation of reported symptoms. Measurement error of this kind would be nondifferential and would therefore bias our estimate toward not showing an effect. There was some evidence of an increase in risk of reporting gastrointestinal illness with increased swimming duration. Swimming duration may be a proxy measure of the volume of ingested seawater, which may directly cause symptoms.

The results of this study suggest that, at Sydney's beaches, fecal coliforms are marginally better predictors of reported symptoms than fecal streptococci. These results are at odds with other studies in which fecal coliforms have been poorer predictors of adverse health outcomes than either streptococci or staphylococci. This discrepancy may be explained by the different relative survival of these microorganisms in effluent that is not chlorinated and in oceans that are warmer than those around North America.

A technical issue prominent in the public debate on ocean water quality was the choice of an appropriate summary measure of water quality. Bacterial counts in water samples are inherently variable and concurrent samples from the same site can differ by orders of magnitude. The geometric mean of serial measurements is traditionally used as a summary index of pollution. Criticism of the use of a geometric mean of bacterial counts has focused on the apparent "leveling" of the data,[1] thereby understanding the true level of pollution. Furthermore, use of the geometric mean count rather than, say, the arithmetic mean or the daily maximum may introduce bias.[24]

To address these concerns we substituted the arithmetic mean and the daily maximum for the geometric mean coliform in the logistic models. There was a small improvement in the fit of the data when the arithmetic mean was used, and this summary measure is therefore preferable. It also has the advantage of being more easily comprehended by the public.

In conclusion, we found a consistent increase in reported illness with increasing pollution levels of all symptom categories except gastrointestinal symptoms. This dose–response relationship provides a quantitative basis for developing a health-based standard for ocean water quality on Sydney's beaches. □

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