ORIGINAL ARTICLE

An Outbreak of Covid-19 on an Aircraft Carrier

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ABSTRACT

BACKGROUND

An outbreak of coronavirus disease 2019 (Covid-19) occurred on the U.S.S. *Theodore Roosevelt*, a nuclear-powered aircraft carrier with a crew of 4779 personnel.

METHODS

We obtained clinical and demographic data for all crew members, including results of testing by real-time reverse-transcriptase polymerase chain reaction (rRT-PCR). All crew members were followed up for a minimum of 10 weeks, regardless of test results or the absence of symptoms.

RESULTS

The crew was predominantly young (mean age, 27 years) and was in general good health, meeting U.S. Navy standards for sea duty. Over the course of the outbreak, 1271 crew members (26.6% of the crew) tested positive for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection by rRT-PCR testing, and more than 1000 infections were identified within 5 weeks after the first laboratory-confirmed infection. An additional 60 crew members had suspected Covid-19 (i.e., illness that met Council of State and Territorial Epidemiologists clinical criteria for Covid-19 without a positive test result). Among the crew members with laboratory-confirmed infection, 76.9% (978 of 1271) had no symptoms at the time that they tested positive and 55.0% had symptoms develop at any time during the clinical course. Among the 1331 crew members with suspected or confirmed Covid-19, 23 (1.7%) were hospitalized, 4 (0.3%) received intensive care, and 1 died. Crew members who worked in confined spaces appeared more likely to become infected.

CONCLUSIONS

SARS-CoV-2 spread quickly among the crew of the U.S.S. *Theodore Roosevelt*. Transmission was facilitated by close-quarters conditions and by asymptomatic and presymptomatic infected crew members. Nearly half of those who tested positive for the virus never had symptoms.

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This article was published on November 11, 2020, and updated on January 28, 2021, at NEJM.org.

N Engl J Med 2020;383:2417-26.
DOI: 10.1056/NEJMoa2019375
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THE U.S.S. *THEODORE ROOSEVELT* WAS conducting operations in the western Pacific Ocean when an outbreak of infection with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) occurred on board. On identification of the outbreak, the ship was diverted to U.S. Naval Base Guam. The base hospital, a 42-bed inpatient facility, provides medical care for U.S. military beneficiaries and others in the region. Although the initial response was handled by the medical staffs of the ship and Naval Hospital Guam, it was quickly augmented by a joint medical task force.

This report provides key findings from the U.S. Navy response and epidemiologic investigation of the outbreak. Over the course of the response, every member of the crew of the U.S.S. *Theodore Roosevelt* was evaluated, tested, placed in isolation or quarantine, and monitored on a daily basis to ensure their well-being. Our findings offer insights into the epidemiology and outcomes of SARS-CoV-2 infection in healthy, fit, military-aged adults who are housed in close quarters.

METHODS

INITIAL RESPONSE TO THE OUTBREAK AND FOLLOW-UP

The ship had been at sea for 13 days when three crew members presented to the medical department with symptoms suggestive of coronavirus disease 2019 (Covid-19). All three underwent testing by real-time reverse-transcriptase polymerase chain reaction (rRT-PCR) and were found to be positive for SARS-CoV-2. Over the next 24 hours, additional symptomatic crew members and approximately 400 close contacts were identified by contact tracing. Four days after the first positive test result was reported, the ship reached Naval Base Guam. Crew members with confirmed cases of Covid-19 were placed in isolation on Naval Base Guam or in the base hospital. Persons with one or more negative Covid-19 tests and no symptoms were quarantined in hotels off base or on Naval Base Guam. In addition, essential personnel who were uninfected stayed aboard the ship in port.

All members of the crew underwent screening for signs and symptoms of Covid-19 and testing by rRT-PCR. Those who tested positive for SARS-CoV-2 were placed in isolation and received twice-daily symptom, temperature, and pulse oximetry checks. Those who tested negative were placed in quarantine. Ultimately, 4079 SARS-CoV-2–negative crew members who did not have symptoms were quarantined in 11 hotels in Guam. All were placed in single-occupancy rooms.

A surveillance model was implemented that relied on in-person health screenings. These screenings were supplemented by self-reporting with the use of a symptom checker developed by Defense Digital Service. Health screenings and symptom-checker data were collated and analyzed each morning by 9 a.m. and again in the evening by 9 p.m. Crew members who had progressive symptoms or were deemed to have conditions potentially placing them at higher risk for poorer outcomes were followed up with additional screening. Any crew members who were determined by on-site medical providers to need closer observation or treatment were transported to Naval Hospital Guam for care. In addition to Covid-19–related health surveillance, crew members received primary care, pharmacy, and psychiatric services to ensure a complete scope of medical coverage.

On completion of prespecified periods of isolation or quarantine, all personnel were required to undergo repeat rRT-PCR testing. To be eligible for exit testing, a crew member had to remain in isolation or quarantine for a minimum of 14 days. Those in isolation were also required to be symptom-free for 3 days before exit testing. Any crew member in quarantine in whom symptoms developed was tested and moved to isolation for at least 14 additional days. All crew members were followed up for a minimum of 10 weeks, regardless of their Covid-19 status.

LABORATORY TESTING

Nasopharyngeal swab specimens were obtained from all members of the crew with the use of viral transport medium swab kits. The presence of SARS-CoV-2 infection was determined by rRT-PCR testing with the Thermo Fisher ABI 7500 or the Bio-Rad CFX96 Touch Real-Time PCR Detection System. Samples were processed with either the Qiagen QIAamp Viral RNA Mini Kit or the Roche MagNA Pure 96 instrument for automated nucleic acid extraction, and testing was performed with the Seegene Allplex 2019-nCOV assay test kit or the Centers for Disease Control

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and Prevention (CDC) emergency-use-authorization assay.[1] These assays included the detection of two targets in the nucleocapsid gene, N1 and N2. Surveillance testing for influenza-like illness was conducted with the Biofire Respiratory 2 Panel.

COLLECTION OF OUTBREAK DATA

The Navy and Marine Corps Public Health Center was tasked with providing public health support for the outbreak investigation and conducting data analysis in alignment with its core public health mission. Data were collected as part of a coordinated public health outbreak investigation conducted by the Navy to bring the outbreak under control, ensure the well-being of the crew, assess the spread and effects of SARS-CoV-2, and implement measures to return the crew to work safely. Under Navy public health support criteria, the intent of the outbreak investigation was to mitigate spread, inform decision making, gather information for use in other outbreaks, and decrease the effect on the health of the crew. This project was deemed to be nonresearch with respect to the use of human subject information and was exempt from review by the institutional review board as an emergency public health outbreak investigation.

A roster of Electronic Data Interchange Personal Identifiers for the shipboard population was matched to Defense Manpower Data Center personnel rosters from February 2020 to identify demographic information for each crew member and to confirm personal identifiers. Civilian personnel and anyone with an Electronic Data Interchange Personal Identifier that did not match with Defense Manpower Data Center were excluded from analysis. The Defense Enrollment Eligibility Reporting System was used to identify race and ethnic group for all crew members. Ages of crew members at time of the outbreak were calculated from the date of birth to March 3, 2020.

Medical surveillance data collected by the ship medical department, Naval Hospital Guam, and the joint medical task force were collated with the roster to create a data set that included dates of symptom onset, daily clinical signs and symptoms, and test results. Data from the Defense Digital Service MySymptoms symptom-tracker application were also collated into the final data set. For the purpose of this analysis, fever is defined as subjective fever reported by the crew member or a measured temperature of 100.0°F or higher. All other symptoms were reported by the crew members. Data on health-related factors were obtained from a number of existing clinical Military Health System data sources, including the Armed Forces Health Longitudinal Technology Application and Military Health System Genesis.

A confirmed case of Covid-19 was defined as one in which a nasopharyngeal swab specimen was positive for SARS-CoV-2 by rRT-PCR. A suspected case of Covid-19 was defined as one that met Council of State and Territorial Epidemiologists clinical criteria for Covid-19 without a positive test result. Confirmed cases were further classified as symptomatic (with symptom onset before the first positive laboratory test), presymptomatic (with the first positive laboratory test before subsequent symptom onset), and asymptomatic (positive laboratory test but clinical criteria never met). Patients with confirmed or suspected infection were classified as having been hospitalized for Covid-19 if the admission diagnosis suggested a Covid-19–related illness.

STATISTICAL ANALYSIS

Data collation and analysis were performed with the use of SAS software, version 9.4 (SAS Institute). Baseline characteristics among crew members who were infected and those who were not infected were compared and univariate odds ratios with 95% confidence intervals were calculated with OpenEpi (www.openepi.com). For denominators of less than 20, odds ratios were not calculated. All reported odds ratios are not adjusted for multiple comparisons.

RESULTS

TIMELINE OF THE OUTBREAK

Between March 23 and May 18, 2020, a total of 1271 crew members (26.6% of the crew) tested positive for SARS-CoV-2. An additional 60 crew members had suspected Covid-19 (Fig. 1). Of the 1331 crew members with confirmed or suspected Covid-19, 572 (43.0%) remained asymptomatic throughout the outbreak, 293 (22.0%) were symptomatic at the time that they tested positive, and an additional 406 (30.5%) were presymptomatic at the time that they tested positive. In all, 978 (76.9%) of the 1271 crew members with labora-

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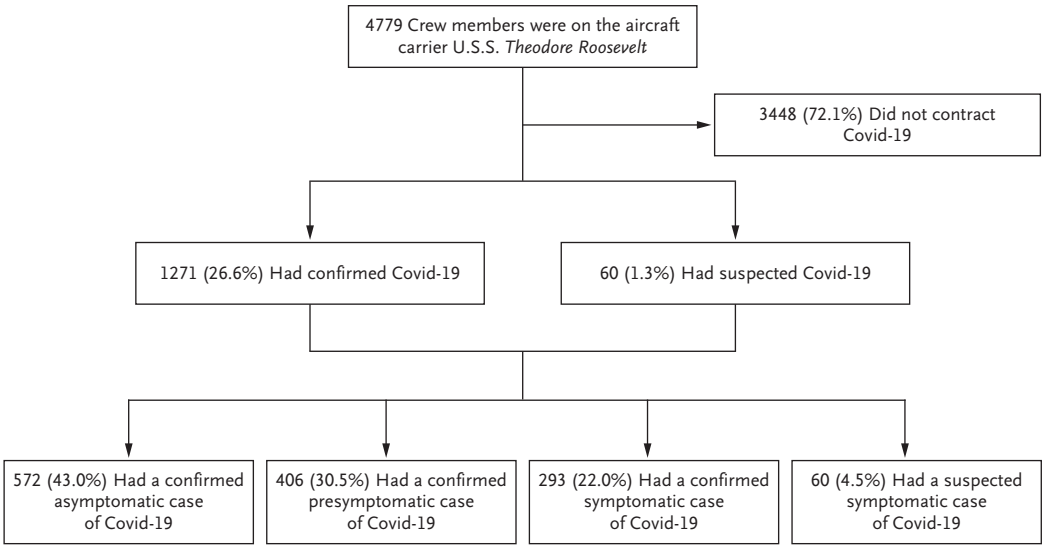

Figure 1. Distribution of Personnel According to Case Status.

A confirmed case of coronavirus disease 2019 (Covid-19) was defined as one in which a nasopharyngeal swab specimen was positive for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) by real-time reverse-transcriptase polymerase chain reaction. A suspected case was defined as one that met Council of State and Territorial Epidemiologists clinical criteria for Covid-19 without a positive test result. Confirmed cases were further classified as symptomatic (with symptom onset before the first positive laboratory test), presymptomatic (with the first positive laboratory test before subsequent symptom onset), and asymptomatic (positive laboratory test but clinical criteria never met).

tory-confirmed Covid-19 did not have symptoms at the time that they tested positive, and 699 (55.0%) had symptoms develop at any time during the clinical course.

Testing for influenza-like illnesses had been conducted on a limited number of specimens before and after the start of the outbreak. Testing of specimens obtained from 5 crew members during the week before the outbreak identified 3 crew members who were positive for human rhinovirus or enterovirus, 1 who was positive for respiratory syncytial virus (RSV), and 1 with no pathogens detected. After the outbreak was identified on March 23, specimens from 16 crew members were tested: 10 crew members had no pathogens detected, 3 were positive for human rhinovirus or enterovirus, 2 were positive for coronavirus OC43 (not SARS-CoV-2), and 1 was positive for both human rhinovirus or enterovirus and RSV.

The outbreak epidemic curve is shown in Figure 2. In retrospect, crew members with symptomatic confirmed or suspected Covid-19 had symptoms as early as March 11, 2020, and continued to receive diagnoses up to the end of the analysis period. Epidemic curves according to sex and crew type show parallel infection rates for men and women. Although the ship docked in Guam on March 27, 2020, the outbreak continued for at least an additional 6 weeks.

CHARACTERISTICS OF THE CREW MEMBERS

The crew was predominantly young (mean age, 27 years) and male (78.3%) and was racially and ethnically diverse. At the time of deployment, all crew members were in general good health and met the U.S. Navy standards for sea duty. Ultimately, Covid-19 cases were evenly distributed across sexes, races and ethnic groups, and crew types (Table 1). Enlisted personnel (90% of the shipboard population) appeared more likely than officers to have confirmed or suspected Covid-19.

Data were analyzed to identify higher-risk work spaces. Those working in tighter spaces (e.g., reactor, engineering, supply, and weapons

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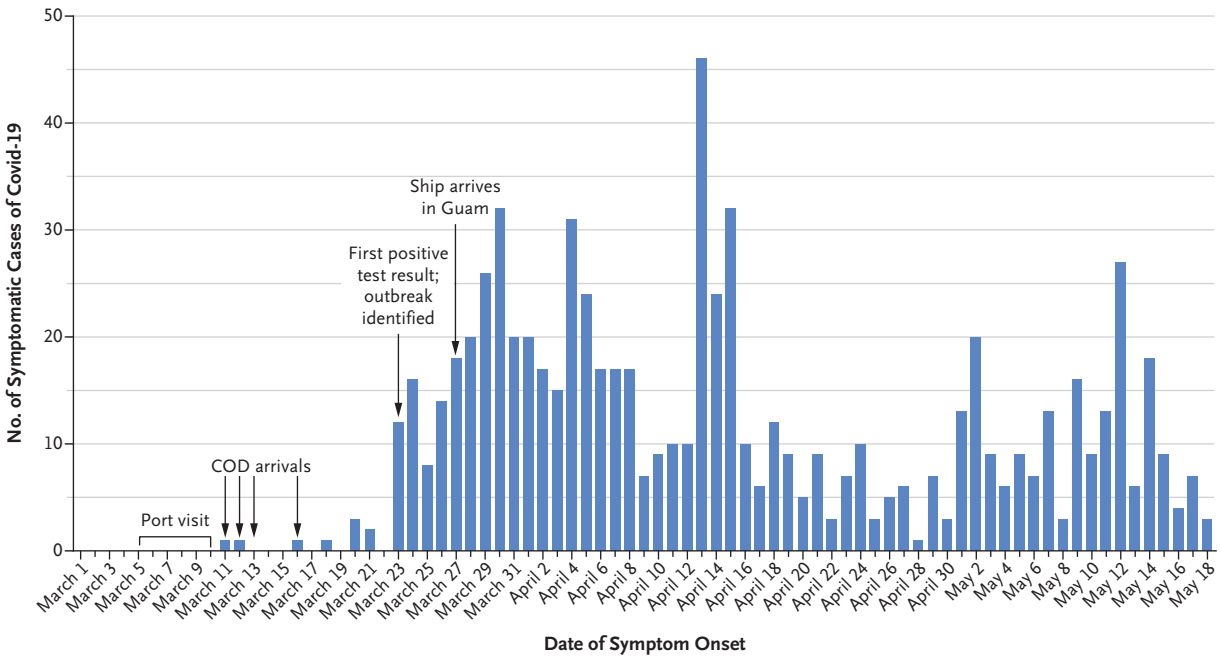

Figure 2. Numbers of Symptomatic Confirmed or Suspected Covid-19 Cases over Time.
Personnel, supplies, and mail are delivered to an aircraft carrier during carrier onboard delivery (COD).

departments) appeared more likely to have confirmed or suspected Covid-19 than those working in a combination of open-air and confined conditions (e.g., air and deck crew). Members of the medical department, who wore personal protective equipment when evaluating crew members, had a somewhat lower attack rate (16.7% [8 cases among 48 personnel) than the overall crew, despite being at highest risk as a result of exposure to patients with Covid-19 in a small space.

SYMPTOMS AND CARE

Among the crew members who had symptomatic Covid-19 (confirmed or suspected), headache was the most common symptom reported at any point during illness (occurring in 68.0%), followed by cough (59.5%), nasal or sinus congestion (43.8%), and altered sense of taste or smell (42.3%) (Fig. 3). The predominant symptoms reported at the onset of illness were cough (32.8%), headache (31.0%), and altered sense of taste or smell (24.1%). Shortness of breath at any point during illness was reported by 20.3% of the crew members with symptomatic cases, and 7.0% noted shortness of breath as an initial presenting symptom. In addition, 26.2% of the crew members with symptomatic Covid-19 reported chest pain or chest pressure at some point during their illness. Fever was reported as an initial presenting symptom by 5.3% of the crew members with symptomatic Covid-19, and fever at any point during illness was reported by 13.2%. Measured temperature readings showed that 2.8% of the crew members who had Covid-19 had a recorded temperature of 100.0°F or above, as compared with 0.3% of the crew members who did not have Covid-19. Among the crew members with Covid-19 for whom pulse oximetry data were available, approximately 0.5% had readings below 95% while breathing ambient air, with 0.08% below 94% and none below 90%.

Of the 1271 crew members who tested positive for SARS-CoV-2 plus the 60 who had suspected Covid-19, 23 (1.7%) received hospital care, for a mean of 16 days after symptom onset. Four crew members (0.3% of those with suspected or laboratory-confirmed Covid-19) were admitted to the intensive care unit, 1 of whom died from Covid-19–related cardiovascular complications. Before hospitalization, crew mem-

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Table 1. Demographic and Health Characteristics of Crew Members According to Covid-19 Status.*

Characteristic	Covid-19 Status			Univariate Odds Ratio, Covid-19 vs. No Covid-19 (95% CI)
	No Covid-19 (N=3448)	Confirmed or Suspected Covid-19 (N=1331)	Hospitalization for Covid-19 (N=23)	
Demographic characteristics				
Age — yr				
Mean	27.2	27.1	29.3	—
Range	18–59	18–53	20–46	—
Interquartile range	22–32	22–31	23–34	—
Sex — no. (%)				
Female	757 (22.0)	289 (21.7)	6 (26.1)	0.99 (0.85–1.15)
Male	2691 (78.0)	1042 (78.3)	17 (73.9)	Reference
Rank status				
Enlisted	3080 (89.3)	1231 (92.5)	23 (100.0)	1.48 (1.17–1.87)
Officer	363 (10.5)	98 (7.4)	0	Reference
Unknown	5 (0.1)	2 (0.2)	0	—
Race or ethnic group — no. (%)†				
American Indian	75 (2.2)	34 (2.6)	1 (4.3)	1.21 (0.80–1.83)
Asian or Pacific Islander	327 (9.5)	106 (8.0)	4 (17.4)	0.86 (0.68–1.10)
Black	590 (17.1)	261 (19.6)	3 (13.0)	1.18 (0.99–1.40)
Hispanic	692 (20.1)	273 (20.5)	5 (21.7)	1.05 (0.89–1.25)
White	1513 (43.9)	568 (42.7)	7 (30.4)	Reference
Other	250 (7.3)	88 (6.6)	3 (13.0)	0.94 (0.72–1.22)
Crew type‡				
Ship's crew	2086 (60.5)	786 (59.1)	13 (56.5)	Reference
Augmented crew	1288 (37.4)	501 (37.6)	9 (39.1)	1.03 (0.90–1.18)
Unknown	74 (2.1)	44 (3.3)	1 (4.3)	1.58 (1.08–2.31)
Select work centers and departments§				
Air	394 (11.4)	65 (4.9)	—	Reference
Combat support division	164 (4.8)	38 (2.9)	—	0.88 (0.58–1.33)
Deck	82 (2.4)	4 (0.3)	—	0.18 (0.07–0.52)
Engineering	137 (4.0)	67 (5.0)	—	1.85 (1.29–2.67)
Medical	40 (1.2)	8 (0.6)	—	0.76 (0.34–1.67)
Reactor	302 (8.8)	138 (10.4)	—	1.73 (1.29–2.36)
Supply	219 (6.4)	139 (10.4)	—	2.41 (1.78–3.26)
Weapons	132 (3.8)	94 (7.1)	—	2.70 (1.92–3.80)
Health characteristics				
Tobacco or nicotine user	1002 (29.1)	382 (28.7)	8 (34.8)	0.98 (0.85–1.13)
Most recent BMI¶				
Underweight or normal	1135 (32.9)	389 (29.2)	9 (39.1)	Reference
Overweight	1450 (42.1)	570 (42.8)	6 (26.1)	1.15 (0.99–1.33)
Obese	584 (16.9)	267 (20.1)	8 (34.8)	1.33 (1.11–1.61)
Unknown	279 (8.1)	105 (7.9)	0	1.10 (0.85–1.41)

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Table 1. (Continued.)

Characteristic	Covid-19 Status			Univariate Odds Ratio, Covid-19 vs. No Covid-19 (95% CI)
	No Covid-19 (N=3448)	Confirmed or Suspected Covid-19 (N=1331)	Hospitalization for Covid-19 (N=23)	
Preidentified health factors of interest‖				
Asthma	236 (6.8)	95 (7.1)	5 (21.7)	1.05 (0.82–1.34)
Cancer	35 (1.0)	10 (0.8)	0	0.74 (0.36–1.50)
Cerebrovascular diseases	2 (0.1)	0	0	—
Chronic lung disease	30 (0.9)	11 (0.8)	2 (8.7)	0.95 (0.47–1.90)
Diabetes	12 (0.3)	4 (0.3)	0	0.86 (0.28–2.68)
Hypertension	226 (6.6)	96 (7.2)	5 (21.7)	1.11 (0.87–1.42)
Immunocompromise	3 (0.1)	0	0	—
Liver disease	20 (0.6)	8 (0.6)	2 (8.7)	1.04 (0.46–2.36)
Sleep apnea	135 (3.9)	50 (3.8)	2 (8.7)	0.96 (0.69–1.33)
Tuberculosis	20 (0.6)	6 (0.5)	0	0.78 (0.31–1.94)

* Percentages may not total 100 because of rounding. Covid-19 denotes coronavirus disease 2019.
† The Defense Enrollment Eligibility Reporting System was used to identify race and ethnic group for all crew members.
‡ Augmented crew reside on the ship only at certain times when a ship is under way and provide specialized capability such as air squadrons, submarine groups, destroyer squadrons, and helicopter maritime strike squadrons.
§ Crew members in the departments of reactor, engineering, supply, weapons and in the combat support division tend to work in more confined spaces than those in the air and deck departments. Crew members in the air and deck departments tend to work in a combination of open-air and confined conditions. Medical personnel work in confined spaces but wear personal protective equipment when caring for crew members.
¶ Underweight was defined as a body-mass index (BMI, the weight in kilograms divided by the square of the height in meters) of less than 18.5; normal or healthy weight, 18.5 to 24.9; overweight, 25.0 to 29.9; and obese, 30 or higher.
‖ Conditions were identified from October 1, 2017, through March 1, 2020, with the use of the following data sources: Theater Medical Data Store, Comprehensive Ambulatory/Professional Encounter Record, Standard Inpatient Data Record, Armed Forces Health Longitudinal Technology Application Clinical Data Repository, Military Health System (MHS) GENESIS, TRICARE Encounter Data, and Periodic Health Assessment.

bers with Covid-19 who became hospitalized were more likely to report cough (68%), body aches (58%), and fever (32%) than those who did not. One third of hospitalized patients reported fever before their hospitalization, as compared with 12% of nonhospitalized crew members with Covid-19. During the outbreak, as a precautionary measure, admission criteria were revised to permit hospitalization of crew members with less severe symptoms.

DISCUSSION

The epidemiology of SARS-CoV-2 infection in young, healthy populations has not been studied extensively.[2] The outbreak of Covid-19 on the U.S.S. *Theodore Roosevelt* provided an unusual opportunity to assess an outbreak in a predominantly young, healthy, working-age population. Approximately 69% of crew members were younger than 30 years of age, and no crew member was older than 65 years. All were up to date with their immunizations. Over the course of the outbreak and the subsequent response by the U.S. Navy, every crew member underwent evaluation, testing, and follow-up. This level of controlled evaluation and documentation is difficult to achieve in civilian populations.

On ships at sea, respiratory viruses such as influenza and enteric pathogens such as norovirus can spread quickly.[3,4] In the early weeks of the pandemic, several outbreaks of Covid-19 occurred on cruise ships, most notably on the *Diamond Princess*.[5,6] The medical department of a ship can be overwhelmed quickly by a major outbreak of disease, as is similarly seen with health care fa-

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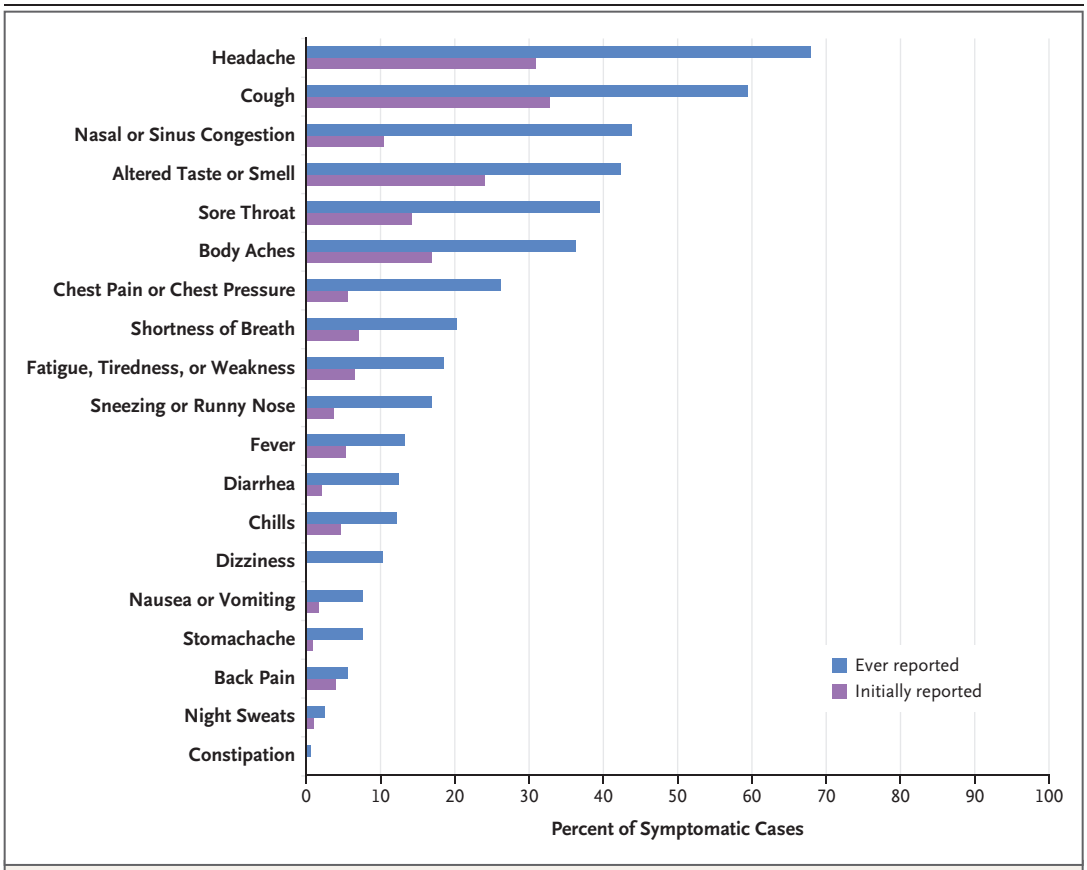

Figure 3. Distribution of Symptomatic Confirmed or Suspected Covid-19 Cases According to Symptoms.

cilities in civilian communities.[7] The shipboard environment on naval vessels is generally more confined. Typically, enlisted crew members sleep in open bays packed with dozens of tightly spaced bunks, work in densely populated areas, and congregate in gathering points such as the gyms and galleys (Figs. S1 and S2 in the Supplementary Appendix, available with the full text of this article at NEJM.org). These conditions probably facilitated the transmission of SARS-CoV-2, as evidenced by the higher likelihood of Covid-19 among enlisted crew members than among officers (Table 1).

Not surprisingly, crew members working in the engine room and other confined areas of the ship faced a higher risk of being infected than their shipmates on deck. A study conducted by the Navy and Marine Corps Public Health Center and the CDC, involving 384 volunteer U.S.S. *Theodore Roosevelt* crew members, showed similar results: those working in confined spaces had higher odds of contracting Covid-19.[8] A majority of infected crew members did not note symptoms at the time that Covid-19 was diagnosed by rRT-PCR testing. In addition, crew members with unusual or atypical symptoms may not have considered themselves to be infected with SARS-CoV-2.[9] These observations suggest that nonsymptomatic or mildly symptomatic crew members played an important role in the rapid spread of the outbreak, much as young adults with asymptomatic infection appear to contribute to spread in civilian populations.[10,11]

Although cases of serious illness occur in younger persons, they are less frequent and typically less severe than those in older persons.[9,11] In the case of the U.S.S. *Theodore Roosevelt*, few crew members were hospitalized. Certain coexisting conditions, such as hypertension, obesity, and diabetes, are associated with higher mortality.[12-14] In our findings, we noted a number of coexisting conditions among hospitalized crew members,

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including uncomplicated, mild, and medically managed asthma, lung disease (e.g., bronchitis), hypertension, and liver disease–related conditions.

Although we were able to confirm the outcomes in all infected crew members, data collection was limited by the quality of records, particularly those generated in the early days of the outbreak. Future studies involving longitudinal cohorts may provide greater insight into the epidemiology of SARS-CoV-2 infection in young adults. Our observations within a military population may not be fully generalizable to civilians. The CDC case definition for Covid-19, along with clinical criteria, changed over time (e.g., the outbreak began in March 2020, and the CDC-published case definition for Covid-19 changed in April 2020). Multiplex testing by polymerase chain reaction identified other causes of influenza-like illness on board the ship. Any effect that the case definition or other respiratory pathogens may have had on classifying a case of Covid-19 is limited, because the majority of cases were confirmed by rRT-PCR testing. Finally, the crew of the U.S.S. *Theodore Roosevelt*, like all members of the U.S. military forces, have equal access to health care. This is not true for all civilians in the United States.

Since this outbreak occurred, the U.S. Navy has incorporated lessons learned to enhance the safety and readiness of its crews. To minimize the risk of deploying with asymptomatic carriers of SARS-CoV-2 on board, the Navy has initiated several procedures to create and sustain Covid-19–free environments on its ships. Before deployment, all members of a ship's crew are placed in "restriction of movement" and insulated from community exposure for 14 days. To identify asymptomatic or presymptomatic carriers, the Navy added rRT-PCR testing at the end of the "restriction of movement" period. Navy ships have sharply reduced shore leaves at foreign ports to prevent crew members from bringing the virus on board. Since these policies (along with preventive measures of mask use, social distancing to the extent possible, small-group cohorting, strict hand hygiene, and regular cleaning of common spaces) were put in place, the Navy has deployed multiple ships without sustaining another serious outbreak. The concept of creating virus-free "bubbles" is a strategy the Navy has used and has been mirrored by the National Basketball Association and Major League Soccer to enable competition while minimizing the risk of player exposure. It is unlikely that this strategy is practical for all employers, much less the general population; however, creating bubbles or cohorts for select populations may be achievable.

Organizations seeking to safeguard their employees, customers, patients, or students may benefit from assuming that Covid-19 will be introduced into their populations and rigorously enforcing measures to minimize viral transmission by all, since persons may be unaware that they are infected.

The views expressed in this article reflect the results of research conducted by the authors and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, or the U.S. government.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

We thank Capt. Ron Schoonover (3rd Medical Battalion), Capt. Maria Young and Cdr. Jackie McDowell (Naval Hospital Guam), Col. William O'Connell (Brian D. Allgood Army Community Hospital), Mr. Donald Brown (Vice President, Maritime Policy with Cruise Lines International Association), Ms. Beth Poitras and Ms. Jessica Newton (Navy and Marine Corps Public Health Center), Cdr. Brian Legendre (Navy Environmental Preventive Medicine Unit 5), and all of those not listed who have responded to this outbreak; Col. James Mancuso (Uniformed Services University of the Health Sciences) and Dr. Art Kellermann (Dean of the School of Medicine at the Uniformed Services University of the Health Sciences), for editorial assistance with an earlier version of the manuscript; and the crew of the U.S.S. *Theodore Roosevelt*, who despite this unprecedented outbreak, demonstrated resilience in returning to sea and to their mission of protecting our country.

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