

# Coronavirus Disease 2019 On Board a Submarine: A Retrospective Review

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## ABSTRACT

### Background:

The submarine environment presents unique challenges in mitigating the spread of respiratory viruses because of the recirculatory atmosphere and lack of ability to physically distance. The atmosphere of a submarine is periodically ventilated and continuously scrubbed. However, the air is recycled for months until the ship is able to ventilate. An outbreak of coronavirus disease 2019 (COVID-19) occurred on a U.S. Navy fast-attack nuclear submarine (SSN) with a crew of 128 personnel.

### Methods:

Demographics, symptom data, and test results for all crew members on board during the outbreak were collected. Testing was completed by real-time reverse-transcriptase polymerase chain reaction, and symptom data were collected via a patient-reported online application. Symptom results were collected from August 4, 2020 to September 1, 2020.

### Results:

The crew was 100% male, with a mean age of 27.0 years. All crew members met the stringent medical standards for submarine and sea duty. Fifty-five Sailors tested positive for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (43.0% of the crew) during the outbreak. Additionally, nine Sailors (7.0% of the crew) met the criteria for infection despite testing negative, resulting in an overall attack rate of 50.0%. Among the 64 crew members with suspected or confirmed COVID-19, 1 (1.6%) was hospitalized. There were no deaths. Out of the 55 positive tests, there were 6 (10.9%) asymptomatic positive cases.

### Conclusions:

As expected, SARS-CoV-2 was able to spread rapidly among a submarine crew. In 11 days, the infection spread to 64 total crewmembers out of 128. Outbreaks such as these have played a role in future COVID-19 testing and mitigation protocols that have affected day-to-day operations.

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## INTRODUCTION

On July 22, 2020, a U.S. Navy nuclear-powered, fast-attack submarine departed homeport for local operations. Onboard were 123 ships' personnel and 5 temporarily assigned squadron staff. Before getting underway, the submarine-enforced standard protocol of verifying all personnel did not exhibit symptoms of coronavirus disease 2019 (COVID-19) utilizing the provided questionnaire and conducting a contactless pyrometer temperature check of the person's forehead to check for fever before embarkation.

The ship was following HPCON B (i.e., Health Protection Condition Bravo) guidelines, which allowed personnel to go to public places with a limit of no more than 10 personnel in a group outing. All personnel were encouraged to report Influenza-like illness (ILI) symptoms to the medical

department representative immediately. At this time, polymerase chain reaction (PCR) and rapid antigen testing were not readily available to test personnel before local operations. Real-time reverse-transcriptase PCR (rRT-PCR) testing was utilized for symptomatic individuals or predeployment sequestration testing.

On July 28, 2020, a single information systems technician (IT) Sailor who slept in FWD (i.e., forward) berthing presented to his Independent Duty Corpsman (IDC) complaining of cough, sore throat, headaches, muscle aches, and chills. He was afebrile. He was removed from the ship the next day and tested negative for SARS-CoV-2. At this point in the pandemic, because of conservative measures, it was recommended to MEDEVAC (i.e., Medical Evacuation) personnel exhibiting COVID-19 symptoms to avoid further spread in the context of having potential riders hot racking. On July 30 and July 31, 2020, two more Sailors from the IT and Machinist's Mates Auxiliary (MMA) divisions, who slept in AFT (aft) crew's berthing, presented to the boat's IDC with ILI symptoms in addition to fevers of 100.4 °F and 103.0 °F, respectively. These Sailors were isolated in the torpedo room until they were removed from the boat on July 31, 2020. Both Sailors tested positive for SARS-CoV-2 later that day. It was later determined that the torpedo room isolation area should

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have been reconsidered to provide more distance from the Weapons Handling Team.

By August 1, 2020, 11 new Sailors from a wide range of rates were reporting symptoms, and the boat moored on August 2, 2020. The divisions included in this group included the following: Culinary Specialist (CS), Torpedoman's Mate (TM), Fire Control Technician (FT), Electronics Technician, Nuclear Power (ETN), MMA, Machinist's Mate, Nuclear Power (MMN), and Yeoman (YN). The majority of the crew was placed in quarantine, except for 33 Sailors who stayed on board to man key watch stations. Three weeks later, 55 Sailors had tested positive for SARS-CoV-2, and 1 had been hospitalized because of severe complications of the disease. This article is a retrospective review of the outbreak. It attempts to replicate aspects of the article published in the *New England Journal of Medicine*, titled "An Outbreak of Covid-19 on an Aircraft Carrier."<sup>1</sup>

## METHODS

### Initial Response

After mooring, most of the crew were isolated in various barracks facilities on base, the Navy Gateway Inn and Suites, and an off-base commercial hotel. A team of 33 was assembled to provide manning of key watch stations while in port. This "caretaker crew" was created from individuals deemed to have the lowest risk of infection based on contact tracing and symptomatic status. Their personal protective equipment included cloth or surgical masks. After individuals in the caretaker crew became symptomatic, all personnel were isolated. EPICON (i.e., Epidemiological Consultation) included consultation with the base Public Health Emergency Officer in combination with current Center for Disease Control (CDC) recommendations. Contact tracings were based on CDC recommendations. A service member was deemed a close contact if the Sailor was within 6 feet of an infected Sailor without a mask for a cumulative 15 minutes. The Medical Department Head from the support squadron advised on specific COVID-19 cases and medical decision-making. There is a potential chance the caretaker crew had contact with the initial 3 or 11 cases; however, the contact tracing was utilized to minimize the chance of this interaction. The contact tracing was performed by the IDC.

### Laboratory Testing

The entire crew of 128 Sailors received a SARS-CoV-2 test within 6 days of returning to port.

Approximately 40 personnel were tested on August 3, August 4, and August 7, 2020, with repeat testing occurring on August 18, August 19, and August 21, 2020. Testing was repeated based on clinical decision-making to ensure capturing cases with enough viral loads that may have peaked 2 weeks later and to determine if continuing quarantine was necessary.

Testing groups were prioritized by symptomatic status and contact tracing. Samples were collected by nasopharyngeal swab and transported to the local military treatment facility in viral transport media tubes. Real-time reverse-transcriptase PCR was used to identify samples containing SARS-CoV-2. The Base Medical Team collected and distributed testing results.

### Collection of Symptom Data

After large outbreaks in the surface fleet, the U.S. Navy designed and implemented an online symptom tracking application, termed the Department of Defense Coronavirus (COVID-19) Symptom Checker, to monitor crew health remotely. During quarantine, each Sailor was instructed to log their symptoms twice a day through an online application, found at <https://mystatus.mil/>. This was an order for service members to complete while in the quarantine barracks. No symptom was also an option. Any failure to log symptoms was a failure to follow instructions. This site has fillable boxes for unit, current location, body temperature, and pulse oximetry. The site also provides a list of selectable symptoms to include the following: cough, fever, headache, chills or repeated shivering with chills, nausea or vomiting, diarrhea, congestion or runny nose, shortness of breath, body aches or muscle pain, sore throat, altered smell/taste, dizziness or lightheadedness, fatigue, confusion or inability to wake/stay awake, persistent pain or pressure in the chest, trouble or difficulty breathing, and bluish lips or face. The data are downloadable via a generated excel spreadsheet to medical personnel. This information was used clinically during the outbreak to assess which Sailors needed individual phone calls from the IDC or the Undersea Medical Officer (UMO) to further stratify illness severity. Not all Sailors received thermometers or pulse oximeters, which were distributed based on availability and severity of symptoms. Shortness of breath, chest pain, fever greater than 100.4 °F were considered severe symptoms.

### Disease Status Classification

Sailors were considered to have a "laboratory-confirmed case" of COVID-19 if they had at least one positive rRT-PCR test within a month of the initial outbreak. Sailors were classified as "presumed cases" of COVID-19 if they did not receive a positive test but met the Council of State and Territorial Epidemiologists' clinical criteria for COVID-19 on at least three separate days of symptom reporting. Sailors were only included as "presumed cases" if they met clinical criteria for COVID-19 infection each day on at least three different days.

### Statistical Analysis

All statistical analysis was completed in Microsoft Excel or by hand.

**TABLE I.** Crew Member Characteristics and COVID-19 Status

Classification	Number of personnel	Confirmed or suspected COVID-19	Rate of infection	Odds ratio
Division				
Officer	17	5	29.41	0.59
Electrician's Mate Nuclear (EMN)	13	9	69.23	1.38
MMN	14	7	50.00	Reference
Electronics Technician Nuclear (ETN)	8	5	62.50	1.25
MMA	12	8	66.67	1.33
Torpedoman (TM)	5	2	40.00	0.80
FT	7	4	57.14	1.14
Sonar Technician Submarines (STS)	14	4	28.57	0.57
Information Systems Technician (ITS)	15	9	60.00	1.20
Electronics Technician Navigation (ETV)	9	5	55.56	1.11
Logistics Specialists Submarines (LSS)	2	NR <sup>a</sup>	–	–
Yeoman Submarines (YNS)	2	NR <sup>a</sup>	–	–
Culinary Specialist Submarines (CSS)	5	3	60.00	1.20
Hospitalman (HM)	1	NR <sup>a</sup>	–	–
Squadron enlisted	4	NR <sup>a</sup>	–	–
Rank				
Total enlisted	110	59	53.64	Reference
Total officer	18	5	27.78	0.52
Crew type				
Ship's crew	123	64	52.03	Reference
Riders	5	0	0.00	0.00
Berthing location (22–28 July)				
Aft	48	30	0.63	1.13
Foreward	22	9	0.41	0.74
Twenty-one man	21	14	0.67	1.20
Chief's quarters	12	5	0.42	0.75
Staterooms	11	3	0.27	0.49
Nine man	9	5	0.56	Reference
Watch section (22–28 July)				
A	37	24	0.65	1.15
B	39	22	0.56	Reference
C	40	19	0.48	0.84
Unassigned	12	0	0.00	0.00
Total	128	64	0.50	Reference

<sup>a</sup>Not reported because of small cell size and identifiability.

## RESULTS

### Crew Member Characteristics

The average crew age was 27.0 years, ranging from 19 to 44 years old, and 100% of the crew was male. Submarine duty is one of the most medically stringent special duty screenings in the U.S. Navy. Thus, Sailors can be presumed to be in good health with few medical comorbidities and no immunocompromising conditions. Sailors frequently serve in remote locations several days away from higher-echelon care, even in emergent situations, which causes most underlying medical conditions to be disqualifying. All members were up to date on their immunizations, including influenza.

### Rates of Infection

Between July 31 and August 21, 2020, a total of 55 crew members (43.0% of the crew) tested positive for SARS-CoV-2. An additional nine (7.0%) crew members met the criteria to be considered a “presumed case” of COVID-19 despite a

negative test. The overall attack rate, or the number of new cases divided by the total population, was 50.0%.<sup>2</sup> Of the 55 crew members testing positive, 6 were entirely asymptomatic throughout the outbreak (10.9%). Enlisted personnel, making up 85% of the crew, were twice as likely to become infected. The likelihood of infection was evaluated for each Sailor based on division, berthing location, and watch section and can be seen in [Table I](#) and [Figures 1](#) and [2](#).

### Symptoms

Crew members logged an average of 21.2 symptom reports. Only one Sailor failed to log a single entry, and the highest number of reports for a single Sailor was 43. The one Sailor that failed to log symptoms did have a test positive for SARS-CoV-2. The most commonly reported symptoms in infected individuals were cough (54.7%), congestion or runny nose (53.1%), body aches and muscle pain (48.3%), altered smell/taste (42.2%), and headache (42.2%). A complete representation of reported symptoms can be seen in [Figure 3](#).

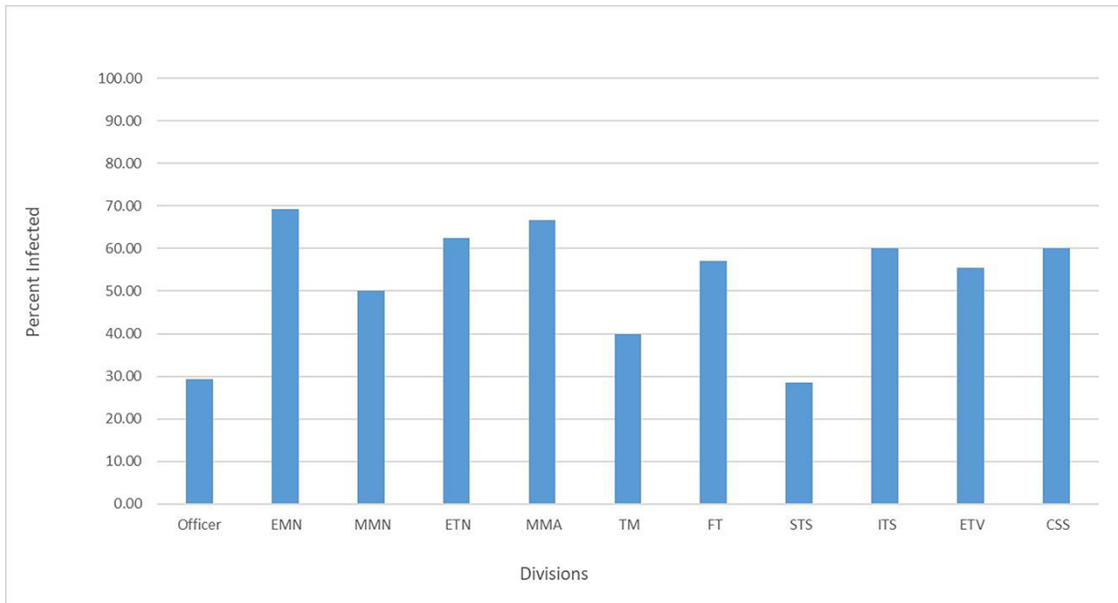


FIGURE 1. Rate of infection by division.

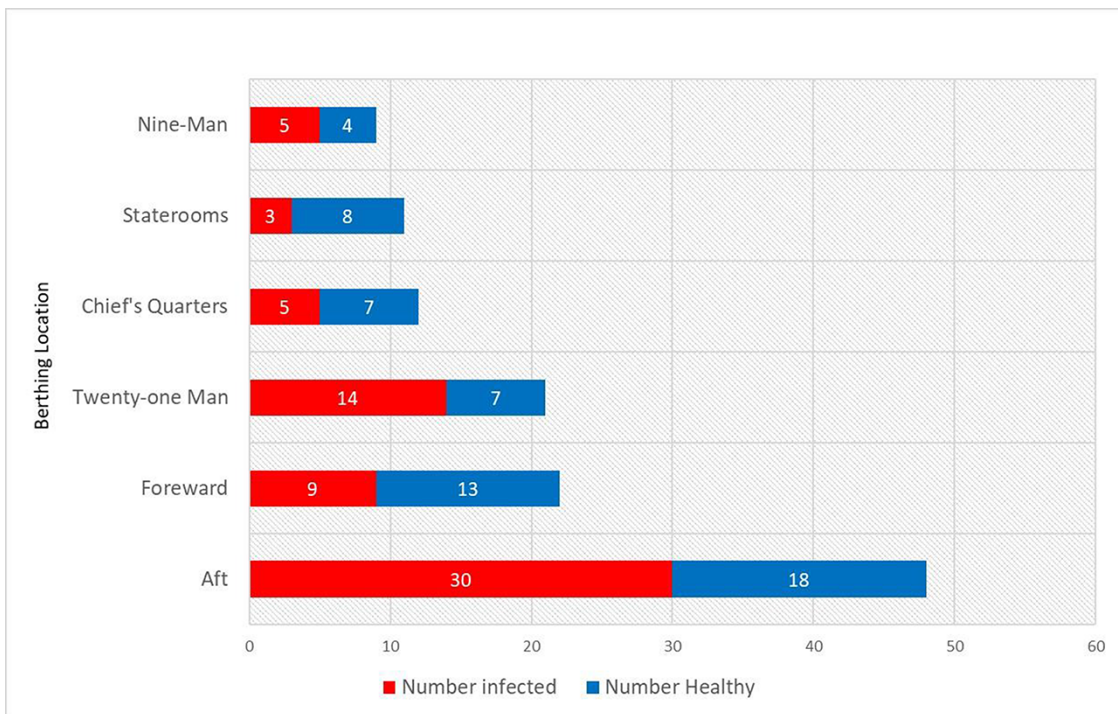


FIGURE 2. Number of infection vs. berthing location.

**DISCUSSION**

The COVID-19 pandemic has presented unique challenges for operational forces across the U.S. military. There are few environments where service members operate in closer quarters than on U.S. Navy fast-attack submarines (SSN). A single positive case on board a submarine puts the entire crew at risk. Although Sailors operate in close proximity on many U.S. Navy vessels, none share a 100% recirculated atmosphere as

submarines do when submerged. Submariners interact with different groups throughout their day and thus may generate various close contacts in their berthing quarters, at work, and during meals. This made the contact tracing more challenging to complete because of the very close quarters. Many enlisted submariners are also required to “hot rack,” the term for sharing a bed, in which three Sailors share two racks, alternating their sleeping and duty schedules. Typically, junior



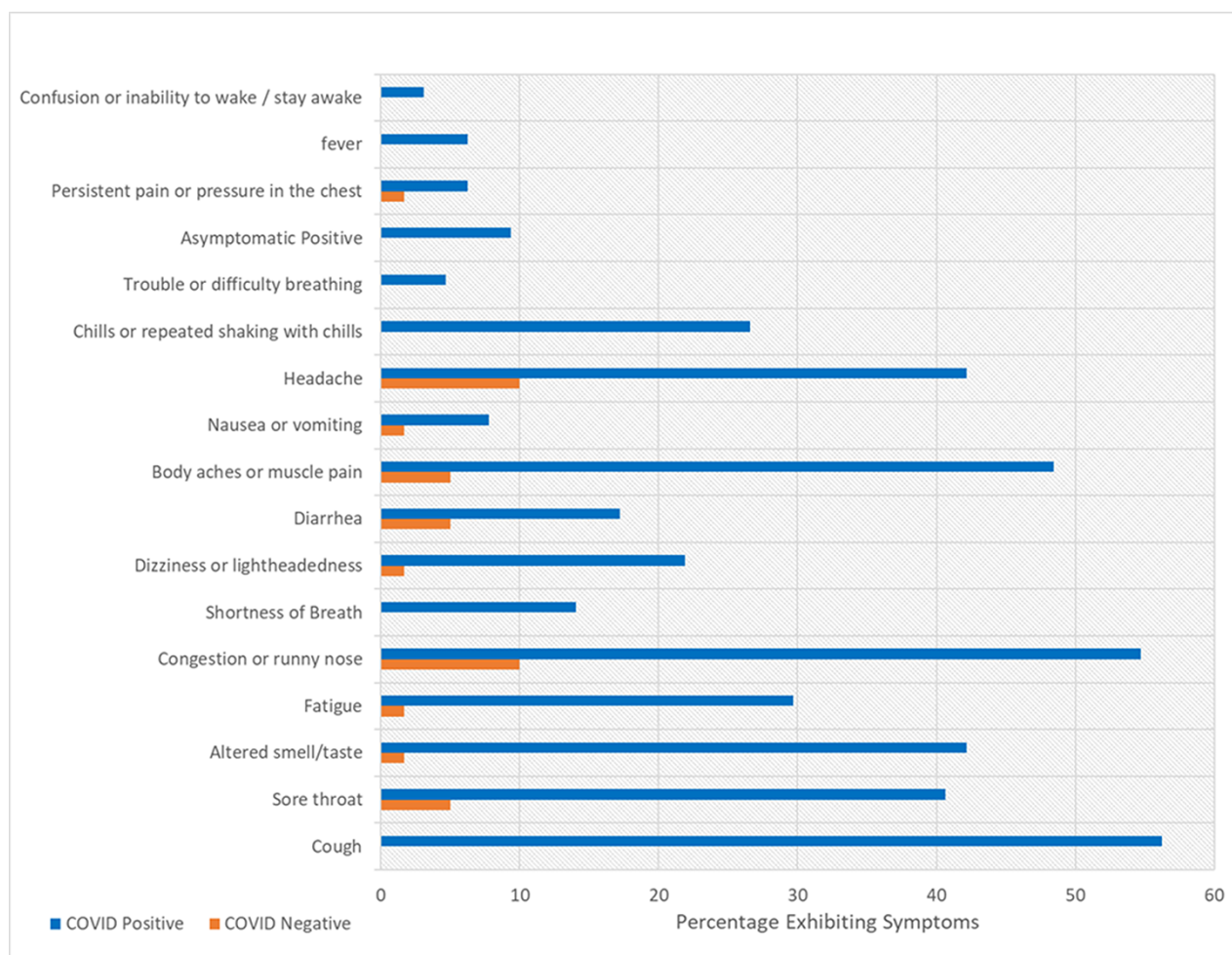


FIGURE 3. Percentage of reported symptoms by COVID-19 status.

enlisted Sailors sleep in berthing rooms consisting of 21 to 39 beds per room. However, the capacity of berthing spaces can be increased by 50% with hot racking. Racks are stacked three high and are separated by a sliding curtain. Officers sleep in staterooms, with three beds per room, or in a nine-man berthing room. Chief Petty Officers sleep in Chief’s Quarter’s, consisting of 12 racks. The Commanding Officer and XO (Executive Officer) have their own staterooms. The increased population density while sleeping likely contributes to the increased infection rates when comparing enlisted personnel to officers. Analysis by squadron leadership immediately following the outbreak found that hot-racking Sailors that replaced their entire pillow and pillowcase versus only changing the pillowcase had significantly lower transmission rates of SARS-CoV-2.

The nature of an underway submarine provides a controlled population to study, and 100% of the crew was tested and required to report symptom data after the outbreak. These factors provide a unique and robust data set to analyze. As with any patient-driven reporting system, there were inconsistencies in reporting frequency, and some Sailors were more

compliant than others. This data comes from July to September 2020, at which point COVID-19 vaccines had not yet been introduced.

The initial attempt to create a clean “caretaker crew” somewhat complicates the data. This crew was created from individuals initially believed to have a low risk of exposure. This effort failed as many of the caretaker crew tested positive during the second round of testing. As restriction of movement (ROM) guidelines required Sailors to ROM for 14 days from symptom onset or positive test, the delayed onset of some of the cases in the caretaker crew resulted in Sailors on different quarantine timelines and added complexity to statistical analysis. Additionally, squadron riders did not board the boat until July 28, 2020 and thus were not equally exposed during the initial outbreak.

A goal of this investigation was to generate key viral statistics. Data on SARS-CoV-2 transmission are constantly evolving, as there are still many unknowns regarding the transmission of the virus. Early estimates suggested a basic reproduction number ( $R_0$ ) of 2.2 (95% CI, 1.4–3.9)<sup>3</sup> while later estimates saw an increase in the  $R_0$  to 5.7 (95% CI,

3.8–8.9)<sup>4</sup> suggesting that there is still a wide range of variance in rates of transmission of SARS-CoV-2.

Infectivity refers to the number of exposed persons who become infected.<sup>5</sup> Assuming the crew was exposed equally, the infectivity of SARS-CoV-2 in this population was 50.0%. A slightly different statistic, pathogenicity, is “the proportion of infected individuals that develop clinically apparent disease.”<sup>3</sup> In total, 58 of 64 infected personnel demonstrated symptoms, resulting in pathogenicity of 90.6%. Finally, virulence is defined as “the number of clinically apparent cases that are severe or fatal.”<sup>3</sup> Although there were no fatal cases in the population studied, one patient was hospitalized for several days, resulting in a virulence rate of 1.7%, and a whole population hospitalization rate of 0.8%. Current COVID-19 data suggest a hospitalization rate of 4.6 per 100,000 population and 2.5 per 100,000 (0.0025%) population for patients 18–49 years old, which is more consistent with the submarine patient population.<sup>6</sup> The elevated hospitalization rate in this study is likely highly related to the increased number of overall infections.

Thermometers and pulse oximeters were issued as supplies allowed and as clinically indicated. About 96 Sailors reported temperature data, and 19 reported pulse oximetry data. These tools were helpful when used clinically to check on individual Sailors reporting concerning symptoms, but these vital signs were not reported robustly enough to generate useful statistical data.

The online symptom reporting system was helpful for triage by identifying Sailors who needed a higher level of care. The UMO at Naval Submarine Support Command would download and examine the symptom data daily and provide the boat’s IDC with a list of patients with more severe symptoms (shortness of breath, fever >100.4 °F, and chest pain). The IDC was responsible for the initial round of patient assessment and would refer any patients with severe symptoms back to the UMO, who would contact these patients for further evaluation. The Base Medical Team consisting of a physician or physician’s assistant and several corpsmen was able to provide limited resources to check on any patients in person if needed. This system worked to identify the single Sailor that required hospitalization during this outbreak. This Sailor presented to the local military treatment facility with a decreased oxygen saturation percentage and required supplemental oxygen. He was discovered to have developed a pulmonary embolism, was hospitalized for several days, and was later disqualified from submarine duty because of complications from COVID-19. He was 32 years old and had no comorbid medical conditions.

### **Additional Areas of Study**

This study was limited by statistical support and manpower. There are additional areas of investigation that would be beneficial to investigate. Health characteristics such as BMI, comorbid conditions, smoking status, and race would all be worthwhile values to compare to rates of infection.

In conclusion, this study demonstrated that the infectivity of SARS-CoV-2 aboard a submarine is significantly higher than in the general population. This is an obvious conclusion, but this article helps detail the level of urgency required when a single case of a serious respiratory virus is discovered while underway. In March 2020, the Navy and Marine Corps Public Health Center prepared estimated attack rates for ships with a single initiation COVID-19 case and 100% crew susceptibility. For a vessel with a crew of 150, the estimated rate of infection after 14 days underway was 14%.<sup>7</sup> Assuming the submarine had a single initial case, the overall attack rate of 50.0% is well over the expected infection rate for a 12-day underway period.

Special thanks to the crew of the submarine, who overcame significant adversity during this outbreak and deployed in the spring of 2021. Bravo Zulu to the boat’s XO, who worked tirelessly to provide education to these Sailors, leading to 159/160 crew members voluntarily choosing to receive both doses of the COVID vaccine before deployment.

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### **CONFLICT OF INTEREST STATEMENT**

None declared.

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