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Association between COVID-19 mitigation strategies and the number of close contacts reported per case at the University of California San Diego

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Association between COVID-19 mitigation strategies and the number of close contacts reported per case at the University of California San Diego

A thesis submitted in partial satisfaction of the requirements for the degree Master

of

Public Health

by

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The thesis of Rochelle-Jan Dionisio Reyes is approved, and it is acceptable in quality and form for publication on microfilm and electronically.

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List of Abbreviations

COVID-19..Coronavirus Disease 2019

WHO...World Health Organization

OGD...Olfactory and Gustatory Disease

SARS-CoV...Severe Acute Respiratory Syndrome Coronavirus

SARS-CoV-2..Severe Acute Respiratory Syndrome Coronavirus 2

MERS..Middle East Respiratory Syndrome

VOC.. Variant of Concern

CDC.. Centers for Disease control and Prevention

CICT.. Case Investigation and Contact Tracing

UCSD...University of California San Diego

RTL..Return to Learn

SDI... Social Distancing Index

CI..Case Investigation

EUA...Emergency Use Authorization

OMB...Office of Management and Budget

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ABSTRACT OF THE THESIS

Association between COVID-19 mitigation strategies and the number of close contacts reported per case at the University of California San Diego

by

Rochelle-Jan Dionisio Reyes

Master of Public Health

University of California San Diego, 2023

Professor Richard Garfein, Chair

Case investigation and contact tracing (CICT) is a strategy for preventing transmission of infectious diseases, deployed during the COVID-19 pandemic, to identify individuals before becoming symptomatic and/or infectious so they could test and quarantine in order to break chains of transmission. Since May 11, 2020, the UC San Diego Return to Learn program conducted CICT for UCSD students, faculty, and staff. Data collected through contact tracing efforts provides an estimate for adherence to social distancing efforts. Our study aimed to identify the number of close contacts per case as well as factors associated with changes in the number of close contacts. Using available data, cases investigated between July 2020 and April 2021, we examined case characteristics and determined the number of close contacts reported by cases over time. Trends in the number of contacts per case over time were examined using linear regression. Of the 968 cases investigated during this period, 33.9% were White/Middle Eastern, 51.1% were female, and 63.2% were 18-29 years old. Cases were stratified based on university affiliation, in which 56.4% were students (including student employees) and 43.6% were employees of UC San Diego. Findings indicated that the number of close contacts per case had a statistically significant association with age group and student status. Analyses showed an increase in the mean number of close contacts per case over time. Furthermore, we observed that the number of contacts per case increased after stay-at-home orders ended in San Diego county ($p<0.001$), but did not decrease after business closures and mask mandates were implemented ($p=0.76$). These findings suggest that changes in time and mitigation protocols (i.e., quarantine) can impact social distancing adherence by proxy of close contacts, which provide insights for future outbreak mitigation efforts and policy planning.

Chapter 1. Introduction

COVID-19 Disease

Coronavirus Disease 2019, known as COVID-19, is a disease that drastically affected global infrastructures. First identified in December 2019 in Wuhan, China, COVID-19 impacted hundreds of thousands of people throughout several countries in a short period of time. COVID-19 became the third leading cause of death in the United States (U.S.) in 2020 and maintained its position in 2021 (1,2). Furthermore, COVID-19's mortality rate increased by 22.5% in 2021 when compared to 2020 (104.1 v. 85.0 deaths per 100,000) (2). As of March 2023, the worldwide statistics gathered by the World Health Organization's (WHO) COVID-19 Dashboard indicated over 700 million confirmed cases and almost seven million deaths from COVID-19 (3).

Types of clinical manifestations of COVID-19 range from asymptomatic to severe illness. An early study on the clinical impacts of COVID-19, symptoms were primarily fever, dry cough, dyspnea, headache, and pneumonia (4). During this time, clinical manifestations were able to progress to more severe symptoms, such as respiratory failure and death (4). However, severity of symptoms decreased over time, based on the implementation of vaccines and medications to address clinical outcomes. A systematic review of 152 studies found fever and cough accounted for over 50% prevalence in the studies and dyspnea (30.8%), malaise (29.8%), and fatigue (28.2%) as the other common symptoms (5). Olfactory and gustatory disorders (OGDs) - commonly presented as loss of taste or smell - are specific to the clinical presentation of COVID-19. Early observational studies found varying levels of OGD prevalence in patients positive for COVID-19 (6–8). In a systematic review and meta-analyses of 8438 patients in 24 articles related to OGDs, 41% of patients with confirmed COVID-19 infections reported olfactory dysfunctions and 38% reported gustatory dysfunctions (9). The presence of symptoms and the shift in severity impacted individuals' COVID-19 testing, isolation, and quarantining practices, which may have led to changes in transmission of the virus.

However, there were many individuals who experienced asymptomatic infection. Asymptomatic infections posed a threat to transmission monitoring and application of mitigation efforts because asymptomatic individuals could unknowingly be carriers for the virus. According to a meta-analysis of 95 studies published through February 2021, 40.5% of those with confirmed COVID-19 cases were asymptomatic (10). Yet, prevalence of asymptomatic cases changed over time with the introduction of more transmissible variants, making it vital to understand the timeline of COVID-19 and the mechanisms of its transmission.

The COVID-19 Pandemic Timeline

The COVID-19 disease rapidly became a global threat to public health. One month after its initial identification in China, the WHO declared COVID-19 to be a Public Health Emergency of International Concern in January 2020 (11). This was due to a myriad of factors, including the rapid spread of the disease globally. At this time, there were over 200 deaths due to COVID-19 and approximately 9,800 cases in several countries (12). This declaration prompted several countries to also declare COVID-19 a public health emergency, including the U.S. (12).

After careful consideration, the WHO declared COVID-19 a global pandemic in March 2020 due to the continuous rapid increase in global cases as well as the severity of symptoms (13). At this time, there were over 118,000 positive cases of COVID-19 and almost 4,300 deaths in 114 countries across the world (14). COVID-19 remained a global threat for three years after the declaration of its pandemic status. Therefore, understanding COVID-19, its etiology, and its transmission factors were imperative in decreasing the impact of COVID-19 across the globe.

The SARS-CoV-2 Virus

The virus that caused COVID-19, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), is a novel member of the coronavirus family found in late 2019 (15). SARS-CoV-2 is similar to other coronaviruses, including severe acute respiratory syndrome coronavirus (SARS-CoV) and Middle East respiratory syndrome virus (MERS). All coronavirus species have enveloped RNA, and they affect the respiratory, enteric, hepatic, and neurologic systems of different species (15). What sets SARS-CoV-2 apart from SARS-CoV and MERS as well as other viruses like influenza A are its novelty as a virus and its etiology. First, because SARS-CoV-2 was a new type of virus, human immune systems were not equipped with the antibodies needed to fight the viral infection (16). This novelty made the initial presence of SARS-CoV-2 potentially fatal in humans. According to a 2020 study, viral load of SARS-CoV-2 was associated with increased severity of COVID-19 symptoms and mortality (17). The increased viral load in the respiratory system - specifically the pulmonary system - led to more severe clinical manifestations of respiratory failure and pneumonia (17). Secondly, SARS-CoV-2 was highly transmissible during the early part of the pandemic; its ability to infect humans rapidly threatened global public health in a short period of time when compared to transmissibility in other respiratory viruses (18,19).

Since March 2020, the SARS-CoV-2 virus has had several variants with differing genetic compositions that affected its transmissibility and its impact on the host. By early 2023, five major SARS-CoV-2 variant types had been identified: Alpha, Beta, Gamma, Delta, and Omicron. These variants were classified by the U.S. Department of Health and Human Services' SARS-CoV-2 Interagency Group to provide context and recommendations based on certain attributes of the variant (20). Many of the SARS-CoV-2 variants were labeled as either a Variant of Interest or a Variant of Concern (VOC) throughout the pandemic; VOC assignment was crucial during the pandemic because variants designated as VOCs were more transmissible, had higher clinical severity, and had shown significant immune reduction or effectiveness in treatment; when VOC was assigned, health agencies recommended an increase in preventative measures and research to decrease transmission of this variant (20). In the context of the pandemic, Alpha was the first variant that circulated around the world, labeled as a VOC in December of 2020, followed by the Beta variant that was also labeled as a VOC in December 2020 (21). By February 2022, the Omicron variant was the most circulated variant of SARS-CoV-2, accounting for more than 98% of the sequences (21). These variants vary in transmissibility of the virus, severity of disease, and vaccination impact. For example, the Omicron variant's original strain was found to be more transmissible than the Delta variant due to mutations on the spike protein that increase infection probability (22). However, it was not found to be as virulent as the Delta variant (22). Overall, variation in transmissibility made it crucial for public health agencies to identify SARS-CoV-2 variants and quickly implement mitigation efforts.

Transmission

Mode of transmission was a large factor in the spread of COVID-19 around the globe. Early studies found that SARS-CoV-2 transmission occurred through direct contact by person-to-person transmission (23,24). According to Chan et al., six patients had respiratory-like signs and symptoms that were in accordance with transmission from one individual to another (24). Furthermore, a case series from the first 12 patients with positive COVID-19 cases in the U.S. found that the RNA of SARS-CoV-2 was present in the respiratory tracts of all patients in the study, suggesting direct transmission of the SARS-CoV-2 virus through the presence of viral replication in the respiratory tract (25). However, the understanding of SARS-CoV-2 transmission evolved over time. Later findings showed that SARS-CoV-2 transmission occurred by more than direct, person-to-person contact. The primary mode of transmission for COVID-19 was found to be through airborne respiratory droplets through direct or indirect contact (24,26).

Direct contact could occur through droplets or secretions transmitted through coughing, sneezing, or talking; indirect contact of respiratory droplets may be transmitted through fomite transmission (26). Other modes of transmission were also possible for the spread of SARS-CoV-2. Airborne transmission occurred through aerosol forms that may have stayed in the air in indoor crowded areas (27).

Due to its high transmission capabilities, many people who had COVID-19 were able to easily infect their close contacts (26). Because of the transmissibility of this virus, many primary prevention measures were implemented to promote transmission reduction among humans through social distancing, using face masks, and washing hands thoroughly.

COVID-19 Event Types & Mitigation Efforts

Throughout the COVID-19 pandemic, many major events occurred due to the spread of the virus along with several international, national, state, and local efforts to mitigate transmission of the virus. The WHO and the U.S. Center of Disease Control and Prevention (CDC) provided updates on the spread of COVID-19 and how many people were impacted. These updates were also provided at the state and county levels to ensure that knowledge regarding the COVID-19 disease was reported to communities. Of these updates, much of the information provided was related to milestones of cases and death counts, vaccination efforts, and the presence of variants.

Mitigation efforts and prevention methods were implemented by different levels of government and public health organizations in order to address these milestones and reduce the spread of COVID-19. Many countries implemented mitigation measures to reduce the transmission of SARS-CoV-2, such as business closures and mask mandates among other methods. Of the countries impacted by COVID-19, 83.7% (164 of 196 countries) utilized some form of mitigation measure or restriction (28). These values are based on the absolute change of stringency by the following metrics: school, workplace, and transportation closures, cancellation of events and public gatherings, stay-at-home orders, campaigns for public information regarding COVID-19, and international travel controls (28). These values varied by country and by time period, but the highest Stringency value in the U.S. was 75.46 out of 100 points in late November 2020 (28).

Of the many preventative measures implemented within the U.S., community mitigation activities were widely used. These activities were categorized by personal protective measures, social distancing, and environmental surface cleaning (29). Social distancing strategies and personal protective measures were widely implemented within communities to decrease transmission of the virus. Examples of these included stay-at-home orders, physical distancing guidelines, and mask mandates.

Stay-at-home orders imposed by health authorities were used to reduce SARS-CoV-2 transmission through limiting physical interactions among people (30). In the U.S., 42 out of 50 states implemented stay-at-home orders to reduce transmission of COVID-19 (30). The timing, region, and implementation depended on the orders issued by the governing body. California was one of the first states to issue a stay-at-home order in March 2020, as a mandatory order in response to a rise in COVID-19 cases (31). However, other states - such as South Dakota and Massachusetts - issued stay-at-home orders that were advisory and not required (30). Nonetheless, these stay-at-home orders were widely used, along with other social distancing measures like physical distancing.

Physical distancing is a type of social distancing strategy that was implemented in many businesses and institutions. The act of physical distancing was recommended by the CDC to maintain a distance of six feet or more between individuals in order to limit potential COVID-19 transmission of airborne droplets (32). Additionally, this preventative measure was meant to reduce transmission by both symptomatic and asymptomatic individuals with COVID-19 since asymptomatic people may not be aware of their infection. Another reason for physical distancing was to reduce the probability of outbreak events. Especially for gatherings in public areas, physical distancing could prevent asymptomatic persons infected with COVID-19 from transmitting the virus to others in public and indoor areas, which could decrease the probability of outbreak occurrence (33). Because of the potential for transmission reduction between physical distancing and stay-at-home orders, many institutions utilized these measures throughout the pandemic.

Assessing Mitigation Measures through CICT and the Return to Learn Program at UC San Diego

Another important aspect of public health measures was Case Investigation and Contact Tracing (CICT), which was used widely throughout the pandemic. CICT is a public health measure that involved interviewing COVID-19 cases, eliciting the identities of close contacts while infectious, and notifying those contacts of the possible need to quarantine and test for COVID-19 in order to interrupt ongoing SARS-CoV-2 transmission (34,35). The premise of case investigation was to identify individuals who were diagnosed with an infectious disease and gather information about their illness, close contacts, and recent activities for the purposes of notifying potentially exposed individuals. Contact tracing efforts involved notifying exposed close contacts and providing them with guidance on isolation procedures and how to protect themselves and others from exposure. The definition of a close contact changed over the course of the pandemic as the characteristics of the virus became better understood, but is currently defined by the CDC as a person who was less than six feet away from an individual diagnosed with COVID-19 for more than 15 minutes during a 24-hour period (36). Overall, CICT was useful for notifying close contacts so they could take protective measures before exposing others and for expanding our understanding of social distancing behaviors.

At the community level, UC San Diego (UCSD) began implementing strategies to monitor social distancing efforts and SARS-CoV-2 transmission. The rapid increase in positive COVID-19 cases within the UCSD community prompted a response from the university to establish the Return to Learn (RTL) program. On May 11, 2020, UCSD launched the program with five major components to brings students back on campus safely and to reduce COVID-19 transmission that included the following: 1) risk assessment for on-campus presence; 2) predictive modeling of transmission; 3) rapid implementation of CICT; 4) use of technological tools for wastewater monitoring and other tracking methods; and 5) identification of case clusters and/or high-risk settings/events to trigger additional investigation (37).

The UCSD RTL Program began conducting routine testing combined with CICT in May 2020 to slow the transmission of SARS-CoV-2 among UCSD students, employees, and other affiliates (37). RTL's CICT program enlisted public health professionals to contact UCSD affiliates who tested positive for COVID-19, obtain contact information for individuals they had been in close contact with during their infectious period, and notify the close contacts of their potential exposure to SARS-CoV-2. The close contacts were given information about quarantining and isolation procedures. These efforts were used in conjunction with the other major components of RTL to identify areas of transmission, notify affiliates of this potential area, and reduce spread of the disease.

Responses and Adherence towards Mitigation Measures

With more than three years of managing and preventing COVID-19, studies have been done to assess behaviors and adherence values towards mitigation efforts. These responses towards COVID-19 were associated with increased disease transmission and mortality. A 2020 study done in eight countries - including the U.S. - reported that low adherence countries were associated with an 81.3% increase in mortality rates from COVID-19 compared to an 8.4% increase in high adherence countries (38). The authors concluded that it is important to understand sentiments and responses to COVID-19.

Four major themes encompassed adherence towards mitigation efforts: risk evaluation, political views, individual needs (e.g., purchasing groceries, obtaining medications), and impacts on mental health. A qualitative study done in 2020 found that adherence to social distancing and lockdown practices was associated with an individual's assessment for their level of risk from COVID-19. Of the 20 participants, three main levels of adherence were identified: caution-motivated super-adherence, risk-adapted partial adherence, and necessity-driven partial adherence (39). Some participants were motivated to adhere to lockdown regulations due to the need for survival and protection of the community, whereas others broke adherence regulations due to the need to visit family, exercise, or obtain financial support (39).

In addition to risk, responses towards mitigation efforts and the pandemic were impacted by needs related to mental well-being. Early studies have shown an association between the pandemic and mental health needs of individuals and communities. In March 2020, U.S. adults were interviewed about their knowledge and the impact of COVID-19; findings from this study showed that 2,812 (44%) participants reported moderate to severe depression and anxiety during the pandemic based on the Patient Health Questionnaire-4 scale (40). In higher education, students reported mental health issues throughout the pandemic due to the shutdown of educational institutions. These students indicated feelings of stress and depression in relation to stay-at-home orders issued (41). This impact on mental well-being correlated with how individuals adhered to mitigation measures over time and by the type of prevention methods.

Sentiments towards the COVID-19 pandemic and the public health mitigation efforts set in place may have contributed to "quarantine fatigue". Quarantine fatigue - also referred to as "lockdown fatigue" or "pandemic fatigue" - was a phenomenon in which people began to lessen their social distancing practices prior to the lifting of mandates and reopening of businesses (42–44). Quarantine fatigue has been assessed through quantitative analyses of indexes, such as the Social Distancing Index (SDI), in which they found that SDI declined, and people reduced their stays at home after a few weeks of a social distancing mandate (42). Furthermore, a survey of 516 adult participants regarding quarantine fatigue found that one in three participants decreased precautions during the pandemic (44). These findings provided evidence that individuals may decrease their adherence to transmission mitigation measures even if the transmission and risk factors are still present.

Lastly, politics played a role in individual and community responses to mitigation efforts. Behaviors and reactions towards COVID-19 transmission mitigation efforts were impacted by social media posts with political views and statements from political leaders. According to a study aimed to identify how public support impacts risk mitigation, researchers found that those who identified as Democrats were more likely to be in favor of mitigation efforts when compared to individuals who identified as Republicans; findings also indicated that an individual's favorability towards a presidential candidate was associated with their support or rejection of COVID-19 transmission prevention strategies (45,46). These findings underscore the association of mitigation efforts with political views and the importance to address health messaging strategies.

Previous Studies & the Current Study

These studies highlight the importance of understanding behaviors and beliefs, impact on mental well-being, and the types of mitigation strategies when implementing public health efforts to address large-scale disease outbreaks. For the COVID-19 pandemic, these studies also suggest that adherence to social distancing and mitigation strategies may have changed over time and by the level of individual risk. Further research is needed to examine whether these behaviors varied over time and what factors may have played a role in this change.

Chapter 2. Manuscript

Introduction

The COVID-19 disease, first identified in Wuhan, China, in December 2019, has impacted millions of people globally. Within a few months, COVID-19 was declared a global pandemic by the World Health Organization (WHO) after nearly 10,000 cases and 200 deaths were reported in many major countries around the world (12). Furthermore, COVID-19 became one of the top three leading causes of death within a year after its identification (2). Clinical manifestations for COVID-19 include fever, dry cough, dyspnea, and headaches (4,5), as well as symptoms like olfactory and gustatory disorders (OGDs) that lead to the loss of taste or smell (6–9). Clinical severity was profound early in the pandemic but decreased over time due to the production of the vaccine, the application of medications to address symptoms, and the emergence of more infectious, but less virulent, viral strains. However, some individuals infected with SARS-CoV-2 – the virus that causes COVID-19 – were asymptomatic. A meta-analysis of 95 studies found that 40.5% of infected individuals were asymptomatic (10). Hence, it was imperative for public health agencies and government institutions to quickly address the spread of COVID-19.

The pathogen that causes COVID-19 is a type of coronavirus called the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (15). The SARS-CoV-2 virus was a novel, highly infectious virus that spread rapidly in humans within a short time span (19). Some SARS-CoV-2 strains became variants of concern (VOCs), a variant classification with attributes of increased transmissibility (20). Transmission of SARS-CoV-2 occurred through various modes, including respiratory droplets via direct, indirect, or close contact as well as through aerosols and fomites (24,26). Moreover, the incubation period of the virus was short, with some studies estimating a median of five days before the onset of symptoms (47). Individuals could remain infectious for several days, with studies of different populations with asymptomatic individuals showing a median number of infectious days ranging from seven days to 19 days (48). Due to its high transmissibility, short incubation period, and prolonged infectious periods, public health agencies needed to quickly address the spread of SARS-CoV-2.

Due to its high and multimodal transmissibility, public health agencies worldwide implemented mitigation strategies to reduce transmission (24,26). It is estimated that 83.7% of countries utilized at least one form of mitigation measure to reduce transmission of the virus (28). In the United States (U.S.), social distancing was one of the most widely used mitigation strategies implemented to reduce physical contact between people (29,32). The Center for Disease Control and Prevention (CDC) developed social distancing guidelines, which were adopted by state and local health departments to include government-mandated stay-at-home orders. These orders were intended to limit physical interactions by requiring individuals to stay at their place of residence except for travel related to essential needs (30). In the U.S., 42 states implemented stay-at-home orders, with California being among the first (30,31).

Another major public health strategy implemented during the pandemic was Case Investigation and Contact Tracing (CICT). CICT was a method widely used to mitigate transmission of SARS-CoV-2 based on the identification of positive COVID-19 cases and their close contacts in order to provide guidance for quarantine and isolation practices (34,35). Furthermore, this practice provided disease investigators a way to determine who cases were in close contact with, defined as an individual who was within six feet of a person who was positive with COVID-19 for more than 15 minutes (36). To help support the county’s CICT efforts, the University of California San Diego (UCSD) Return to Learn (RTL) program began conducting CICT in May 2020 for all students, staff, and faculty infected with SARS-CoV-2 (37).

Although mitigation strategies were implemented, responses and levels of adherence to these efforts varied by time and type of strategy. Responses towards transmission efforts, like stay-at-home orders, were impacted by an individual’s perception of risk, political values, necessity, and mental well-being. A study in 2021 found that people adhered to lockdown measures based on whether it would protect their community or whether they needed to do an activity (e.g., grocery shopping, visiting family, and obtaining financial support) (39). Furthermore, COVID-19 lockdown practices impacted mental well-being. A study in March 2020 found that 44% of U.S. adult interviewees had scores for moderate to severe depression and anxiety during the pandemic (40). These impacts on mental health may have led to “quarantine fatigue”, a phenomenon where individuals began decreasing their adherence to mitigation measures (42–44). A study among 516 adults found that one in three survey participants reduced their adherence to mitigation efforts throughout the pandemic (44). Lastly, adherence to mitigation efforts were impacted by the political climate. During the pandemic, the presidential election was occurring, and candidates were providing statements in regard to the COVID-19 pandemic. These statements may have impacted how people responded to mitigation efforts and COVID-19. A study found that individuals who favored one candidate over the other were associated with their sentiments towards COVID-19 transmission prevention strategies (46).

Understanding the acceptance of COVID-19 mitigation strategies such as social distancing is essential to guide preparedness for future pandemics. Given the multifactorial nature of public response in public health interventions and the complexity of evaluating interventions in the context of an ongoing pandemic, we examined the number of close contacts reported by COVID-19 cases during CICT as a proxy for social distancing practices. First, we investigated the number of close contacts elicited from cases investigated by the RTL program and identified factors associated with the number of contacts per case. Second, we examined whether the mean number of contacts reported varied over the course of the pandemic and whether shifts were observed following major changes in health policies, disease status, or mitigation strategies. We hypothesized that a higher number of close contacts would be reported by cases who were students (versus campus employees), younger, and living off campus (versus on campus). Furthermore, we hypothesized that the mean number of close contacts per case increased over time and after relaxation of mitigation efforts.

Methods

Study Design and Population

We conducted a retrospective study using existing, de-identified CICT data collected by UCSD's RTL Public Health COVID-19 Response Team. Beginning in June 2020, all UCSD-affiliated students and employees who tested positive for COVID-19 were informed about the need to isolate and asked to identify all their close contacts since the start of their infectious period. Close contacts were defined as being within six feet of the case for a total of 15 minutes or more over a 24-hour period (36). Cases were interviewed either by telephone or online to elicit information about sociodemographics, symptoms, close contacts, and campus locations visited. Supplemental telephone interviews were conducted when necessary to ensure complete data collection. Given that all data used for this analysis were de-identified, the University of California San Diego Human Research Protection Program reviewed the study protocol and designated it as non-human subjects research.

Participant Selection

Beginning in June 2020, 16,782 CICT interviews were conducted by the RTL team and supplemented by staff from Student Health Services and UCSD Medical Center to varying degrees over the course of the pandemic due to changes in COVID-19 case rates and human resource availability. Given changes in CI data collection protocols over the course of the pandemic, we restricted our analysis to data from 3091 CIs that took place before December 31, 2021 when the CI form was most comprehensive. This period also represents a crucial time in infectious disease tracking and CICT, in part due to the pandemic and transmission mitigation efforts as a new phenomenon in this time period. When restricted to this date range, only cases from August 2020 to April 2021 were available.

Given the possibility that cases disclosed their close contacts differently depending on who conducted the interview, we only included data from cases interviewed by the RTL team for this analysis (Figure 1). We also excluded cases that were affiliated with UCSD through ancillary programs, such as UCSD Health, summer camps, and a campus-affiliated charter school. This exclusion was due to differing protocols of CICT within these programs. After the selection process, the final study population was limited to 968 COVID-19 cases between August 20, 2020 and April 18, 2021, including 546 cases within the student group and 422 cases in the employee group.

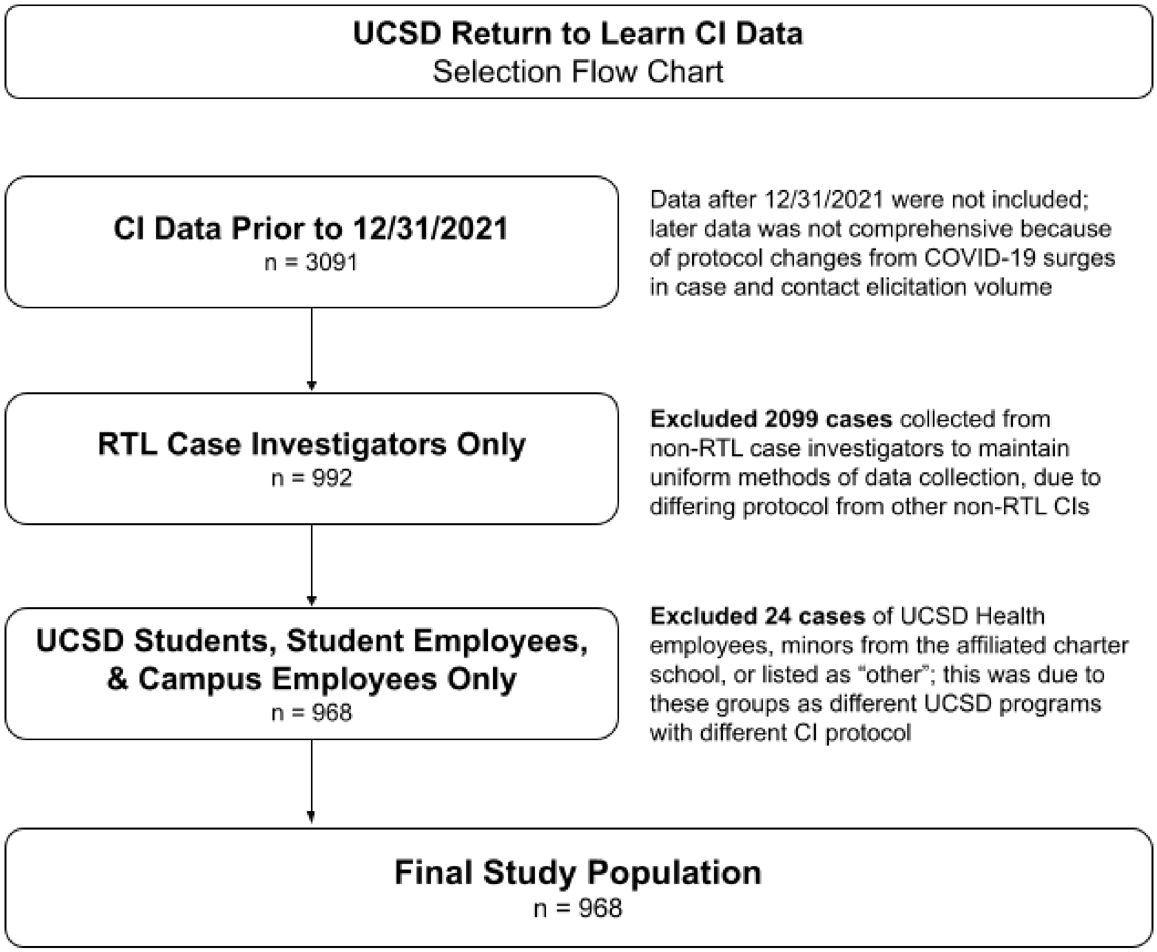

Figure 1. Flow diagram of the inclusion and exclusion criteria for the study population.

Study Variables

The dependent variable for this analysis was the number of close contacts per case. The number of close contacts per case were calculated in three ways: (1) the sum of close contacts per case, and (2) the mean number of close contacts per case per day. The sum of close contacts per case were used to assess the association between the number of contacts per case and sociodemographics. Second, the mean number of close contacts per case per day was calculated to be used for analysis over time and for comparison before and after COVID-19 mitigation strategy.

The independent variables in this analysis were obtained from the cases during case investigations. Sociodemographic variables included race, ethnicity, gender, age, UCSD affiliation (student, student employee, employee), housing status (on-campus vs. off-campus), and academic level (undergraduate vs. graduate). Sociodemographic variables with multiple binary values were re-coded to one categorical variable, including race and UCSD affiliation.

UCSD affiliation status was categorized by student, student employees, and campus employees. Analyses of the differences between the affiliation groups indicated a statistically significant difference in campus employees when compared to students, but students and student employees were not significantly different. Therefore, based on these findings, we re-coded student employees as students to create a binary variable for UCSD affiliation such that students (including student employees) were compared to employees.

Race groups were also re-coded and renamed to encompass the population within the group. For example, “White” was renamed “White, European, or Middle Eastern” to include those who racially identified as Middle Eastern more clearly in the analyses. Furthermore, a large amount of race and ethnicity data were missing either because it was optional for cases to provide this information or because cases were given the option to write-in their race and ethnicity. To include the written responses in the analysis, write-in race and ethnicity values were re-coded and integrated into the seven existing groups.

Age was re-coded into an ordinal variable with the following categories: 0-17 years old, 18-29 years old, 30-44 years old, 45-59 years old, and 60+ years old. Only three individuals were present in the 0-17 year old population. Two of these individuals were infants (0 years old), and the other individual was 17 years old. Based on the small sample size of this group, the one 17-year-old was placed into the 18-29 year old group and the two infants were excluded from analysis.

Lastly, housing status and academic level questions only applied to students. Therefore, analysis for housing and academic level were limited to cases that identified as students.

Statistical Analysis

Descriptive statistics (mean, SD, frequencies) for sociodemographic variables were computed. Univariate linear regression was used to investigate the association between number of close contacts and sociodemographic. Significance level for hypothesis testing (i.e., rejection of null hypothesis) was set at 0.05.

To assess the trajectory of the number of close contacts per case over time, we first summed the number of close contacts reported each day and divided by the total number of cases that day to obtain a mean number of contacts per case per day. We then examined this mean over the study period and used linear regression to determine whether it changed overall. Beta-coefficients, F-statistics, p-values, and 95% confidence intervals were computed for each regression model.

To examine whether key events were associated with a change in the number of contacts per case, we chose two events that we anticipated to impact the likelihood of social distancing practices: the California State Closure and Mask Mandate on November 16, 2020 (Event 1) and the lifting of the County of San Diego’s Stay-At-Home Orders on January 25, 2021

(Event 2) (49,50). For this analysis, we calculated the mean number of close contacts per case during a 30-day period before and after each event. The 30-day period was chosen based on COVID-19's infectious time period and isolation protocol of up to 20 days (51). We used linear regression analysis to determine whether the mean number of close contacts per case changed in the month following each event compared to the month prior to the event while controlling for potential confounding factors. Beta-coefficients, F-statistics, p-values, and 95% confidence intervals were calculated for each model. All analyses were performed using R statistical software (R Version 4.2.1) in RStudio.

Results

Demographics

Sociodemographic values were available for all 968 individuals (Table 1). Overall, 33.9% of the sample reported their race as White, European, or Middle Eastern and 46.7% reported their ethnicity as Non-Hispanic or Latino. Gender of the sample was distributed between females and males as 51.1% and 45.4%, respectively. Only a small proportion of the population identified themselves as other/not provided (3.3%) or as non-binary (0.2%). Overall, most cases were 18-29 years old (63.2%) or 30-44 years old (17.4%). As expected, students tended to be younger than employees.

Among the student population (N = 546) and employee population (N=422), the White, European, or Middle Eastern race group constituted a majority of each population at 34.4% and 33.2%, respectively. Both populations also had similar gender groups, with females constituting 50.5% of the student population and 51.9% of the employee population. However, age group and ethnicity differed between the two populations. The student population was largely 18-29 years old (94.0%), and those who were 30-44 years old (35.5%) constituted the majority of the employee population. Furthermore, those who identified as Hispanic or Latino encompassed 41.7% of the employee population, whereas Non-Hispanic or Latinos comprised 40.0%. In comparison, the student population was largely Non-Hispanic or Latino (52.2%) with a smaller percentage identifying as Hispanic or Latino (34.2%).

Those who did not identify their race, ethnicity, and age group made up 22.2%, 13.6%, and 2.0% of the student population, respectively. Approximately 2.2% of the student population did not provide a gender identity or identified with a gender not included in one of the stated categories. Regarding academic level and housing status most students lived off-campus (67.9%) and were undergraduate students (82.1%).

Table 1. Characteristics of COVID-19 cases who completed case investigation interviews by UCSD affiliation, August 20, 2020 - April 18, 2021.

	Total (N = 968) n (%)	**Student (N = 546) n (%)**	**Employee (N = 422) n (%)**
Race			
American Indian or Alaskan Native	2 (0.2)	2 (0.4)	0 (0.0)
Asian	183 (18.9)	143 (26.2)	40 (9.5)
Black or African American	37 (3.8)	13 (2.4)	24 (5.7)
Native Hawaiian or Other Pacific Islander	4 (0.4)	1 (0.2)	3 (0.7)
White, European, or Middle Eastern	328 (33.9)	188 (34.4)	140 (33.2)
Other Race or Multiple Races	146 (15.1)	78 (14.3)	68 (16.1)
Unknown/Not Provided	268 (27.7)	121 (22.2)	147 (34.8)
Ethnicity			
Hispanic or Latino	363 (37.5)	187 (34.2)	176 (41.7)
Not Hispanic or Latino	454 (46.9)	285 (52.2)	169 (40.0)
Other or Not Provided	151 (15.6)	74 (13.6)	77 (18.3)
Gender			
Female	495 (51.1)	276 (50.5)	219 (51.9)
Male	439 (45.4)	256 (46.9)	183 (43.4)
Non-Binary	2 (0.2)	2 (0.4)	0 (0.0)
Other or Not Provided	32 (3.3)	12 (2.2)	20 (4.7)
Age Group			
0-17	3 (0.3)	3 (0.5)	0 (0.0)
18-29	612 (63.2)	513 (94.0)	99 (23.5)
30-44	168 (17.4)	18 (3.3)	150 (35.5)
45-59	121 (12.5)	1 (0.2)	120 (28.4)
60+	29 (3.0)	0 (0.0)	29 (6.9)
Unknown/Not Provided	35 (3.6)	11 (2.0)	24 (5.7)

Table 1. Continued.

	Total (N = 968) n (%)	Student (N = 546) n (%)	Employee (N = 422) n (%)
Housing*			
On-Campus Housing		166 (30.4)	
Off-Campus Housing		371 (67.9)	
Not Provided		9 (1.6)	
Academic Level*			
Undergraduate Student		448 (82.1)	
Graduate Student		88 (16.1)	
Unknown/Not Provided		10 (1.8)	

**Only applicable for students*

Contacts Per Case

The number of cases per day and the number of close contacts per day were calculated overall and by student status over the entire study period (Table 2). The mean number of cases per day was 5.41; 4.63 among students and 2.93 among employees. The mean number of close contacts per case was 1.23 overall, 1.48 among students, and 0.91 among employees.

Table 2. Number of cases per day and close contacts per case for all cases, students only, and employees only.

	Number of Cases per Day		Number of Close Contacts per Case	
	Mean (SD)	**Median (IQR)**	**Mean (SD)**	**Median (IQR)**
All Cases	5.41 (7.38)	3.00 (1.00 - 6.50)	1.23 (2.02)	0.00 (0.00 - 2.00)
Students	4.63 (6.58)	3.00 (1.00 - 5.00)	1.48 (2.16)	1.00 (0.00 - 3.00)
Employees	2.93 (2.62)	2.00 (1.00 - 4.00)	0.91 (1.78)	0.00 (0.00 - 1.00)

SD: standard deviation
IQR: interquartile range (1st quartile, 3rd quartile)

Factors Associated with the Number of Close Contacts per Case

We observed a statistically significant difference in the number of contacts per case by age group and student status, but not by race, ethnicity, gender, housing status, or academic level (Table 3). The number of close contacts per case were 0.57 less on average for employees when compared to students ($p<0.001$). Furthermore, the number of contacts per case appeared to decrease with increasing age. The number of close contacts was 0.41 less in the 30-44 year old group and 0.48 less in the 45-59 year old group when compared to the 18-29 year old group, respectively ($p=0.02$). No differences were observed in the number of close contacts per case by race, ethnicity, or gender; however, the number of contacts per case was lower among cases who did not provide responses to these variables compared to those who did ($p<0.05$). Because individuals in these groups may not have provided data or refused to answer, data were excluded from further analyses.

Among students, there was no difference in the mean number of contacts per case by campus housing status (1.5 vs. 1.5, $p=0.82$). As expected, we found that undergraduate students had more contacts than graduate students, although the difference was not statistically significant (1.6 vs. 1.1, $p=0.08$).

Table 3. Number of close contacts per case by covariates among students and employees.

Group	Total (n=968)			Student Only (n=546)			Employee Only (n=422)		
	Mean	β (95% CI)	P-Value	Mean	β (95% CI)	P-Value	Mean	β (95% CI)	P-Value
Student v. Employee									
Student	1.5	Reference	<0.001*						
Non-Student	0.9	-0.57 (-0.82, -0.31)							
Race									
White, European, or Middle Eastern	1.3	Reference	0.5	1.5	Reference	0.32	1.0	Reference	0.93
American Indian or Alaskan Native	2.0	0.74 (-2.20, 3.68)		2.0	0.52 (-2.60, 3.63)		NA	NA	
Asian	1.4	0.16 (-0.22, 0.54)		1.5	0.01 (-0.47, 0.50)		1.2	0.19 (-0.47, 0.84)	
Black or African American	1.0	-0.29 (-1.01, 0.43)		1.4	-0.10 (-1.36, 1.16)		0.8	-0.21 (-1.02, 0.59)	
Native Hawaiian or Other Pacific Islander	0.5	-0.76 (-2.85, 1.32)		0.0	-1.48 (-5.88, 2.91)		0.7	-0.30 (-2.42, 1.83)	
Other Race or Multiple Races	1.6	0.31 (-0.11, 0.72)		2.1	0.64 (0.05, 1.23)*		0.9	-0.04 (-0.58, 0.50)	
Ethnicity									
Not Hispanic or Latino	1.4	Reference	0.32	1.6	Reference	0.81	1.0	Reference	0.52
Hispanic or Latino	1.3	-0.15 (-0.44, 0.14)		1.6	-0.05 (-0.47, 0.36)		1.1	-0.13 (-0.52, 0.27)	
Gender									
Female	1.2	Reference	0.93	1.6	Reference	0.79	0.8	Reference	0.22
Male	1.3	0.04 (-0.22, 0.31)		1.4	-0.11 (-0.48, 0.26)		1.1	0.22 (-0.14, 0.58)	
Non-Binary	1.0	-0.24 (-3.08, 2.59)		1.0	-0.56 (-3.58, 2.47)		NA	NA	
Age Group									
18-29^	1.4	Reference	0.02*	1.5	Reference	0.45	0.8	Reference	0.88
30-44	1.0	-0.41 (-0.76, -0.07)*		0.9	-0.65 (-1.67, 0.38)		1.0	0.18 (-0.29, 0.64)	
45-59	1.0	-0.48 (-0.87, -0.08)*		2.0	-0.46 (-3.81, 4.74)		0.9	0.09 (-0.39, 0.58)	
60+	1.1	-0.36 (-1.12, 0.40)		NA	NA		1.1	0.22 (-0.54, 0.98)	
Housing#									
Off-Campus				1.5	Reference	0.82			
On-Campus				1.5	0.05 (-0.35, 0.44)				
Academic Level#									
Undergraduate Student				1.6	Reference	0.08			
Graduate Student				1.1	-0.44 (-0.94, 0.05)				

^ This group includes one individual aged 17 years old.
# Housing and academic level only include values for the student only population.

Trends in the Mean Close Contacts per Case

Mean Number of Close Contacts per Case Over Time

A temporal trend was observed in the daily mean number of close contacts per case over time. Between August 20, 2020 and April 18, 2021, the mean number of close contacts per case increased by 0.02 each day (Figure 2). This increase in the mean number of close contacts was statistically significant ($p<0.001$). However, prior to December 2020, the average number of contacts per case was approximately zero.

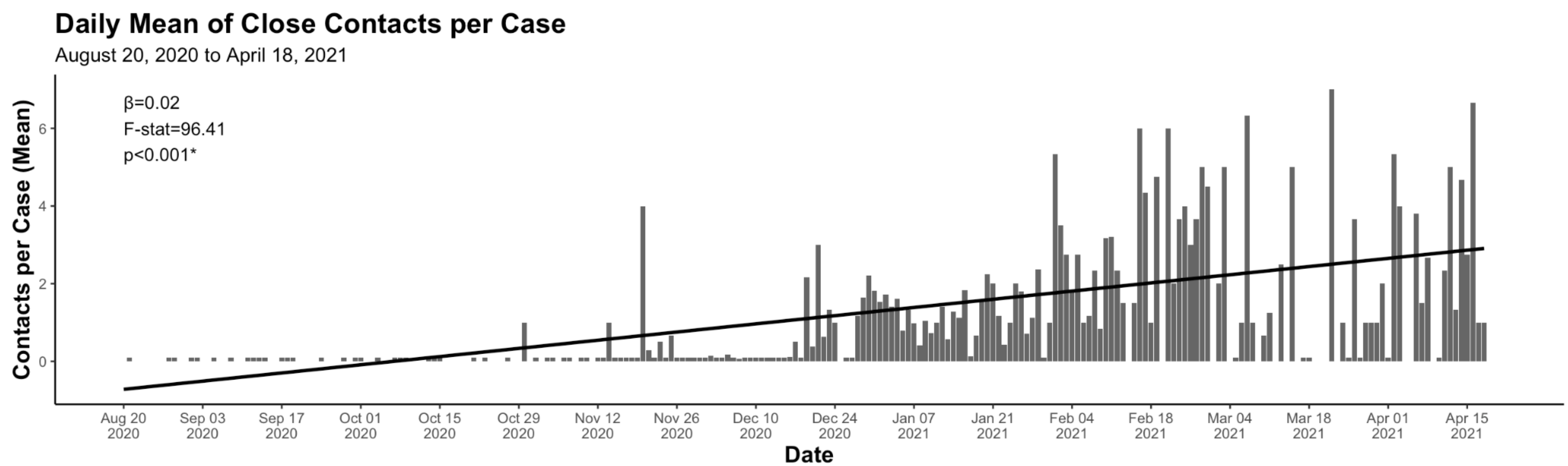

Figure 2. Mean number of close contacts per case by day between August 20, 2020 and April 18, 2021.

Change in Mean Number of Close Contacts per Case following COVID-19-Related Events

To determine whether the average number of close contacts per case changed after statewide business closures and mask mandates were instituted, we calculated the means for each period by summing the mean number of contacts per day and dividing by 30 days (Figure 3, Table 4). The mean numbers of close contacts per case before (0.13) and after (0.19) Event 1 were not statistically significantly different (p=0.76).

Table 4. Mean number of close contacts per case before and after the implementation of the California Closure and Mask Mandate.

Date Range	Mean	β (95% CI)	F-stat	p-value
California Closure and Mask Mandates Institued (Event 1) *November 16, 2020*				
Oct 16 - Nov 15	0.13	Reference	0.09	0.76
Nov 16 - Dec 16	0.19	0.06 (-0.34, 0.47)		

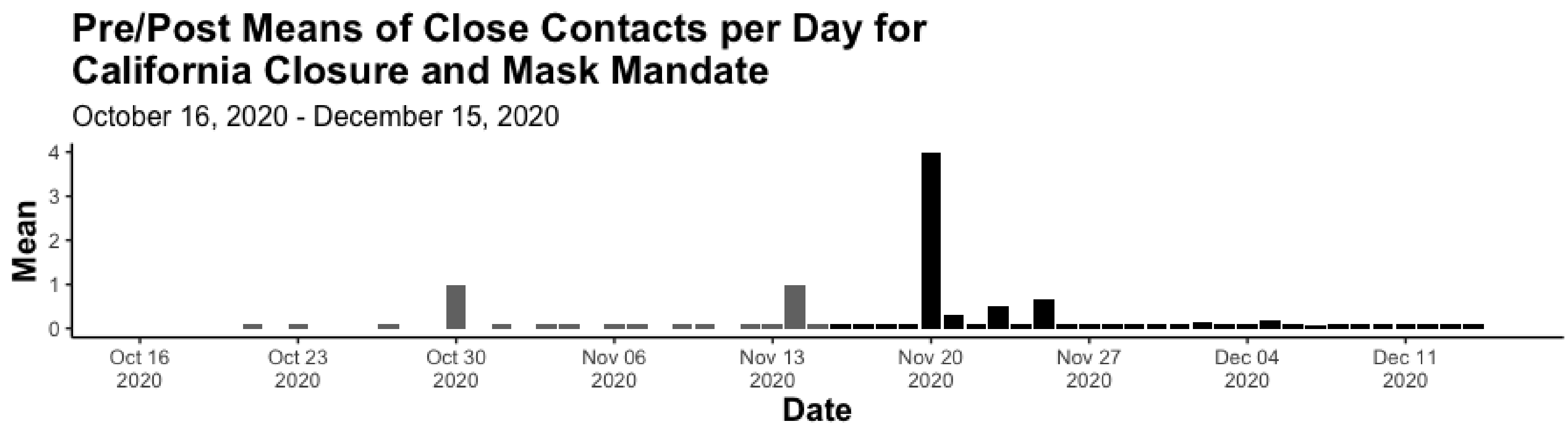

Figure 3. Mean number of close contacts per case per day for the California Closure and Mask Mandate event. The mean number of close contacts were categorized by before and after the event. Dark bars represent dates before the event and light bars represent dates after the event.

For the County of San Diego lifting of stay-at-home orders (Event 2), we observed a statistically significant increase in the mean number of contacts per case after Event 2 (Figure 4, Table 5) The mean number of contacts per case before the stay-at-home orders were lifted was 1.16 contacts/case in comparison to after the lifting of the orders at 2.55 mean number of contacts per case, respectively (p<0.001).

Table 5. Mean number of close contacts per case before and after the lifting of the County of San Diego stay-at-home orders.

	Date Range	**Mean**	**β (95% CI)**	**F-stat**	**p-value**
Stay-at-Home Orders Lifted (Event 2) *January 25, 2021*					
Pre	Dec 25 - Jan 24	1.13	Reference	19.36	<0.001*
Post	Jan 25 - Feb 25	2.55	1.39 (0.76, 2.02)		

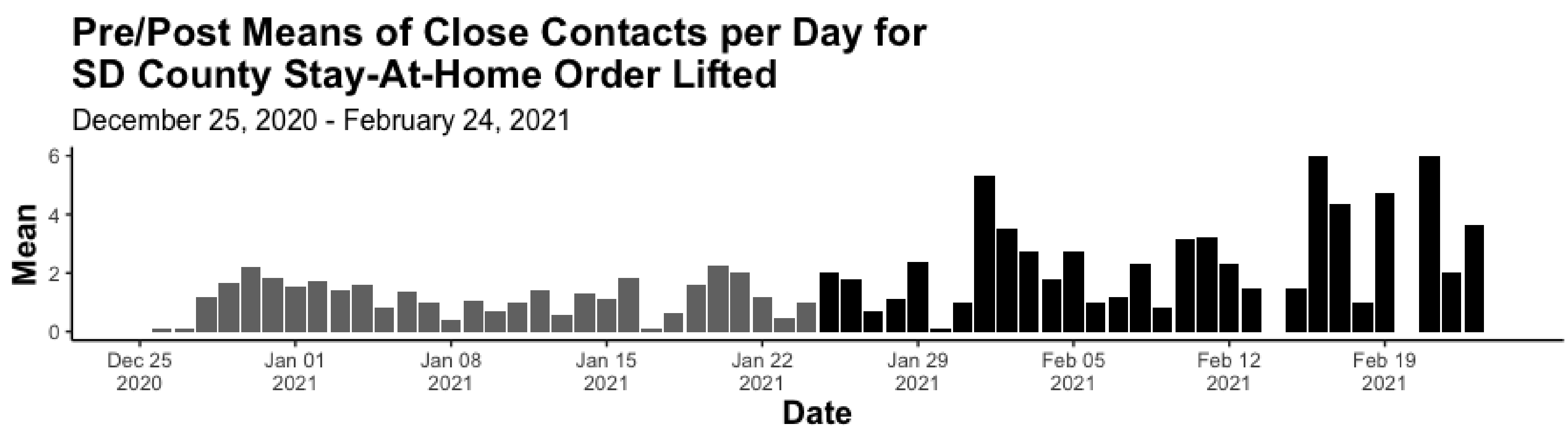

Figure 4. Mean number of close contacts per case per day for the lifting of the County of San Diego stay-at-home orders. The mean number of close contacts were categorized by before and after the event. Dark bars represent dates before the event and light bars represent dates after the event.

Considering the possibility that the increased number of close contacts per case following Event 2 was due to a difference in the demographics of the cases over time, we computed multivariable linear regression models adjusting for age and student status. We assessed these factors as potential confounders and effect modifiers (Table 6). After assessing for confounding, we found that student status and age groups (all p-values >0.05) were not significantly influencing the mean difference in the close contacts per case before and after Event 2. Furthermore, our findings indicate that student status and age were not effect modifiers (all p-values >0.05). Therefore, student status and age groups did not confound on or interact with the difference in mean close contacts for Event 2.

Table 6. Mean number of close contacts per case before and after the Stay-at-Home Orders were lifted (January 25, 2021), with adjustment for student status and age.

	β **(95% CI)**	**t-value**	**Pr(>|t|)**	**F-stat**	**p-value**
Model 1 (Adjusting for Student Status)					
Post *(Ref: Pre)*	1.17 (0.61, 1.73)	4.16	<0.001	8.78	<0.001
Employee *(Ref: Student)*	0.22 (-0.33, 0.78)	0.78	**0.43**		
Model 2 (Interaction by Student Status)					
Post *(Ref: Pre)*	1.06 (0.31, 1.82)	2.79	0.006	5.87	<0.001
employee *(Ref: Student)*	0.11 (-0.64, 0.87)	0.30	0.77		
Post * Employee	0.24 (-0.89, 1.37)	0.43	**0.67**		
Model 3 (Adjusting for Age Group)					
Post *(Ref: Pre)*	1.28 (0.73, 1.82)	4.65	<0.001	5.68	<0.001
30-44 years old *(Ref: 18-29 years old)*	0.33 (-0.33, 0.98)	0.99	**0.33**		
45-59 years old *(Ref: 18-29 years old)*	0.17 (-0.52, 0.86)	0.49	**0.62**		
60+ years old *(Ref: 18-29 years old)*	-0.06 (-1.07, 0.96)	-0.11	**0.91**		
Model 4 (Interaction by Age Group)					
Post *(Ref: Pre)*	1.29 (0.47, 2.10)	3.13	0.002	3.21	0.003
30-44 years old *(Ref: 18-29 years old)*	0.41 (-0.47, 1.29)	0.92	0.36		
45-59 years old *(Ref: 18-29 years old)*	0.13 (-0.74, 1.00)	0.29	0.77		
60+ years old *(Ref: 18-29 years old)*	-0.12 (-1.35, 1.12)	-0.19	0.85		
Post * 30-44 years old	-0.20 (-1.55, 1.14)	-0.30	**0.77**		
Post * 45-59 years old	0.16 (-1.31, 1.63)	0.21	**0.83**		
Post * 60+ years old	0.21 (-2.03, 2.46)	0.19	**0.85**		

Discussion

In this study of 968 UCSD students and employees, we found the number of close contacts were associated with sociodemographic factors, time, and COVID-19 events. The number of close contacts per case were significantly associated with the sociodemographic factors of age and student status (0.02 and <0.001, respectively). We also found a positive trend in the mean number of close contacts per case over time (<0.001). Lastly, the mean number of close contacts per case per day significantly differed when assessing values before and after the lifting of COVID-19 stay-at-home orders but not for the California closure and mask mandate implementation (<0.001 and 0.76, respectively).

First, older age groups had significantly fewer close contacts per case in comparison to the 18-29 year old age group, and the number of close contacts differed between students and employees affiliated with the university. These findings aligned with our hypothesis that students and younger cases would have more contacts than cases who were employees and older. Importantly, we did not observe a difference in the number of close contacts between cases that lived on versus off campus.

This may be due to a multitude of reasons, such as adherence values as well as knowledge of COVID-19 cases, hospitalization, and mortality rates. A study done on early COVID-19 data from the National Center for Health Statistics and the U.S. Census Bureau found that COVID-19 mortality rates increased by age in all sex, racial, and ethnic groups in March to June 2020 and November 2020 to February 2021 (52). News and announcements may have increased adherence to social distancing practices in older age groups in order to reduce the risk of getting COVID-19. A study done in older adults with chronic health conditions found that many perceived the COVID-19 outbreak as a serious threat and that the outbreak impacted their daily routine (53). These perceptions and mortality rates in older adults could have increased adherence to mitigation efforts like social distancing that would reduce the number of close contacts and transmission of the virus.

In addition, over 83% (513 students v. 612 total) of the study population were students in the 18-29 year old age group. This large number of students in the study population could potentially have had more close contacts with others due to their presence on campus, attending classes. During the early months of the pandemic, UCSD shut down most in-person campus activities, moved course instruction online, and vacated campus housing (Supplemental File 1). Students and many campus employees were advised to stay home and not go to campus unless required. However, students were able to return back to in-person courses in Fall 2021 (Supplemental File 1). The shift back to in-person learning brought a large number of students back into classrooms, leading to an increase in the number of close contacts. This appears to be reflected in our findings, as the number of close contacts overall were higher in students when compared to employees (1.48 v. 0.91; Table 2).

Second, there was a positive trend in the mean number of close contacts per case over time. We found that there was an increase in the mean number of close contacts per case each day between August 2020 and April 2021. These findings aligned with our hypothesis that the mean number of close contacts increased as more people had natural or vaccine-induced immunity to COVID-19, business reopened, and pandemic fatigue set in. However, the mean number of close contacts did not steadily increase from zero until mid-December 2020. This phenomenon may have been due to perceptions of COVID-19 severity as well as adherence to social distancing protocols throughout the pandemic. According to a study done within the U.S., many individuals felt the negative emotions of stress and worry early in the pandemic, but these emotions decreased by mid-2021 (54). This decrease in stress and worry could be attributed to changes in behavior due to quarantine fatigue, psychological resilience, and adaptation to the presence of COVID-19 (42–44,54,55).

The approval and first implementation of the vaccine could be associated with the decrease in stress and worry along with an increase in mean close contacts (Supplemental File 1). The first COVID-19 vaccine was introduced in early December 2020 under an emergency use authorization (EUA) by the U.S. Food and Drug Administration (14). Distribution of the vaccine followed shortly after the EUA, with the first vaccination announced widely through several news outlets and its authorized use for people 18 years or older in mid-December 2020 (14,56). These events may have decreased negative emotions and adherence to social distancing efforts, leading to an increase in the mean number of close contacts per case.

Lastly, there was a statistically significant increase in the mean number of close contacts per case after the San Diego County lifted its Stay-at-Home orders, in comparison to when the orders were in place one month prior. These findings are in agreement with our hypothesis that the mean number of close contacts would increase after COVID-19 mandate-related orders were lifted. The increase in mean close contacts per case after the orders were lifted potentially led to a decrease in social distancing and an increase in social gathering, which suggests an inverse relationship between the two. Case rates from the County of San Diego depicted a decrease in cases during this time (57). This case rate decreased after the end of Stay-at-Home orders may have given UCSD affiliates confidence that it was safe to socialize again and contributed to the increase in the number of contacts.

Age group and student status did not confound or interact with these values. The increase in mean close contacts per case may have been due to Quarantine Fatigue and the impact of lockdown measures on an individual's mental health (40–44,58,59). Specifically, two studies on higher education students and the impact of stay-at-home orders found that students reported mental health issues during the shutdown of academic institutions; participants indicated feelings of stress, anxiety, and depression (41,58). Similarly, a study among older adults found increases in reported loneliness, anxiety, and depression (59). These negative impacts on mental well-being for younger and older adults may have led to decreased social distancing after the stay-at-home orders were lifted in order for individuals to address their mental well-being.

Limitations

Some limitations should be considered when interpreting the results of this study. First, the date range for the analyses was limited to eight months due to the availability of complete data from cases. Because of this narrow date range, we were unable to examine the impact of other important COVID-19-related events (e.g., the end of the California Tiered mandates, Delta and Omicron variants becoming a VOC, and the Omicron surge). Second, some variables in this analysis contained subgroups with small sample sizes (e.g., gender and race). Consequently, findings may not exhibit the true association of gender and race with the number of close contacts and may not be generalizable to all races and genders.

Second, linear regression was used as the statistical method to analyze associations with the number of close contacts per case over time and by mitigation effort. Our findings from this analytic method may have been skewed due to a non-normal distribution of a large number of zeros reported by cases. Further research with a different statistical method that compares medians rather than means may address the non-normal distribution of the zeros in the data.

Third, an underreporting of close contacts may have been a limitation in our study. This phenomenon may have been influenced by a fear of repercussion after indicating their close contacts, reducing a case's willingness to provide information. Changes in policies for students and quarantining may have deterred cases to indicate close contacts if there was a relationship to the case. In turn, the number of contacts per case could have been artificially lower and may have changed later on due to a greater willingness to name contacts. However, there was no way to indicate whether this occurrence happened, and therefore, we reported data as we observed it.

Lastly, a non-trivial number of cases did not report their race (27.7%), ethnicity (15.6%), or gender (3.3%), which may impact the generalizability of our study. Further research is needed to understand why cases refused to report their race, ethnicity, or gender, and how they differ from those who did. There are myriad reasons why cases might not enumerate all of their contacts during CI (e.g., problems with recall, not knowing the identity of their contacts, fear of disclosure, distrust of the health system, etc.); thus, the number of contacts elicited during CIs could underestimate the actual number of contacts. However, this reporting bias should be uniform over the study period such that it should not bias our measurement of the trends and associations with values for contacts per case.

Conclusion

Our findings provide evidence that the number of close contacts reported by cases during university-led case investigations increased over time and was associated with age and student status, but not associated with campus housing, race, ethnicity, or gender. Among students, there was a trend towards undergraduates having more contacts than graduate students, but this was not statistically significant. The number of contacts per case did not decrease after instituting business closures and mask mandates, as expected, perhaps because people were already practicing social distancing at the time of implementation. Conversely, there was a statistically significant increase in the number of contacts per case following the lifting of Stay-at-Home orders in San Diego County, which was not attributable to age or housing location among the cases. This study included a large, diverse population of COVID-19 cases affiliated with a public university, which sheds light on how individuals behaved during the COVID-19 pandemic. Future research could investigate whether other COVID-19 milestones might impact social distancing and other mitigation measure adherence in larger populations. Overall, our findings suggest that COVID-19 mitigation measures had a positive impact on promoting social distancing among university-affiliated students and employees.

Chapter 3. Discussion

This study was done in order to evaluate the behaviors of social distancing through close contacts of cases within the UCSD community. Within this study, a timeline of COVID-19 events, data curation, and analysis were done in order to provide insight on how COVID-19 information and events could be associated with the amount of close contacts.

Literature Review

Data from transmission mitigation efforts were collected through a literature review of historical information from several sources at different levels of governing bodies. COVID-19 information about campus mitigation efforts was obtained through the RTL program and website documentation. County and state-level mandates were gathered from government websites and online sources with timelines. Mitigation measures at the national level were assessed through a timeline assembled by the Center of Disease Control and Prevention (CDC) (14). Secondly, COVID-19 variant information was collected through county-level data.

This historical information was utilized to produce a timeline showing when important mitigation strategies were implemented at the national, state, local and university levels (Supplemental File 1; *see Appendix*). This timeline was utilized to determine COVID-19 milestones for assessment of mean close contacts per case per day.

Data Curation

Race/Ethnicity and Case Status

When data were obtained from the RTL team, some variables in the dataset were indexed based on the output of REDCap into binary variables. In order to address this for sociodemographic variables, the data were re-coded in R to combine all binary variable options into one categorical variable. This process included uniting all of the binary variables together and outputting values in the following format: 0/1_0/1_0/1_etc. These values were then re-coded to the indicated value.

Race was one survey question with seven options (e.g., White, Black or African American, American Indian or Alaska Native, Native Hawaiian or Pacific Islander, Asian, Other Race or Mixed Race, and Unknown) in the interviewer-administered questionnaire, but it was represented in the dataset as several variables with binary values (0, 1) (e.g., race_white = 0 or 1). All race variables were united and outputted in the following format: 0/1_0/1_0/1_0/1_0/1_0/1_0/1, with each 0/1 being either 0 (no) or 1 (yes) (Supplemental Table 1; *see Appendix*). Those who only had one value of 1 within the new variable were re-coded to a value; those who had more than one value of 1 in the new variable were categorized as "Other Race or Mixed Race". Furthermore, those who wrote in their race were re-coded to be one of the seven value options. These groups for race were based on the standards set in place by the 1997 Office of Management and Budget (OMB) standards utilized by the U.S. Census Bureau (60).

One major change to the Race category of those who identified as White was the inclusion of European or Middle Eastern individuals. OMB standard and RTL collection processes utilize the name "White" for those who identify themselves as White, European, or Middle Eastern. To be more inclusive to the European and Middle Eastern communities in the study population, the name in the analysis was changed from "White" to "White, European, or Middle Eastern".

Case status followed a similar format to the Race variable for the re-coding process. There were six values for case status: Student, Campus Employee, Health System Employee, UCSD Community Minor, Preuss, and Other. After uniting the values from each binary variable, the values were re-coded to be Student, Student Employee, Campus Employee, and Other. Student employees were individuals that selected 1 for both Student and Campus Employee. Other encompassed Minors, Health System Employees, and those who identified as Other.

The variable of Student Status was obtained through analysis of the Case Status variable. Case status pertained to UCSD affiliations of students, student employees, and campus employees. When compared to the student group, the number of close contacts for campus employees was significantly different but were not statistically different for student employees (Supplemental Table 2, *see Appendix*). Because student employee close contact values were not statistically different to students, they were combined into one group “Student” and the campus employees were referred to as “Employee”.

Ethnicity, Gender, Housing Status, and Academic Level

Ethnicity, Gender, Housing Status, and Academic Level were outputted as categorical variables with values starting at 1. Ethnicity had three values: Not Hispanic or Latino (1), Hispanic or Latino (2), and Other or Not Provided (3). Gender had four values: Male (1), Female (2), Non-binary (3), and Other or Not Provided (4). Housing status and Academic Level were obtained from the questionnaire with input from students only, with two variable values each. Housing Status values were either on-campus (1) or off-campus (2), and Academic Level values were undergraduate student (1) or graduate student (2). All values for Ethnicity, Gender, Housing, and Academic Level were re-coded to their categorical names for analysis.

Some individuals did not select one of the standard categories for race and ethnicity, but rather wrote it out in the questionnaire. Written values for race and ethnicity were re-coded based on standards by OMB and the U.S. Census Bureau (61).

Age

Data on age were collected as a numerical value. For analysis purposes, age was re-coded to a categorical variable by grouping ages together. There were five categorical values made for the age group variable: 0-17 years old, 18-29 years old, 30-44 years old, 45-59 years old, and 60+ years old. Only three cases were found in the 0-17 year old group, with one individual 17 years old and the other two identified as 0 years old. Because of the small sample size of this group, the 17 year old was included in the 18-29 year old group and the two who were identified as 0 years old were excluded from analyses.

Close Contacts (Cumulative and Mean)

Valid close contacts were utilized in the study, which were close contacts that case investigators validated as true close contacts to the case. The cumulative number of valid close contacts per case was calculated by summing the number of values present within each valid close contact column. This numerical value was listed in a new column for the number of close contacts by case. Furthermore, the mean number of close contacts per case per day was calculated through counting the close contact count values within a respective day and dividing by the number of cases per day that included a value for close contacts.

Timeline

The timeline of June 2020 to December 2021 was utilized for the analysis of this study. Although data existed for dates after December 2021, we wanted to assess the preliminary accounts of close contacts and social distancing behaviors in the early stages of the pandemic. This time period included the introduction of new mitigation measures such as stay-at-home orders, vaccinations, and new variant information for COVID-19. Additionally, we wanted to look at the initial responses to mitigation measures and social distancing before the Delta and Omicron variant spikes. These spikes were associated with changes in social distancing protocols as well as CICT data gathering protocols. For the temporal analysis of mitigation measures with the average number of close contacts, only the time range of August 2020 to April 2021 was utilized. This was due to a limited number of mean close contact values within the student and employee populations.

This 8 month time frame to identify preliminary behaviors of social distancing by proxy of close contacts limited our analysis. Many mitigation measures and COVID-19-related events occurred after April 2021 and were not included in the study. These events, such as the implementation of vaccines and the presence of new, more transmissible variants were integral in the social distancing behaviors of individuals and communities.

Study Findings

Demographics

Demographics for each case within the sample population were obtained, which included race, ethnicity, gender, and age. The population was primarily White (33.9%), including those who identified as European or Middle Eastern. Asians (18.9%) were the second largest racial group, followed by those who identified as a race not listed or as more than one race (15.1%). Furthermore, those who did not provide information regarding their race comprised 27.7% of the population. In terms of ethnicity, the population was distributed between Hispanic or Latino and Not Hispanic or Latino groups at 37.5% and 46.9%, respectively. Only 15.6% of the population did not provide ethnicity data. Gender was also evenly distributed by male and female (45.4% and 51.1%), but also included some individuals who identified as non-binary (0.2%). There were also 3.3% that did not provide data on their gender. Among the age groups, 18-29 year olds were the largest group at (63.5%), followed by 30-44 year olds (17.4%), and 45-59 year olds (12.5%). Those who identified as 60 years or older made up 3.0% of the population, and those who did not provide an age group constituted 3.6% of the population.

Students and employees constituted 56.4% and 43.6% of the population, respectively. For students within the sample population, housing and academic level were also obtained. The majority of students lived off-campus (69.7%). Additionally, 30.4% of students lived on-campus during the time of their interview and only 9% did not provide data on their housing situation. For student’s academic level, the majority were undergraduate students (82.1%). Graduate students made up 16.1% of the sample population. Overall, the sample population included a diverse set of communities among the sociodemographic factors of race, ethnicity, gender, housing, and academic level.

Sociodemographics & Number of Close Contacts

Sociodemographic factors were assessed in relation to the number of close contacts per case. Unknown, Other, or Not Provided values for race, ethnicity, and gender were excluded from the analysis. Based on our findings, student status and age group were the only sociodemographic factors that were statistically associated with the number of close contacts per case, with p-values of <0.001 and 0.02, respectively. Individuals within the 30-44 year old age group and 45-59 year old age group were significantly different in the number of close contacts per case when compared to the reference population of 18-29 year olds.

There was no statistically significant association between the number of close contacts per case and race ($p>0.05$), ethnicity ($p=0.32$), gender ($p=0.93$) among the entire study population. Housing and academic level for the student only population was also not statistically significant with the number of close contacts per case with p-values of 0.82 and 0.08, respectively. Additionally, no group within race and gender were statistically different in the number of close contacts per case in comparison to their respective reference groups.

When looking at the student and employee populations separately for each sociodemographic factor, similar outcomes were found. There were no statistically significant associations for the number of close contacts and race ($p=0.32$), ethnicity ($p=0.81$), gender ($p=0.79$), and age group ($p=0.45$) for the student-only population. In the employee population (i.e., campus employees only), the variables of race ($p=0.93$), ethnicity ($p=0.52$), gender ($p=0.22$), and age group ($p=0.88$) were also not associated with the number of close contacts per case. Furthermore, there were no significant differences in the number of close contacts per case for gender and age groups when compared to their respective reference group in both the student and employee populations. For race, only the Other Race or Multiple Race group was significantly different when compared to the White, European, or Middle Eastern race group.

Overall, our findings align with our hypothesis that age group and student status would be associated with the number of close contacts per case. However, our findings did not indicate an association between housing status and the number of close contacts per case. These associations may be due to a variety of factors, including the risk levels of COVID-19 infection in older populations compared to younger populations. During the early period of the pandemic, older age groups were more likely to face higher mortality rates from COVID-19, when compared to younger age groups (62). Furthermore, older adults with chronic health conditions were found to perceive the COVID-19 outbreak as a serious threat that negatively impacted their daily routine (53). These factors may have led to younger age groups to lessen their adherence to social distancing efforts, potentially increasing the number of close contacts. Because age group and student status were significantly associated with the number of close contacts per case, these sociodemographic factors were included in analyses for the mean number of close contacts as potential confounding and interaction variables.

Trends & Mean Number of Close Contacts

The mean number of close contacts per case per day were assessed by two trends. First, we assessed the mean number of close contacts per case over time. We found an 0.02 statistically significant increase in the mean number of close contacts each day (Table 3). However, the mean number of close contacts per case did not begin to increase until mid-December 2020. This trend may be due to a variety of factors, including changes to an individual's perception of risk towards potential exposure to COVID-19, quarantine fatigue, and the negative impact of isolation on mental well-being due to prolonged stay-at-home orders (40–44,58,59). These findings support our hypothesis that the mean number of close contacts was associated with time.

Second, the mean number of close contacts per case were assessed before and after two COVID-19-related events (Table 4, Table 5). On November 16, 2020, Governor Gavin Newsom ordered all non-essential businesses to close down for all California counties (49). Only essential businesses, such as grocery stores, pharmacies, and hospitals, were allowed to operate during the California closure. In addition, all California residents were required to follow the mask mandate. The mask mandate stated that masks must be worn at all times when outside of one's place of residence (49). The other event related to COVID-19 efforts was the lifting of Stay-at-Home orders on January 25, 2021. Stay-at-Home orders were set in place to increase social distancing by requiring people to stay within their household unless for essential business purposes (50). This event occurred at the state and county level for California, allowing individuals to leave their homes for non-essential reasons (63).

Based on pre/post regression analysis of the mean close contacts per case, Event 1 did not have a statistically significant difference when comparing one month after the event to one month before ($p=0.76$). California's state closure and the mask mandate may not have impacted social distancing and close contacts due to a few factors. First, the months surrounding the state closure and mask mandate were part of a season with several federal and observed holidays. These holidays designate a time where students and campus employees may have gone to social gatherings and visited family and friends. Therefore, there may not have been a statistically significant change before and after Event 1, or there were not enough students and employees on campus to test for COVID-19 at that time.

For Event 2, the mean of close contacts per case differed significantly before and after the Stay-at-Home orders were lifted. More specifically, there was an increase in the mean number of close contacts per case in the month after the Stay-at-Home orders were lifted ($p<0.001$) after evaluation of confounding and effect modification for age group and student status, which provided evidence to support our hypothesis. Aside from the freedom to leave their homes, this statistically significant change in the mean number of close contacts per case may have been due to Quarantine Fatigue, in which people were decreasing their adherence to social distancing and other mitigation measures due to exhaustion of adhering to mitigation efforts. This fatigue may have been due to the impact of lockdown orders and isolation on mental health. According to studies investigating mitigation efforts and mental well-being, many people had an increase in mental health issues - including anxiety, depression, and loneliness - during the pandemic (39–45,58,59). In these studies, both student-aged individuals and older adults had similar issues with their mental well-being during lockdown measures (41,58,59). These studies provide an understanding for our findings that show how social distancing behaviors impacted individuals, regardless of student status and age.

Conclusion

Future research can be done to identify other COVID-19-related events and milestones, such as the presence of new transmissible variants and the implementation of vaccines, to determine whether these factors may impact on social distancing behaviors. Furthermore, future studies can assess individual and community perceptions of adherence to mitigation efforts through qualitative assessment and community interviews. Future studies can also utilize other statistical methods, such as median value analysis for the number of contacts per case rather than the mean, which may address the non-normal distribution of zero values in the study.

Findings from this study showed that COVID-19-related events, time, and sociodemographic factors may have an impact on responses and adherence to social distancing measures. These findings suggest that a disease's impact through time, type of mitigation efforts, and sociodemographic factors should be taken into consideration when applying mitigation efforts within communities. Future mitigation efforts for COVID-19 and other potential infectious diseases need to address phenomena like quarantine fatigue in order to support different communities and reduce the spread of disease. Overall, our study can guide future mitigation efforts and policy planning towards global health diseases.

Appendix

Supplemental File 1. Timeline of COVID-19 Milestones and Mitigation Efforts.

This file includes a table with a list of mitigation measures that were enacted, updated, changed, or terminated as well as milestones that occurred throughout the first 2+ years of the COVID-19 pandemic. The events are categorized into four groups: International/National, State (All 50), County of San Diego, and UC San Diego campus.

Supplemental Table 1. Frequency of united Race values during the re-coding process, categorized by the number of case-indicated race values.

Race	Race Code	Count	Race	Race Code	Count
0-1 Case-Indicated Race Values					
No race values obtained	0_0_0_0_0_0_0	33	American Indian or Alaskan Native	0_0_0_1_0_0_0	2
White, European, or Middle Eastern	1_0_0_0_0_0_0	308	Native Hawaiian or Other Pacific Islander	0_0_0_0_1_0_0	3
Asian	0_1_0_0_0_0_0	165	Other Race or Mixed Race	0_0_0_0_0_1_0	197
Black or African American	0_0_1_0_0_0_0	38	Unknown (case cannot/refuses to declare)	0_0_0_0_0_0_1	193
2 Case-Indicated Race Values					
White, European, or Middle Eastern; Asian	1_1_0_0_0_0_0	9	Asian; Native Hawaiian or Other Pacific Islander	0_1_0_0_1_0_0	2
White, European, or Middle Eastern; Black or African American	1_0_1_0_0_0_0	2	Asian; Other Race or Mixed Race	0_1_0_0_0_1_0	19
White, European, or Middle Eastern; Native Hawaiian or Other Pacific Islander	1_0_0_0_1_0_0	1	American Indian or Alaskan Native; Other Race or Mixed Race	0_0_0_1_0_1_0	1
White, European, or Middle Eastern; Other Race or Mixed Race	1_0_0_0_0_1_0	15	Native Hawaiian or Other Pacific Islander; Other Race or Mixed Race	0_0_0_0_1_1_0	1
Asian; Black or African American	0_1_1_0_0_0_0	1	Other Race or Mixed Race; Unknown	0_0_0_0_0_1_1	1
3+ Case-Indicated Race Values					
White, European, or Middle Eastern; Asian; Other Race or Mixed Race	1_1_0_0_0_1_0	1	White, European, or Middle Eastern; Black or African American; American Indian or Alaskan Native; Native Hawaiian or Pacific Islander	1_0_1_1_1_0_0	1

Supplemental Table 2. Comparison of the number of close contacts per case by case status (students, student employees, and campus employees).

	Beta (95% CI)	**p-value**
Student	Reference	
Student Employee	-0.15 (-0.55, 0.25)	0.47
Campus Employee	-0.61 (-0.88, -0.34)	<0.001*

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