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Original article

Temporal variation in individual social risk factors associated with testing positive for SARS-CoV-2 among veterans in the veterans health administration

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ABSTRACT

Purpose: Marginalized communities have been disproportionally impacted by SARS-CoV-2. How the associations between social determinants of health and the risk of SARS-CoV-2 infection shifted across time is unknown. In this evaluation, we examine individual-level social determinants of health as social risk factors for SARS-CoV-2 infection across the first 12 months of the pandemic among US Veterans.
Methods: We conducted a retrospective cohort analysis of 946,358 Veterans who sought testing or treatment for SARS-CoV-2 infection in U.S. Department of Veterans Affairs medical facilities. We estimated risk ratios for testing positive by social risk factors, adjusting for demographics, comorbidities, and time. Adjusted models were stratified by pandemic phase to assess temporal fluctuations in social risks.
Results: Approximately 19% of Veterans tested positive for SARS-CoV-2. Larger household size was a persistent risk factor and this association increased over time. Early in the pandemic, lower county-level population density was associated with lower SARS-CoV-2 infection risk, but between June 1 and August 31, 2020, this trend reversed.
Conclusions: Temporal fluctuations in social risks associated with Veterans' SARS-CoV-2 infection suggest the need for ongoing, real-time tracking as the social and medical environment continues to evolve.

Introduction

Marginalized communities and people of color have been heavily impacted by the COVID-19 pandemic [1–6]. Social determinants of health (SDoH) have been increasingly acknowledged as powerful drivers of COVID-19-related health inequities [7–18]. Key SDoH such as access to health care, precarious or essential work, limited transportation, living in areas of higher population density, and economic instability have been associated with increased SARS-CoV-2 infection risk [7–18]. In particular, persons with lower incomes are more frequently employed in precarious jobs with lim-

Abbreviations: SDoH, Social determinants of health; USVETS, United States Veterans Eligibility Trends and Statistics; VA, U.S. Department of Veterans Affairs; FPL, Federal poverty level.

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ited autonomy over working hours, jobs with limited sick leave or, 'essential' jobs that put them at higher risk of exposure to SARS-CoV-2 [19, 20]. Additionally, crowded living arrangements can further increase SARS-CoV-2 transmission rates [19–22]. While many industries shifted to remote work to reduce infection rates, this unequally favored jobs belonging to highly educated or higher income persons; excluding those with 'essential' jobs such as grocery store clerks or meat-processing workers [5, 16]. Population density or rurality is also an important social risk to consider as higher population density can promote the spread of SARS-CoV-2 [5, 23]. Conversely, rural residents experience additional contributing factors such as poverty, limited transportation, lower healthcare access, lower engagement in preventative health behaviors such as mask wearing [24, 25].

While the role of SDoH in SARS-CoV-2 infection risk has been highlighted during the pandemic, most data on social risk factors are collected on an aggregate level (e.g., county) that may introduce exposure misclassification. SDoH data on an individual level, which are more proximal to individual health outcomes, are not commonly available. Furthermore, while the role of SDoH and SARS-CoV-2 positivity has been well established, it is unknown how the associations may have shifted over the first year of the pandemic as SARS-CoV-2 spread from metropolitan centers to rural areas [26]. In this analysis, we examine individual-level SDoH such as household size, poverty levels, and education as risk factors for SARS-CoV-2 infection across the first 12 months of the pandemic among a large nationwide population of US Veterans, controlling for underlying chronic conditions and site of care. We furthermore examine these associations over time as new hotspots of SARS-CoV-2 infection appeared across the US and as new knowledge about SARS-CoV-2 transmission and prevention developed.

Methods

Data source and study population

We conducted a retrospective cohort analysis of 1,108,172 Veterans enrolled in U.S. Department of Veterans Affairs (VA) health care who sought testing or treatment for SARS-CoV-2 infection in VA facilities between February 27, 2020 (earliest reported test) and February 16, 2021 and were included in the 2019 annual United States Veterans Eligibility Trends and Statistics (USVETS) dataset. Drawing from 35 data sources (e.g., Department of Defense, Veterans Health Administration, and Social Security Administration), USVETS provides a comprehensive profile on US Veteran military history, socioeconomic characteristics, and utilization of VA benefits and services. We identified Veterans tested or treated for SARS-CoV-2 infection using the VA COVID-19 Shared Resource, a national database intended to be the single authoritative source for positive and negative SARS-CoV-2 cases within VA.

We retrieved patient demographics (e.g., age, sex, race/ethnicity, zip code) and diagnoses of chronic medical conditions from VA electronic health record data from the VA Corporate Data Warehouse [27]. Race and ethnicity was combined into a single race/ethnicity variable, with individuals of Hispanic ethnicity included in the Hispanic group regardless of any other race. Individuals without a race or ethnicity recorded in their health record were categorized as "Missing/Unknown." We included chronic conditions documented by the Centers for Disease Control (CDC) to increase the risk of severe morbidity and mortality post-SARS-CoV-2 infection: lung cancer, chronic obstructive pulmonary disease, heart failure, ischemic heart disease, diabetes, hemodialysis, end stage chronic kidney disease, cigarette smoking, and obesity (body mass index > 30) [28].

We sourced individual-level SDoH data from the 2019 USVETS dataset. We selected key SDoH variables a priori based on existing literature on health inequalities for COVID-19: including household size, presence of child in the house, income, marital status, and education [16, 18]. Variables were recoded where necessary: household size (1,2,3,4,>4), presence of child in the household (y/n), marital status (married/ not married), education level (high school/vocational, college, graduate school), household income level (<100% federal poverty level (FPL), 100%–200% FPL, >200%–400% FPL, >400% FPL). Household income status was created by combining data from the household size and categorized income variables based on the 2019 federal poverty guidelines, adjusting for differences among the 48 contiguous states, Alaska, and Hawaii [29].

We also created a proxy variable of rurality of home based on the population density of the county of residence. Population density categories were adapted from urban/rural standards commonly used in VA: fewer than 2.7 people/km^2 was chosen from a VA definition of highly rural (<7 people per square mile) and the cut off of 387 people/km^2 was adapted from the US census for an urbanized area (1000 persons per square mile) [30, 31]. Categories of population density between the two a priori definitions were defined such that each category was a quantile of equal size.

We matched each Veteran's home zip code to the county-level population density (persons per square mile) from the U.S. 2010 Census and the 7-day rolling county-level per capita SARS-CoV-2 cases from the Johns Hopkins COVID-19 Dashboard in the previous week before each individual test date [32, 33]. For individuals with multiple tests, we used the date of the first positive test or the date of the first negative test if they never tested positive.

To assess temporal changes in risk factors, we identified five phases of the pandemic based on distinct cyclical patterns in national SARS-CoV-2 incidence data from when incidence levels began to rise, crested, and then reached the lowest point before rising again. Phases included: February 27–May 31, 2020; June 1–August 31, 2020; September 1–November 30, 2020; December 1–December 31, 2020; and January 1–February 16, 2021.

Veterans missing data on age, sex, household size, child in the household, poverty level, marital status, education and/or home zip code were excluded ($N = 161{,}814$). Our final dataset comprised 946,358 Veterans.

Statistical analysis

Using generalized linear mixed models with random effects for VA medical facility, we estimated risk ratios (RR) and 95% confidence intervals (CI) for testing SARS-CoV-2 positive by social risk factors (i.e., individual-level SDoH) and select demographic characteristics (i.e., age, sex, race/ethnicity) that have been identified in prior COVID-19 reports as key characteristics for disparities in COVID-19 positivity across time [1, 2, 34–36]. We mutually adjusted for demographic characteristics, chronic medical conditions, 7-day rolling SARS-CoV-2 county-level per capita incidence, county-level population density, time period, and social risk factors. To evaluate if time modified the associations between testing SARS-CoV-2 positive and social risks, we stratified our models by phase of the pandemic. We conducted all statistical analyses using SAS Enterprise 8.3 (SAS Institute, Cary, NC). The Veterans Health Administration determined this evaluation was not research and did not require institutional review board review.

Results

Sample characteristics

Of the 946,358 Veterans with a SARS-CoV-2 test result between February 27, 2020 and February 16, 2021, the majority were male (89%) and White (62%), with a median age of 62 years (Table 1).

Table 1
Demographics, individual social determinants of health, and pandemic time period among 946,358 veterans seeking testing or treatment for SARS-CoV-2 infection at the U.S. Department of Veterans Affairs (VA), February 27, 2020–February 16, 2021.

	Total		Positive		Negative	
	N	%	N	%	N	%
	946,358	100%	181,058	19%	765,300	81%
Age						
18–39	114,142	12%	24,000	21%	90,142	79%
40–49	92,704	10%	20,023	22%	72,681	78%
50–59	157,120	17%	31,568	20%	125,552	80%
60–69	223,289	24%	37,067	17%	186,222	83%
70–79	275,741	29%	49,729	18%	226,012	82%
≥80	83,362	9%	18,671	22%	64,691	78%
Race/ethnicity						
American Indian/Alaska Native	6385	1%	1423	22%	4962	78%
Asian	9917	1%	1623	16%	8294	84%
Black/African American	208,751	22%	40,407	19%	168,344	81%
Hispanic	76,876	8%	17,850	23%	59,026	77%
Missing/Unknown	41,593	4%	8476	20%	33,117	80%
Multiracial	8355	1%	1495	18%	6860	82%
Native Hawaiian/Pacific Islander	6860	1%	1353	20%	5507	80%
White	587,621	62%	108,431	18%	479,190	82%
Sex						
Female	101,256	11%	18,070	18%	83,186	82%
Male	845,102	89%	162,988	19%	682,114	81%
Household size						
1	285,469	30%	48,902	17%	236,567	83%
2	257,719	27%	48,568	19%	209,151	81%
3	197,454	21%	39,565	20%	157,889	80%
4	106,911	11%	22,153	21%	84,758	79%
>4	98,805	10%	21,870	22%	76,935	78%
Child in household						
Yes	601,492	64%	110,747	18%	490,745	82%
No	344,866	36%	70,311	20%	274,555	80%
Household income						
<100% federal poverty level	68,108	7%	13,934	20%	54,174	80%
100%–200% federal poverty level	205,791	22%	41,138	20%	164,653	80%
>200%–400% federal poverty level	325,287	34%	63,397	19%	261,890	81%
>400% federal poverty level	347,172	37%	62,589	18%	284,583	82%
Marital status						
Married	455,261	48%	93,314	20%	361,947	80%
Not married	491,097	52%	87,744	18%	403,353	82%
Education						
High school/vocational/technical	688,603	73%	133,637	19%	554,966	81%
College	151,987	16%	29,035	19%	122,952	81%
Graduate school	105,768	11%	18,386	17%	87,382	83%
County population density						
≤2.7 people/km^2	7003	1%	1692	24%	5311	76%
>2.7–<60 people/km^2	233,775	25%	50,387	22%	183,388	78%
60–<195 people/km^2	243,845	26%	49,214	20%	194,631	80%
195–<387 people/km^2	144,848	15%	25,896	18%	118,952	82%
387–<600 people/km^2	109,026	12%	18,733	17%	90,293	83%
600–<1000 people/km^2	100,793	11%	17,648	18%	83,145	82%
1000–27,820 people/km^2	107,068	11%	17,488	16%	89,580	84%
Time era						
February 27–May 31, 2020	121,660	13%	22,124	18%	99,536	82%
June 1–August 31, 2020	298,906	32%	44,244	15%	254,662	85%
September 1–November 30, 2020	305,293	32%	52,019	17%	253,274	83%
December 1–December 31, 2020	102,131	11%	32,770	32%	69,361	68%
January 1–February 16, 2021	118,368	13%	29,901	25%	88,467	75%

Overall, 29% of Veterans lived in households with income less than 200% FPL, 10% lived in a household with more than 4 people, and 34% lived in counties with 387 or more people per km^2 (i.e., urban areas).

Demographic and social factors associated with testing positive

Approximately 19% of Veterans included in the analysis tested positive for SARS-CoV-2. As shown in Table 1, there was a higher prevalence of positivity among Veterans who were Hispanic (23% tested positive) and American Indian/Alaska Native (22%). The prevalence of SARS-CoV-2 increased with increasing household size and was also higher among Veterans living in counties with lower county-level population density. There were minor variations in SARS-CoV-2 prevalence by age, sex, household income, education level, and by presence of a child in the household. The SARS-CoV-2 prevalence fluctuated between 16.3% and 32% across the time periods examined.

In an adjusted model including all time periods (Table 2), Veterans aged 80 years or more were 43% more likely to test positive for SARS-CoV-2 compared to Veterans aged 60–69 years [RR 1.42 (95% CI: 1.40, 1.46)]. SARS-CoV-2 positivity rates were higher among Veterans who were American Indian/Alaska Native, Asian, Black, Hispanic, or Native Hawaiian/Pacific Islander compared to

Table 2
Adjusted risk ratios for testing SARS-CoV-2 positive among 946,358 veterans seeking testing or treatment for SARS-CoV-2 infection at the U.S. Department of Veterans Affairs (VA), February 27, 2020–February 16, 2021.

	Pooled model[a] February 27, 2020–February 16, 2021 N = 946,358 RR	95% CI
Age		
18–39	1.23	(1.21, 1.25)
40–49	1.21	(1.19, 1.23)
50–59	1.12	(1.11, 1.14)
60–69	1.00	–
70–79	1.09	(1.08, 1.11)
80+	1.43	(1.40, 1.46)
Race/ethnicity		
American Indian/Alaska Native	1.16	(1.10, 1.22)
Asian	1.06	(1.01, 1.12)
Black/African American	1.08	(1.06, 1.09)
Hispanic	1.30	(1.28, 1.33)
Missing/Unknown	1.09	(1.07, 1.12)
Multiracial	1.00	(0.95, 1.06)
Native Hawaiian/Pacific Islander	1.15	(1.09, 1.21)
White	1.00	–
Sex		
Female vs. male	0.88	(0.87, 0.89)
Household size		
1 person	1.00	–
2 persons	1.03	(1.02, 1.05)
3 persons	1.07	(1.05, 1.09)
4 persons	1.09	(1.06, 1.11)
>4 persons	1.15	(1.12, 1.17)
Child in household		
Yes vs. no	0.99	(0.98, 1.01)
Poverty		
<100% FPL	1.02	(1.01, 1.03)
100%–200% FPL	1.01	(0.99, 1.02)
>200%–400% FPL	1.00	(0.98, 1.02)
>400% FPL	1.00	–
Married		
Married vs. not married	1.05	(1.03, 1.06)
Education		
High school/vocational	1.00	–
College	0.97	(0.96, 0.99)
Graduate school	0.96	(0.94, 0.97)
County population density		
≤2.7 people/km^2	1.28	(1.22, 1.36)
>2.7–<60 people/km^2	1.15	(1.13, 1.18)
60–<195 people/km^2	1.05	(1.03, 1.08)
195–<387 people/km^2	1.04	(1.01, 1.06)
387–<600 people/km^2	1.00	–
600–<1000 people/km^2	1.00	(0.97, 1.02)
1000–27,820 people/km^2	1.01	(0.99, 1.04)

FPL = federal poverty level; RR = risk ratios.
[a] Models mutually adjusted for variables in rows and adjusted for individual level social determinants of health (household size, child in household (yes/no), poverty level, marital status, education level, county-level population density, 7-day rolling county SARS-CoV-2 per capita rate, presence of comorbidities (lung cancer, chronic obstructive pulmonary disease, heart failure, ischemic heart disease, diabetes, hemodialysis, end stage chronic kidney disease), and clinical conditions (cigarette smoking, obesity (BMI > 30)) and pandemic time period (February 27–May 31; June 1–August 31, 2020; September 1–November 30, 2020; December 1–December 31, 2020; January 1–February 16, 2021). All models have a random effect for VA medical facility location.

White Veterans. Women Veterans were less likely to test positive compared to men [RR 0.88 (0.87, 0.89)].

Of the social risk factors included in the same adjusted model, currently married Veterans and Veterans with a household income <100% FPL had slightly increased risk ratios for testing positive [RR 1.02 (1.01, 1.03)] (Table 2). Higher education levels had a slight protective association for testing positive and having children in the household was not associated with testing positive. Risk of testing positive for SARS-CoV-2 increased with household size, with risk ratios ranging from 1.03 (95% CI 1.02, 1.05) to 1.15 (95% CI 1.12, 1.17) for Veterans in households with 2 to greater than 4 persons, respectively, compared to those living alone.

Time variation in associations of demographic and social factors with risk of testing positive

The strength of association between race/ethnicity and SARS-CoV-2 test positivity, varied by phase of the pandemic (Table 3). Specifically, Black-White disparities present in February–May 2020 [RR 1.29 (1.25, 1.34)] and June–August 2020 [RR 1.24 (1.21, 1.27)] were no longer observed in September–November 2020 [RR 0.96 (0.94, 0.99)] and beyond. However Hispanic-White, American Indian/Alaska Native-White, and Native Hawaiian/Pacific Islander-White disparities persisted through all pandemic phases.

The magnitude of some social risk factors' associations with SARS-CoV-2 positivity also varied by pandemic phases (Table 3). Among Veterans tested between February and May 2020, Veterans in households larger than 4 persons had an 11% higher risk of testing positive [RR 1.11 (1.04, 1.19)], but between January 1 and February 16, 2021 they were 21% more likely to test positive [RR 1.21 (1.15, 1.28)] compared to Veterans living alone. Between February and May 2020, Veterans living in highly rural areas (≤2.7 people per km^2) had lower risk for testing SARS-CoV-2 positive [RR 0.81 (0.62, 1.04)] than Veterans living in urban areas (387 to <600 people per km^2). However, by June 2020, this association had flipped and in December 2020, the risk ratio increased to 1.47 (1.31, 1.65). Associations between testing SARS-CoV-2 positive and having a child in the household, household income levels, marital status, or education levels did not vary over time.

Discussion

In this study of nearly 1 million Veterans, we found larger household size, lower education, and residing in counties with lower population density (i.e., more rural) were associated with increased risk for testing SARS-CoV-2 positive. Notably, the association for household size and SARS-CoV-2 infection varied over time.

Several of our findings are consistent with studies conducted in different populations. For example, our finding of a dose-response effect of household size on SARS-CoV-2 positivity rates among Veterans is similar to studies that have found poor housing conditions, which can include household crowding, to be linked with worse health outcomes and higher incidence rates of SARS-CoV-2 [23]. Our results suggest that with each additional person living in the household, the risk of contracting SARS-CoV-2 increases: an association that strengthened as the pandemic progressed. Similar to prior reports of SARS-CoV-2 incidence among Veterans, disparities in SARS-CoV-2 positivity were observed among non-White and Hispanic Veterans and these disparities have attenuated over time [1, 35–37].

We also found that married Veterans had a slightly elevated risk of testing positive than unmarried Veterans. This marginal increase may be indicative of the additional infection risk conferred by an intimate household contact where social distancing may be more difficult to implement (e.g., shared sleeping spaces) compared to other household members. Additionally, we found a marginally protective effect for higher education levels and SARS-CoV-2 risk of testing positive. This may reflect the reduced transmission rates among persons with a college or graduate degree may have job more adaptable to physical distancing and working from home (e.g., white collar vs. blue collar employment). Persons with higher income are also less likely to have precarious jobs, which may afford them schedule flexibility and sick leave to reduce SARS-CoV-2 spread. It was surprising that having a child in the household and income level were not associated with the risk of SARS-CoV-2 positivity. This may be because many children

Table 3
Adjusted risk ratios for testing SARS-CoV-2 positive, stratified by time, among 946,358 veterans seeking testing or treatment for SARS-CoV-2 infection at the U.S. Department of Veterans Affairs (VA), February 27, 2020–February 16, 2021 – social risk factors.

	Time stratified models[a]									
	February 27–May 31, 2020 N = 121,660		June 1–August 31, 2020 N = 298,906		September 1–November 30, 2020 N = 305,293		December 1–December 31, 2020 N = 102,131		January 1–February 16, 2021 N = 118,368	
	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI
Age										
18–39	1.06	(1.01, 1.12)	1.40	(1.35, 1.44)	1.26	(1.22, 1.30)	1.13	(1.08, 1.17)	1.13	(1.09, 1.18)
40–49	1.06	(1.00, 1.12)	1.29	(1.24, 1.34)	1.26	(1.22, 1.30)	1.16	(1.11, 1.20)	1.17	(1.12, 1.22)
50–59	1.04	(0.99, 1.08)	1.18	(1.15, 1.22)	1.17	(1.13, 1.20)	1.09	(1.05, 1.13)	1.07	(1.03, 1.11)
60–69	1.00	–	1.00	–	1.00	–	1.00	–	1.00	–
70–79	1.13	(1.09, 1.18)	1.06	(1.03, 1.09)	1.09	(1.06, 1.11)	1.11	(1.08, 1.13)	1.10	(1.06, 1.14)
80+	1.40	(1.34, 1.47)	1.32	(1.27, 1.37)	1.43	(1.38, 1.48)	1.44	(1.38, 1.51)	1.48	(1.42, 1.55)
Race/ethnicity										
American Indian/Alaska Native	1.33	(1.14, 1.56)	1.27	(1.14, 1.41)	1.10	(1.00, 1.21)	1.08	(0.95, 1.22)	1.14	(1.00, 1.31)
Asian	1.17	(1.01, 1.36)	1.08	(0.97, 1.19)	1.06	(0.96, 1.17)	1.02	(0.91, 1.15)	1.04	(0.92, 1.18)
Black/African American	1.29	(1.25, 1.34)	1.24	(1.21, 1.27)	0.96	(0.94, 0.99)	0.95	(0.92, 0.98)	0.96	(0.92, 0.99)
Hispanic	1.35	(1.28, 1.42)	1.45	(1.41, 1.50)	1.26	(1.22, 1.31)	1.23	(1.18, 1.28)	1.16	(1.11, 1.22)
Missing/Unknown	1.11	(1.03, 1.19)	1.14	(1.09, 1.20)	1.08	(1.04, 1.13)	1.05	(1.00, 1.11)	1.03	(0.98, 1.09)
Multiracial	1.02	(0.88, 1.18)	1.04	(0.94, 1.15)	1.02	(0.93, 1.12)	0.97	(0.87, 1.10)	0.95	(0.84, 1.09)
Native Hawaiian/Pacific Islander	1.18	(1.00, 1.40)	1.18	(1.06, 1.32)	1.16	(1.05, 1.28)	1.04	(0.91, 1.19)	1.15	(1.01, 1.31)
White	1.00	–	1.00	–	1.00	–	1.00	–	1.00	–
Sex										
Female vs. male	0.88	(0.84, 0.92)	0.83	(0.88, 0.94)	0.86	(0.83, 0.89)	0.93	(0.90, 0.97)	0.94	(0.91, 0.98)
Household size										
1 person	1.00	–	1.00	–	1.00	–	1.00	–	1.00	–
2 persons	1.02	(0.98, 1.06)	1.01	(0.98, 1.04)	1.02	(1.00, 1.05)	1.06	(1.03, 1.10)	1.07	(1.03, 1.11)
3 persons	1.06	(1.00, 1.12)	1.03	(0.99, 1.07)	1.06	(1.02, 1.10)	1.08	(1.03, 1.13)	1.13	(1.08, 1.18)
4 persons	1.04	(0.98, 1.11)	1.05	(1.00, 1.10)	1.09	(1.05, 1.13)	1.12	(1.06, 1.18)	1.15	(1.09, 1.22)
>4 persons	1.11	(1.04, 1.19)	1.12	(1.07, 1.17)	1.15	(1.10, 1.20)	1.15	(1.09, 1.21)	1.21	(1.15, 1.28)
Child in household										
Yes vs. no	1.02	(0.98, 1.06)	1.00	(0.98, 1.03)	0.99	(0.96, 1.01)	1.00	(0.97, 1.03)	0.97	(0.94, 1.00)
Poverty										
<100% FPL	1.01	(0.97, 1.05)	1.04	(1.01, 1.07)	1.00	(0.98, 1.03)	1.00	(0.97, 1.03)	1.02	(0.99, 1.06)
100%–200% FPL	1.00	(0.96, 1.05)	1.02	(1.00, 1.04)	1.00	(0.98, 1.02)	1.00	(0.97, 1.02)	1.00	(0.97, 1.03)
>200%–400% FPL	0.98	(0.92, 1.03)	1.03	(0.99, 1.07)	1.02	(0.98, 1.06)	0.99	(0.94, 1.03)	0.95	(0.91, 1.00)
>400% FPL	1.00	–	1.00	–	1.00	–	1.00	–	1.00	–
Married										
Married vs. not married	1.01	(0.98, 1.05)	1.03	(1.00, 1.05)	1.05	(1.03, 1.08)	1.06	(1.03, 1.09)	1.05	(1.02, 1.08)
Education										
High school/vocational	1.00	–	1.00	–	1.00	–	1.00	–	1.00	–
College	0.98	(0.94, 1.01)	0.98	(0.95, 1.00)	0.97	(0.94, 0.99)	0.98	(0.95, 1.01)	0.99	(0.96, 1.02)
Graduate school	0.98	(0.94, 1.02)	0.95	(0.92, 0.98)	0.94	(0.91, 0.96)	0.96	(0.93, 1.00)	0.99	(0.95, 1.03)
County population density										
≤2.7 people/km^2	0.81	(0.62, 1.04)	1.23	(1.08, 1.41)	1.27	(1.17, 1.38)	1.47	(1.31, 1.65)	1.37	(1.19, 1.58)
>2.7–<60 people/km^2	0.95	(0.89, 1.01)	1.11	(1.06, 1.15)	1.16	(1.11, 1.21)	1.23	(1.18, 1.30)	1.19	(1.13, 1.26)
60–<195 people/km^2	0.96	(0.90, 1.02)	1.02	(0.98, 1.07)	1.06	(1.02, 1.10)	1.13	(1.08, 1.19)	1.09	(1.04, 1.15)
195–<387 people/km^2	1.01	(0.95, 1.08)	1.06	(1.01, 1.10)	1.05	(1.01, 1.10)	1.05	(1.00, 1.11)	1.01	(0.96, 1.07)
387–<600 people/km^2	1.00	–	1.00	–	1.00	–	1.00	–	1.00	–
600–<1000 people/km^2	1.03	(0.97, 1.10)	1.01	(0.96, 1.06)	0.99	(0.94, 1.04)	0.99	(0.93, 1.06)	0.96	(0.90, 1.03)
1000–27,820 people/km^2	1.03	(0.97, 1.09)	1.04	(0.99, 1.09)	1.04	(0.99, 1.10)	1.07	(1.00, 1.14)	1.01	(0.94, 1.08)

FPL = federal poverty level; RR = risk ratios.

[a] Models mutually adjusted for variables in rows and adjusted for age, sex, race/ethnicity, 7-day rolling county SARS-CoV-2 per capita rate, presence of comorbidities (lung cancer, chronic obstructive pulmonary disease, heart failure, ischemic heart disease, diabetes, hemodialysis, end stage chronic kidney disease), and clinical conditions (cigarette smoking, obesity (BMI > 30)). All models have a random effect for VA medical facility location.

stayed home and were educated remotely during the worst parts of the pandemic. A contemporaneous CDC report in 2020 indicated that even when school aged children do go to school, the incidence of SARS-CoV-2 does not significantly increase [38]. Our null association with individual reported household income adjusted for household size is of interest as previous studies have reported individuals with lower income to be more likely to test SARS-CoV-2 positive [2, 39]. Our lack of an association with income may be due to the lower access barriers for testing and healthcare at VA, as all qualifying Veterans can receive care at VA regardless of their income. Additionally, our associations may be different as we categorized individual household income into categories relative to federal poverty levels based on locality and the number of persons in the house rather than using neighborhood aggregate socioeconomic measures [40].

The temporal patterns in social risk factors are a new contribution to the literature. Our results indicate that a Veteran's SARS-CoV-2 infection risk fluctuated depending on their individual social risk factors such as household size. These temporal associations may be shifting for a variety of reasons [41]. While we adjusted for local infection rates in our analysis, there may be additional confounders related to 'surges' in infection rates such as the local shelter-in-place policies and variations in risk mitigation polices. Early in the pandemic when shelter in place policies were the most stringent, the additional risk of another household member could have been lower compared with later in the pandemic as shelter in place policies relaxed, masking became optional. The strongest associations between SARS-CoV-2 infection risk and household size in late 2020 may also reflect individuals' exhaustion of adhering to social distancing policies as it became more challenging to stay isolated during holiday periods and group gatherings increased.

While population density is at the county-level, we included it in our evaluation as a key SDoH as rural residents are more likely to face higher levels of poverty, lower education levels, and higher employment in blue-collar professions which inhibit social distancing [26, 35]. Additionally, health services to identify and treat SARS-CoV-2 cases were more available in higher population density areas which could impact individuals' likelihood of contracting SARS-CoV-2 and receiving a test [24]. In our work, Veterans living in counties with the lowest population density had lower risk of testing SARS-CoV-2 positive early in the pandemic compared to those living in more densely populated areas. However, after June 2020, this protective association was no longer seen and Veterans living in highly rural areas were more likely to test positive. Work from Carozzi and colleagues supports our findings by showing that population density in the U.S. does not dictate incidence rates, but rather is a surrogate for the time periods and localities affected by the outbreak [42]. Therefore, differences in risk by population density may also be due in part to the spread of the virus as pandemic epicenters early in the pandemic were cities [26].

Overall, we found an increased risk of SARS-CoV-2 positivity among Veterans by household size, a slightly decreased risk by education level, and no association by income level. This suggests that household size may play a more important role in the risk of testing SARS-CoV-2 positive than education level or income among Veterans. Given the intertwined nature of SDoH, further work is needed to elucidate the relative contributions and roles of education, income, and household size for SARS-CoV-2 infection risk.

Strengths and limitations

The VA electronic health record database offers a comprehensive nationwide health data resource. Linkage with USVETS data enabled the unique addition of individual-level social risk data; however, some limitations of these combined data include a primarily male population and lacking information on other key social risks. There may be selection bias in our study population for Veterans who accessed VA care during the first year of the pandemic and who had complete data on the study variables. Veterans who tested negative at a third-party location such as a public health department would be unlikely to seek testing or treatment at a VA facility after receiving a negative result and therefore are less likely to be included in our analysis. However, Veterans who test positive at a third-party location may be more likely to seek treatment at VA due to the subsidized care provided at VA – resulting in undercounting individuals who tested negative. Further analysis is needed to identify how Veterans who come to VA for treatment alone may differ from Veterans who come to VA for testing. We did not have information on occupation thus we could not examine the association between essential workers and positive tests. While using 2019 USVETS data was a strength of our analysis as we captured individual SDoH, we were not able to assess changes in social risks that may have occurred during the pandemic, meaning that some of our estimates may be inaccurate. Additionally, some Veterans were excluded due to missing data on SDoH and the exclusion of those with missing data could further limit generalizability of these findings. Finally, our population included US Veterans who are older and have a higher prevalence of chronic conditions and risk behaviors than the general US population [43–45]. In our work we have adjusted for age and chronic conditions, which prior research has demonstrated to be an effective control for differences between US Veterans and the general population [1, 45].

Our study has several additional strengths. First, the social risks we examined were captured on an individual level which tend to have less misclassification than area-based measures. Our analysis also leveraged self-reported data on race/ethnicity from electronic health records which had 4% missing data; a small fraction compared to state and national databases of SARS-CoV-2 incidence. We also were able to match Veterans to their home county, rather than relying on their site of care, which more accurately captures information on the prevalence of SARS-CoV-2 in their area and the population density of their home neighborhoods. However, further research is needed to understand the interactive and overlapping effects of SDoH such as occupation, poverty, education, and household size. SDoH are a consequence of a complex history and multilevel risk factors that propagate health inequities. Recognizing and evaluating the dynamic nature and feedback loops of co-occurring SDoH could help inform population-based approaches for the prevention of SARS-CoV-2 infection.

Conclusions

Despite the increasing recognition that SDoH play a critical role in shaping an individual's clinical and economic outcomes, social risk factors are not routinely captured in electronic health records [46, 47]. Incorporating SDoH into health care records could help predict which VA patients may be at increased risk for SARS-CoV-2 infection, as well as severe illness and mortality which may be helpful for future pandemics responses for highly communicable infectious diseases. Variation in the effect size of certain risks of SARS-CoV-2 positivity such as household size over time further suggests the need for ongoing, real-time tracking as the social and medical environment continues to evolve.

Author contributions

Concept and Design: JMF, CM, TS, EM, LRMH, AJC. Drafting of the manuscript: JMF, CM, LRMH. Acquisition, analysis, or interpretation of the data: All authors. Critical revision of the manuscript for important intellectual content: All authors. Statistical Analysis: JMF, CM, TS. Administrative, technical, or material support: EM, KJ, LRMH. Supervision: EM, KJ, LRMH.

Disclaimer

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Ethics

The Veterans Health Administration determined this evaluation was non-research and did not require institutional review board review.

Data availability

Due to US Department of Veterans Affairs (VA) regulations and our ethics agreements, the analytic data sets used for this study are not permitted to leave the VA firewall without a Data Use Agreement. This limitation is consistent with other studies based on VA data. However, VA data are made freely available to researchers with an approved VA study protocol. For more information, please visit https://www.virec.research.va.gov or contact the VA Information Resource Center at VIReC@va.gov.

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