

An Investigation into Community Behaviors, Socioeconomic Factors, and Breakthrough COVID-19 Infections Among Vaccinated Individuals: A Cross- Sectional Study

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Abstract

Background: Despite widespread COVID-19 vaccination, breakthrough infections remain a public health concern, with transmission risks potentially linked to community behaviors and age-specific preventive practices. While mask-wearing and social distancing are well-established mitigation strategies, their adoption patterns across age groups, particularly among vaccinated individuals, are poorly understood.

Objective: This study focuses on understanding breakthrough infections among vaccinated individuals, high-risk behaviors and socioeconomic determinants of COVID-19 susceptibility to guide effective public health interventions.

Methods: A 31-question voluntary survey was distributed using convenience sampling through the Qualtrics survey platform. Log-binomial regression model was used to estimate the Relative Risk (RR) to measure the association between testing COVID positive and the different activities.

Results: Among the vaccinated individuals, those who tested positive were 11.103 times more likely to engage in going to a restaurant or bar compared to those who tested negative ($p=0.010$). There was a significant difference in practicing social distancing and mask wearing between the different age groups ($p=0.015$) with 100% of the participants above 70 years old practicing it followed by 96.8% of the 18-29 years old. The study found lower infection rates in the same age groups compared to the other age groups. Moreover, the 18-29 age group demonstrated notable associations with practising social distancing and mask-wearing in various settings.

Conclusions: Compliance with social distancing and mask-wearing was higher among older and younger participants, and non-compliance with social distancing and mask wearing was associated with a higher positivity rate. Activities like going to a restaurant or bar was significantly associated with testing COVID-19 positive in vaccinated individuals.

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Type of manuscript: Original research



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Conclusions: Compliance with social distancing and mask-wearing was higher among older and younger participants, and non-compliance with social distancing and mask wearing was

associated with a higher positivity rate. Activities like going to a restaurant or bar was significantly associated with testing COVID-19 positive in vaccinated individuals.

Keywords: High-risk behaviors, vaccinated individuals, socioeconomic factors, breakthrough infections, COVID-19, social distancing

Introduction

Since late 2019, the emergence of coronavirus disease 2019, commonly known as COVID-19, disrupted much of society and resulted in over 1.1 million reported deaths in the United States [1]. Early on in the pandemic, the Centers for Disease Control and Prevention (CDC), local public health departments and other public health authorities sought to mitigate the transmission and the potential loss through various public health measures, which included public masking requirements, social distancing, lockdowns, and school and business closures.

The transmission of COVID-19 is variable and dependent on many factors including the type of contact with an infected individual, duration of exposure, host immune factors, and ventilation [2]. The dominant route of transmission of COVID-19 is respiratory, and it is known that the COVID-19 spreads effectively in enclosed and crowded settings [3]. Masking and social distancing have been shown to reduce transmission of COVID-19 in many settings [4-6].

The CDC had been tracking new cases of COVID-19 until early 2023. Guidance on personal protective measures had previously been based on community levels of circulating COVID-19 infections. However, in 2023, the CDC changed their data collection and reporting, focusing on the weekly number of hospitalizations and deaths rather than new cases of infection, as well as monitoring variants based on data from a limited number of areas in the United States [7].

Many of the stringent public health restrictions implemented early on in the pandemic have been replaced by less strict, practical measures that place the responsibility of social distancing and masking when sick on individuals in conjunction with local transmission rates [2]. In March of 2024, the CDC released updated recommendations for individuals to prevent the spread of upper respiratory viruses when sick, intending to simplify public health recommendations rather than have separate, pathogen-specific guidelines. The new guidelines allow individuals who have confirmed or suspected COVID-19 infection to resume normal activities if their symptoms are improving and they have been afebrile (without antipyretics) for at least 24 hours. With newer guidelines allowing infected individuals the ability to re-enter the community while still symptomatic and potentially infectious, research pertaining to specific community settings and behaviors that increase one's risk for infection is necessary to help individuals reduce their own risk of infection [8].

Understanding the types of community behaviors and settings that are associated with a high risk of COVID-19 transmission is important because individuals can make more informed decisions about the types of behaviors and settings they are willing to engage in based on the risk of infection. Individuals will be better informed about the potential risk of infection, allowing them to determine if personal protective measures to reduce the risk of infection, such as social distancing or masking, are more appropriate in specific settings. For policymakers and public health experts, this study will provide information about the behaviors and settings that are associated with a risk of COVID-19 infection, allowing them to develop tailored infection prevention strategies and guidance for community members pertaining to COVID-19 and other respiratory viral infections.

This study aims to identify community behaviors, settings, and close contact exposures of

vaccinated individuals that are associated with testing positive for COVID-19 despite vaccination status. Additionally, this study investigates socioeconomic factors associated with COVID-19 infection, including demographics, household income, and type of residence.

Methods

The Institutional Review Board of Massachusetts College of Pharmacy and Health Sciences in Boston, MA approved this cross-sectional research study. This research study was conducted adhering to the pertinent guidelines and regulations set forth by the IRB committee of MCPHS University. An online survey was created using Qualtrics® and all survey responses were recorded between January 6th, 2022 and September 26th, 2022. The survey was adapted from several validated studies regarding demographics, community behaviors, and personal preventative measures for COVID-19 infection and transmission.¹¹⁻¹³ Convenience sampling was used to recruit respondents for the survey, and included e-mail, social media postings, and in-person recruitment. Respondents included students and faculty at Massachusetts College of Pharmacy and Health Sciences, as well as faculty at several medical and physician assistant programs at various universities across the United States. Informed consent was obtained from all participants through the Qualtrics® survey, and all responses were anonymous. The survey consisted of a range of 22 to 31 questions. Inclusion criteria included being at least 18 years-old and each respondent must have received at least primary vaccination against COVID-19 infection. Primary vaccination included the original vaccine regimens in the United States: two doses of the original mRNA vaccines by Pfizer-BioNTech or Moderna; or one dose of the Johnson & Johnson vaccine. Respondents were included if they received a vaccine regimen approved in a non-US country, but the type of vaccine was not collected. A survey answer option of “Other” was included in the question where respondents were asked about receiving a vaccine

that was not specifically listed. It was also decided to end the survey once a second booster shot was authorized as our survey did not include questions regarding a second booster and this could confound the study's results.

Logistic regression analysis was utilized to estimate the odds of COVID-19 infection in relation to various risk factors identified within the survey dataset. A p-value of less than 0.05 was established for statistical significance. IBM SPSS Statistics, version 29.0 was used for statistical analysis.

Results

The primary goal of this investigation is to unveil the community behaviours, settings, and close contact scenarios correlated with positive COVID-19 test results among vaccinated individuals. Additionally, the study explores the socioeconomic factors related to COVID-19 infection, including demographics, household income, and type of residence. A total of 272 participants answered the survey, among which 76.5% were females, 22.8% were males and 0.8% identified themselves as either non-binary/third gender or preferred not to say. The majority of respondents to the survey fell within the 18-29 age bracket, constituting 44.9% of participants, a demographic typically representative of college students. Furthermore, a substantial proportion of the survey participants identified as White, accounting for 83.8% as shown in Table 1.

Table 1: Demographics of the survey participants

Gender	N (%)
Male	62 (22.8%)
Female	208 (76.5%)
Non-binary/third gender	1 (0.4%)
Prefer not to say	1 (0.4%)
Age	
18-29 years old	122 (44.9%)
30-39 years old	39 (14.3%)
40-49 years old	39 (14.3%)
50-59 years old	30 (11.0%)
60-69 years old	31 (11.4%)
>70 years old	10 (3.7%)
Race/ethnicity	
Asian Indian	12 (4.4%)
Black or African American	7 (2.6%)
Chinese	5 (1.8%)
Filipino	1 (0.4%)
Hispanic or Latino	9 (3.3%)
Multiracial or Biracial	3 (1.1%)
Native American/ Alaskan Native	2 (0.7%)
Vietnamese	1 (0.4%)
White	228 (83.8%)
Other race not listed	2 (0.7%)

A logistic regression was employed to assess the impact of community activities on the likelihood of COVID-19 infection in vaccinated individuals. The model exhibited statistical significance ($\chi^2(11) = 25.048$, $p < .0005$), indicating its ability to elucidate 33.0% (Nagelkerke R^2) of the variance in COVID-19 vaccinated individuals and correctly classify 79.2% of cases. The "Variables in the Equation" table provides insights into the influence of specific activities (see Table 2) on COVID-19 infection in vaccinated individuals. Notably, those who tested positive were 11.103 times more likely ($p=0.010$) to engage in going to a restaurant or bar compared to those who tested negative (Table 2). These results suggest a significant association between community activities and COVID-19 infection in vaccinated individuals, emphasizing the importance of specific behaviours in influencing infection outcomes.

Table 2: Variables in the Equation: In the 14 days prior to testing positive for COVID-19, about how often did you take part in the following activities in-person:

Activity	B	S.E.	Wald	df	Sig.	Exp(B)
Shop for items	-.008	.665	.000	1	.990	.992
Go to an indoor church or a religious gathering/place of worship	-1.407	.672	4.386	1	.036	.245
Go to a restaurant or bar	2.407	.929	6.719	1	.010	11.103
Go to a coffee shop	-.264	.589	.200	1	.655	.768
Use public transportation	-1.415	.734	3.721	1	.054	.243
Travel via airplane	-.715	.645	1.227	1	.268	.489
Go to an office setting	1.125	.836	1.808	1	.179	3.079
Go to a gym or fitness center	-1.940	.951	4.166	1	.041	.144
Go to a salon or barber	.446	.611	.533	1	.465	1.563
Travelled in a vehicle	.872	.615	2.010	1	.156	2.391
Go to an indoor entertainment venue	-1.045	.651	2.575	1	.109	.352

Among the different age groups who responded to the survey, we found the infection rates were

the lowest in the >70 years age group (27.5%) and 18-29 years age group (40.7%) compared to the other age groups although the difference did not achieve statistical significance. Then we sought to find if there is any difference between the positivity rate with a specific activity in respondents who reported social distancing/wearing their mask most of the time and those who did not most of the time. The initial model, which included no predictors (null model), displayed a classification table with an overall correct classification rate of 59.9%, indicating suboptimal performance in predicting COVID-19 positivity based on the specified variables.

After incorporating predictors from the question that asked for “social distancing and mask-wearing behaviours in specific settings”, the model showed statistically insignificant results ($\chi^2(11) = 17.612$, $p > .05$). The model elucidated only 8.5% (Nagelkerke R^2) of the variance in COVID-19 positivity among vaccinated individuals and accurately classified 60.7% of cases. A detailed examination of the "Variables in the Equation" table (Table 3) indicated that none of the predictors achieved statistical significance. For example, participants who tested positive were 3.001 times more likely to go to an office setting compared to those who did not test positive, but this result did not reach statistical significance ($p = 0.089$).

In summary, the logistic regression model did not provide substantial evidence of a significant difference in COVID-19 positivity rates based on specific activities among respondents reporting varying levels of social distancing and mask-wearing. The overall model did not attain statistical significance, and the predictors included did not significantly contribute to explaining the variability in COVID-19 positivity.

Table 3: Variables in the Equation: *In the 14 days prior to testing positive for COVID-19, estimate the number of individuals around you that were socially distancing or wearing a cloth face covering/mask in the following settings:*

Activity	B	S.E.	Wald	df	Sig.	Exp(B)
Shop for items	-.617	.544	1.287	1	.257	.539
Go to an indoor church or a religious gathering/place of worship	.256	.569	.203	1	.652	1.292
Go to a restaurant or bar	.536	.650	.679	1	.410	1.709
Go to a coffee shop	.322	.644	.251	1	.617	1.380
Use public transportation	.536	.665	.650	1	.420	1.710
Travel via airplane	.571	.626	.833	1	.361	1.770
Go to an office setting	1.099	.646	2.892	1	.089	3.001
Go to a gym or fitness center	.086	.566	.023	1	.879	1.090
Go to a salon or barber	-.136	.591	.053	1	.819	.873
Travelled in a vehicle	.377	.599	.396	1	.529	1.458
Go to an indoor entertainment venue	-1.394	.639	4.759	1	.029	.248

We then tested if any of the following demographic variables associated with a higher COVID-19 positivity rate including household income, type of residence, education level, race, and

number of individuals living in a household. The logistic regression aimed to investigate whether specific demographic variables were correlated with a higher COVID-19 positivity rate among participants. The initial model, representing the null model with no predictors, exhibited a classification table with an overall correct classification rate of 59.9%, indicating suboptimal performance in predicting COVID-19 positivity based on the specified variables. Subsequent inclusion of demographic variables also yielded statistically insignificant findings ($\chi^2(25) = 22.128$, $p > .05$). The model elucidated 10.6% (Nagelkerke R^2) of the variance in COVID-19 positivity among participants and accurately classified 61.0% of cases. A detailed examination of the "Variables in the Equation" table (Table 4) revealed that none of the predictors achieved statistical significance. This suggests that none of the demographic variables were independently associated with a higher COVID-19 positivity rate.

In summary, the logistic regression model revealed no statistically significant associations between demographic variables (e.g., income, education, race) and COVID-19 positivity in our vaccinated cohort. While this suggests that socioeconomic factors alone may not independently predict breakthrough infections in this population, it underscores the potential dominance of behavioural or environmental determinants (e.g., activity-related risks, as identified in our other analyses).

Table 4: Variables in the Equation: Demographic variables						
	B	S.E.	Wald	df	Sig.	Exp(B)
Annual Income						
Under \$25000	.133	.508	.069	1	.793	1.142
\$25000 to \$49999	-.847	.697	1.477	1	.224	.429
\$50000 to \$74999	.285	.606	.221	1	.638	1.330
\$75000 to \$99999	-.412	.706	.340	1	.560	.662
\$100000 to \$149999	.202	.643	.099	1	.754	1.223
\$150000 to \$199999	.087	.502	.030	1	.863	1.091
Over \$200000	-.441	.626	.497	1	.481	.643
Residence Type						
Single-family House	.144	.866	.028	1	.868	1.155
A two-family home/duplex	-.088	.324	.073	1	.787	.916
Apartment or Condo	-18.897	40192.970	.000	1	1.000	.000
Education						
High School	.823	56841.443	.000	1	1.000	2.278
Some College – no degree	21.457	40192.970	.000	1	1.000	20824403 58.597
Associate Degree	.162	.778	.043	1	.835	1.176
Bachelor's Degree	.592	.783	.570	1	.450	1.807
Graduate Degree	.966	1.285	.566	1	.452	2.628
Race						
White	-21.388	40192.970	.000	1	1.000	.000
Black or African American	-1.182	.851	1.930	1	.165	.307
Hispanic or Latino	.315	.860	.135	1	.714	1.371
Native American or Alaskan Native	.030	.989	.001	1	.976	1.031
Asian Indian	-21.198	40192.970	.000	1	1.000	.000
Multiracial or Biracial	-1.004	.840	1.429	1	.232	.366
Chinese	-20.918	23078.408	.000	1	.999	.000
Filipino	.114	1.649	.005	1	.945	1.120
Vietnamese	.284	1.450	.038	1	.845	1.328
Other race not listed	-21.045	40192.970	.000	1	1.000	.000

We then investigated if living with someone who worked in healthcare was associated with a higher positivity rate. Contrary to expectations, our analysis found no significant association

between living with a healthcare worker and COVID-19 positivity rates among vaccinated individuals (Table 5). This suggests that, in our cohort, household exposure to healthcare personnel, who likely had frequent occupational exposure to SARS-CoV-2, did not translate into higher infection risk for vaccinated cohabitants. These findings may reflect the success of infection control measures in healthcare settings, the protective effect of vaccination in household contexts, or potential compensatory behaviours (e.g., stricter hygiene practices) in these households. While reassuring, these results should be interpreted in context: the study period (2022) coincided with widespread vaccine availability and improved workplace protections, which may have mitigated risks that were more prominent earlier in the pandemic

Table 5: Variables in the Equation: How many individuals whom you live with work in healthcare, not including yourself?

	B	S.E.	Wald	df	Sig.	Exp(B)
None	-20.788	28420.72	.000	1	.999	.000
One	.136	.293	.215	1	.643	1.146
More than one	-.096	.448	.046	1	.830	.908

We also tested whether there was an association between a specific vaccine (Moderna, Pfizer, or Johnson & Johnson (J&J)) and a higher or lower hospitalization rate among respondents. The

logistic regression model did not yield evidence of a significant association between the type of vaccine and the hospitalization rate among participants. The overall model was statistically insignificant, and the predictor included in the model did not substantially contribute to explaining the variability in hospitalization rates among the participants (Tables 6). This indicates that all three vaccines are equally effective in reducing hospitalizations due to COVID-19.

Table 6: Variables in the Equation: Type of vaccine and the hospitalization rate among participants.						
Vaccine	B	S.E.	Wald	df	Sig.	Exp(B)
Moderna	-.020	.665	.001	1	.976	.980
Pfizer-Biontech	.791	.665	1.413	1	.234	2.205
Johnson & Johnson	-.144	.271	.281	1	.596	.866

We then analyzed the relationship between distinct age groups and their adherence to social distancing and mask-wearing practices in various scenarios. We identified a statistically significant difference among the different age groups in practising social distancing and mask-wearing practices ($p=0.015$). The highest prevalence was found in >70 years age group, where 100% of the respondents reported social distancing practices, followed by 18-29 years age group (96.8%). The results reveal significant associations, particularly within the 18-29 age group, consistently exhibiting a higher likelihood of practising these preventive measures across diverse settings. When it comes to shopping for items, individuals aged 18-29 consistently showed a significant association with "Always or Most of the time," engaging in social distancing and mask-wearing. Similarly, this age group displayed significant associations in scenarios involving people gathering indoors, whether with more than 10 people or with 10 people or fewer.

Moreover, the 18-29 age group demonstrated notable associations with practising social distancing and mask-wearing in various settings, including attending indoor church or religious gatherings, going to restaurants or bars, visiting coffee shops, using public transportation, travelling via aeroplane, going to an office setting (excluding healthcare purposes), going to a gym or fitness centre, and visiting a salon or barber. The consistent pattern emphasizes the inclination of the 18-29 age group to adhere to social distancing and mask-wearing guidelines across a spectrum of activities. The statistical significance of these associations, as indicated by p-values, underscores the robustness of these observed patterns. These insights can inform targeted public health interventions and communication strategies, recognizing the variations in behaviour across different age demographics (Table 7).

Table 7: Table to explore the relationship between distinct age groups and their adherence to social distancing and mask-wearing practices in various scenarios

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Activity	Age	Never Rarely Sometimes	or or	Always Most of the time	or the P-value
Shop for items (groceries, prescriptions, home goods, clothing, etc.)	>70 years-old	1		9	<0.001
	18 - 29 years-old	24		98	
	30- 39 years old	2		37	
	40 - 49 years-old	0		39	
	50-59 years-old	0		30	
	60-69 years-old	1		30	
Have people visit you inside your home or go inside someone else's home where there were more than 10 people	>70 years-old	2		8	<0.001
	18 - 29 years-old	43		79	
	30- 39 years old	2		37	
	40 - 49 years-old	0		39	
	50-59 years-old	1		29	
	60-69 years-old	1		30	
Have people visit you inside your home or go inside someone else's home where there were 10 people or less	>70 years-old	1		9	<0.001
	18 - 29 years-old	35		87	
	30- 39 years old	2		37	
	40 - 49 years-old	1		38	
	50-59 years-old	2		28	
	60-69 years-old	2		29	
Go to an indoor church or a religious gathering/place of worship	>70 years-old	0		10	<0.001
	18 - 29 years-old	33		89	
	30- 39 years old	2		37	
	40 - 49 years-old	0		39	
	50-59 years-old	2		28	
	60-69 years-old	2		29	
Go to a restaurant or bar (dine-in, any area designated by the restaurant including patio seating)	>70 years-old	2		8	<0.001
	18 - 29 years-old	29		93	
	30- 39 years old	1		38	
	40 - 49 years-old	0		39	
	50-59 years-old	1		29	
	60-69 years-old	1		30	
Go to a coffee shop	>70 years-old	1		9	<0.001
	18 - 29 years-old	28		94	
	30- 39 years old	1		38	
	40 - 49 years-old	0		39	
	50-59 years-old	0		30	
	60-69 years-old	1		30	
Use public transportation (bus, subway, streetcar, train, etc.)	>70 years-old	1		9	<0.001
	18 - 29 years-old	26		96	
	30- 39 years old	1		38	
	40 - 49 years-old	0		39	
	50-59 years-old	1		29	
	60-69 years-old	2		29	

Travel via airplane	>70 years-old	2	8	<0.001
	18 - 29 years-old	42	80	
	30- 39 years old	2	37	
	40 - 49 years-old	0	39	
	50-59 years-old	2	28	
	60-69 years-old	1	30	
Go to an office setting (other than for healthcare purposes)	>70 years-old	0	10	<0.001
	18 - 29 years-old	36	86	
	30- 39 years old	2	37	
	40 - 49 years-old	2	37	
	50-59 years-old	1	29	
	60-69 years-old	1	30	
Go to a gym or fitness center	>70 years-old	0	10	<0.001
	18 - 29 years-old	40	82	
	30- 39 years old	1	38	
	40 - 49 years-old	1	38	
	50-59 years-old	2	28	
	60-69 years-old	2	29	
Go to a salon or barber (e.g., hair salon, nail salon, etc.)	>70 years-old	1	9	<0.001
	18 - 29 years-old	43	79	
	30- 39 years old	2	37	
	40 - 49 years-old	0	39	
	50-59 years-old	0	30	
	60-69 years-old	2	29	

Discussion

Determining the type of community activities and settings that are associated with COVID-19 in

vaccinated individuals is important for individuals to risk assess the type of activities they are willing to engage in. Identifying the behaviours and community settings that are associated with COVID-19 infection will also help enhance our understanding about the types of settings that which social distancing and masking may be more efficacious. This knowledge can help local health departments develop tailored public health guidance based on the behaviours of individuals and the types of community settings in their localities.

Principal Results:

One of the primary goals of this study was to reveal community behaviours linked to positive COVID-19 test results among vaccinated individuals. The present study demonstrates that vaccinated individuals were more likely to get infected with the virus while visiting a restaurant or a bar, emphasising the importance of specific behaviours in shaping infection outcomes. This explains the infection rate among vaccinated individuals and aligns with the results reported by Zhang *et al* [9, 10] who found higher infection rates among people visiting a restaurant. This might be a result of inadequate ventilation, which could lead to a rise in the concentration of airborne SARS-CoV-2. The current research revealed that individuals from the youngest (18-29 years) and oldest (>70 years) demographic were notably diligent about practising social distancing behaviour and mask wearing, potentially linked to elevated levels of COVID-19-related anxiety among this cohort. This might also stem from the fact that individuals in the youngest age group are highly socially connected and actively engaged in extensive community interactions [11].

We sought to examine the difference in positivity rates related to specific activities between respondents who reported adhering to social distancing/wearing masks most of the time and

those who did not. Nevertheless, our analysis did not provide strong evidence of a significant difference in COVID-19 positivity rates based on specific activities among respondents with varying levels of social distancing and mask-wearing. The overall model did not achieve statistical significance, and the predictors included did not substantially contribute to explaining the variability in COVID-19 positivity. Nevertheless, the present study revealed lower infection rates among both the oldest and youngest age groups, which coincided with their high adherence to social distancing measures. These findings are well corroborated by a recent study that found that each one-unit increase in social distancing was associated with a 26% reduced risk of COVID-19 incidence and a 31% reduced risk of COVID-19 mortality at the county level [12]. Additionally, another study observed that COVID-19 epidemic case growth rates declined by approximately 1% per day, beginning four days after the implementation of state-wide social-distancing measures [13]. These findings contribute to the existing body of evidence by estimating the impact of social distancing in the community on individual-level outcomes.

Comparison with Prior Work:

Numerous studies have consistently indicated a connection between face mask usage and a decreased risk of COVID-19 at the population level. Specifically, three prior studies examining the impact of self-reported face mask use on the risk of COVID-19 reported odds ratios (ORs) ranging from 0.21 to 0.30, which align with our finding of a 0.36 hazard ratio (HR) for always using masks [14-16]. While the protective role of face masks for other individuals is well-established, our observation suggests that wearing a face mask may also help to reduce the viral load, as noted by others [17].

This study investigated whether demographic variables were associated with a higher COVID-19

positivity rate. However, the logistic regression model did not provide significant evidence of an association between demographic variables (household income, type of residence, education level, race, and number of individuals living in a household) and COVID-19 positivity. The overall model was statistically insignificant, and the predictors included did not substantially contribute to explaining the variability in COVID-19 positivity among participants. Our study results also did not provide evidence of a significant association between living with someone in healthcare and the COVID-19 positivity rate among participants.

This study also explored if there is an association between a specific vaccine (Moderna, Pfizer, or Johnson & Johnson) and hospitalization rates. However, we did not find evidence of a significant association between the type of vaccine and hospitalization rates among participants. This indicates that all three vaccines are similarly effective in preventing severe outcomes that require hospitalization. It suggests that public health benefits can be achieved with any of the available vaccines and supports their continued use in efforts to reduce the burden of severe illness.

The unprecedented speed and scale of data accumulation on breakthrough infections and related topics have not answered several important questions. For instance, though there's evidence that vaccines against SARS-CoV-2 reduce transmission in households [18] and communities[19], achieving sustained high levels of herd immunity against SARS-CoV-2 infection through vaccination is questioned. This scepticism arises from the mucosal nature of the infection without an obligate stage of dissemination through lymph or blood. Even with high vaccine coverage, a combination of waning immunity and antigenic variation may create enough susceptibility in the population to maintain endemic transmission of SARS-CoV-2, similar to the four other coronaviruses circulating in the human population [20]. However, it is unlikely that

this situation will result in the same level of disruption seen in the first two years of the COVID-19 pandemic. Pandemics are rare events where virtually all humans lack exposure to a novel pathogen, putting them at risk for severe disease and transmission, especially older individuals and those with certain comorbidities. Similar to the influenza virus [21], or even more so with human coronaviruses, this pandemic pattern may gradually transition into a pattern of milder disease. Virtually everyone will experience multiple exposures through one or more vaccine doses and/or one or more exposures to viral (possibly breakthrough) infection [22]. In this view, the role of vaccines is not to provide durable herd immunity, as with measles or smallpox, but to prevent severe outcomes during the transition to endemicity.

Limitations:

It is important to note the limitations of the study. This study employed convenience sampling, primarily recruiting participants affiliated with academic institutions (e.g., students, faculty), which may limit the generalizability of our findings. The overrepresentation of younger, female, and White individuals in our cohort (see Table 1) could introduce selection bias, as behavioral responses to COVID-19 (e.g., mask-wearing, dining out) may systematically differ in older or more diverse populations. For instance, our observed high adherence to social distancing among those aged >70 years (100%) should be interpreted cautiously, given the small sample size (n=10) in this subgroup. Since the study was conducted using an anonymous survey, we could not verify responses. Recall bias was mitigated by using validated surveys as a resource, and by comparing the behaviors and community settings of respondents who reported testing positive for COVID-19 infection and those who had never tested positive for COVID-19. However, it is possible that there could be some inaccuracies in the responses from both cohorts of respondents. Public health measures, such as public masking, social distancing, and reduced maximum

occupancy limits for social gathering settings were variable across the United States, and the degree of adherence to those recommendations was also variable, which could confound the study results regarding which settings were more or less likely to be associated with COVID-19 infection in vaccinated individuals. However, this heterogeneity was distributed evenly among both cohorts of respondents. Future studies should prioritize stratified or population-based sampling to ensure broader applicability of results.

Conclusion

In summary, this cross-sectional study aimed to investigate the factors influencing breakthrough COVID-19 infections among vaccinated individuals. The findings revealed significant associations between specific community activities and breakthrough infections in vaccinated individuals, underscoring the importance of targeted interventions. Particularly noteworthy was the consistent higher adherence to social distancing and mask-wearing across various settings among the 18-29 age group, providing valuable insights for the formulation of effective public health strategies. However, the study did not identify significant associations between breakthrough infections and demographic variables, vaccine types, or specific activities related to social distancing and mask-wearing. This underscores the nuanced and multifaceted nature of breakthrough infections, suggesting that individual behaviours and contextual factors play crucial roles. Despite the inherent limitations and challenges in predicting breakthrough infections, this study contributes to our understanding of the complex interplay between vaccination status, community behaviours, and infection risks. The findings highlight the ongoing need for research and flexible public health strategies to adapt to the evolving landscape of the COVID-19 pandemic. As we transition toward endemicity, the role of vaccines becomes pivotal in preventing severe outcomes, and the insights from this study can inform future

interventions and policies.

Declarations

- Consent for publication – Not applicable
- Availability of data and materials - The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request
- Competing interests - The authors declare that they have no competing interests
- Funding – Not applicable
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