Covid-19 vaccination in the province of Ontario: A geographical and socio-economical analysis

Ariel Mundo Ortiz

Abstract

Keywords

Background

The COVID-19 pandemic continues around the world with more than 600 million confirmed cases as of November of 2022[1]. During the first months of the pandemic in early 2020, non-pharmaceutical interventions such as masking and social distancing were the only methods available to manage the spread of the disease; however, the rapid development of vaccines permitted their approval and use in some countries towards the last month part of 2020. For example, in the US and Canada vaccine campaigns began in mid-December of 2020[2,3]. Although it has been estimated that vaccines against COVID-19 have prevented around 14 millions of deaths worldwide[4], the rollout of COVID-19 vaccines has faced multiple challenges since its inception.

Indeed, multiple obstacles that have complicated vaccination efforts against COVID-19 have been identified: inequality in vaccine access, vaccine hesitancy, and differences in vaccination rates across different segments of the population[5–7]. In the case of Canada, lower vaccine uptake has been associated with socio-economic factors such as younger age, educational level, presence of children in the household, lack of a regular healthcare provider, ethnic origin, and financial instability[8–10].

Additionally, vaccination is influenced by changes in geography. In this regard, it has been shown that there have been spatial differences in COVID-19 vaccination rates due to regional differences in attitudes towards vaccination[7], geographical differences in vaccine access and supply, vaccination location availability, and lack of prioritization of vulnerable groups[3,11].

Studies that analyze geographical variations in vaccine uptake are important as they can help inform public health decision-makers to design policies to that consider spatial changes to address vaccination disparities. In this regard, previous geographical (spatial) analyses of vaccination rates have shown that variations in vaccine uptake can occur within small governmental administrative units (e.g., counties in the case of the US)[12–15], and that geographical analyses can be predictive of booster uptake patterns[16].

In Canada, studies that have used a spatial approach to analyze vaccine uptake have shown disparities in vaccination rates across low and high income neighborhoods in the city of Toronto[17], among adolescents from deprived neighborhoods in the city of Montreal[18], and have also highlighted disparities in vaccination status depending on age, income, and ethnic origin at the provincial level[8]. However, there is limited information on differences in vaccination status inside the provinces. Such analysis is important as it can help identify inequalities that may exist within these geographical areas while providing a granular view of intra-provincial differences that can help understand the barriers for vaccine uptake.

In this study we examined self-reported COVID-19 vaccination status within the province of Ontario using a combination of socio-economic factors(such as ethnic origin, age, and income) and geographical analysis (at the level of the Health Regions) in order to determine intra-provincial disparities in vaccine uptake and address the ongoing need of socio-economic information that can provide a rationale for the disparities in vaccination observed within some racial groups[19].

Methods

Data source: survey overview

We used data from the *Survey of COVID-19 related Behaviours and Attitudes*, a repeated cross sectional survey focused on the Canadian province of Ontario which ran from Sept 30, 2021 until January 17, 2022 and that was comissioned by the Fields Institute for Research in Mathematical Sciences (henceforth Fields) and the Mathematical Modelling of COVID-19 Task Force. The survey was conducted by a third-party service provider (RIWI Corp.), under ethical guidance from the University of Toronto.

Briefly, the survey was deployed used random domain intercept technology, where if users clicked on a registered but commercially inactive web link or typed in a web address for a site that was dormant, they had a random chance of that link being temporarily managed by the company that administered the survey and instead of coming across a notification about the status of the site("this page does not exist"), the survey was deployed to the user[20]. Users then decided whether to anonymously participate, and those that participated were able to exit the survey at any time. After the survey closed, regardless if it was complete or incomplete, access was denied to any further users with the same internet protocol (IP) address and the domain entry point rotated such that if a user were to attempt to access the survey again, share the link, or enter via the same address using an alternative IP address, the survey would not deploy. This effectively meant that a user could participate only once in the survey.

Additionally, users who indicated they were under the age of 16 were exited from the survey without creating a record, furthermore, these users were unable to navigate back to the "age select" screen. The personal identifier information from each user that participated in the survey was automatically scrubbed and replaced by a unique ID. Respondents were drawn exclusively from the province of Ontario, as per their devices meta-data.

Survey responses

Socio-economic information selected from the survey answers included age group, income bracket, and race/ethnicity. The levels of each socio-economic factor used for analysis appear in Table 1.

Table 1: Selected socio-economic factors from the survey

Variable	Levels
Age group	16-34,35-54,55 and over
Income bracket (CAD)	under 25,000, 25,000-59,999, 60,000 and above
Race/ethnicity	Arab/Middle Eastern, Black, East Asian/Pacific Islander, Indigenous, Latin American, Mixed, South Asian, White Caucasian, Other

Furthermore, the information on vaccination status was provided by survey participants who answered the question “Have you received the first dose of the COVID vaccine?”, with possible answers “yes” and “no”.

Data cleaning

The original dataset contained 39,029 entries (where each entry corresponded to a set of answers provided by a unique respondent). Following a preliminary analysis, the dataset was cleaned in order to only contain the socio-economic information provided in Table 1 and vaccination status. The cleaning process also included removing outliers that were identified during the preliminary analyses. Specifically, we removed those respondents that indicated to be below 25 years of age, living in a household of size 1, and that reported an income above CAD 110,000. The next step consisted in processing the geographical information in the survey (city where the survey was responded) in order to match each city to its correspondent Health Region. Details of this process are given below.

Geographical location

For each survey participant certain data was automatically captured, including the nearest municipality (city). This resulted in a total of 578 different municipalities within the clean dataset. Due to our interest in analyzing the differences between Health Regions, we assigned the city of each entry to its correspondent Health Region following a multi-step process. Briefly, we used Local Health Integrated Networks (LHINs) to assign a Health Region to each entry in the survey. LHINs were the geographical divisions for health used by Ontario before the adoption of the Health Regions; because of the lack of a publicly available list of all municipalities within each Health Region, we used a dataset of long-term care homes and LHINs to match each city to LHIN, followed by matching each LHIN to a Health Region following the information provided on the Ontario Health Website, where the list of LHINs and corresponding Health Regions is available. In the case of municipalities that did not appear in the long-term dataset, we manually searched each city in the LHINs websites in order to provide geographical information. The raw dataset, clean dataset, details of the data cleaning process, and the addition of Health Region and LHIN information are described in detail in the github repository: https://github.com/aimundo/Fields_COVID-19/.

Following an assessment of the number of entries corresponding to each Health Region in the final dataset, only 107 observations (4.3% of the total) corresponded to cities located in the

North West and North East Health Regions. Due to the low number of entries, we omitted these Health Regions from further analyses. Therefore, the total number of unique entries used for analysis was 3,551 which included the East, Central, Toronto, and West Health Regions.

Corrections

We identified differences between the proportions of all the socio-economic factors included in the analysis (Table 1) and the 2016 Canada Census data for Ontario. Additionally, because the Census divisions do not match the exact boundaries of the Health Regions, we also obtained population estimates for each Health Region from the Ontario Health website in order to correct for the population totals. We used an iterative proportional fitting procedure (*raking*)[21] to correct for socio-economic factors and Health Region populations using the R `survey` package. Details about the correction can be found in the Appendix.

Statistical analyses

We used a logistic regression model to estimate the probability of vaccination depending on the socio-economic factors described in Section , the Health Regions from Section , and the interactions between Race and Health Region, and Race and income as previous studies have shown that socio-economic factors and their interactions are significant predictors of intent of vaccination and vaccination status[22–24]. The model appears in Equation 1,

$$\log\left(\frac{p(\text{vac})}{1-p(\text{vac})}\right) = \beta_0 + \beta_1(\text{Age group}) + \beta_2 \text{ Race} + \beta_3 \text{ Health Region} + \beta_4 \text{ Income}+ \\ \beta_5(\text{Health Region} \times \text{Race}) + \beta_6 \text{ (Income} \times \text{Race)} \tag{1}$$

Where $p(\text{vac})$ indicates the probability of having received the first dose of a Covid-19 vaccine, β_0 indicates the population intercept, and $\beta_1 ... \beta_6$ indicate the coefficients for each term. The the model was fitted using the function `svyglm` from the `survey` R package in order to incorporate the correction in sampling probability obtained from raking.

All analyses were conducted in RStudio (2022.12.0 Build 353), using R 4.2.2 and the packages `survey`[25],`tidyverse`[26], and `quarto`[27].

Results

Survey Results

Table 2 shows the descriptive statistics (uncorrected) from the Fields Covid-19 survey data for vaccination status and each of the covariates analyzed. The total number of entries from the survey in the dataset after cleaning was 3,551. Overall, 26.9% of survey respondents (958) reported not having received the first dose of the vaccine, whereas 73.1% (2,593) reported having received it. Within each socio-economic factor, respondents who reported living in a household with an income under CAD 25,000 represented 37% of the total number of entries, those within the CAD 25,000-59,999 income bracket represented 25% of the total sample, and those with an income above CAD 60,000 represented 38 % of the sample; across all income brackets, the percentage of individuals that reported having received a first dose of the vaccine was consistent, above 69%.

Within the age groups of survey respondents, the age group between 16-34 years had the highest representation in the survey responses (1,521, 42.8% of all responses). Within this age bracket, 73% of respondents indicated having received the vaccine, whereas the lowest vaccination rate was in the bracket of those 55 years of age and above, with a total of 72%. The Health Region with highest representation in the survey was Toronto, accounting for 1,324 entries (37.2%), with a vaccination rate of 72%. Regarding race/ethnicity, individuals that identified as White/Caucasian represented 1313 (37%) of all entries and had the highest vaccination uptake with 82% of them indicating to have received the COVID-19 vaccine. On the other hand, the ethnic group with the lowest number of entries in the survey was Latin American, with a total of 180, or 5% of all entries. Vaccination rates across all minority groups were below the value reported by White/Caucasians, with the lowest vaccination rate (60%) being reported by individuals that identified as Indigenous.

Multivariate Regression

Table 3 shows the results of the logistic regression on vaccination status using socio-economic factors (age group, income, race), geographical areas (Health Regions) and the interactions between income and race and Health Region and race. The reference groups were set as follows:

Table 2: Descriptive Statistics of the Fields Covid-19 Survey

Variable	**no**, N = 958	**yes**, N = 2,593
income_ord		
60000_and_above	305 (23%)	1,049 (77%)
25000_59999	253 (28%)	636 (72%)
under_25000	400 (31%)	908 (69%)
Age_group_ord		
16_34	409 (27%)	1,112 (73%)
35_54	252 (26%)	712 (74%)
55_and_over	297 (28%)	769 (72%)
Health_Region		
Toronto	371 (28%)	953 (72%)
Central	224 (28%)	581 (72%)
East	135 (23%)	448 (77%)
West	228 (27%)	611 (73%)
Race		
white_caucasian	233 (18%)	1,080 (82%)
arab_middle_eastern	76 (36%)	138 (64%)
black	114 (38%)	184 (62%)
east_asian_pacific_islander	69 (23%)	234 (77%)
indigenous	76 (40%)	115 (60%)
latin_american	69 (38%)	111 (62%)
mixed	105 (34%)	205 (66%)
other	128 (35%)	239 (65%)
south_asian	88 (23%)	287 (77%)

[1] n (%)

16 to 34 years (age group), White Caucasian (Race), Toronto (Health Region), CAD 60,000 and over (Income). There were no statistically significant differences in vaccination rates within the age groups, but significant odds ratios were estimated for individuals within the rest of the covariates. Within household income brackets, individuals with an income under CAD 25,000 or between CAD 25,000-59,999 had significantly lower odds of vaccination than those with an income above CAD 60,000 (ORs=0.37 and 0.59, respectively). Within Race/Ethnicity, individuals who identified as Arab/Middle Eastern, Black, or Latin American, had significantly lower odds of vaccination than those in the White/Caucasian group (ORs=0.31, 0.32, 0.28, respectively); additionally, those individuals in the Other Race/Ethnicity group (a group that included Southeast Asian, Filipino, West Asian, and Minorities Not Identified Elsewhere) had even lower odds of vaccination than the other minority groups, with an OR of 0.22. Regarding Health Regions, individuals that reported living in the West Health Region (which comprises the regions of Waterloo and Niagara, the counties of Wellington, Essex, and Lambton, and the cities of Hamilton, Haldimand, Brant, and Chatham-Kent) had significantly higher odds of vaccination than those in the Health Region of Toronto (OR=1.55).

Moreover, statistically-significant higher odd ratios were determined in the case of the interaction of income and race; specifically, for individuals with a household income below CAD 25,000 who identified as Arab/Middle Eastern (OR=3.05), Black (OR=3.19), Latin American (OR=2.80), or that belonged to other minority groups (OR=4.59). Within the CAD 25,000-59,999 income bracket, individuals who identified as belonging to other racial minority groups had significantly higher odds of vaccination (OR=6.93).

For the interaction of Health Region and race, significant lower vaccination odds were identified for Black individuals in the Central Health Region, which comprises the region of York, counties of Dufferin and Simcoe and the district of Muskoka (OR=0.44). Finally, individuals that identified as part of other racial minorities or South Asian iand that lived in the West Health Region had significantly lower odds of vaccination (ORs=0.41).

Table 3: Multiple Regression Analysis-Predictors of Vaccination Status

Characteristic	**OR**	**95% CI**	**p-value**
Age Group			
16_34	—	—	
35_54	0.90	0.67, 1.21	0.5
55_and_over	0.99	0.74, 1.32	>0.9
income_ord			
60000_and_above	—	—	
25000_59999	0.59	0.39, 0.89	0.011
under_25000	0.37	0.25, 0.56	<0.001
Race			
white_caucasian	—	—	
arab_middle_eastern	0.31	0.14, 0.69	0.004
black	0.32	0.17, 0.60	<0.001
east_asian_pacific_islander	1.15	0.50, 2.66	0.7
indigenous	0.44	0.19, 1.02	0.056
latin_american	0.28	0.11, 0.67	0.004
mixed	0.64	0.25, 1.65	0.4
other	0.22	0.12, 0.41	<0.001
south_asian	0.91	0.49, 1.69	0.8
Health Region			
Toronto	—	—	
Central	1.47	0.92, 2.35	0.11
East	1.42	0.90, 2.23	0.13
West	1.55	1.05, 2.30	0.029
income_ord * Race			
25000_59999 * arab_middle_eastern	1.79	0.67, 4.83	0.2
under_25000 * arab_middle_eastern	3.05	1.26, 7.39	0.013
25000_59999 * black	1.34	0.59, 3.05	0.5
under_25000 * black	3.19	1.45, 6.99	0.004
25000_59999 * east_asian_pacific_islander	0.42	0.17, 1.05	0.062
under_25000 * east_asian_pacific_islander	1.16	0.47, 2.86	0.8
25000_59999 * indigenous	1.36	0.48, 3.89	0.6
under_25000 * indigenous	1.45	0.55, 3.80	0.5
25000_59999 * latin_american	1.24	0.45, 3.43	0.7
under_25000 * latin_american	2.80	1.04, 7.51	0.041
25000_59999 * mixed	0.85	0.32, 2.26	0.7
under_25000 * mixed	1.10	0.37, 3.27	0.9
25000_59999 * other	6.93	2.65, 18.1	<0.001

(continued)

Characteristic	OR	95% CI	p-value
under_25000 * other	4.59	2.33, 9.05	<0.001
25000_59999 * south_asian	1.20	0.51, 2.85	0.7
under_25000 * south_asian	2.00	0.93, 4.30	0.077
Race * Health Region			
arab_middle_eastern * Central	0.66	0.26, 1.70	0.4
black * Central	0.44	0.19, 0.98	0.046
east_asian_pacific_islander * Central	0.98	0.38, 2.53	>0.9
indigenous * Central	0.63	0.22, 1.79	0.4
latin_american * Central	0.67	0.23, 1.96	0.5
mixed * Central	0.73	0.24, 2.22	0.6
other * Central	0.80	0.36, 1.78	0.6
south_asian * Central	0.54	0.25, 1.20	0.13
arab_middle_eastern * East	0.43	0.13, 1.45	0.2
black * East	0.83	0.34, 2.04	0.7
east_asian_pacific_islander * East	0.86	0.29, 2.56	0.8
indigenous * East	0.69	0.23, 2.08	0.5
latin_american * East	1.03	0.32, 3.34	>0.9
mixed * East	0.91	0.28, 3.03	0.9
other * East	1.05	0.39, 2.83	>0.9
south_asian * East	0.52	0.19, 1.45	0.2
arab_middle_eastern * West	1.00	0.37, 2.73	>0.9
black * West	0.76	0.32, 1.80	0.5
east_asian_pacific_islander * West	0.52	0.20, 1.34	0.2
indigenous * West	0.39	0.14, 1.09	0.073
latin_american * West	0.94	0.32, 2.72	>0.9
mixed * West	0.37	0.12, 1.16	0.089
other * West	0.41	0.18, 0.93	0.032
south_asian * West	0.41	0.18, 0.95	0.037

[1] OR = Odds Ratio, CI = Confidence Interval

Discussion

The rapid development of COVID-19 vaccines has been considered as a major achievement of modern medicine[28]. The availability of vaccines at the end of 2020 made some believe that they would be a determinant factor in a rapid ending of the pandemic[29]. However, despite previous successful vaccination campaigns that were crucial to control diseases such as smallpox and polio[30], vaccination efforts in the case of Covid-19 have faced multiple challenges that have complicated the achievement of global immunity.

Among the different challenges faced by Covid-19 vaccination efforts are the development of new variants due to inadequate public health measures[31] and inequity in vaccine access between low and high income countries[32]. However, it is also well established that even in the case of high income countries that have had ample access to vaccines since 2020, such as the US, the UK, and Canada, there have been challenges in vaccination efforts due to differences in vaccine uptake among different segments of the population. More specifically, lower vaccine uptake has been associated with socio-economic factors such as race (i.e., identifying as Black, Asian, Indigenous) and household income (typically within lower income brackets)[33–36]. Reasons given for this association have included medical mistrust due to systemic medical racism, mistrust in vaccines, and the influence of conspiracy theories[33,35,37–39].

In addition, vaccine uptake is influenced by geography as shown by different studies that have identified intra-regional differences in vaccine uptake[12,40,41]. However, in the case of Canada, most studies that have analyzed spatial differences in vaccination have been focused in country-wide or province-wide estimates[8,42]. Therefore, we explored spatial and socio-economic determinants of vaccination status in the province of Ontario. This province is of particular interest as it has seen recently major structural health changes with the dissolution of the Local Health Integrated Networks (LHINs) and their incorporation into larger Health Regions[43]. The idea behind the change aimed at reducing the inequalities in healthcare that were identified under the LHIN approach[44], and thus, examining if there are significant differences in vaccination between the Health Regions could be important to consider by decision-makers in the development of public health policies that aim to address intra-provincial health disparities.

Our results indicate that across the most densely populated Health Regions of Ontario, almost three quarters of the surveyed individuals reported having received the first dose of the Covid-19 vaccine (Table 2). This is consistent with overall vaccination rates reported for Canada, which have been relatively higher when compared to other high income countries[45]. However, we also identified differences in vaccination likelihood based on different socio-economic factors. More specifically, our results show that those that were above 65 years old were only 44% likely to have received a vaccine when compared to those between 16 and 24 years old, that individuals with a household income below CAD 39,999 were around 60% less likely of having received the vaccine when compared to individuals in high income households (with an income above 90,000 CAD), and that individuals who identified as Arab and Middle Easterns, Black, Indigenous, Latin American, South Asian, Southeast Asian, Filipino, West Asian, and minorities not identified elsewhere had significantly lower probability of vaccination (ranging between 15% and 40%) when compared to White/Caucasian individuals (Table 3).

These results are consistent with other studies that have shown an association between lower vaccination rates in racial minorities and lower household income[8–10,46]. However, it is interesting to note reduced vaccination likelihood in those aged 65 and over, as other studies have reported higher vaccination acceptance in this age group[8,47].

Although there was no significant difference between vaccination odds among the Health Regions, there was a significant lower vaccination odds in the Central Health Region in individuals with a household income between CAD 15,000-24,999 (OR=0.4, Table 3). The Central Health Region comprises the former Central, Central West, Mississauga Halton, and North Simcoe Muskoka LHINs with 48.3% of immigrant population and 47% of the population identifying as visible minority, the highest percentage among all Health Regions[48]; moreover, the fact that the Central West LHIN, now within the Central Health Region, had the highest proportion of low-income families in 2018 (12.9% of males and 16.7% of females among the lowest 20% of Canadian family incomes[49])

- Influence of geography
- ontario and Health Regions: find information about poverty and racial groups.
- Results
- Limitations

References

1. World Health Organization Coronavirus (COVID-19) Dashboard. Accessed November 27, 2022. https://covid19.who.int/

2. Tanne JH. Covid-19: FDA panel votes to authorise pfizer BioNTech vaccine. *BMJ*. Published online December 2020:m4799. doi:10.1136/bmj.m4799

3. Bogoch II, Halani S. COVID-19 vaccines: A geographic, social and policy view of vaccination efforts in ontario, canada. *Cambridge Journal of Regions, Economy and Society*. Published online November 2022. doi:10.1093/cjres/rsac043

4. Watson OJ, Barnsley G, Toor J, Hogan AB, Winskill P, Ghani AC. Global impact of the first year of COVID-19 vaccination: A mathematical modelling study. *The Lancet Infectious Diseases*. 2022;22(9):1293-1302. doi:10.1016/s1473-3099(22)00320-6

5. Gerretsen P, Kim J, Caravaggio F, et al. Individual determinants of COVID-19 vaccine hesitancy. Inbaraj LR, ed. *PLOS ONE*. 2021;16(11):e0258462. doi:10.1371/journal.pone.0258462

6. Nafilyan V, Dolby T, Razieh C, et al. Sociodemographic inequality in COVID-19 vaccination coverage among elderly adults in england: A national linked data study. *BMJ Open*. 2021;11(7):e053402. doi:10.1136/bmjopen-2021-053402

7. Malik AA, McFadden SM, Elharake J, Omer SB. Determinants of COVID-19 vaccine acceptance in the US. *EClinicalMedicine*. 2020;26:100495. doi:10.1016/j.eclinm.2020.100495

8. Guay M, Maquiling A, Chen R, et al. Measuring inequalities in COVID-19 vaccination uptake and intent: Results from the canadian community health survey 2021. *BMC Public Health*. 2022;22(1). doi:10.1186/s12889-022-14090-z

9. Muhajarine N, Adeyinka DA, McCutcheon J, Green KL, Fahlman M, Kallio N. COVID-19 vaccine hesitancy and refusal and associated factors in an adult population in saskatchewan, canada: Evidence from predictive modelling. Gesser-Edelsburg A, ed. *PLOS ONE*. 2021;16(11):e0259513. doi:10.1371/journal.pone.0259513

10. Hussain B, Latif A, Timmons S, Nkhoma K, Nellums LB. Overcoming COVID-19 vaccine hesitancy among ethnic minorities: A systematic review of UK studies. *Vaccine*. 2022;40(25):3413-3432. doi:10.1016/j.vaccine.2022.04.030

11. Nguyen KH, Nguyen K, Corlin L, Allen JD, Chung M. Changes in COVID-19 vaccination receipt and intention to vaccinate by socioeconomic characteristics and geographic area, united states, january 6 – march 29, 2021. *Annals of Medicine*. 2021;53(1):1419-1428. doi:10.1080/07853890.2021.1957998

12. Mollalo A, Tatar M. Spatial modeling of COVID-19 vaccine hesitancy in the united states. *International Journal of Environmental Research and Public Health*. 2021;18(18):9488. doi:10.3390/ijerph18189488

13. Yang TC, Matthews SA, Sun F. Multiscale dimensions of spatial process: COVID-19 fully vaccinated rates in u.s. counties. *American Journal of Preventive Medicine*. 2022;63(6):954-961. doi:10.1016/j.amepre.2022.06.006

14. Tiu A, Susswein Z, Merritt A, Bansal S. Characterizing the spatiotemporal heterogeneity of the COVID-19 vaccination landscape. *American Journal of Epidemiology*. 2022;191(10):1792-1802. doi:10.1093/aje/kwac080

15. Bhuiyan MAN, Davis TC, Arnold CL, et al. Using the social vulnerability index to assess COVID-19 vaccine uptake in louisiana. *GeoJournal*. Published online December 2022. doi:10.1007/s10708-022-10802-5

16. Wood AJ, MacKintosh AM, Stead M, Kao RR. Predicting future spatial patterns in COVID-19 booster vaccine uptake. Published online September 2022. doi:10.1101/2022.08.30.22279415

17. Choi KH, Denice PA, Ramaj S. Vaccine and COVID-19 trajectories. *Socius: Sociological Research for a Dynamic World*. 2021;7:237802312110529. doi:10.1177/23780231211052946

18. McKinnon B, Quach C, Dubé Ève, Nguyen CT, Zinszer K. Social inequalities in COVID-19 vaccine acceptance and uptake for children and adolescents in montreal, canada. *Vaccine*. 2021;39(49):7140-7145. doi:10.1016/j.vaccine.2021.10.077

19. Cénat JM, Noorishad PG, Bakombo SM, et al. A systematic review on vaccine hesitancy in black communities in canada: Critical issues and research failures. *Vaccines*. 2022;10(11):1937. doi:10.3390/vaccines10111937

20. Sargent RH, Laurie S, Weakland LF, et al. Use of random domain intercept technology to track COVID-19 vaccination rates in real time across the united states: Survey study. *Journal of Medical Internet Research*. 2022;24(7):e37920. doi:10.2196/37920

21. Deming WE, Stephan FF. On a least squares adjustment of a sampled frequency table when the expected marginal totals are known. *The Annals of Mathematical Statistics*. 1940;11(4):427-444. doi:10.1214/aoms/1177731829

22. Nguyen KH, Anneser E, Toppo A, Allen JD, Parott JS, Corlin L. Disparities in national and state estimates of COVID-19 vaccination receipt and intent to vaccinate by race/ethnicity, income, and age group among adults $\geq$ 18 years, united states. *Vaccine*. 2022;40(1):107-113. doi:10.1016/j.vaccine.2021.11.040

23. Shih SF, Wagner AL, Masters NB, Prosser LA, Lu Y, Zikmund-Fisher BJ. Vaccine hesitancy and rejection of a vaccine for the novel coronavirus in the united states. *Frontiers in Immunology*. 2021;12. doi:10.3389/fimmu.2021.558270

24. Cénat JM, Noorishad PG, Farahi SMMM, et al. Prevalence and factors related to COVID-19 vaccine hesitancy and unwillingness in canada: A systematic review and meta-analysis. *Journal of Medical Virology*. 2022;95(1). doi:10.1002/jmv.28156

25. Lumley T. *Complex Surveys*. John Wiley & Sons; 2011.

26. Wickham H, Averick M, Bryan J, et al. Welcome to the tidyverse. *Journal of Open Source Software*. 2019;4(43):1686. doi:10.21105/joss.01686

27. Allaire J. *Quarto: R Interface to 'Quarto' Markdown Publishing System.*; 2022. https://CRAN.R-project.org/package=quarto

28. Davis CJ, Golding M, McKay R. Efficacy information influences intention to take COVID-19 vaccine. *British Journal of Health Psychology*. 2022;27(2):300-319. doi:https://doi.org/10.1111/bjhp.12546

29. Microbe TL. COVID-19 vaccines: The pandemic will not end overnight. *The Lancet Microbe*. 2021;2(1):e1. doi:10.1016/s2666-5247(20)30226-3

30. Kayser V, Ramzan I. Vaccines and vaccination: History and emerging issues. *Human Vaccines & Immunotherapeutics*. 2021;17(12):5255-5268. doi:10.1080/21645515.2021.1977057

31. Li Q, Wang J, Tang Y, Lu H. Next-generation COVID-19 vaccines: Opportunities for vaccine development and challenges in tackling COVID-19. *Drug Discoveries & Therapeutics*. 2021;15(3):118-123. doi:10.5582/ddt.2021.0105

32. Yamey G, Garcia P, Hassan F, et al. It is not too late to achieve global covid-19 vaccine equity. *BMJ*. Published online March 2022:e070650. doi:10.1136/bmj-2022-070650

33. Willis DE, Andersen JA, Bryant-Moore K, et al. COVID-19 vaccine hesitancy: Race/ethnicity, trust, and fear. *Clinical and Translational Science*. 2021;14(6):2200-2207. doi:10.1111/cts.13077

34. Skirrow H, Barnett S, Bell S, et al. Women's views on accepting COVID-19 vaccination during and after pregnancy, and for their babies: A multi-methods study in the UK. *BMC Pregnancy and Childbirth*. 2022;22(1). doi:10.1186/s12884-021-04321-3

35. Stoler J, Enders AM, Klofstad CA, Uscinski JE. The limits of medical trust in mitigating COVID-19 vaccine hesitancy among black americans. *Journal of General Internal Medicine*. 2021;36(11):3629-3631. doi:10.1007/s11606-021-06743-3

36. Khubchandani J, Sharma S, Price JH, Wiblishauser MJ, Sharma M, Webb FJ. COVID-19 vaccination hesitancy in the united states: A rapid national assessment. *Journal of Community Health*. 2021;46(2):270-277. doi:10.1007/s10900-020-00958-x

37. Bogart LM, Ojikutu BO, Tyagi K, et al. COVID-19 related medical mistrust, health impacts, and potential vaccine hesitancy among black americans living with HIV. *JAIDS Journal of Acquired Immune Deficiency Syndromes*. 2021;86(2):200-207. doi:10.1097/qai.0000000000002570

38. Mosby I, Swidrovich J. Medical experimentation and the roots of COVID-19 vaccine hesitancy among indigenous peoples in canada. *Canadian Medical Association Journal*. 2021;193(11):E381-E383. doi:10.1503/cmaj.210112

39. Freeman D, Loe BS, Chadwick A, et al. COVID-19 vaccine hesitancy in the UK: The oxford coronavirus explanations, attitudes, and narratives survey (oceans) II. *Psychological Medicine*. 2020;52(14):3127-3141. doi:10.1017/s0033291720005188

40. Pallathadka A, Chang H, Han D. What explains spatial variations of COVID-19 vaccine hesitancy?: A social-ecological-technological systems approach. *Environmental Research: Health*. 2022;1(1):011001. doi:10.1088/2752-5309/ac8ac2

41. Huang Q, Cutter SL. Spatial-temporal differences of COVID-19 vaccinations in the u.s. *Urban Informatics*. 2022;1(1). doi:10.1007/s44212-022-00019-9

42. Lavoie K, Gosselin-Boucher V, Stojanovic J, et al. Understanding national trends in COVID-19 vaccine hesitancy in canada: Results from five sequential cross-sectional representative surveys spanning april 2020–march 2021. *BMJ Open*. 2022;12(4):e059411. doi:10.1136/bmjopen-2021-059411

43. Dong L, Sahu R, Black R. Governance in the transformational journey toward integrated healthcare: The case of ontario. *Journal of Information Technology Teaching Cases*. Published online December 2022:204388692211473. doi:10.1177/20438869221147313

44. Tsasis P, Evans JM, Owen S. Reframing the challenges to integrated care: A complex-adaptive systems perspective. *International Journal of Integrated Care*. 2012;12(5). doi:10.5334/ijic.843

45. Dubé E, Gagnon D, MacDonald N. Between persuasion and compulsion: The case of COVID-19 vaccination in canada. *Vaccine*. 2022;40(29):3923-3926. doi:10.1016/j.vaccine.2022.05.053

46. Carter MA, Biro S, Maier A, Shingler C, Guan TH. COVID-19 vaccine uptake in southeastern ontario, canada: Monitoring and addressing health inequities. *Journal of Public Health Management and Practice*. 2022;28(6):615-623. doi:10.1097/phh.0000000000001565

47. MacDonald NE, Comeau J, Dubé Ève, et al. Royal society of canada COVID-19 report: Enhancing COVID-19 vaccine acceptance in canada. Blais JM, ed. *FACETS*. 2021;6:1184-1246. doi:10.1139/facets-2021-0037

48. *Annual Business Plan 2022/23.* Ontario Health; https://www.ontariohealth.ca/sites/ontariohealth/files/2022-05/OHBusinessPlan22_23.pdf; 2022.

49. Buajitti E, Watson T, Kornas K, Bornbaum C, Henry D, Rosella LC. Ontario atlas of adult mortality, 1992-2015: Trends in Local Health Integration Networks. Published online 2018. https://tspace.library.utoronto.ca/handle/1807/82836