Differences in COVID-19 vaccination in the province of Ontario across Health Regions and socio-economic strata

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Abstract

The COVID-19 pandemic continues to be a worldwide public health concern. Although vaccines against this disease were rapidly developed, vaccination uptake has not ben equal across all the segments of the population. In particular, it has been shown that there have been differences in vaccine uptake across different segments of the population. However, there are also differences in vaccination across geographical areas, which might be important to consider in the development of future public health policies against COVID-19. In this study, we examined the relationship between vaccination status (having received the first dose of a COVID-19 vaccine), and different socio-economic and geographical factors. Our results show that during the last three months of 2021, individuals in certain equity-deserving groups (visible minorities) were three times less likely to be vaccinated than White/Caucasian individuals across the province and that in some cases, within these groups individuals in low income brackets had significantly higher odds of vaccination when compared to their peers in high income brackets. Finally, we identified significantly lower odds of vaccination in the West Health Region of Ontario within certain equity-deserving groups. This study shows that there is an ongoing need to better understand and address differences in vaccination uptake across diverse segments of the population of Ontario that have been largely impacted by the pandemic.

Keywords

Covid-19, vaccination, survey, socio-economic factors, visible minorities.

Background

As of May of 2023 there have been 765 million confirmed cases of COVID-19 around the world, including 6.8 million deaths[1]. Although this disease is no longer categorized as a global health emergency by the World Health Organization (WHO)[2], there is ongoing concern due to continued transmission, surges in cases and deaths due to new variants[3], and weaknesses in health systems around the world that could be exploited by a novel virus or another public health emergency in the future[4].

In particular, a major weakness that has received attention during the pandemic has been related to vaccine uptake. The rapid development of vaccines against COVID-19 initially brought the hope of a rapid end to the pandemic due to the start of vaccination campaigns in certain parts of the world toward the end of 2020[5–8]) but inequalities in vaccine uptake made these pharmaceutical interventions ultimately unable to replicate the experience of smallpox, where vaccination on a global scale and was crucial to control this disease[9].

Although the problematic on vaccine uptake is a multifaceted issue resulting from a combination of factors, among which are failed public health measures[10], inequality in vaccine access between high- and low-income countries[11,12], and vaccine hesitancy[13], it is well established that individuals in certain equity-deserving groups (e.g., Black, Asian, or Indigenous) as well as individuals with socio-economic disadvantages have been disproportionately impacted by it, as indicated by the low vaccine uptake observed in these groups[14–20].

Reasons given for this problematic have included medical mistrust due to systemic medical racism[16], mistrust in vaccines[14], and the influence of conspiracy theories[21–23]. However, it is important to also consider that vaccination uptake can be influenced by geographical (spatial) factors. In this regard, differences in COVID-19 vaccination rates have been associated with varied regional attitudes towards vaccination[24], spatial differences in vaccine access and supply, vaccination location availability, and lack of prioritization of areas where vulnerable groups reside[7,25]. Other studies have also shown heterogeneity in vaccine uptake within small governmental administrative units such as counties[26–29], and that accounting for geographical differences in vaccination can help predict patterns of booster uptake[30].

However, such analyses have been carried mostly in territories outside of Canada, where available studies have been focused in certain cities (such as Toronto[31], or Montreal[32]), or have explored differences at a province-wide level[18]. Therefore, there is a need for studies that explore spatial differences in vaccination within the Canadian territory and that consequently, can help identify disparities that need to be addressed within specific areas in each province.

This is particularly important in the case of Ontario, the most populated province in Canada. Between 2006 and 2019, Ontario provided healthcare access to its inhabitants using 14 intra-provincial divisions called the Local Health Integrated Networks (LHINs). However, due to is complexity, bureaucratic burden, and lack of collaborative work this approach resulted in disparities such as excessive expenditures and differences in mortality rates[33,34]. In an effort to improve the healthcare system of the province, in late 2019 the 14 LHINs were phased out and the areas they covered were incorporated into 6 Health Regions (North East, North West, Central, Toronto, West, and East)[35]. Due to the relatively recent adoption of the Health Region model and its alignment with the onset of the COVID-19 pandemic, there is a need to analyze if there are ongoing disparities in health access under this approach that need to be addressed before they are exploited by a new disease or public health threat. In this regard, analyzing differences in vaccination uptake within the Health Regions and can help identify which socio-demographic groups are the most vulnerable and what areas of the province deserve special attention by decision-makers.

Therefore, in this study we hypothesized that there were differences in vaccination uptake between the different Health Regions of Ontario between October of 2021 and January of 2022. By including socio-economic factors in our analysis, we aimed at identifying in which groups these differences were significant in order to provide an assessment of the current state of healthcare access in Ontario.

Methods

Data and Methods

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 that was commissioned by the Fields Institute for Research in Mathematical Sciences and the Mathematical Modelling of COVID-19 Task Force under ethical guidance from the University of Toronto, and which ran between September 30th, 2021 and January 17th,2022. The survey collected socio-economic information from participants (Table 1), their location (nearest municipality, as shown in Figure 1), the date of access to the survey, and asked information on vaccination status by using the question "Have you received the first dose of the COVID vaccine?", with possible answers "yes" and "no". The original dataset contained 39,029 observations (where each observation corresponded to a unique respondent).

Preliminary analyses of the data included the removal of outliers (**should we still do this? it's only 19 observations with income >110k and household of 1, but we are not even using such income bracket in the analysis because we re-grouped the data, and the household size variable has 90% missing rate**), of observations where respondents did not provide answers in all the covariates of interest, matching the city of each observations with its corresponding LHIN and Health Region, and removing observations from

areas with low representation (107 observations corresponding to the North West and North East Health Regions). After all the preliminary analyses indicated above, the total number of observations used for analysis was 3,549 which included the East, Central, Toronto, and West Health Regions covering the period between October 1st,2021 and December 12th, 2021. The original dataset, clean dataset, and details on the data cleaning process are described in detail in the GitHub repository for this paper.

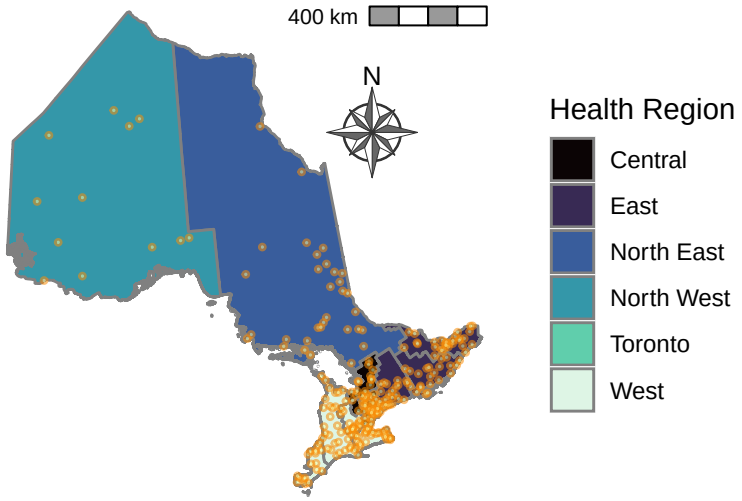

Figure 1: Geographic representation of the data collected by the *Survey of COVID-19 related Behaviours and Attitudes*, collected by the Fields Institute in Ontario. The municipalities (cities) from where survey participants provided answers (in the clean dataset) appear as points. The Health six Regions are color-coded. Internal boundaries within certain Health Regions indicate areas that belonged to the Local Integrated Health Networks (LHINs), the geographic areas for healthcare in Ontario before the adoption of the Health Regions.

Statistical analyses

We used a logistic regression model to examine the impact of the Health Regions in vaccination rates while considering the socio-economic factors and and months covered by the survey (Table 1) and certain interactions (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[36–38]. Because we identified differences in representativity between the survey data and the estimates from the Census, we used an iterative proportional fitting procedure (*raking*)[39] to correct the data using data from the Census and Health Region population totals; and fitted the regression model to the uncorrected and cor-

rected data. Details regarding the correction can be found in the Appendix. All analyses were conducted in R 4.2.2 using the packages `survey`[40],`tidyverse`[41], `quarto`[42], `modelsummary`[43], and `gtsummary`[44].

Results

Sample Characteristics

Table 1 shows the characteristics of the data from the Fields COVID-19 survey used for analysis. The sample contained **6,236** observations, from which 24.8% (1,547) corresponded to individuals that reported not having received the first dose of the vaccine. Vaccination rates ranged between 71-79% across household income brackets, age groups, Health Regions, and the months considered in the survey. However, the highest vaccination rates in each category were reported by individuals in the highest income bracket (79%), those between 16 and 34 years of age (77%), individuals that lived in the East Health Region (77%), and during January of 2022 (78%). Differences were higher between racial/ethnic groups, where the higher vaccination rate was reported by White/Caucasian individuals (84%), against vaccination rates between 63-66% reported in the case of Arab/Middle Eastern, Black, Indigenous, Latin American individuals, and those that reported belonging to "Other" racial groups, which included Southeast Asian, Filipino, West Asian, and minorities not identified elsewhere.

Table 1: Descriptive Statistics of the Fields COVID-19 Survey (by Vaccination Status)

Variable	**no**, N = 1,547[1]	**yes**, N = 4,689[1]	**p-value**[2]
Income (CAD)			<0.001
60000 and above	542 (21%)	1,996 (79%)	
25000-59999	347 (25%)	1,046 (75%)	
under 25000	658 (29%)	1,647 (71%)	
Age Group			0.002
16-34	645 (23%)	2,117 (77%)	
35-54	411 (24%)	1,305 (76%)	
55 and over	491 (28%)	1,267 (72%)	
Health Region			0.3
Toronto	593 (26%)	1,709 (74%)	
Central	372 (26%)	1,083 (74%)	
East	236 (23%)	783 (77%)	
West	346 (24%)	1,114 (76%)	
Month			<0.001
October	469 (27%)	1,263 (73%)	
November	376 (28%)	980 (72%)	
December	181 (24%)	565 (76%)	

January	521 (22%)	1,881 (78%)	
Race			<0.001
White/Caucasian	354 (16%)	1,871 (84%)	
Arab/Middle Eastern	111 (34%)	220 (66%)	
Black	159 (34%)	303 (66%)	
East Asian/Pacific Islander	94 (19%)	404 (81%)	
Indigenous	112 (37%)	194 (63%)	
Latin American	99 (34%)	195 (66%)	
Mixed	177 (30%)	411 (70%)	
Other[3]	315 (34%)	606 (66%)	
South Asian	126 (21%)	485 (79%)	

[1]n (%)

[2]Pearson's Chi-squared test

[3]Southeast Asian, Filipino, West Asian, and minorities not identified elsewhere according to the Census.

Multivariate Regression

Figure 2 presents the estimates (as odd ratios) from the logistic regression models for vaccination status using the socio-demographic factors collected by the survey, and their interactions. Generally speaking, lower odds of vaccination were identified in both cases in individuals characterized by a low household income, or that identified as part of equity-deserving groups. However, the magnitude of the estimates differed between the uncorrected and corrected models and more importantly, certain estimates were not deemed to be statistically-significant after the correction, in contrast to the estimates from the uncorrected model. Specifically, the corrected model showed no significant differences in vaccination odds between the age groups considered, the East Health Region, Latin American individuals with a household income under CAD 25,000, and Indigenous individuals living in the Central Health Region (Figure 2,B).

However, significantly lower odds of vaccination were identified in the corrected model for those with a household income under CAD 25,000 (OR=0.37, CI=[0.27,0.51]) and those with an income between CAD 25,000 and 59,999 (OR=0.58, CI=[0.42,0.81]). Additionally, individuals who identified as Arab/Middle Eastern, Black, Latin American, of mixed background, or that belonged to other racial groups (a category that included Southeast Asian, Filipino, West Asian, and minorities not identified elsewhere), had significantly lower odds of vaccination than those in the White/Caucasian group (ORs and CIs=0.28 [0.16,0.51], 0.27 [0.16,0.45], 0.40 [0.21,0.76], 0.53 [0.30,0.92], 0.23 [0.15,0.36]). Additionally, individuals that reported living in the Central and West Health Regions had higher odds of vaccination than those in the Health Region of Toronto (ORs and CIs=1.61 [1.10,2.34], and 1.59 [1.16,2.19], respectively).

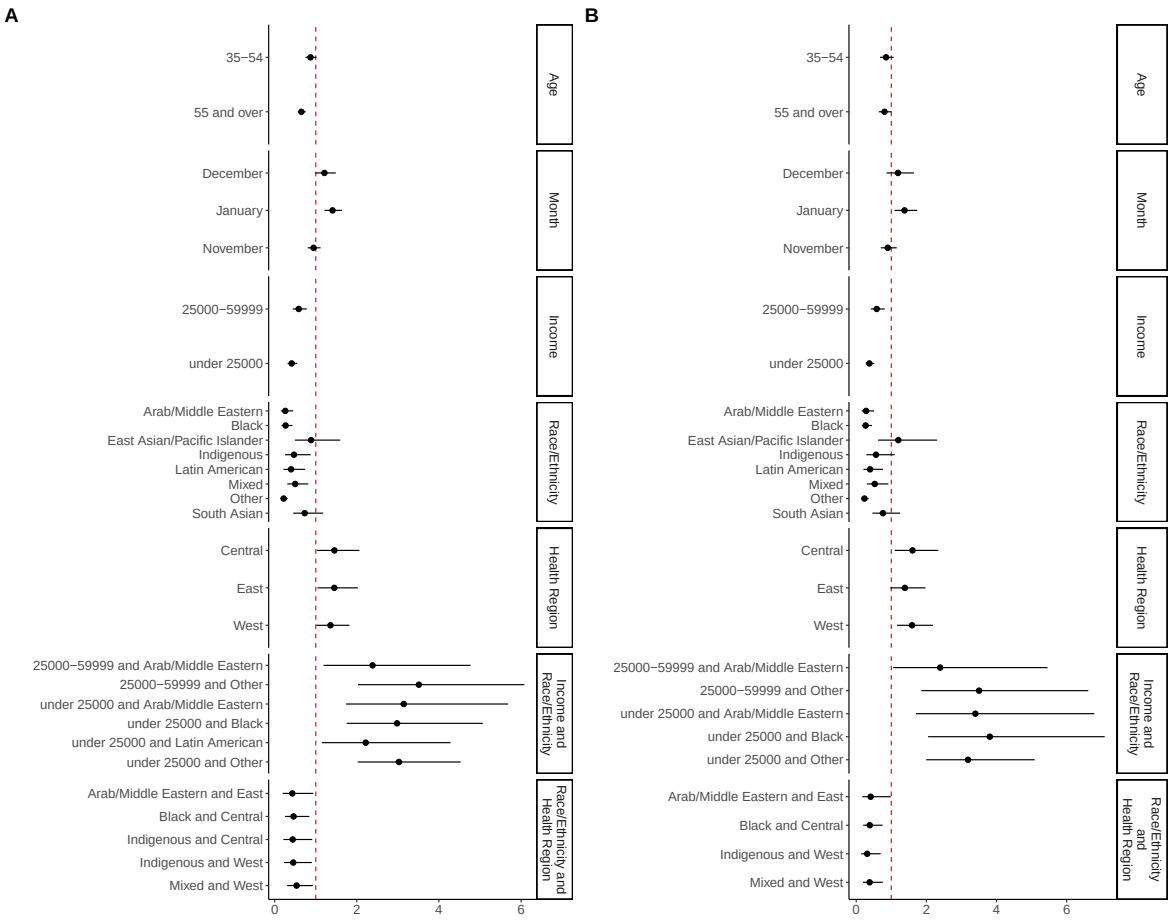

Figure 2: Coefficient estimates and confidence intervals for the uncorrected model. Only statistically significant interaction terms are shown. Full interaction terms can be found in Supplementary Figure A-3.

Interestingly, individuals in equity-deserving groups with a household income below CAD 25,000 had higher odds of vaccination (when compared to those with a household income above CAD 60,000). This held true in the case of Arab/Middle Eastern (OR=34, CI=[1.70,6.79]), Black individuals (OR=3.81, CI=[2.05, 7.09]), or those in other racial or ethnic groups (OR=3.19, CI=[2.00,5.09]). Additionally, individuals with an income between CAD 25,000 and 59,999 in the Arab/Middle Eastern and other racial ethnic groups had higher odds of vaccination (ORs and CIs=6.96 [2.67,18.16], and 3.5 [1.85,6.62]).

Finally, significantly lower odds of vaccination were identified (when compared to the Toronto Health Region) for Black individuals in the Central Health Region (OR=0.39, CI=[0.2,0.75]), Arab/Middle Eastern individuals in the East Health Region (OR=0.41 [0.17, 0.98]), and in the Indigenous and mixed groups in the West Health Region (ORs and CIs=[0.31 [0.14, 0.7] and 0.38 [0.19, 0.76], respectively).

Discussion

West Health Region includes the regions of Waterloo and Niagara, the counties of Wellington, Essex, and Lambton, and the cities of Hamilton, Haldimand, Brant, and Chatham-Kent. The Central Health Region includes the regions of Peel and Halton, the regional municipality of York, the district of Muskoka, the counties of Dufferin, Simcoe, Grey, and the city of Etobicoke.

had significantly higher odds of vaccination than those in the Health Region of Toronto

The existence of healthcare disparities in Ontario motivated the recent change in the health-care system of the province, which switched from the LHIN model to the Health Region model in late 2019[33,35]. This change is relatively recent, and because of this, is likely that there are ongoing differences in healthcare access across the province. In this study we hypothesized that differences in COVID-19 vaccination uptake were present between the Health Regions, aiming at determining which socio-demographic groups could be impacted by these disparities and to provide decision-makers with information that could be used to develop policies focused on reducing or eliminating these differences and ensure that the Health Region model is able to improve health access for the inhabitants of Ontario, a province that faces unique challenges due to its condition as the most populated and the most ethnically diverse province of Canada.

Our results indicate that across the most densely populated Health Regions of Ontario, almost three quarters of surveyed individuals reported to have received the first dose of the COVID-19 vaccine (Table 1). We identified significant intra-provincial differences in vaccination based on socio-economic and geographical factors. First, our results show differences in odds of vaccination in individuals with a household income below CAD 60,000 and in individuals belonging to visible minority groups. Those who identified as Arab/Middle Eastern, Black, Latin American, or that belonged to a minority group not included in the survey (Southeast

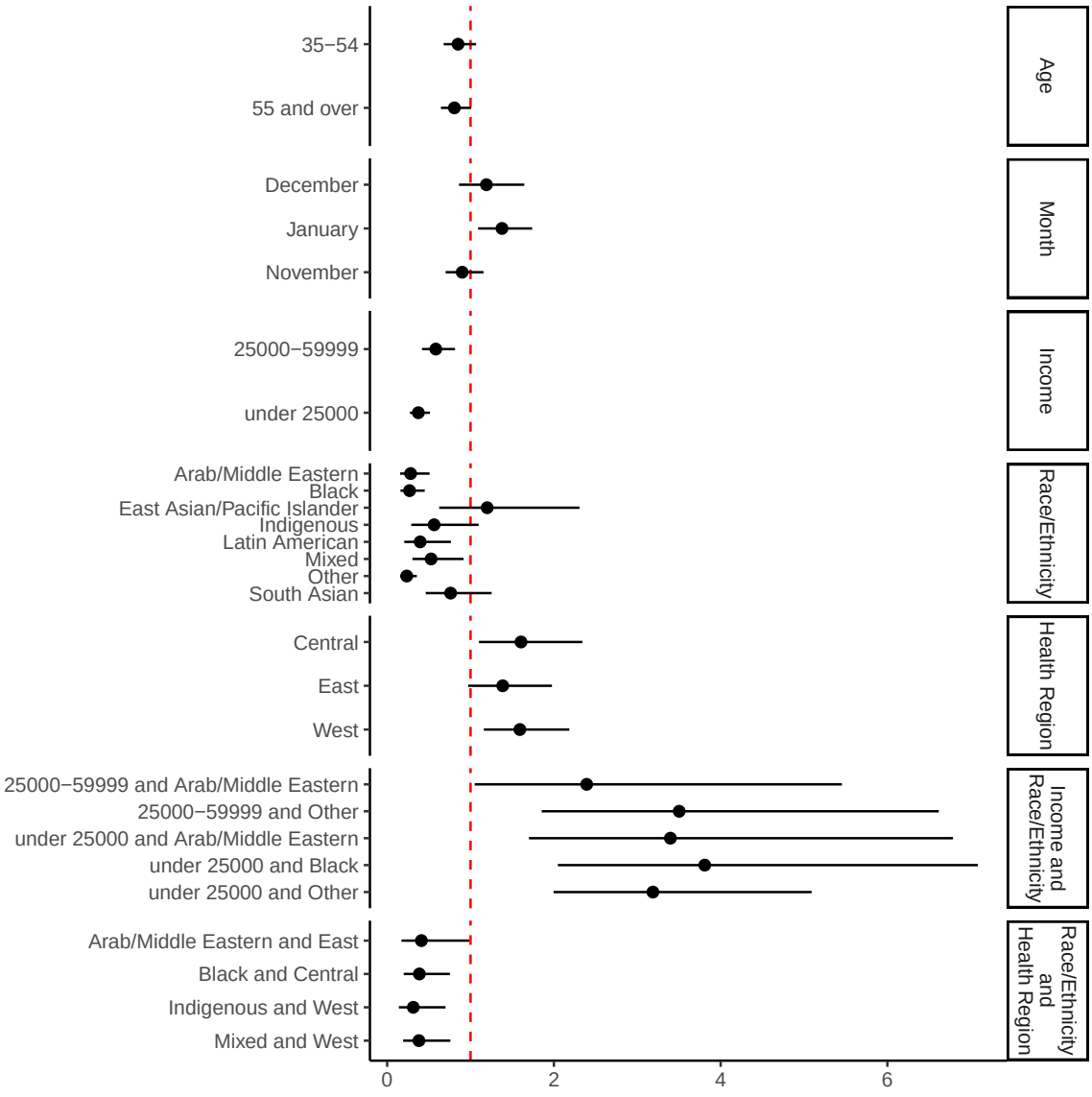

Figure 3: Coefficient estimates and confidence intervals for the corrected model. Only statistically significant interaction terms are shown. Full interaction terms can be found in Supplementary Figure A-4.

Asian, Filipino, West Asian, and minority groups not identified elsewhere) had vaccination odds that were less than a third of individuals that identified as White/Caucasian (Figure 3). These results are consistent with other studies that have shown lower vaccination rates in individuals that identify as part of a racial minority, or that have a low household income[18–20,45]. In the case of Ontario, a possible rationale for this difference is vaccine access, which has been identified as an important contributing factor of disparities in vaccination for equity-deserving groups[46], and that occurred in Toronto earlier in 2021, where it has been shown that vaccination venues were scarce in low socio-economic areas that had the highest burden of COVID-19 at the time[7].

It is interesting to note that although overall self-reported vaccination rates were found to be statistically significantly lower in various racial minority groups when compared to White/Caucasian individuals, the change in odds of vaccination within certain racial groups and income strata was actually positive, in contrast to the White/Caucasian group, where vaccination odds decreased in lower income brackets (when compared to the CAD 60,000 and over bracket, Supplementary Figure A-5). More specifically, the change in odds of vaccination increased in individuals who identified as Arab/Middle Eastern, Black, Latin American, or belonging to other minority groups with a household income below CAD 25,000, which was also true for individuals in other racial minority groups with an income between CAD 25,000-59,999.

This result is likely due in part to the fact that individuals that belong racial minority groups tend to perform occupations that have been deemed as "essential" in the context of the pandemic[47,48], which include grocery store workers, gas station, warehouse, distribution, and manufacturing workers, all being occupations for which an income within the significant brackets identified in the analysis is to be expected. In the case of Ontario, essential workers had priority for COVID-19 vaccination[49], which would explain the higher odds of vaccination for these individuals. In other words, it is possible that the type of occupation from individuals in equity-deserving groups played an important role in increasing the odds of vaccination.

Additionally, significant higher vaccination odds were identified in the West Health Region when compared to the Health Region of Toronto (Figure 3). The West Health Region comprises the regions of Waterloo and Niagara, the counties of Wellington, Essex and Lambton, and the cities of Hamilton, Haldimand, Brant, and Chatham-Kent. In this case, these results could reflect the fact that in the survey, about half of the entries for this Health Region corresponded to White/Caucasian individuals, who reported a vaccination rate of 83% (Supplementary Table A-6). However, the interaction effect of Health Region and race was also significant in the case of individuals identifying as South Asian or other minorities not included in the survey Figure 3. In this case, the results of the interaction term in the model indicate that the odds of vaccination for those within the South Asian and Other minority groups in the West Region decreased when compared to the other Health Regions (Supplementary Figure A-6).

According to Ontario Health, 13.2% of the population in the West Health Region identifies as a visible minority, whereas 2.5% identifies as Indigenous[50]. Therefore, the estimated lower odds are likely to be explained from a socio-economic perspective. In fact, 50% of the answers from

this region in the survey came from the former LHINs of Hamilton Niagara Haldimand Brant, and Erie St. Clair, both which are among the regions of Ontario with the highest proportion of their population (more than 20%) in the lowest income quintile[51] (Supplementary Table A-7). Interestingly, a disproportionate number of COVID-19 cases and low vaccination rate (under 50%) have been also reported in the South Asian community of Ontario[52]. These results provide context to the observed differences in vaccination among the Health Regions of the province, showing which equity-deserving and socio-demographic groups in certain regions need to be prioritized in future vaccination strategies. Moreover, these results provide a rationale for future studies that explore how vaccination uptake varies across different minority groups within Ontario and other Canadian provinces.

There are some limitations to the present study. First, the data collection design, which allowed respondents to withdraw from the survey at any point, resulted in a high number of unique entries in the survey with multiple missing answers. Because we focused on entries that had complete observations in the covariates of interest for our analysis, it is possible that some information was not considered by excluding observations that had information in other variables (such as work from home, or number of persons in the household). However, we attempted to minimize this possibility by correcting the dataset using information from the Census. More granular corrections, which for example could be based on demographic information by municipality, could be used in the future to obtain a more accurate approximation to the population totals of the province. Moreover, our analysis did not consider the North West and North East Health Regions, due to the low number of entries from these areas in the survey (Figure 1). Although low representation from these areas is based on the fact that these regions only account for 5% of the total population of Ontario, these regions are the home to more than 100,000 individuals that identify as Indigenous[50], a minority group that has historically suffered from reduced access to health care and discrimination[22]. Therefore, there is a need for additional studies that focus on these low-populated Health Regions in Ontario where disparities in vaccination might be significant and understudied.

It is also worth mentioning that province-wide vaccination rates for the period of interest are somewhat different from those of the survey, particularly in the case of those 55 years of age and older, which in the survey had a vaccination rate of 72%, against a rate of 88.4% reported for the closest age bracket (50 years of age and older) reported by Public Health Ontario at the start of the period covered by the data[53]. However, we found good agreement between the estimates from the model and overall vaccination rates reported for Canada, which have been relatively higher when compared to other high income countries[54], and with vaccination uptake rates across different age groups presented in other studies[18,55].

In other words, although vaccination rates obtained from the survey were slightly lower than the provincial estimates, these values still represented a valid approximation to overall trends; this notion is reinforced by the consistency in the proportion of vaccination rates (Table 1) and vaccination odds (Figure 3) across the period covered by the survey, which closely match the vaccination rates from Public Health Ontario and which indicate that due to the relatively high coverage achieved in the population at that point, vaccination rates increased by around

3% across all age groups during the three months covered by the survey[53]. It is also important to mention that to this day, differences in vaccination rates within the province continue. As of March of 2023 some regions still have less than 75% vaccination rate[56], and although data for the period analyzed in this study is not publicly-available, it is likely that differences in vaccination rates were higher at the time, being partially captured by the survey.

The results in this study are based on self-reported data, where bias might be present. However, because in the context of COVID-19 it has been shown that good agreement exists between self-reported and documented vaccination status[57], we believe that our data was able to provide a valid assessment of vaccination in the province. Finally, this study focused on first-dose vaccination status within a relatively short time window, and therefore can only provide a snapshot of the societal dynamics behind the pandemic. Nonetheless, the results presented here can serve as a starting point to motivate the collection of robust longitudinal data that can be used to quantify geographical and temporal differences within vulnerable segments of the population, and that can be used to inform the development of adequate public health policies within the province of Ontario or across other provinces that aim to minimize disparities in health access.

Conclusion

This study explored differences in COVID-19 vaccination across the province of Ontario during the last quarter of 2021 taking into consideration socio-economic factors, such as income and race, their interactions, and the Health Regions within the province. Our results show that during the period analyzed, differences in vaccination uptake existed across multiple equity-deserving groups in the province, and that these differences were significant in two of the Health Regions analyzed. It is important that future public health policies in Ontario take into consideration how to adequately reach individuals from equity-deserving groups that might live in areas of the province where access to healthcare might be difficult. Only in this way the goal of the Health Region model, which aims at reducing disparities, will become successful.

References

1. World Health Organization Coronavirus (COVID-19) Dashboard. Accessed May 11, 2023. https://covid19.who.int/
2. Rigby J, Satija B. WHO declares end to COVID global health emergency. *Reuters*. Published online May 8, 2023. Accessed May 11, 2022. https://www.reuters.com/business/healthcare-pharmaceuticals/covid-is-no-longer-global-health-emergency-who-2023-05-05/

3. Nations U. WHO chief declares end to COVID-19 as a global health emergency. *UN News*. Published online May 5, 2023. Accessed May 11, 2022. https://news.un.org/en/story/2023/05/1136367

4. Mackey K, Ayers CK, Kondo KK, et al. Racial and ethnic disparities in COVID-19–related infections, hospitalizations, and deaths. *Annals of Internal Medicine*. 2021;174(3):362-373. doi:10.7326/m20-6306

5. 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

6. 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

7. 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

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

9. 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

10. 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

11. 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

12. 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

13. 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

14. 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

15. 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

16. 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

17. 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

18. 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

19. 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

20. 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

21. 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

22. 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

23. 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

24. 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

25. 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

26. 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

27. 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

28. 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

29. 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

30. 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

31. 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

32. 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

33. 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

34. Muratov S, Lee J, Holbrook A, et al. Regional variation in healthcare spending and mortality among senior high-cost healthcare users in ontario, canada: A retrospective matched cohort study. *BMC Geriatrics*. 2018;18(1). doi:10.1186/s12877-018-0952-7

35. 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

36. 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

37. 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

38. 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

39. 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

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

41. 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

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

43. Arel-Bundock V. modelsummary: Data and model summaries in R. *Journal of Statistical Software*. 2022;103(1):1-23. doi:10.18637/jss.v103.i01

44. Sjoberg DD, Whiting K, Curry M, Lavery JA, Larmarange J. Reproducible summary tables with the gtsummary package. *The R Journal*. 2021;13:570-580. doi:10.32614/RJ-2021-053

45. 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

46. Njoku A, Joseph M, Felix R. Changing the narrative: Structural barriers and racial and ethnic inequities in COVID-19 vaccination. *International Journal of Environmental Research and Public Health*. 2021;18(18):9904. doi:10.3390/ijerph18189904

47. Hawkins D. Differential occupational risk for COVID-19 and other infection exposure according to race and ethnicity. *American Journal of Industrial Medicine*. 2020;63(9):817-820. doi:10.1002/ajim.23145

48. Côté D, Durant S, MacEachen E, et al. A rapid scoping review of COVID-19 and vulnerable workers: Intersecting occupational and public health issues. *American Journal of Industrial Medicine*. 2021;64(7):551-566. doi:10.1002/ajim.23256

49. Mishra S, Stall NM, Ma H, et al. *A Vaccination Strategy for Ontario COVID-19 Hotspots and Essential Workers*. Ontario COVID-19 Science Advisory Table; 2021. doi:10.47326/ocsat.2021.02.26.1.0

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

51. 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

52. Anand SS, Arnold C, Bangdiwala SI, et al. Seropositivity and risk factors for SARS-CoV-2 infection in a south asian community in ontario: A cross-sectional analysis of a prospective cohort study. *CMAJ Open*. 2022;10(3):E599-E609. doi:10.9778/cmajo.20220031

53. Ontario COVID-19 Data Tool. Accessed February 27, 2023. https://www.publichealthontario.ca/en/data-and-analysis/infectious-disease/covid-19-data-surveillance/covid-19-data-tool?tab=vaccine

54. 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

406 55. 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
407
408 56. Ontario COVID-19 Data Tool. Accessed March 24, 2023. https://www.publichealthontario.ca/en/data-and-analysis/infectious-disease/covid-19-data-surveillance/covid-19-data-tool?tab=maps
409
410 57. Stephenson M, Olson SM, Self WH, et al. Ascertainment of vaccination status by self-report versus source documentation: Impact on measuring COVID-19 vaccine effectiveness. *Influenza and Other Respiratory Viruses*. 2022;16(6):1101-1111. doi:10.1111/irv.13023
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