COVID-19 vaccination in Ontario: Exploring intra-provincial variations within 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 differences in vaccination due to race/ethnicity, income, Health Regions (geographical areas used for health service access in Ontario), and their interactions. In particular, we show that individuals who identified as Arab/Middle Eastern, Black, or Latin American, had significantly lower odds of vaccination than White/Caucasian individuals (ORs=0.31, 0.32, 0.28, and p=0.004, p<0.001 and p=0.004, respectively), and that individuals with a household income below CAD 25,000 who identified as Arab/Middle Eastern (OR=3.05, p=0.013), Black (OR=3.19, p=0.004), Latin American (OR=2.80, p=0.041), or that belonged to other minority groups (OR=4.59, p<0.001) had higher odds of vaccination than individuals from the same racial/ethnic group in higher income brackets. Finally, we also identified lower odds of vaccination within certain minority groups 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. This study shows that there is an ongoing need to better understand and address differences in vaccination uptake across diverse segments of the population that have been largely impacted by the pandemic.

Keywords

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

Background

The vaccines against COVID-19 have been considered a major achievement of modern medicine as their rapid development[1] allowed the start of broad vaccination campaigns towards the end of 2020 in certain countries such as the US[2] and Canada[3]. This made some believe that vaccines were destined to be a determinant factor in a rapid ending of the pandemic[4]. However, although it has been estimated that COVID-19 vaccines have prevented around 14 million of deaths worldwide[5], their implementation has been far from being equal to that of the vaccines of smallpox and polio, which were implemented on a global scale and that were indeed crucial to control these diseases[6]. In fact, the rollout of COVID-19 vaccines has faced multiple challenges since its inception which ultimately have hampered the goal of global immunity.

This ongoing lack of a successful global rollout of the COVID-19 vaccines is a multifaceted issue resulting from, as among other things, the development of new variants due to inadequate public health measures[7], inequality in vaccine access between high- and low-income countries[8,9], vaccine hesitancy[10], and differences in vaccination uptake across different segments of the population[11]. In particular, it is well established that differences in vaccination uptake have been present even in the case of countries that have had ample access to vaccines since 2020 (such as the US, the UK, and Canada), where lower vaccine uptake has been observed within racial minorities (i.e., individuals that identify as Black, Asian, or Indigenous), and in individuals within low income brackets[12–15]. Reasons given for lower vaccine uptake in these cases have included medical mistrust due to systemic medical racism, mistrust in vaccines, and the influence of conspiracy theories[12,14,16–18]. More specifically, in the case of Canada, lower vaccine uptake has been observed in young individuals, those with a low educational level, households with children, those without a regular healthcare provider, individuals that identify as part of a visible minorities or Indigenous, and those that are financially unstable[19–21].

However, it is important to consider that vaccination uptake can also be influenced by geographical (spatial) factors. In this regard, differences in COVID-19 vaccination rates have been associated with varied regional attitudes towards vaccination[11], spatial differences in vaccine access and supply, vaccination location availability, and lack of prioritization of areas where vulnerable groups reside[3,22]. Other studies have also shown heterogeneity in vaccine uptake within small governmental administrative units such as counties[23–26], and that and that accounting for geographical differences in vaccination can help predict patterns of booster uptake[27]. Overall, the existing body of research on geographical/spatial differences in vaccination has provided valuable information that can be used by decision-makers in the development of public health policies that are focused on improving vaccination within specific administrative or geographical areas. However, spatial analyses of vaccination have been very limited in Canada, as existing studies have been focused only at certain cities (such as Toronto[28], or Montreal[29]), or have explored differences at a province-wide level[19]. However, there is a lack of studies that explore spatial heterogeneities in vaccination at the intra-provincial level.

Ontario is the most populated province in Canada, and has recently seen major changes on its healthcare structure as between 2006 and 2019, it provided healthcare access using 14 intra-provincial divisions called the Local Health Integrated Networks (LHINs). However, this approach was complex and caused systemic inequalities[30]. 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) in an effort to improve the healthcare system of the province[31]. Because the adoption of the Health Regions has been recent, there is an ongoing need to analyze the impact of their adoption and intra-regional differences that might exist, which is specially important in the context of the COVID-19 pandemic.

To address this need, in this study we analyzed differences in self-reported COVID-19 vaccination status using socio-economic (e.g., income, racial/ethnic identification), and spatial information at the level of the Health Regions, to identify the existence of intra-provincial differences that might need to be addressed to ensure that the healthcare system of Ontario is more inclusive and that responds to the needs of its most vulnerable population.

Methods

Data

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 (henceforth Fields) and the Mathematical Modelling of COVID-19 Task Force under ethical guidance from the University of Toronto. The survey collected socio-economic information from participants (Table 1), recorded their location (using the nearest municipality), 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 entries (where each entry corresponded to a unique respondent).

This dataset was cleaned to remove outliers that were identified during preliminary analyses, and processing the geographical information in the survey (city where the survey was responded) in order to match each city to its correspondent Health Region.

Table 1: Socio-economic factors from the Fields COVID-19 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

The clean dataset contained responses from more than 200 different municipalities within Ontario (Figure 1). 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 care home dataset, we manually searched each city in the LHINs websites in order to provide geographical information. The original dataset, clean dataset, and details on the data cleaning process are described in detail in the GitHub repository for this paper, which can be found at 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. The low representation of these Health Regions in the dataset is noticeable in Figure 1, where the number of cities in each Health Region is relatively low compared to the most populated Health Regions, such as the Toronto or Central Regions. We omitted the North East and North East Health Regions from further analyses due to the low number of entries. Therefore, the total number of unique entries used for analysis was 3,551 which included the East, Central, Toronto, and West Health Regions.

Statistical analyses

We used a logistic regression model to estimate the probability of vaccination depending on the socio-economic factors described in Table 1, the Health Regions from Ontario indicated in 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[32–34].

The model was fitted first to the clean dataset to obtain uncorrected estimates. Additionally, because we identified differences between the proportions of all the socio-economic factors included in the analysis (Table 1) and the Census data for Ontario, we used an iterative

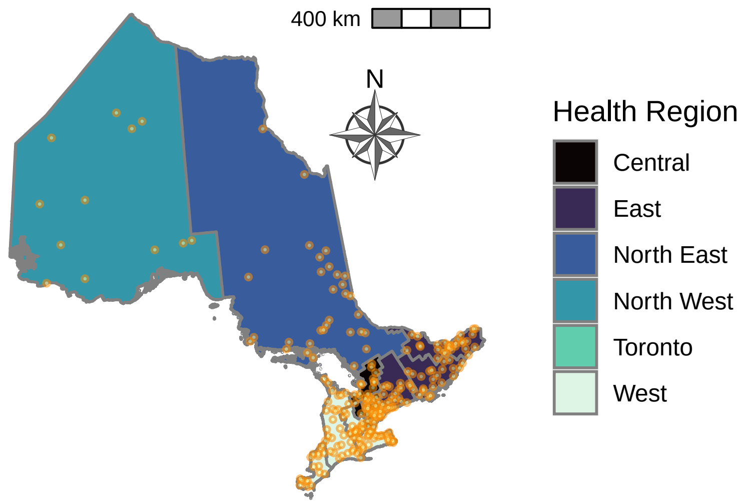

Figure 1: Geographic representation of the data collected by the *Survey of COVID-19 related Behaviours and Attitudes*, collected by the Fields Institute in Ontario. The municipalities (cities) from where survey participants provided answers (in the clean dataset) appear as points. The Health six Regions 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.

proportional fitting procedure (*raking*)[35] to correct the data using Census socio-economic data and Health Region population totals, in order to obtain corrected estimates from the model. Details regarding the correction can be found in the Appendix. All analyses were conducted in R 4.2.2 using the packages `survey`[36],`tidyverse`[37], and `quarto`[38].

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

Table 2: Descriptive Statistics of the Fields COVID-19 Survey (by Vaccination Status)

Variable	**no**, N = 958	**yes**, N = 2,593
Income		
60000_and_above	305 (23%)	1,049 (77%)
25000_59999	253 (28%)	636 (72%)
under_25000	400 (31%)	908 (69%)
Age Group		
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 (%)

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 models (for the uncorrected and corrected data) 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. There were no statistically significant differences in vaccination rates within the age groups from the survey, but significant odds ratios were estimated for other 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, p=0.011 and <0.001, 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, and p=0.004,<0.001 and 0.004, 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 (OR=0.22, p<0.001). 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, p=0.029).

Moreover, statistically-significant 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, p=0.013), Black (OR=3.19, p=0.004), Latin American (OR=2.80, p=0.041), or that belonged to other minority groups (OR=4.59, p<0.001). 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, p<0.001).

For the interaction of Health Region and race, significant odds of vaccination 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, p=0.046), and in individuals that identified as part of other racial minorities or South Asian that lived in the West Health Region (ORs=0.41, p=0.032 and p=0.037, respectively).

Table 3: Multiple Regression Analysis-Predictors of Vaccination Status

	Uncorrected			**Corrected**		
Characteristic	**OR**	**95% CI**	**p-value**	**OR**	**95% CI**	**p-value**
Age Group						
16_34	—	—		—	—	
35_54	0.93	0.77, 1.13	0.5	0.90	0.67, 1.21	0.5
55_and_over	0.74	0.61, 0.89	0.002	0.99	0.74, 1.32	>0.9
Income						
60000_and_above	—	—		—	—	
25000_59999	0.59	0.41, 0.84	0.004	0.59	0.39, 0.89	0.011
under_25000	0.41	0.29, 0.58	<0.001	0.37	0.25, 0.56	<0.001
Race						
white_caucasian	—	—		—	—	
arab_middle_eastern	0.24	0.12, 0.50	<0.001	0.31	0.14, 0.69	0.004
black	0.30	0.17, 0.54	<0.001	0.32	0.17, 0.60	<0.001
east_asian_pacific_islander	0.74	0.36, 1.52	0.4	1.15	0.50, 2.66	0.7
indigenous	0.37	0.17, 0.81	0.013	0.44	0.19, 1.02	0.056
latin_american	0.28	0.13, 0.59	<0.001	0.28	0.11, 0.67	0.004
mixed	0.59	0.31, 1.12	0.11	0.64	0.25, 1.65	0.4
other	0.20	0.11, 0.35	<0.001	0.22	0.12, 0.41	<0.001
south_asian	0.80	0.44, 1.45	0.5	0.91	0.49, 1.69	0.8
Health Region						
Toronto	—	—		—	—	
Central	1.30	0.85, 2.00	0.2	1.47	0.92, 2.35	0.11
East	1.54	1.01, 2.34	0.044	1.42	0.90, 2.23	0.13

(continued)

Characteristic	Uncorrected			Corrected		
	OR	**95% CI**	**p-value**	**OR**	**95% CI**	**p-value**
West	1.35	0.95, 1.94	0.10	1.55	1.05, 2.30	0.029
Income * Race						
25000__59999 * arab__middle__eastern	2.16	0.93, 4.99	0.072	1.79	0.67, 4.83	0.2
under__25000 * arab__middle__eastern	2.96	1.39, 6.26	0.005	3.05	1.26, 7.39	0.013
25000__59999 * black	1.19	0.60, 2.39	0.6	1.34	0.59, 3.05	0.5
under__25000 * black	2.88	1.48, 5.59	0.002	3.19	1.45, 6.99	0.004
25000__59999 * east__asian__pacific__islander	0.95	0.44, 2.07	>0.9	0.42	0.17, 1.05	0.062
under__25000 * east__asian__pacific__islander	1.91	0.90, 4.04	0.090	1.16	0.47, 2.86	0.8
25000__59999 * indigenous	1.81	0.74, 4.43	0.2	1.36	0.48, 3.89	0.6
under__25000 * indigenous	1.64	0.73, 3.69	0.2	1.45	0.55, 3.80	0.5
25000__59999 * latin__american	0.89	0.38, 2.10	0.8	1.24	0.45, 3.43	0.7
under__25000 * latin__american	3.09	1.33, 7.16	0.009	2.80	1.04, 7.51	0.041
25000__59999 * mixed	0.86	0.39, 1.93	0.7	0.85	0.32, 2.26	0.7
under__25000 * mixed	1.26	0.64, 2.47	0.5	1.10	0.37, 3.27	0.9
25000__59999 * other	5.46	2.41, 12.3	<0.001	6.93	2.65, 18.1	<0.001
under__25000 * other	4.06	2.25, 7.31	<0.001	4.59	2.33, 9.05	<0.001
25000__59999 * south__asian	1.13	0.54, 2.36	0.7	1.20	0.51, 2.85	0.7
under__25000 * south__asian	1.59	0.83, 3.06	0.2	2.00	0.93, 4.30	0.077
Race * Health Region						
arab__middle__eastern * Central	0.75	0.33, 1.71	0.5	0.66	0.26, 1.70	0.4
black * Central	0.48	0.23, 1.01	0.055	0.44	0.19, 0.98	0.046
east__asian__pacific__islander * Central	0.84	0.37, 1.88	0.7	0.98	0.38, 2.53	>0.9
indigenous * Central	0.60	0.24, 1.51	0.3	0.63	0.22, 1.79	0.4
latin__american * Central	0.69	0.28, 1.72	0.4	0.67	0.23, 1.96	0.5
mixed * Central	0.63	0.29, 1.35	0.2	0.73	0.24, 2.22	0.6
other * Central	0.96	0.48, 1.92	>0.9	0.80	0.36, 1.78	0.6
south__asian * Central	0.70	0.34, 1.45	0.3	0.54	0.25, 1.20	0.13
arab__middle__eastern * East	0.58	0.20, 1.65	0.3	0.43	0.13, 1.45	0.2
black * East	0.82	0.36, 1.86	0.6	0.83	0.34, 2.04	0.7
east__asian__pacific__islander * East	0.82	0.30, 2.24	0.7	0.86	0.29, 2.56	0.8
indigenous * East	0.55	0.21, 1.44	0.2	0.69	0.23, 2.08	0.5
latin__american * East	0.79	0.28, 2.23	0.7	1.03	0.32, 3.34	>0.9
mixed * East	0.71	0.31, 1.60	0.4	0.91	0.28, 3.03	0.9
other * East	0.86	0.37, 1.99	0.7	1.05	0.39, 2.83	>0.9
south__asian * East	0.50	0.20, 1.24	0.14	0.52	0.19, 1.45	0.2
arab__middle__eastern * West	1.16	0.48, 2.77	0.7	1.00	0.37, 2.73	>0.9
black * West	0.77	0.36, 1.65	0.5	0.76	0.32, 1.80	0.5
east__asian__pacific__islander * West	0.54	0.24, 1.20	0.13	0.52	0.20, 1.34	0.2
indigenous * West	0.44	0.19, 1.02	0.056	0.39	0.14, 1.09	0.073
latin__american * West	0.97	0.39, 2.43	>0.9	0.94	0.32, 2.72	>0.9
mixed * West	0.53	0.25, 1.11	0.092	0.37	0.12, 1.16	0.089
other * West	0.55	0.27, 1.12	0.10	0.41	0.18, 0.93	0.032
south__asian * West	0.50	0.23, 1.07	0.075	0.41	0.18, 0.95	0.037

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

Discussion

The change from LHINs to Health Regions for healthcare in Ontario was aimed at reducing healthcare disparities[30]. The relatively recent nature of the change, which occurred in late 2019, highlights the importance of studies that can determine if there are intra-regional differences in healthcare that need to be addressed, particularly in the context of the COVID-19 pandemic.

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), and that there were no significant differences in vaccination odds among the age groups considered in the survey. This result is consistent with overall vaccination rates reported for Canada, which have been relatively higher when compared to other high income countries[39], with vaccination uptake rates across different age groups presented in other studies[19,40], and with the vaccination information provided by Public Health Ontario, which shows that for the period where the Fields survey ran (Sept 30, 2021-Jan 17, 2022) there was a minimum of 80% of first dose vaccination coverage among all the age groups considered in the survey[41].

However, we identified intra-provincial differences in vaccination based on socio-economic and geographical factors. First, our results show significant differences in vaccination odds in individuals with a household income below CAD 60,000 and in individuals belonging to visible minority groups. Those who identified as Black, Latin American, or belonging to a minority group not included in the survey (Southeast Asian, Filipino, West Asian, and Minority not identified elsewhere) had vaccination odds below 33% when compared to individuals that identified as White/Caucasian (Table 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[19–21,42].

In this study, we also decided to explore the interactions between income and race and race and Health Region, as it is known that many individuals within racial minority groups perform tend to occupy certain types of occupations that fall within income brackets that have been shown to be associated with differences in vaccination uptake. In other words, we decided to explore if there were differences in vaccination within racial groups in certain income brackets and in certain the Health Regions. In this regard, 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 (Table 3), the change in odds of vaccination within certain racial groups and income strata was actually positive, in contrast to the White/Caucasian group, for which vaccination odds decreased in lower income brackets (when compared to the CAD 60,000 and over bracket, Supplementary Figure A-3). 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 (Table 3, Supplementary Figure A-3).

This result is likely due 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[43,44], which include occupations such as grocery store workers, gas station workers, warehouse and distribution workers, and manufacturing workers, all being occupations for which an income within the significant brackets is to be expected. In the case of Ontario, essential workers had priority for COVID-19 vaccination[45], which would explain the higher odds of vaccination for these individuals in certain income brackets, in contrast to the lower odds of vaccination for the same type of individuals with higher household income. In other words, it is possible that the type of occupation played an important role in increasing the odds of vaccination in these racial minority groups.

Additionally, significant higher vaccination odds were identified in the West Health Region when compared to the Health Region of Toronto (Table 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, a possible rationale for the results is the fact that in the survey, about 47% of the entries for this Health Region corresponded to White/Caucasian individuals, who reported an overall 83% vaccination rate (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 Table 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-4).

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[46]. In the case of this analysis, 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[47] (Supplementary Table A-7). Therefore, this result partly reinforces the well-known existing association between low vaccination rates and income, but it additionally indicates that there were intra-regional differences in vaccination. Interestingly, a disproportionate number of COVID-19 cases and low vaccination rate (under 50%) have been previously reported in the South Asian community of Ontario[48]; in this regard, our result provides additional context by showing that within the South Asian community, there were differences in vaccination uptake across Ontario. Moreover, because significant lower odds of vaccination were also identified other minority groups, this provides 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[46], a minority group that has historically suffered from reduced access to health care and discrimination[17]. 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.

The results in this study are based on self-reported data, where the risk of bias exist. Despite this, because in the context of COVID-19 it has been shown that good agreement exists between self-reported and documented vaccination status[49], the effect of self-reported bias is likely to not be significant in this case. Finally, it is likely that there have been differences in vaccination across the province as more doses of the vaccine were administered and as successive variants emerged. Because this study focused only on vaccination status regarding the first dose of the vaccine within a relatively short time window, it 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 future longitudinal research that aims to quantify geographical differences within vulnerable segments of the population, and that can be used to inform the development of 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 between late 2021 and early 2022 by 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, significant differences in vaccination existed across different visible minority groups, income brackets, and Health Regions, showing intra-provincial disparities in vaccine uptake. As the COVID-19 continues around the world, it important that future public policies take into consideration how to adequately reach individuals within minority groups that live across geographical areas where less probabilities of being vaccinated are likely. At the moment, this is an ongoing issue that needs to be addressed to ensure a more homogeneous outcome from the pandemic.

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