Health & Place 78 (2022) 102919

Contents lists available at ScienceDirect

Health and Place

journal homepage: www.elsevier.com/locate/healthplace

The social ecology of COVID-19 prevalence and risk in Montreal, QC, Canada

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ARTICLE INFO

Keywords:
Social ecology of place
COVID-19
Neighborhoods
Montreal
Quebec
Canada

ABSTRACT

This descriptive study examined the social ecology of COVID-19 risk exposure across Montreal (Quebec, Canada) by comparing fifteen neighborhoods with contrasting COVID-19 prevalence. Census 2016 data were combined with an online survey (n = 502) of residents living in the targeted neighborhoods. Chi-square and *t*-test were used to analyze the differences in sample proportions and means.

As of October 1, 2020, compared to the least affected Montreal neighborhoods, the most Impacted neighborhoods had a 2.6 times higher COVID-19 prevalence (2370.9 active cases per 100,000 residents) and a 2.5 times higher death rate (260.6 deaths per 100,000 people). High prevalence neighborhoods were lower income, more highly racialized, denser, and had a larger share of public transit users than least affected neighborhoods.

Compared with respondents from the least affected neighborhoods, survey respondents in high prevalence neighborhoods were more likely to report a lower income, hold at-risk occupations, live in apartment buildings, use public transit, and perceive themselves at risk of becoming infected with COVID-19 and less capable of avoiding COVID-19 transmission, but less likely to comply with stay-at-home recommendations. No significant differences between neighborhoods were found in terms of compliance with recommended COVID-19 hygiene preventive measures (mask wearing and hand washing).

Results: suggest that at-risk occupations and a lower capacity to avoid COVID-19 exposure, but not differences in compliance with public sanitary directives, were key factors associated with higher neighborhood prevalence of COVID-19.

1. Introduction

For centuries pandemics have disproportionately affected the poor and disadvantaged. In the 14th century, the highest mortality rate of the bubonic plague was observed among the poorest populations, often malnourished and overworked peasants (Ahmed et al., 2020). It is well known that the combination of social determinants of health operating at individual, family, community, and institutional levels shapes health disparities (Institute of Medicine, 2006). The key role played by social vulnerability and social determinants of health on the rates of infectious disease is probably best exemplified by the decline in incidence of tuberculosis in the 19th and early 20th century in Europe and North America, which began even before the advent of effective medications, thanks to better living conditions, reduced overcrowding, and improved housing and nutrition (Butler-Jones and Wong, 2016).

Natural disasters, like earthquakes and hurricanes, but also pandemics, reveal the interconnection between the vulnerability of the human population and the occurrence of extreme physical events (O'Keefe, 1976). The sociologist Eric Klinenberg in his account of the 1995 Chicago heat wave argued that the social morphology of Chicago neighborhoods and the living conditions of their most vulnerable residents, combined with the political factors that determined this vulnerability, such as the massive reduction of public services in the 1980s and Chicago government's unresponsiveness to the needs of the most marginalized residents, were mostly responsible for the unequal spatial and demographic mortality trends caused by the record-high temperatures (Klinenberg, 1999). Likewise, vulnerability to COVID-19 is socially constructed and an array of social, economic, and environmental factors shapes not only risk exposure, but also the overall capacity of a community to respond to the pandemic (Kim and Bostwick, 2020).

It is becoming increasingly clear that COVID-19 morbidity and mortality are profoundly and unevenly shaped by social inequalities, and that the interplay of several social determinants of health, including low socioeconomic status, physical environment, and ethnicity, can

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https://doi.org/10.1016/j.healthplace.2022.102919
Received 6 August 2021; Received in revised form 12 September 2022; Accepted 14 September 2022
Available online 26 September 2022

have a serious impact on COVID-19 prevalence and outcomes (Patel et al., 2020). There is evidence that large disparities in COVID-19 prevalence exist among city neighborhoods, and several studies conducted in different urban settings have shown the spatial correlation between COVID-19 and a variety of demographic factors, and the tendency of low-income communities and ethnic minorities to be disproportionately affected (Almagro and Orane-Hutchinson, 2020; Borjas, 2020; Braga et al., 2020; Schmitt-Grohé et al., 2020; Whittle and Diaz-Artiles, 2020).

Social ecological theory explains social inequalities and health disparities by considering the complex associations between individual behaviors and attitudes, social and structural factors, the physical environment, and public policies (Krieger, 2001). Besides biological factors, the social ecological model theorizes that human health is the outcome of a variety of multi-level factors, which include: 1) individual demographic characteristics, attitudes, behaviors, and knowledge, 2) formal and informal interpersonal relationships, 3) social institutions that shape behaviors and attitudes through social norms and cultural expectations, 4) community resources and the built environment, and 5) public policies at the local, state, and federal level (McLeroy et al., 1988). This broad theoretical approach has been often used by researchers and health professionals to identify risk factors and promote disease prevention strategies. For instance, social ecological models have been used to describe the multilevel infection risks of different HIV epidemics (Baral et al., 2013), the environmental determinants of community syphilis rates (Thomas et al., 1999), and the environmental risk factors associated with the obesity epidemic (Thorpe, 2007). More recently, researchers have also adopted a social ecological framework to understand COVID-19 health disparities and explore the geographical variations in COVID-19 prevalence by showing that less walkable, poorer, and more Black/Hispanic neighborhoods were more susceptible to the spread of COVID-19 (Oishi et al., 2021).

Nevertheless, the social ecology of COVID-19 morbidity and mortality is still somehow overlooked (Abrams and Szefler, 2020), and it remains unclear through which specific pathways and mechanisms COVID-19 places particular people and locations at greater risk of exposure and poorer outcomes (Burström and Tao, 2020). Following the socioecological framework, this descriptive study sought to increase our understanding of the social ecology of COVID-19 risk by examining geographic patterns of COVID-19 prevalence in the city of Montreal, the epicenter of the early stages of the COVID-19 pandemic in Canada (Lalonde, 2020). Through the combination of Census information at the neighborhood level and individual survey data, we explored the extent to which the spatial variation of COVID-19 prevalence was associated with: 1) Montreal neighborhoods' socioeconomic conditions and physical characteristics, and 2) survey participants' demographic background and COVID-19 risk exposures. We also examined whether the geographic patterns of COVID-19 prevalence were associated with survey respondents' COVID-19 risk perceptions and level of compliance with COVID-19 preventive behaviors.

2. Methods

2.1. COVID-19 and sociodemographic data

COVID-19 prevalence estimates were based upon the cumulative number of COVID-19 positive cases per 100,000 residents as of October 1, 2020. Data on COVID-19 prevalence and mortality rates by Montreal neighborhoods were obtained from the website of Santé Montréal (Santé Montréal, 2020) (Table 1). Data on sociodemographic characteristics and physical properties of Montreal neighborhoods were retrieved from Statistic Canada (Statistics Canada, 2017) and included 2016 census data (the most recent available) on population size, median residents' age, population density, median household income, percentage of single-family houses, percentage of visible minorities, and percentage of working residents taking public transportation on a daily basis (Table 2).

Table 1
COVID-19 prevalence in montreal as of October 1, 2020.

	Total Number of Positive Cases	Cases per 100,000 Residents	Total Number of Deaths	Deaths per 100,000 Residents
Least Impacted Neighborhoods				
Senneville	<5	[a]	0	0.0
Beaconsfield	75	388.1	9	[a]
Sainte-Anne-de-Bellevue	20	403.4	<5	[a]
Montréal-Ouest	37	732.7	<5	[a]
Kirkland	153	759.3	23	114.1
Pointe-Claire	252	803.1	41	130.7
Baie D'urfé	32	837.0	<5	[a]
Pierrefonds-Roxboro	667	962.5	39	56.3
Dollard-des-Ormeaux	548	1120.7	83	169.7
Westmount	233	1147.1	37	182.2
	≈ 2017	**≈ 899.9**	**≈ 232**	**≈ 103.5**
Dorval	220	1159.1	50	263.4
Hampstead	81	1161.6	<5	[a]
L'Île-Bizard–Sainte-Geneviève	247	1341.4	46	249.8
Plateau Mont-Royal	1397	1343.3	140	134.6
Montréal Est	54	1402.6	5	[a]
Saint-Laurent	1405	1421.7	120	121.4
Rosemont–La Petite Patrie	2036	1458.6	239	171.2
Sud-Ouest	1216	1556.0	182	232.9
Mont-Royal	317	1563.4	77	379.8
Ville-Marie	1401	1571.2	87	97.6
Verdun	1122	1620.7	159	229.7
Côte-des-Neiges–Notre-Dame-de-Grâce	2725	1636.4	261	156.7
Lachine	757	1701.5	100	224.8
LaSalle	1414	1839.9	183	238.1
Saint-Léonard	1447	1847.9	62	79.2
Outremont	458	1912.0	12	50.1
Villeray–Saint-Michel–Parc-Extension	2758	1917.2	133	92.5
Anjou	854	1995.5	51	119.2
Most Impacted Neighborhoods				
Cote-Saint-Luc	653	2102.5	64	197.2
Mercier-Hochelaga-Maisonneuve	2777	2041.6	373	274.2
Ahuntsic-Cartierville	2787	2076.1	360	268.2
Rivière-des-Prairies–Pointe-aux-Trembles	2520	2360.8	242	226.7
Montreal-Nord	2968	3523.5	248	294.4
	11,705	**2370.9**	**1287**	**260.6**
City of Montreal	**34,412**	**1665.9**	**3482**	**168.6**

[a] Because of the very small number of reported cases in relation with the total population, the precision of the rate value was considered too low to be published.
Source: Santé Montréal (Santé Montréal, 2020)

COVID-19 data were collected for all 33 Montreal neighborhoods defined by present-day administrative boundaries, which divide the island of Montreal in 19 different boroughs (known in French as "arrondissements"), and 14 independent municipalities. Our analyses focused on fifteen Montreal neighborhoods contrasted by the highest and the lowest COVID-19 prevalence.

2.2. Survey data

Survey data were collected from residents aged 18 and older and living in the fifteen neighborhoods identified. The survey was carried

Table 2
Demographic characteristics of sampled montreal Neighborhoods (2016).

	Population	Median Age	Population Density[a]	Median Household Income[b]	PCT of Single-Family Houses	PCT of Visible Minority	PCT of Working Individuals Using Public Transp.
Least Affected Neighborhoods							
Senneville	921	49	123.3	116,224	88.4	8.1	11
Beaconsfield	19,324	44.8	1759.9	123,392	86.4	12.9	18.5
Sainte-Anne-de-Bellevue	4958	44.5	470	67,200	42.6	14.4	14.8
Montréal-Ouest	5050	43.6	3596.9	115,029	43.5	21.8	25.7
Kirkland	20,151	45.5	2093.8	115,381	86.6	24.2	11.6
Pointe-Claire	31,380	47.6	1665.6	80,242	53	22.1	19.3
Baie D'urfé	3823	49	635.8	118,784	92.5	11.5	16.5
Pierrefonds-Roxboro	69,297	41	2560.9	70,547	50.8	43.1	20.4
Dollard-des-Ormeaux	48,899	43.3	3223.4	78,981	57.8	38.8	17.5
Westmount	20,312	46.7	5055.3	100,153	12.4	18	21.7
Total Population & Averages	**224,115**	**45.5**	**2118.4**	**98,593**	**61.4**	**21.4**	**17.7**
Most Affected Neighborhoods							
Cote-Saint-Luc	32,448	45.7	4675.5	58,935	14.6	19.8	21
Mercier-Hochelaga-Maisonneuve	136,024	39.3	5353.2	48,544	4.3	21.6	41.6
Ahuntsic-Cartierville	134,245	40.8	5556.5	51,054	8.7	37.5	36
Rivière-des-Prairies–Pointe.	106,743	43.5	2524.7	62,867	25.7	25.5	24
Montreal-Nord	84,234	41	7623.0	42,548	7.3	48.7	34
Total Population & Averages	**493,694**	**42.0**	**5146.5**	**52,789**	**12.1**	**30.6**	**31.3**
City of Montreal	**1,704,694**	**38.5**	**4668.3**	**50,227**	**7.3**	**34.2**	**36.6**

[a] Residents per km.[2].
[b] Median Household Income in 2015.
Source: Canadian 2016 Census (Statistics Canada, 2017)

out by using an opinion panel via an online platform. Most of the panel members (60%) were randomly recruited over the phone in the past ten years, which makes this panel comparable to the existing Canadian population on a number of demographic characteristics (Leger, 2020). The data collected show that the survey sample does reflect the demographic differences between the corresponding Montreal neighborhoods established by the 2016 Census, in terms of income, age, prevalent dwelling types, and public transportation use. However, the survey sample does not fully represent visible minorities and the consistent presence of minority groups in the Montreal neighborhoods most affected by the COVID-19 pandemic (Tables 2–4).

A total of 502 participants completed the survey and were included in the analysis. The data collection took place between October 28, 2020 and November 2, 2020. Potential participants (stratified by age and postal code) were randomly selected, and invited by email to complete the survey. Participants had the option to complete the survey either in French or in English and took the online survey by using different devices: desktop computers, smartphones, and tablets. On average, it took about 18 min for respondents to complete the survey. The survey was anonymous, and all participants provided written informed consent before starting the online survey. After completing the questionnaire, respondents received a remuneration of CAD$ 1.50 paid by the data collector, and this incentive was deposited automatically into their Leger account upon completion of the questionnaire. The survey and consent to participate were reviewed and approved by the Research Ethics Boards Office of McGill University (REB File #: 20-09-004).

The sample questionnaire developed by the World Health Organization to conduct behavioral studies on COVID-19, which includes a combination of validated knowledge and behavioral questions (World Health Organization, 2020), was used as a general guide to design the survey. Questions were also adapted for the local context from additional authoritative sources, such as the Statistics-Canada COVID-19 Data Collection Series (Statistics Canada, 2020). In total, the survey included forty-seven questions, divided into different sections that covered a variety of topics, including: 1) sociodemographic background, 2) COVID-19 risk exposures, 3) COVID-19 risk perceptions, and 4) COVID-19 preventive behaviors. Additional sections collected data on:

Table 3
Survey Respondents' demographic characteristics (%).

	Least Affected	Most Affected	All Neighborhoods
Language (Survey Completed in French) [c]	27	85.6	56.2
Age (Mean, SD) [c]	54.0 (18.2)	43.2 (14.0)	48.6 (17.1)
Age Category			
18 to 44 [c]	31.0	54.0	42.4
45 to 64	38.1	37.6	37.8
64 and older [c]	31.0	8.4	19.8
Sex (Female) [b]	57.1	44.4	50.8
Marital Status			
Never Legally Married [c]	25.0	44.4	34.7
Living with a common-law partner [b]	14.7	26.0	20.3
Legally Married, and not Separated [c]	46.8	21.2	34.1
Divorced	5.2	6.4	5.8
Widowed [c]	6.7	0.4	3.6
Education Level (Bachelor's Degree or Higher) [c]	61.2	45.2	53.1
Employment Status			
Unemployed	6.0	7.2	6.6
Student (Part Time/Full Time)	4.8	9.2	7.0
Employed (Part Time/Full Time) [c]	41.3	58.8	50.0
Self-employed	7.1	6.8	7.0
Retired [c]	32.5	11.6	22.1
Income Level			
Less than $40,000 [c]	8.3	26.4	17.3
$40,000 to just under $80,000	28.6	30.4	29.5
More than $80,000 [a]	46.8	37.2	42
Ethnicity			
White [a]	78.6	85.6	82.1

[a] Difference is significant at the 0.05 level (2-sided).
[b] Difference is significant at the 0.01 level (2-sided).
[c] Difference is significant at the 0.001 level (2-sided).

Table 4
Survey respondents' COVID-19 risk exposures (%).

	Least Affected	Most Affected	All Neighborhoods
Tested for COVID-19			
Never Tested [b]	80.6	65.2	72.9
I had COVID-19-like symptoms, but never got tested	0.8	2.8	1.8
Tested Negative [b]	16.7	31.6	24.1
Tested Positive	2.0	0.4	1.2
Hospitalized because of COVID-19 (Yes)	1.6	1.6	1.6
Come in Close Contact with Someone who Tested Positive			
Not that I know of	87.7	82.8	85.3
In my Household	2.4	2.4	2.4
In the Community	5.2	5.6	5.4
In my Workplace [a]	3.6	9.6	6.6
Job Category			
In-person Contact with the General Public [b]	15.5	28.8	22.1
Working in a Health-care Setting [a]	2.8	10.4	6.6
Working in a Long-term Care Facility (CHSLDs)	–	1.6	0.8
Providing Essential Services [a]	7.1	17.2	12.2
Protective Equipment at Workplace			
Not at All/Rarely	2.4	6.0	4.2
Some of the Time	1.2	4.0	2.6
Most of the Time/All of the Time [b]	34.9	52.8	43.9
Usual Mode of Transport during COVID-19 Pandemic			
Walking	3.6	7.6	5.6
Biking	1.2	2.4	1.8
Public Transportation[b]	4.8	20.8	12.7
Private Vehicle	38.1	38.0	38.0
Household Type			
Rented Room in House /Apartment	2.4	3.2	2.8
Flat /Apartment[b]	22.6	56.0	39.2
Rowhouse /Terrace Home /Townhouse	9.1	6.8	8.0
Semi-detached Single Family House	7.9	10.8	9.4
Detached Single Family House[b]	50.8	16.4	33.7
Household Size (Mean, SD)	2.4 (1.1)	2.3 (1.2)	2.4 (1.2)

[a] Difference is significant at the 0.01 level (2-sided)
[b] Difference is significant at the 0.001 level (2-sided)

A) respondents' current health status, B) participants' information level on COVID-19, and C) the impacts of the COVID-19 pandemic on survey respondents' lifestyle behaviors, mental health, social relationships, employment status, income level, and access to healthcare services (data not presented here).

In order to investigate risk exposures and social transmission dynamics, survey respondents were asked: "Since the start of the COVID-19 pandemic, have you come in close physical proximity with someone who tested positive for COVID-19?", and response options allowed respondents to identify potential exposure channels, such as their household, community, and/or workplace. To evaluate participants' COVID-19 exposure risk associated with public transit use, respondents were asked to identify their typical form of transport during the pandemic ("Since the start of the COVID-19 pandemic, what is your usual mode of transport to go to work, school, etc.?"). In order to estimate COVID-19 occupational exposure risk, respondents were asked to indicate whether the job they performed during the pandemic involved the provision of essential services, being in contact with the general public, and/or working in health-care setting, and whether they had access to protective equipment in the workplace, with responses rated on a 5-point Likert-type scale (1 = not at all, 5 = yes, all of the time).

COVID-19 risk perceptions were also investigated. For perceived probability of contracting the virus, participants answered: "What do you consider to be your own probability of getting infected with COVID-19?" (1 = extremely unlikely, 5 = extremely likely). To evaluate perceived feelings of safety at home and in the neighborhood, respondents were asked: "Since the start of the COVID-19 pandemic, how safe do you feel in your home/neighborhood?" (1 = not safe at all, 5 = very safe), whereas participants' self-assessed efficacy to avoid COVID-19 contagion was assessed by asking: "For you, avoiding an infection with COVID-19 in the current situation is?" (1 = very difficult, 5 = very easy).

Finally, the survey probed respondents' compliance with the COVID-19 preventive behaviours recommended by the government of Quebec to limit the spread of COVID-19, such as: 1) hygiene measures (wearing facial masks in public spaces and washing/sanitising hands), and 2) physical distancing measures (staying at least 2 m apart from other people when going out, and staying/working at home rather than going to work/school). Participants were asked: "Since the start of the COVID-19 pandemic, how often have you been practicing the following recommendations?", and responses were ranked on a 5-point Likert-type scale ranging from 1 to 5 with 1 = never and 5 = always.

2.3. Statistical analyses

The survey sample was divided in two subgroups according to respondents' postal code: the participants residing in the 10 least affected neighborhoods (n = 252), and the respondents living in the five most affected neighborhoods of Montreal (n = 250). A larger number of neighborhoods with low COVID-19 prevalence was required for sample size balancing, given the differences in population size and the corresponding pools of potential panel members. Categorical variables were represented as percentage, while continuous variables were represented as mean and standard deviation (SD). The Pearson Chi-Square test was used to analyze the differences between the two subgroups for categorical variables, while the *t*-test for independent samples was used to compare the group means of continuous variables. IBM's Statistical Package for Social Sciences (SPSS, Version 26.0 for Windows) was used for analyses.

3. Results

3.1. Socio-spatial variation in Covid-19 Prevalence in Montreal

On October 1, 2020, about ten months after the city of Montreal confirmed the first COVID-19 case and at the beginning of the second COVID-19 wave in Canada, the city of Montreal had 34,412 confirmed COVID-19 cases and 3482 COVID-19-related deaths; the prevalence rate was 1665.9 active COVID-19 cases per 100,000 residents, while the mortality rate was 168.6 deaths per 100,000 population (Table 1). Compared to the ten least affected neighborhoods, the five most impacted neighborhoods had a 2.6 times higher COVID-19 prevalence (2370.9 active cases per 100,000 residents) and a 2.5 times higher death rate (260.6 deaths per 100,000 people).

The neighborhoods most affected by the COVID-19 pandemic were mainly concentrated in the East and North-East sides of the city (Fig. 1), and Montreal Nord, the neighborhood with the second lowest median household income in Montreal (Statistics Canada, 2017), had the highest COVID-19 infection rate, more than double the city's average. Key sociodemographic attributes of the neighborhoods selected help illustrate the link between the geographic spread of COVID-19 prevalence and economic and social vulnerability (Table 2). According to 2016 Census data, the five Montreal neighborhoods most affected by the COVID-19 pandemic had a 47% lower median household income than the ten least affected neighborhoods ($52,789; $98,593), and a 1.4 times greater share of residents that belonged to a visible minority (30.6%; 21.4%). Public transit use and physical features of the built environment, such as population density and prevalent dwelling type, are additional examples of risk factors operating at the community level that

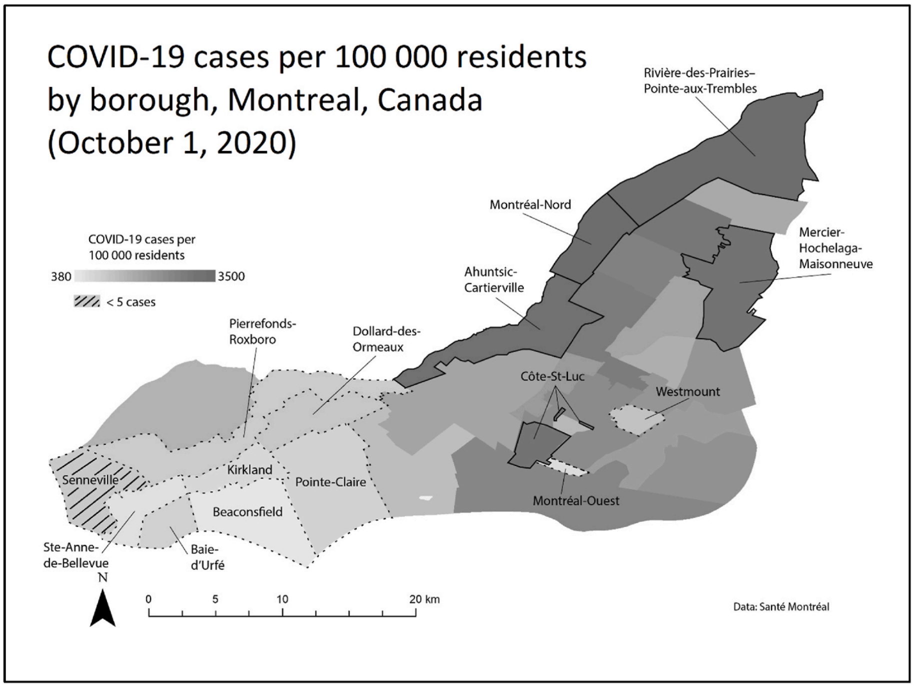

Figure 1. COVID-19 Prevalence in Montreal as of October 1, 2020

can potentially increase COVID-19 exposure levels. High COVID-19 prevalence neighborhoods had a 1.7 times higher proportion of local residents taking public transportation daily to go to work (31.3%; 17.7%), more than twice the population density (4668.3 residents per km^2; 2118.4 residents per km^2), and a 5 times smaller proportion of single-family private dwellings (12.1%; 61.4%). Although age is a well-known risk factor for COVID-19 severity and mortality (DeCaprio et al., 2020), the median age of the population in 2016 was slightly lower in the most affected neighborhoods (42 years; 45.5 years).

3.2. Survey respondents' socio-demographic characteristics

The sociodemographic profile of the survey respondents further illustrates the association between economic and social deprivation and COVID-19 risk vulnerability (Table 3). In the most affected neighborhoods, the proportion of survey respondents with a household income of less than $40,000 was significantly higher (26.4%; 8.3%; $p < .001$), and survey participants were less likely to hold a university degree (45.2%; 61.2%; $p < .001$) than respondents in low COVID-19 prevalence neighborhoods. Working-age and active employment status may also increase the likelihood of COVID-19 exposure. In the most affected neighborhoods, participants' average age was lower (43.2 years; 54 years $p < 001$), and respondents were more likely of being employed (58.8%; 41.3%; $p < .001$). Finally, in high prevalence neighborhoods, participants were less likely to be females (44.4%; 57.1%; $p < .01$) and being married (21.2%; 46.8%; $p < .001$), and a greater proportion of respondents took the survey in French (85.6%; 27%; $p < .001$).

3.3. Respondents' risk of exposures to COVID-19

No significant differences between neighborhoods were found in terms of survey respondents' COVID-19 positivity rates, as only a small percentage of the overall sample (~1%) declared to have tested positive to COVID-19 and to have been hospitalized because of COVID-19 (~1%). However, a larger proportion of survey participants from the least affected neighborhoods (80.6%; 65.2%; $p < .001$) reported to have never taken a COVID-19 test, which could be related to different COVID-19 risk perceptions, but also to the higher proportion of health care workers living in the most affected neighborhoods potentially being tested more often at work (Table 4).

Participants from the most impacted neighborhoods were 2.6 times more likely (9.6%; 3.6%; $p < .01$) to identify their job place as the location where they could have been potentially exposed to the COVID-19 virus, while the proportions of respondents who indicated either their household or the community as the locations where they could have come in close physical proximity with someone who had tested positive to COVID-19 were almost identical between the most and least affected neighborhoods. In the Montreal neighborhoods most affected by the pandemic, a larger proportion of survey participants worked in a health-care setting (10.4%; 2.8%; $p < .01$), held jobs involving in-person contact with the general public (28.8%; 15.5%; $p < .001$) or provided essential services, such as grocery stores and public transportation (17.2%; 7.1%; $p < .01$). Participants from high COVID-19 prevalence neighborhoods were also more likely to report not having access to the necessary personal protective equipment to do their jobs safely (6.0%; 2.4%), even though this difference was not statistically significant. In addition, survey respondents from the most affected neighborhoods were more likely to indicate public transit (20.8%; 4.8%; $p < .001$) as their usual mode of transportation during the COVID-19 pandemic. Finally, while no significant differences were found between the neighborhoods sampled in terms of average household size, participants from high COVID-19 prevalence neighborhoods were more likely to live in a flat/apartment (56%; 22.6%; $p < 001$).

3.4. Respondents' COVID-19 risk perceptions

The proportion of survey participants who perceived themselves to be either likely or extremely likely at risk of contracting COVID-19 was almost 2 times larger in the most affected neighborhoods (39.2%; 20.3%; $p < .001$) (Table 5). Respondents from these neighborhoods were more likely to feel in danger of contracting COVID-19 in their neighborhood (15.6%; 6.0%; $p < .001$), while no significant differences were found in terms of perceived feeling of safety in the household. Survey participants from high COVID-19 prevalence neighborhoods were also more likely to report it being difficult or very difficult avoiding being infected with COVID-19 (22%; 14.7%; $p < .05$).

Table 5
Survey Respondents' COVID-19 Risk Perceptions (%)

	Least Affected	Most Affected	All Neighborhoods
Perceived Probability of Getting Infected with Covid-19			
Extremely Unlikely /Unlikely [b]	43.7	27.6	35.7
Neutral	35.7	32.8	34.3
Likely /Extremely Likely [b]	20.3	39.2	29.7
Self-assessed Efficacy to Avoid Covid-19 Contagion			
Very Difficult /Difficult [a]	14.7	22.0	18.3
Neutral	33.3	32.8	33.1
Easy /Very Easy	52	44.4	48.2
Perceived Feeling of Safety at Home (in terms of getting infected with Covid-19			
Not Safe at All /Not Very Safe	2.0	4.4	3.2
Neutral	5.2	4.4	4.8
Somewhat Safe /Very Safe	92.4	91.2	91.8
Perceived Feeling of Safety in the Neighborhood (in terms of getting infected with Covid-19)			
Not Safe at All /Not Very Safe [b]	6.0	15.6	10.8
Neutral [b]	11.1	21.6	16.3
Somewhat Safe /Very Safe [b]	82.9	62.8	72.9

[a] Difference is significant at the 0.05 level (2-sided)
[b] Difference is significant at the 0.001 level (2-sided)

3.5. *Respondents' compliance with COVID-19 preventive behaviors*

The majority of survey respondents reported a high degree of compliance with recommended COVID-19 preventive behaviors (Table 6), and no significant differences were found between the neighborhoods sampled in terms of wearing a face-covering mask, practicing proper hand hygiene, and keeping a safe distance from others when going out. However, a smaller percentage of survey participants living in the most affected neighborhoods (54.4%; 71.4%; $p < .001$) reported being able to comply with the recommendation to work and stay at home.

4. Discussion

This descriptive study explored the geographic variation in COVID-19 prevalence in Montreal through a social ecology perspective by examining how individual demographic background and neighborhood socioeconomic and physical characteristics were associated with disparities in COVID-19 prevalence and exposure, risk perceptions, and compliance to preventive behaviors.

Table 6
Survey Respondents' COVID-19 Preventive Behaviors (%)

	Least Affected	Most Affected	All Neighborhoods
Hand Washing with Soap and/or Using Hand Sanitizer			
Never/Rarely	1.2	0.8	1.0
Sometimes	3.2	5.2	4.2
Often /Always	95.3	94.0	94.6
Wearing a Face-covering Mask in Public Spaces			
Never /Rarely	1.6	1.2	1.4
Sometimes	1.2	1.6	1.4
Often /Always	96.9	97.2	97.0
Staying Two Meters Away from Other People in Public Spaces			
Never /Rarely	0.4	2.0	1.2
Sometimes	6.7	9.6	8.2
Often /Always	92.5	88.0	90.2
Staying/Working at Home Rather Than Going to Work/School			
Never /Rarely [a]	15.9	33.2	24.5
Sometimes	7.1	7.2	7.2
Often /Always [a]	71.4	54.4	63.0

[a] Difference is significant at the 0.001 level (2-sided)

Resembling other metropolitan areas around the world, the city of Montreal was characterized by substantial spatial variation in COVID-19 prevalence. Montreal neighborhoods varied widely not only in COVID-19 prevalence, but also in terms of socioeconomic conditions and physical characteristics. As revealed by Census data, the most affected neighborhoods had on average a lower income and a larger share of visible minorities. Hard-hit neighborhoods were also more densely populated, and residents were more likely to live in multi-unit dwellings and be daily public transit users. Similarly, in Montreal high prevalence neighborhoods, survey respondents were more likely to report a lower household income and education level, live in apartment buildings, and use more frequently public transportation during the pandemic. In the most affected neighborhoods, respondents were also more likely to hold high-risk job occupations, perceive themselves at risk of becoming infected with COVID-19, reveal a lower self-assessed efficacy to avoid COVID-19 transmission, and report more often to be unable to comply with the recommendation to work and stay at home. However, no significant differences were found in terms of compliance with COVID-19 hygiene preventive measures (mask wearing and hand washing).

As of October 1, 2020, in Montreal, the unequal geographic distribution of COVID-19 prevalence and mortality mirrored the longstanding Montreal East-West divide along socioeconomic and linguistic lines, as socioeconomically disadvantaged, and mainly francophone, neighborhoods have consistently been more likely to concentrate in the East End of Montreal (Twigge-Molecey, 2014). These findings support the notion that socio-ecological vulnerability to pandemics does vary across space, and eventually determines an uneven disease geographic distribution and disproportionate post-pandemic impacts (Snyder and Parks, 2020). Possible specific causal mechanisms may include underlying health conditions, and in particular the psychological stress and the comorbidities associated with poverty. A low socioeconomic status can contribute to decrease the immune system's capacity to fight the COVID-19 virus. This is because economically disadvantaged individuals are more likely to experience precarious work conditions and unstable incomes, conditions that may be even worsened by the responses to COVID-19 and its aftermath (Patel et al., 2020). It is well known that financial insecurity disproportionally affects the mental health and the stress levels of economically disadvantaged people (Algren et al., 2018), which in turn may weaken the immune system, and increase the vulnerability to a range of diseases and the likelihood of unhealthy behaviors (Algren et al., 2018; Segerstrom and Miller, 2004). People of low socioeconomic status may have an increased susceptibility to COVID-19 mortality also because poverty is a notable risk factor for several chronic diseases, including heart disease, hypertension, obesity, and diabetes (Marmot et al., 2014), which have been shown to be risk factors for death from COVID-19 (Guan et al., 2020). Ethnicity can also be a risk factor. Minority groups may be at increased risk of COVID-19 acquisition and disease severity as specific ethnic groups, like South Asians and African-Americans, tend to have higher rates of some comorbidities (diabetes, hypertension, and cardiovascular diseases) that have been associated with severe disease and mortality in COVID-19 (Tillin et al., 2013). Besides, individuals from different ethnic background may vary in genetic susceptibility, immune profiles, heath-seeking behaviors, vaccine uptake, nutrition quality, socioeconomic status, and environmental factors (like household overcrowding), which could challenge the adoption of pandemic control measures (Zhao et al., 2015).

The results of this study highlight how economic and social deprivation may be associated with a social gradient in COVID-19 risk exposures. Physical distancing measures, which are necessary to prevent the spread of COVID-19, are significantly more challenging for the most economically disadvantaged people who often hold jobs that increase their potential exposure to COVID-19 as they do not allow to work remotely from home. In the Montreal neighborhoods hardest hit by the pandemic, larger proportions of survey respondents held essential service jobs and/or worked in healthcare settings, and identified their workplace as the location where they had come in contact with someone who tested positive for COVID-19. These findings reinforce anecdotal evidence about the pandemic in Montreal, which described the COVID-19 pandemic as largely an occupational disease driven by the higher likelihood of residents in some neighborhoods to hold low-paying essential service jobs and work in healthcare institutions, including many immigrants and asylum seekers who typically join the local workforce as health workers in long-term care homes (McKie, 2020). Essential worker status has been found to be strongly associated with physical distancing measures (Gouin et al., 2021), and survey results support existing evidence from different geographic settings indicating that occupations with a higher degree of human interaction played a crucial role in explaining differences in COVID-19 prevalence in the early stage of the pandemic (Almagro and Orane-Hutchinson, 2020; Barbieri et al., 2020; Lewandowski, 2020), and that the workers who were most exposed to COVID-19 infection were health professionals and essential service workers (Lewandowski, 2020).

Poorer residents, who often lack their own mode of transportation, may experience an increased exposure to COVID-19 also during their daily commutes to work, and survey respondents from the most impacted Montreal neighborhoods were more likely to be daily public transit users during the COVID-19 pandemic. Although, the association between public transportation and increased risk of COVID-19 transmission is still uncertain (Public Health Ontario, 2020), public transport vehicles are confined spaces that may be conducive for the spread of respiratory viruses (Shen et al., 2020), while there is evidence that the subway system was a major disseminator of COVID-19 infection in New York City during the early stage of the pandemic (Harris, 2020), and that the frequency of flights, trains, and buses played a critical role in the spread of COVID-19 in China (Zheng et al., 2020). Since the start of the pandemic, public transit demand in many cities around the world has decreased (Transitapp, 2021); however, the decline in transit ridership across different socioeconomic groups is considerably different, and studies show that low-income residents, people of color, and the less educated experienced the least changes in travel behavior. Therefore, the majority of passengers who remained public transit users during the COVID-19 pandemic were overwhelmingly essential workers (Brough et al., 2020; Hu and Chen, 2021; Sy et al., 2020), who may have experienced increased levels of COVID-19 exposure.

Increased exposure to COVID-19 may also be related to housing characteristics, and survey participants from the most affected neighborhoods in Montreal were more likely to live in apartments. Financially disadvantaged people are more likely to live in overcrowded living conditions with limited access to personal outdoor space, which not only may reduce compliance with physical distancing measures, but also represents a risk factor for lower respiratory tract infections (Cardoso et al., 2004). Overcrowded housing has been found to be associated with COVID-19 incidence and mortality (Ahmad et al., 2020), while other studies show that living in a multi-residential building may increase COVID-19 risk exposure, as higher occupant density induces more frequent close interactions between individuals, especially in shared common areas like lobbies and elevators (Dietz et al., 2020; Eykelbosh, 2021). Interestingly, there is also evidence that the relative importance of intra-household contagion has increased as the COVID-19 pandemic has progressed, which could be the consequence of stay-at-home policies (Almagro and Orane-Hutchinson, 2020). The higher densities of the Montreal neighborhoods most affected by the COVID-19 pandemic appear to support the hypothesis that population density is another ecological factor that may affect disease transmission as it could constraint physical distancing behaviors (Rocklöv and Sjödin, 2020). Density has been found to be associated to COVID-19 prevalence in different geographic settings (Coşkun et al., 2021; Sy et al., 2021; Tammes, 2020); however, the impact of population density on COVID-19 prevalence is still a complex and disputed topic (Teller, 2021), and authors have argued that it is overcrowding conditions (density at the household rather than neighborhood level) that place especially vulnerable populations at risk of contracting COVID-19 (Moos et al., 2020).

Objective differences in COVID-19 risk exposures may translate into dissimilar subjective COVID-19 risk perceptions, and in high prevalence Montreal neighborhoods survey respondents were more likely to perceive themselves at risk of becoming infected with COVID-19 and less capable of avoiding COVID-19 transmission. Demographic and occupational differences may explain variations in perceptions of risk, as higher levels of perceived risk of contracting COVID-19 infection have been found among lower socioeconomic status individuals and workers in essential sectors who experienced a greater exposure to COVID-19 during the pandemic (Brown et al., 2021). Only half of respondents living in the Montreal neighborhoods hardest hit by the pandemic were able to comply with the health recommendation to work and stay at home, and this finding is comparable with the results of a COVID-19 behavioral survey conducted in the United Kingdom reporting that while economically disadvantaged individuals are willing to self-isolate if needed, they are often unable to work from home and adopt physical distancing measures (Atchison et al., 2020). Evidence shows that working individuals report a less frequent adoption of certain public health preventive measures, such as working remotely and avoiding the use of public transportation, as these preventive measures may not be feasible for them (Li et al., 2020). For instance, in the United States, stay-at-home orders did not significantly reduce the work-related trips of the very low-income, while high-income groups were significantly more likely to stay at home under shelter-in-place orders, and this disparity was at least partially explained by work-related trips of essential workers (Jay et al., 2020; Lou et al., 2020). The result that no significant differences were found in terms of respondents' compliance with wearing a face-covering mask and hand hygiene seems to further indicate that, rather than the lack of adherence to recommended protective behaviors, differences in COVID-19 prevalence between Montreal neighborhoods more likely reflected work-related constraints that made it more challenging for socioeconomically disadvantaged individuals to avoid COVID-19 transmission.

5. Strengths and limitations

One of the main strengths of this study was a survey sample comprised of participants randomly selected from a representative pool of panel members matching the general population in terms of demographic characteristics. However, as above mentioned, the survey sample did not fully reflect the large presence of minority groups living in the Montreal neighborhoods most affected by the COVID-19 pandemic, and this important bias does limit the generalizability of the study findings. Given that minorities may experience a lower socioeconomic status and a higher risk of contracting COVID-19, it is likely that the results of the online survey may be underestimating differences between the most and the least affected Montreal neighborhoods.

Online panels may limit the participation of socially vulnerable population groups, such as minorities, recent migrants, and refugees, which often experience limited internet access (AAPOR, 2010). Online questionnaires may also exclude potential participants who are illiterate and do not understand either French or English. In order to mitigate these limitations, future similar studies could increase the overall representativeness of the study sample trough the implementation of tailored and targeted surveys with certain hard-to-reach population groups by for instance conducting multilingual phone interviews as a supplement of online panels.

Given COVID-19 physical distancing guidelines, internet-based data collection (with automatic data entry and no interviewer requirement) provides a cost-effective way of data collection; however, survey fraud (when a participant takes the online survey more than once), respondents' disinterest, and survey fatigue may affect the validity of online survey findings (Singh and Sagar 2021). To increase data quality, panel members were not allowed to participate more than once. In addition, potential respondents were asked to complete the survey only if they were truly interested, while the total number of questions was kept to a minimum to decrease respondent burden. Finally, the cross-sectional survey design does not allow inferences on the causal relationship between the variables and only shows measures of associations.

6. Conclusions

Developing evidence-based strategies is key for governments and public health agencies to rapidly respond to the COVID-19 pandemic and future infectious diseases. COVID-19 preventive policies have been mostly informed by a medical model of disease risk, which tends to overlook social factors and principally targets people with multiple comorbidities, after classifying them as the most likely to get severely ill from COVID-19 (Patel et al., 2020).

The results of this study suggest that containment policies should be based upon a broader definition of COVID-19 risk vulnerability, which includes social and ecological conditions as critical COVID-19 risk factors. This social-ecological framework is necessary to implement more effective preventive and mitigation strategies as it allows a better understanding of COVID-19 health disparities, a deeper recognition of the unequal patterns of community vulnerability, and a more precise identification of the health and economic impacts across different socioeconomic groups. In particular, this study contributed to current literature on the social ecology of COVID-19 by underlining the importance of adverse working conditions, as a key mechanism that may place socioeconomically more vulnerable people at higher risk of being exposed to the COVID-19 virus. Results suggest that holding high-risk occupations is a significant structural risk factor that may often prevent socially and economically vulnerable individuals from complying with public health measures and protecting themselves against COVID-19 transmission.

Preventive measures should identify and prioritize at-risk communities with specific information campaigns and increased access to COVID-19 screening. In particular, our findings support the recommendations of collecting data on the demographic profiles of COVID-19 patients (Choi et al., 2020), identifying high-risk job categories, and targeting these segments of the workforce with greater monitoring and the distribution of protective equipment (St-Denis, 2020), but also testing and vaccination, as these would benefit not only those workers facing work with high proximity to others, but the rest of the population as well, by providing extra protection to all those ones who are likely to be in contact with essential workers (Almagro and Orane-Hutchinson, 2020).

Data availability

Data will be made available on request.

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