BMJ Open

Understanding national trends in COVID-19 vaccine hesitancy in Canada: results from five sequential cross-sectional representative surveys spanning April 2020–March 2021

Kim Lavoie ,[1,2] Vincent Gosselin-Boucher ,[1,2] Jovana Stojanovic ,[2,3] Samir Gupta ,[4,5] Myriam Gagné ,[5] Keven Joyal-Desmarais ,[2,3] Katherine Séguin,[1,2] Sherri Sheinfeld Gorin ,[6] Paula Ribeiro,[2,7] Brigitte Voisard,[1,2] Michael Vallis ,[8] Kimberly Corace,[9,10] Justin Presseau ,[11,12] Simon Bacon ,[2,3] for the iCARE Study Team

To cite: Lavoie K, Gosselin-Boucher V, Stojanovic J, *et al*. Understanding national trends in COVID-19 vaccine hesitancy in Canada: results from five sequential cross-sectional representative surveys spanning April 2020–March 2021. *BMJ Open* 2022;**12**:e059411. doi:10.1136/bmjopen-2021-059411

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2021-059411).

Received 22 November 2021
Accepted 15 February 2022

For numbered affiliations see end of article.

Correspondence to
Dr Kim Lavoie;
lavoie.kim@uqam.ca

ABSTRACT

Objective To examine rates of vaccine hesitancy and their correlates among Canadian adults between April 2020 and March 2021.

Design Five sequential cross-sectional age, sex and province-weighted population-based samples who completed online surveys.

Setting Canada.

Participants A total of 15 019 Canadians aged 18 years and over were recruited through a recognised polling firm (Leger Opinion). Respondents were 51.5% female with a mean age of 48.1 (SD 17.2) years (range 18–95 years) and predominantly white (80.8%).

Primary and secondary outcome measures Rates of vaccine hesitancy over the five surveys (time points) and their sociodemographic, clinical and psychological correlates.

Results A total of 42.2% of respondents reported some degree of vaccine hesitancy, which was lowest during surveys 1 (April 2020) and 5 (March 2021) and highest during survey 3 (November 2020). Fully adjusted multivariate logistic regression analyses revealed that women, those aged 50 and younger, non-white, those with high school education or less, and those with annual household incomes below the poverty line in Canada were significantly more likely to report vaccine hesitancy, as were essential and healthcare workers, parents of children under the age of 18 and those who do not get regular influenza vaccines. Endorsing prevention behaviours as important for reducing virus transmission and high COVID-19 health concerns were associated with 77% and 54% reduction in vaccine hesitancy, respectively. Having high personal financial concerns was associated with 1.33 times increased odds of vaccine hesitancy.

Conclusions Results highlight the importance of targeting vaccine efforts to specific groups by emphasising the outsized health benefits compared with risks of vaccination. Future research should monitor changes in vaccine intentions and behaviour to better understand underlying factors.

Strengths and limitations of this study

- Assesses changes in vaccine intentions over time across three critical waves of the pandemic in Canada through five survey waves from April 2020 to March 2021.
- Large sample size with good distribution across provincial regions, age groups, gender, employment status and income compared with census data available through Statistics Canada.
- Sample under-represents people of colour and perhaps non-native English and French speakers, as the survey was only available in these two languages.
- Data reflect trends in vaccine intentions over time but not in the same individuals.
- Results reflect a subanalysis of Canadian representative data from the International COVID-19 Awareness and Responses Evaluation (iCARE) study (100 000 participants from 190 countries) alongside ongoing efforts to collect similarly representative samples in eight other countries (see www.icarestudy.com), which will enable comparisons with international datasets.

INTRODUCTION

The SARS-CoV-2 virus causing COVID-19 has caused a global pandemic, resulting in significant morbidity, mortality, and economic and social disruption in Canada and around the world.[1] Key to reducing disease morbidity and mortality and reducing the need for future lockdowns is widespread acceptance of COVID-19 vaccines, several of which have been approved for those aged 5 and older by Health Canada.[2 3] . High rates of vaccine acceptance were thought to be necessary for achieving target levels of herd immunity,[4] but it has proven difficult to

estimate the minimum threshold of immunisation needed to achieve this due to the emergence of highly virulent strains like Delta, whose R0 has been estimated to be five to six times greater than the original Wuhan SARS-CoV-2 strain.[5 6] This has led experts to recommend vaccinating as much of the population as possible and exploring the need for additional 'booster' or yearly doses.[7] Regardless of how COVID-19 vaccination schedules unfold over the short and longer terms, the ultimate success of vaccination programmes depends on people's willingness to get vaccinated. However, several reports from nations where vaccines have been widely available indicate that intentions to get a COVID-19 vaccine have been steadily declining (and rates of vaccine hesitancy steadily increasing)[8] since the first pandemic wave. For example, a longitudinal study in the USA reported significant declines in the likelihood of getting vaccinated (somewhat or very likely to get vaccinated), from a high of 74% in early April 2020 to a low of 56% by early December 2020.[9] These declines were observed for both men and women and in all age, racial/ethnic and education subgroups. Similar trends were also observed in Australia, where 31.9% of Australians reported being less willing to get vaccinated between August 2020 and January 2021, and were particularly prevalent among Indigenous populations and those who did not complete high school.[10] Since then, 175 studies worldwide have been published on vaccine hesitancy through to the end of August 2021, including 21 reporting data from Canada. According to a living systematic review by Crawshaw *et al*,[11] the IQR of vaccine hesitancy was 12%–24%, with a mean of 17%. Overall, these results raise important questions about vaccine attitudes and intentions among Canadians, whose willingness to get vaccinated now and in the future will be critical for optimising the success of Canada's vaccine strategy and our successful transition out of the pandemic.

Vaccine hesitancy has been defined as '…a delay in acceptance or refusal of vaccination despite availability of vaccination services'.[8] Key to optimising vaccination rates is understanding patterns and correlates of hesitancy over time. This will allow us to improve vaccine policy planning, develop targeted interventions and enhance tailoring of vaccine messaging to vulnerable groups. To this end, we examined rates of vaccine hesitancy and their correlates among Canadians by analysing data from five cross-sectional age, sex and province-weighted population-based samples who completed online surveys between April 2020 and March 2021. In order to explore the factors associated with vaccine hesitancy over time, data across all surveys were examined as a function of key sociodemographics, clinical characteristics and psychological factors known to be important for vaccine behaviour.[12]

METHODS

Study design

The International COVID-19 Awareness and Responses Evaluation (iCARE) Study (www.icarestudy.com)[13] is an ongoing international, multiwave, cross-sectional observational survey study of public awareness, attitudes and responses to COVID-19 public health policies. The study is led by researchers from the Montreal Behavioural Medicine Centre (www.mbmc-cmcm.ca) in collaboration with a team of over 200 international collaborators from more than 40 countries. The survey was designed with international experts to assess constructs from the capability, opportunity, motivation–behaviour model of the behaviour change wheel[14] and from the health belief model.[15 16] The survey also includes questions on sociodemographics, physical and mental health conditions, general health behaviours, previous COVID-19 infection, awareness of local government prevention policies, perceptions and attitudes about these policies, adherence to prevention behaviours, COVID-19-related concerns and impacts, and vaccine attitudes and intentions. The surveys include approximately 75 questions (approximately one per page), take 15–20 min to complete, and can all be found online (www.osf.io/nswcm). Questions were presented in the same order, but the response set order was randomised for questions with multiple subitems to reduce bias. Some questions were conditionally displayed based on responses to previous items to reduce the number and complexity of the items. Completing all questions is mandatory to move forward, but many questions included the option 'I don't know/prefer not to answer'. Full details about survey development and general methodology have been published elsewhere,[13] and the Checklist for Reporting Results of Internet E-Surveys (CHERRIES) can be found in online supplemental table S1.

Participants

For this study, we report data from five nationally representative online surveys of Canadians aged 18 years and over using a recognised polling firm which recruits participants through their closed, proprietary online panel (Leger Opinion). This panel includes over 400 000 Canadians, the majority of which (61%) were recruited within the past 10 years. Two-thirds of the panel were recruited randomly by telephone, with the remainder recruited via publicity and social media. Respondents are invited to complete the survey via email and did so voluntarily. Leger Opinion sends panellists a unique link to complete the survey so they cannot complete it more than once (receive a message: 'you have already completed this survey'). Using data from Statistics Canada, results were weighted within each province according to the sex and age of the respondents. Then, the weight of each province was further adjusted to represent their actual weight within the Canadian federation. Data were collected between 9 and 20 April 2020 (survey 1), 5 and 17 June 2020 (survey 2), 29 October and 11 November 2020 (survey 3), 27 January and 7 February 2021 (survey 4), and 11 and 29 March 2021 (survey 5), respectively, using a self-administered computer-assisted web interface. Online consent is provided by participants prior to completing the survey. No personal identifying information is collected from any participant. Participants are offered nominal compensation through the polling

firm (participants collect points that can be traded in for gift cards); no direct compensation is provided by the research team.

Assessment of vaccine intentions and hesitancy

To assess vaccine hesitancy, we asked: 'If a vaccine for COVID-19 were available today, what is the likelihood that you would get vaccinated?' Response options (very unlikely, unlikely, somewhat likely, extremely likely, I don't know/prefer not to answer) were dichotomised into 'very unlikely, unlikely, somewhat likely' to describe those indicating at least some degree of hesitancy, versus 'very likely' to describe those with very high intentions to get vaccinated. A dichotomous outcome was chosen to identify all those who could benefit from intervention, with those responding 'very likely' to get vaccinated treated as the comparator/reference.

Assessment of psychological factors

We assessed two psychological factors that are often important motivators of engaging in protective health behaviours: perceived importance of engaging in infection prevention behaviours, and the nature and extent of people's COVID-19-related concerns.[15–17] Perceived importance of engaging in COVID-19 prevention behaviours (including getting vaccinated) was assessed using a single question: 'To what extent do you believe that the measures asked of you by your government or local health authority *are important* to prevent and/or reduce the spread of COVID-19?' Response options (not at all important, not very important, somewhat important, very important and I don't know/prefer not to answer) were dichotomised into 'very important' versus all others.

To assess the concerns people have about the COVID-19 virus and its impacts, individuals were presented with the following prompt: 'Because of COVID-19, I am concerned about…'. Respondents then had to indicate the extent which they had 10 specific concerns, choosing among 'not at all', 'very little', 'somewhat', 'to a great extent' and 'I don't know/prefer not to answer'. To cluster COVID-19-related concerns, we performed a principal component analysis on a polychoric correlation matrix of the 10 variables in the concerns module (ordinal scale, as detailed earlier), details of which can be found elsewhere.[18] We observed a three-component structure that included 'health concerns', 'personal financial concerns' and 'social and economy concerns'. Mean values (M) and SD for each of the three components are reported as a score out of 4, from 1=not at all to 4=to a great extent. Internal consistency for the components ranged from satisfactory (social/economy concerns α=0.69) to excellent (personal financial concerns α=0.82, health concerns α=0.91) for the individual components.[18]

Statistical analysis

Several survey questions included an answer I don't know/I prefer not to answer, which was recoded as a missing value, and analyses were based on complete case records. Descriptive statistics (weighted means, SDs, and proportions) were calculated to describe the sample in terms of demographic characteristics, across all surveys. Univariate analyses were conducted to examine differences in sociodemographic characteristics (weighted proportions) as a function of vaccine hesitancy across the five time points. Three separate multivariable logistic regression models were performed to assess associations between vaccine hesitancy (dependent variable) and participant sociodemographic (ie, age, sex, ethnicity, education, employment status, annual household income, parental status, worker status and provincial region) and clinical characteristics (ie, health risk conditions, history of influenza vaccine and previous COVID-19 infection) (independent variables: model 1), vaccine hesitancy (dependant variable) and perceived importance of prevention behaviours (independent variable: model 2), and vaccine hesitancy (dependent variable) and the nature and extent of the three types of COVID-19-related concerns (independent variables: model 3). Analyses were conducted across all surveys combined and models were partially (covariates included age, sex, ethnicity and survey wave) and fully adjusted (covariates included age, sex, ethnicity, survey wave, education, employment status, annual household income, health risk condition, essential worker, healthcare worker, parental status, history of influenza vaccine and COVID-19 test result). All variables were selected a priori based on pre-existing data.[12] Analyses were also conducted as a function of time point/survey to examine trends over time, assessed using the Welch test. All statistical tests were two-sided and a p value of <0.05 was considered as statistically significant. Statistical analysis was performed in SAS V.9.4.

Patient and public involvement

This study was designed in collaboration with over 200 international collaborators, many of which are from the general public (https://mbmc-cmcm.ca/covid19/research/icare-collaborators/). As such, we were able to use both input from the community and behavioural theory to inform the construction of our surveys. The use of a series of survey waves also enabled us to adapt each questionnaire to the changing nature of the pandemic and of its impact on the population. Finally, the public has been called on to contribute to the dissemination of study results through sharable infographics made available on the study website.

RESULTS

Participant characteristics

Our sample included a total of 15 019 respondents (survey 1, n=3003; survey 2, n=3005; survey 3, n=3005, survey 4, n=3000; and survey 5, n=3006) who completed a survey between 9 April 2020 and 29 March 2021. Response rates (total number of completed surveys divided by total number of invitations) ranged between 16% (survey 4) and 25% (survey 5), which is average for online panels.[19]

However, participation and completion rates as defined by CHERRIES ranged between 86.6% (survey 1) and 95.4% (surveys 3 and 4) and 90.5% (survey 2) and 94.7% (survey 5), respectively. Participant characteristics collapsed across all surveys and then as a function of survey round can be found in table 1 and online supplemental table S2, respectively. Respondents across all five surveys were 51.6% female (range 18–95 years) with a mean age of 48.1 (SD 17.2) years. The majority of the sample were white (81.8%), had a high school or less education (72.3%) and reported total family annual incomes over $60 000 (51.7%). Nearly half (49.7%) reported being currently employed. Just over 44% reported having at least one physician-diagnosed health risk condition (eg, cardiovascular or lung disease, cancer, diabetes and obesity), and just over a quarter (26%) reported having a physician-diagnosed psychiatric disorder (eg, depressive or anxiety disorder). About 16.0% identified as being an essential service worker; just over 4.0% identified as being a healthcare worker; and 21.5% identified as being parents of children under 18. Approximately 17% of respondents had gotten tested for COVID-19, with nearly 1% reporting testing positive. Only 43% of respondents reported getting an influenza vaccine at least three times or more over the past 5 years. In general, compared with census data available through Statistics Canada, participants across all five surveys were well distributed across provincial regions, age groups, employment status and income, and there were equal proportions of men and women. However, those with a graduate or postgraduate degree and people of colour were less represented.

Estimates of vaccine hesitancy and changes over time

Rates of vaccine hesitancy across time/survey round are presented in figure 1. Overall, 42.2% of respondents reported vaccine hesitancy over the course of the study period, though we observed significant variations in vaccine hesitancy rates over time (survey 1: 36.8%, survey 2: 44.6%; survey 3:52.9%, survey 4: 39.6%, survey 5: 36.9%). As can be seen in figure 1, vaccine hesitancy was lowest during surveys 1 (April 2020) and 5 (March 2021), and highest during survey 3 (November 2020).

Participant characteristics presented as a function of vaccine hesitancy status across all surveys/time points are presented in figure 2 (individual survey data can be found in online supplemental table S3). Across all surveys, rates of vaccine hesitancy were significantly higher among younger age groups (<25 years and 26–50 years compared with those aged 50+), non-white, those currently employed, those reporting less than $60 000 in annual family income, and those living in Western provinces (British Columbia, Alberta, Saskatchewan and Manitoba) and Ontario compared with Quebec and the Atlantic provinces. In addition, rates of vaccine hesitancy were significantly higher among those without a health risk condition, those identifying as essential workers, those identifying as healthcare workers, and parents of children under 18. Finally, rates of vaccine hesitancy were

Table 1 Participant characteristics (weighted proportions)

All surveys (N=15 019)	
Variable	**N (%)**
Sex	
Male	7239 (48.4)
Female	7724 (51.6)
Age (numerical)	48.1±17.2
Age (years) (categorical)	
≤25	1808 (12.2)
26–50	6138 (41.4)
≥51	6897 (46.5)
Race/ethnicity	
Non-white	2687 (18.2)
White	12 047 (81.8)
Education level	
High school or lower	10 642 (72.3)
Graduate or postgraduate degree	4085 (27.7)
Current employment status	
Unemployed	7412 (50.3)
Employed	7338 (49.7)
Annual household income	
<$60 000/year	6405 (48.3)
≥$60 000/year	6853 (51.7)
Provincial region	
Western*	4702 (31.3)
Ontario	5762 (38.4)
Quebec	3523 (23.5)
Atlantic†	1032 (6.9)
Health-risk condition‡	
No	8192 (55.4)
Yes	6596 (44.6)
Psychiatric disorder§	
No	10 680 (74.0)
Yes	3747 (26.0)
Essential service worker	
No	12 192 (84.1)
Yes	2307 (15.9)
Healthcare worker	
No	13 867 (95.6)
Yes	632 (4.4)
Parent of children <18 years	
No	11 490 (78.5)
Yes	3145 (21.5)
Results of COVID-19 test	
Others	14 702 (99.0)
COVID-19 positive	144 (1.0)
History of getting influenza vaccine	

Continued

Table 1 Continued

All surveys (N=15 019)	
Variable	**N (%)**
<3 times in the past 5 years	8348 (57.0)
≥3–5 times in the past 5 years	6304 (43.0)

*Western provinces: British Columbia, Alberta, Saskatchewan and Manitoba.
†Atlantic provinces: Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland/Labrador.
‡Health risk conditions: cardiovascular disease, chronic respiratory disease, diabetes, obesity, cancer and other autoimmune diseases.
§Psychiatric disorders: any mood and/or anxiety disorder and dementia.

significantly higher among those reporting getting the influenza vaccine less than three times in the past 5 years (all p<0.05).

Sociodemographic predictors of vaccine hesitancy

Multivariable logistic regression analyses examining associations between vaccine hesitancy and sociodemographic and clinical variables across all surveys/time points are presented in table 2. The partially adjusted model revealed that women were 19% more likely to be vaccine hesitant (OR_{padj} 1.19, 95% CI 1.08 to 1.32), those aged less than 25 years (OR_{padj} 2.07, 95% CI 1.74 to 2.46) and 26–50 years (OR_{padj} 2.41 95% CI 2.16 to 2.69) were 2.07 times and 2.41 times more likely to be hesitant compared with those aged 51 and over, and those who identified as non-white were 1.3 times more likely to be vaccine hesitant compared with those who identified as white (OR_{adj} 1.30, 95% CI 1.14 to 1.49). The fully adjusted model revealed that in addition to women, younger age groups and non-white, those with high school or less education were 1.15 times more likely to be vaccine hesitant compared with those with graduate or postgraduate degrees (OR_{adj} 1.15, 95% CI 1.041 to 1.28); those earning less than $60 000 per year in household income were 1.42 times more likely to be vaccine hesitant that those earning $60 000 or more ($OR_{adj}$ 1.42, 95% CI 1.26 to 1.61); essential and healthcare workers were 1.44 (OR_{adj} 1.44, 95% CI 1.21 to 1.71) and

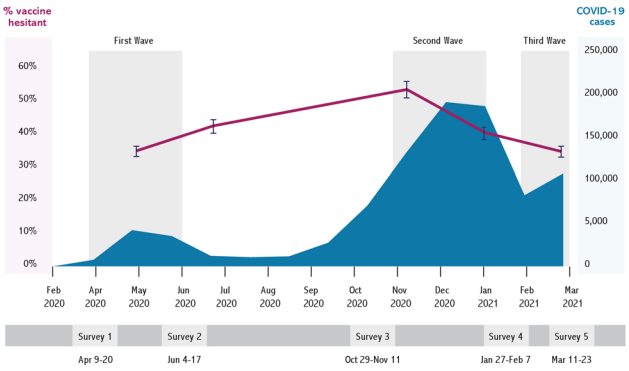

Figure 1 Rates of vaccine hesitancy across the five surveys/time points.

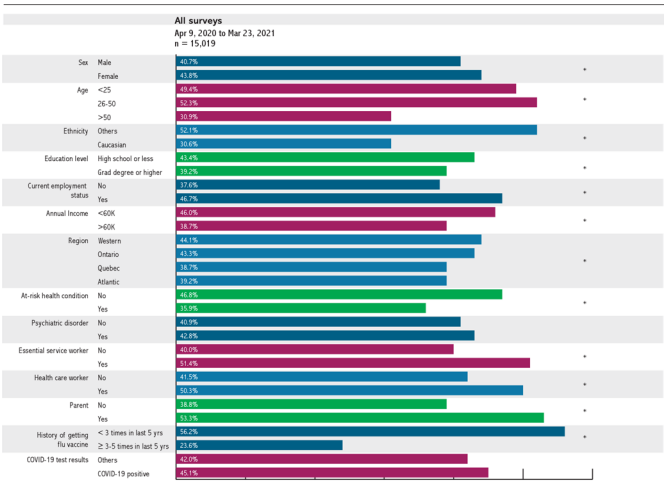

Figure 2 Participant characteristics presented as a function of being hesitant* versus extremely likely to get a COVID-19 vaccine across the three surveys: univariate analyses. Western provinces: British Columbia, Alberta, Saskatchewan. Manitoba Atlantic provinces: Nova Scotia, New Brunswick, Prince Edward Island, and Newfoundland/Labrador. * High-risk health conditions: cardiovascular disease, chronic respiratory disease, diabetes, obesity, cancer, autoimmune disease. Psychiatric disorders: any mood and/or anxiety disorder and dementia. *Hesitant: those reporting being 'somewhat likely', 'unlikely' or 'extremely unlikely' to seek out the COVID-19 vaccine.

1.35 (OR_{adj} 1.35, 95% CI 1.04 to 1.75) times more likely to be vaccine hesitant, respectively, compared with those not in those fields. Finally, parents of children under 18 were 1.51 times more likely to be vaccine hesitant compared with non-parents (OR_{adj} 1.51, 95% CI 1.30 to 1.75); and those reporting getting the influenza vaccine three times or more in the past 5 years were 73% less likely to be vaccine hesitant compared with those reporting getting the influenza vaccine less than three times in the past 5 years (OR_{adj} 0.27, 95% CI 0.23 to 0.30).

Psychological predictors of vaccine hesitancy

Perceptions of the importance of engaging in infection prevention behaviours across the five surveys/time points is presented in figure 3. Overall, 76% of respondents reported believing that engaging in infection prevention behaviours was extremely important, though we observed significant variations in perceived importance over time. Perceived importance was highest at survey 1 (87%), which then dropped to 71.3% by survey 2 and remained generally stable across survey 3 (74.5%), survey 4 (75.7%) and survey 5 (71.3%). Concern trends generally followed a similar pattern: M for each concern type were highest at survey 1 and dropped significantly by survey 2 and remained generally stable across surveys 3–5 (p<0.0001 for trend, see figure 3). Across all five surveys/time points, respondents reported having the greatest concerns about the social and economic impacts of the pandemic (M=3.18, SD 0.76), followed by health concerns (M=2.98,

Table 2 Multivariate associations between sociodemographic characteristics and COVID-19 vaccine hesitancy

Variable	Estimate	SE	P value	OR	95% CI Lower	95% CI Upper
Partially adjusted						
Intercept	−1.163	0.070	<0.0001			
≤25 years vs ≥51 years	0.729	0.087	<0.0001	2.073	1.749	2.457
26–50 years vs ≥51 years	0.880	0.056	<0.0001	2.411	2.161	2.690
Woman versus man	0.173	0.052	0.0008	1.189	1.075	1.316
Fully adjusted model*						
Intercept	−0.910	0.101	<0.0001			
≤25 years (vs ≥51 years)	0.371	0.107	0.006	1.449	1.174	1.788
26–50 years (vs ≥51 years)	0.403	0.075	<0.0001	1.496	1.292	1.732
Woman (vs man)	0.198	0.059	0.0008	1.218	1.085	1.368
White (vs non-white)	0.388	0.082	<0.0001	1.474	1.254	1.733
Graduate/postgraduate degree (vs high school or lower)	0.143	0.053	0.007	1.154	1.041	1.279
Employed (vs unemployed)	0.020	0.074	0.791	1.02	0.882	1.178
Annual household income ≥$60 000 vs <$60 000	0.354	0.062	<0.0001	1.424	1.26	1.609
Parent (vs not)	0.411	0.077	<0.0001	1.508	1.297	1.753
Essential worker (vs not)	0.364	0.087	<0.0001	1.439	1.214	1.705
At-risk health condition (vs none)	−0.077	0.062	0.217	0.926	0.82	1.046
Influenza vaccine ≥3–5 times in last 5 years (vs <3 times in the last 5 years)	−1.329	0.063	<0.0001	0.265	0.234	0.299
Positive COVID-19 test result (vs negative)	0.282	0.307	0.358	1.326	0.726	2.421

SD=0.86) and personal financial concerns (M=2.43, SD=1.08).

Partially and fully adjusted multivariate logistic regression analyses examining associations between vaccine hesitancy and perceived importance of engaging in infection prevention behaviours and COVID-19-related concern types across all surveys/time points are presented in tables 3 and 4. Respondents who perceived engaging in infection prevention behaviours to be extremely important were 78% (partially adjusted) and 77% (fully adjusted) less likely to be vaccine hesitant than those who believed engaging in these behaviours was only somewhat, not very or not at all important (OR_{padj} 0.22, 95% CI 0.19 to 0.25, and OR_{adj} 0.23, 95% CI 0.20 to 0.27, respectively). Although social and economy concerns were the most endorsed by respondents, they were not predictive of vaccine hesitancy in partially or fully adjusted analyses. However, health concerns were associated with a 58% (partially adjusted) and 54% (fully adjusted) reduced odds of vaccine hesitancy (OR_{padj} 0.42, 95% CI 0.39 to 0.46, and OR_{adj} 0.46, 95% CI 0.42 to 0.50, respectively), while having high personal financial concerns was associated with a 1.41 and 1.34 times greater odds of vaccine hesitancy in partially (OR_{padj} 1.41, 95% CI 1.32 to 1.49) and fully adjusted (OR_{adj} 1.34, 95% CI 1.25 to 1.43) models.

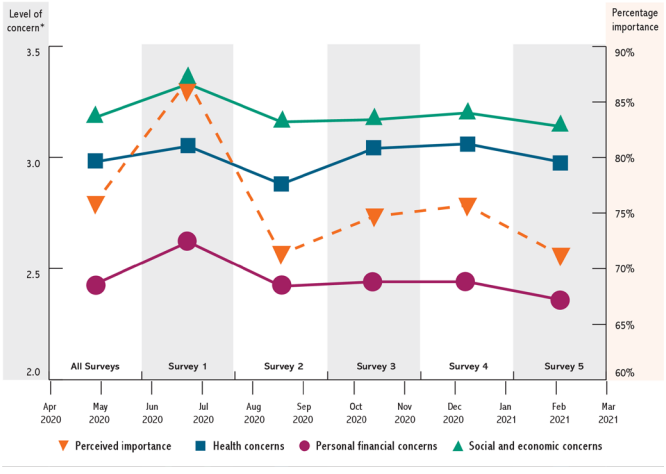

Figure 3 Perceptions of the importance of engaging in infection prevention behaviours (percentage of respondents reporting 'extremely important', dashed line) and mean COVID-19 concern levels (solid lines) across the five surveys/time points.

DISCUSSION

The present study analysed Canadian survey data from five age, sex and province-weighted population-based samples to describe vaccine intentions between April 2020 and March 2021 and their correlates. Over 40% of Canadians reported some degree of vaccine hesitancy over the course of the study period. Vaccine hesitancy was lowest during pandemic waves 1 and 3, and highest during pandemic wave 2, just prior to vaccine approval in Canada (December 2020). These results are consistent with data from the USA covering the same time period, which also demonstrated significant increases in vaccine hesitancy between April and December 2020 among 8167 online

Table 3 Multivariate logistic regression model estimating the association between COVID-19-related concerns and vaccine hesitancy

Variable	Estimate	SE	P value	OR	95% CI Lower	95% CI Upper
Partially adjusted models*						
Intercept	0.701	0.154	<0.0001			
Health concerns	−0.861	0.040	<0.0001	0.423	0.391	0.458
Personal financial concerns	0.341	0.031	<0.0001	1.406	1.324	1.493
Social and economy concerns	−0.035	0.042	0.394	0.966	0.891	1.047
Fully adjusted models†						
Intercept	0.914	0.184	<0.0001			
Health concerns	−0.780	0.043	<0.0001	0.458	0.421	0.499
Personal financial concerns	0.290	0.035	<0.0001	1.336	1.248	1.429
Social and economy concerns	−0.064	0.046	0.1633	0.938	0.858	1.026

*Partially adjusted for sex, age, ethnicity/race and survey/time point.
†Fully adjusted for sex, age, ethnicity/race, and survey/time point, education, employment status, annual household income, health risk condition, essential worker, healthcare worker, parental status, history of influenza vaccine and COVID-19 test result.

respondents in the Understanding America Study.[9] These results are also aligned with those of a study conducted by the World Economic Forum, which reported a decline in positive vaccine intentions between August (77%) and October 2020 (73%) among 18 526 respondents from 15 countries (including 1000 from Canada).[20]

Profile of Canadians who are vaccine hesitant

We examined the profile of Canadians who were more likely to report being vaccine hesitant and found that in fully adjusted analyses (including survey/time point), women, younger individuals (aged 50 and younger), non-white individuals, those with lower levels of education (high school or less), and those reporting lower annual household incomes (less than $60 000/year) were significantly more likely to report being vaccine hesitant over the study period. Overall, this profile is consistent with the results of similar studies in Canada and other Western nations (eg, USA, UK, France, Italy, Germany and Australia),[21–31] suggesting a robust phenomenon of higher vaccine hesitancy among women, younger individuals, non-white individuals and those of lower socioeconomic status.

The reasons for the lower vaccine intentions among women remains poorly understood and seems paradoxical, given evidence that women are more adherent to COVID-19 prevention measures in general.[18 32] Some speculate it might be related to their tendency to have greater health risk perceptions in general,[33] which may lead to heightened fears of experiencing vaccine side effects compared with men, resulting in less willingness to get vaccinated. These fears may not be completely unfounded, in light of evidence showing that women tend to have stronger immune reactions to vaccines than men, which may lead to more adverse events following

Table 4 Multivariate logistic regression model estimating the association between perceived importance of COVID-19 prevention measures and vaccine hesitancy

Variable	Estimate	SE	P value	OR	95% CI Lower	95% CI Upper
Partially adjusted models*						
Intercept	0.168	0.092	0.0665			
Perceived importance	−1.536	0.065	<0.0001	0.215	0.19	0.245
Very important versus others†						
Fully adjusted models‡						
Intercept	0.371	0.123	0.0026			
Perceived importance	−1.462	0.073	<0.0001	0.232	0.201	0.267
Very important versus others†						

*Partially adjusted for sex, age, ethnicity/race and survey/time point.
†Others: somewhat important, not very important, not at all important.
‡Fully adjusted for sex, age, ethnicity/race and survey/time point, education, employment status, annual household income, at-risk health condition, essential worker, healthcare worker, parental status, history of flu vaccine and COVID-19 test result.

vaccination.[34 35] More recent data suggest that women may be more reluctant to get vaccinated due to reproductive factors, as women who are pregnant or planning to get pregnant appear to be delaying vaccination due to safety concerns affecting the fetus.[36 37] Given evidence to suggest that pregnancy in the presence of COVID-19 may confer increased risk for severe illness, hospitalisation and intensive care unit admission, and preliminary findings of no obvious safety concerns among pregnant women who received mRNA vaccines,[38] addressing vaccine hesitancy in this group will be important for protecting this vulnerable population.

Contrary to women, younger adults may be less willing to get vaccinated due to *lower* COVID-19 risk perception compared with older adults.[39] These perceptions may have been fuelled by early reports of lower risks of COVID-19 hospitalisation and complications among younger age groups.[40] While overall COVID-19-related mortality among those under age 20 remains low (proportion of all-cause deaths attributed to COVID-19 has been estimated to be 0.48%[41]), those aged 2–59 have accounted for 63% of all infections and 30% of all hospitalisations in Canada since the start of the pandemic.[42] This suggests that this age group remains an important vector of community virus transmission, and a need to optimise vaccination uptake in this age cohort.

Our results also revealed lower vaccine intentions among non-white individuals, those with high school or less education and those with annual household incomes of less than $C60 000/year (below the poverty line in Canada).[43] These results are consistent with those from previous studies in the USA,[21 23 24 44] Australia[28] and across Europe.[29 30 45 46] Results of greater vaccine hesitancy among people of colour are a cause for concern, given that these individuals are more likely to work in industries worst affected by the COVID-19 pandemic, such as food and beverage, hospitality and long-term care services.[47] Reasons for higher rates of hesitancy among these groups may include lower health literacy[48] and lack of trust in vaccines and the healthcare system,[49] the latter of which may be exacerbated by low representation of people of colour in vaccine trials and experience with discrimination and systemic racism.[50] Clearly, greater efforts need to be made to motivate and enable those from racial and ethnic minority groups to get vaccinated.

We also identified two important groups of individuals at greater risk of being vaccine hesitant: essential and healthcare workers. Evidence of greater hesitancy among essential and healthcare workers was both surprising and a cause of concern, given that they are the individuals most likely to be exposed, and expose others to COVID-19. However, our results do seem to be in line with US data from a survey of 16 970 employed adults in the USA showing that those working in essential service sectors (ie, leisure and hospitality, manufacturing, construction, retail, transportation, and food and beverage) had the highest rates of vaccine hesitancy (45%–54%) compared with non-essential sectors like technology (25%), financial services (26%), public administration (36%) and entertainment (37%).[51] Our finding of high vaccine hesitancy among healthcare workers is also consistent with other studies both within[52] and outside[53–55] of Canada. Though we were not able to determine what types of healthcare workers are more likely to be vaccine hesitant, data from previous reports suggests this is more common among female healthcare workers,[52 53 56] as well as nurses and paramedical professionals rather than physicians or health administrators.[54–56] While the reasons for vaccine hesitancy among healthcare workers remain poorly understood, available evidence suggest their hesitancy is linked to vaccine novelty and concerns about safety.[52 55] Further research is needed to identify barriers to vaccination among essential and healthcare workers due to their high risk of virus exposure and transmission.

There were two additional findings from our analyses that warrant discussion. The first is that vaccine hesitancy was higher among those with an inconsistent history of getting the influenza vaccine. This is consistent with previous reports[22 44 46 57 58] and suggests that having favourable vaccine attitudes and behaviours in general is associated with greater likelihood of getting vaccinated against COVID-19. The other finding is that parents of children under age 18 were 1.5 times more likely to be vaccine hesitant compared with non-parents. Given the recent approval of vaccines among children 5–11 years of age in Canada, this finding is a cause for concern and consistent with at least one study out of the UK that also found that parents of young children were more likely to report vaccine hesitancy or refusal.[59] The reasons for this are remain poorly understood but may reflect more general trends of parental hesitancy to vaccinate their children against common infectious diseases (eg, mumps, measles and pertussis).[60] Given that COVID-19 infection rates are currently highest among school-aged children in Canada,[61] parents represent an important target for vaccination. Further research is needed to understand the reasons for vaccine hesitancy in this group and the impact of personal vaccine hesitancy on their willingness to get their children vaccinated against COVID-19, in order to optimise vaccination rates in this vulnerable group.

Psychological predictors of vaccine hesitancy

In addition to sociodemographic predictors, we also assessed psychological predictors of vaccine hesitancy. One of the strongest predictors of positive vaccine intentions was the extent to which Canadians believed engaging in preventive health behaviours (eg, vaccination) was important for reducing virus transmission. Those who believed that engaging in preventive health behaviours (like getting vaccinated) was ‘extremely important’ were 77% less likely to be vaccine hesitant after adjustment for covariates including sociodemographics and survey period/time point. This finding is consistent with previous reports linking high perceived benefits (of getting vaccinated) to positive vaccine intentions,[62] highlighting the need for vaccination campaigns to clearly and consistently

emphasise how the benefits of getting vaccinated far outweigh any risks. We also found that different types of COVID-19-related concerns were important determinants of vaccine hesitancy. Interestingly, even though social and economy concerns were the most highly endorsed at each survey/time point, only high health-related concerns and personal financial concerns were significant predictors of vaccine hesitancy—but not in the same direction. In fact, we found that those with high health concerns (ie, concerned about becoming infected and/or infecting others) were 54% less likely to be vaccine hesitant, while those with high concerns about their personal financial situation (eg, were worried about job and income loss or not having enough money to feed their family) were 1.33 times *more likely* to report being vaccine hesitant. Results linking high health concerns to lower vaccine hesitancy are consistent with those of other studies in Canada, the USA, Australia and Europe,[21 23 24 26 29 58 63–66] and provide further support of the need for vaccination campaigns to highlight how getting vaccinated is going to be health protective. However, to our knowledge, this is the first study to date to observe a link between high personal financial concerns and increased vaccine hesitancy, and suggests that those whose livelihoods were negatively impacted by the virus may be less willing or able to get vaccinated. Further research is needed to determine the extent to which this reflects a lack of motivation or desire to get vaccinated, or a perceived inability to get vaccinated due to practical barriers or limitations (eg, lack of access to paid leave to get vaccinated).

Limitations and strengths

This study should be interpreted in light of some methodological limitations. First, although we included large, national samples of Canadians with representation across age, sex and province, the absolute number of participants in certain provinces (eg, Atlantic) was lower, making interprovincial comparisons difficult. Second, the survey was available only in English and French, which may have led to an under-representation of certain non-native English or French speaking groups. Further, our surveys included fewer people of colour, which may reflect participation on online panels, so results might not generalise as well to non-white participants. Third, since the surveys were voluntary and participants were drawn from a polling firm's subject pool, participation may have been subject to some degree of selection bias. Fourth, though this study presents data depicting vaccine intentions over time, it was drawn from three separate cohorts of online panels, so data reflect trends in vaccine intentions over time but not in the same individuals. Finally, data were self-reported, which may have been subject to social desirability bias.[67] However, the fact that the surveys were anonymous likely mitigated this limitation.

Despite some limitations, this study also had a number of important strengths. The study included a large sample size; respondents were well distributed across provincial regions, age groups, employment status and income compared with census data available through Statistics Canada; and there were equal proportions of men and women. This study also collected data during peak lockdown of the first wave (April 2020) through to the end of the third wave (end of March 2021) when vaccines started becoming available in Canada. This allowed for the assessment of changes in vaccine intentions over time across three critical waves of the pandemic in Canada. We conducted principal component analysis to determine the structure of our concerns module, which was found to have excellent internal consistency, which is important for ensuring the validity of our results linking concern types to vaccine hesitancy. Finally, results reflect a subanalysis of Canadian representative data from the iCARE Study, which has collected data from more than 100 000 people from 190 countries to date alongside ongoing efforts to collect similarly representative samples in eight other countries (see: www.icarestudy.com). This will facilitate comparisons with international datasets to contribute important evidence to support the development and implementation of COVID-19 vaccine policy strategies worldwide.

CONCLUSIONS

Over 40% of Canadians reported some degree of vaccine hesitancy betweenApril 2020 and March 2021. Vaccine hesitancy was lowest during pandemic waves 1 and 3, and highest during pandemic wave 2, just prior to vaccine approval in Canada. Women, individuals aged 50 and younger, non-white individuals, those with high school education or less, and those with annual household incomes below the poverty line in Canada (ie, $60 000) were significantly more likely to report being vaccine hesitant over the study period. Three important groups of Canadians were identified as being vaccine hesitant: essential and healthcare workers, parents of children under the age of 18 and those without a previous history of influenza vaccination. Finally, perceived importance of engaging in infection prevention behaviours (like vaccination) and having high COVID-19-related health concerns were predictive of lower levels of vaccine hesitancy, whereas having high COVID-19-related personal financial concerns was predictive of higher levels of vaccine hesitancy. Overall, results point to the importance of targeting vaccine efforts to subgroups who may be socioeconomically disadvantaged, who also happen to be disproportionately represented in essential service occupations including healthcare. Finally, vaccine messaging should emphasise how the benefits of getting vaccinated (particularly to health) far outweigh the risks, particularly those associated with personal financial losses. Future research is needed to monitor ongoing changes in vaccine intentions and behaviour, as well as to better understand motivators and facilitators of vaccine acceptance, particularly among vulnerable groups.

Author affiliations
[1]Psychology, Université du Québec à Montréal, Montreal, Québec, Canada
[2]Montreal Behavioural Medicine Centre, CIUSSS-NIM Research Centre, Montreal, Québec, Canada
[3]Health, Kinesiology and Applied Physiology, Concordia University, Montreal, Québec, Canada
[4]Keenan Research Center, St Michael's Hospital Li Ka Shing Knowledge Institute, Toronto, Ontario, Canada
[5]Medicine, St Michael's Hospital, Toronto, Ontario, Canada
[6]Family Medicine, University of Michigan, Ann Arbor, Michigan, USA
[7]Montreal Behavioural Medicine Centre, Montreal, Québec, Canada
[8]Family Medicine, Dalhousie University, Halifax, Nova Scotia, Canada
[9]Psychiatry, University of Ottawa, Ottawa, Ontario, Canada
[10]Institute of Mental Health Research, University of Ottawa, Ottawa, Ontario, Canada
[11]Clinical Epidemiology Program, Ottawa Hospital Research Institute, Ottawa, Ontario, Canada
[12]School of Epidemiology and Public Health, University of Ottawa, Ottawa, Ontario, Canada

Acknowledgements We acknowledge the support from our Montreal Behavioural Medicine Centre International COVID-19 Awareness and Responses Evaluation Team, particularly administrative support by Mr Guillaume Lacoste and Dr Genevieve Szczepanik; web, graphics and technical support from Johanne O'Malley (Wordcrafting); and analytical support by Ms Mariam Atoui and Dr Julian Esse Atto.

Collaborators International COVID-19 Awareness and Responses Evaluation Study collaborators: lead investigators: Kim L Lavoie, PhD, University of Quebec at Montreal (UQAM) and CIUSSS-NIM, Canada; Simon L Bacon, PhD, Concordia University and CIUSSS-NIM, Canada. Collaborators (in alphabetical order by country): Argentina: Analía Verónica Losada, PhD, University of Flores; Australia: Jacqueline Boyle, PhD, Monash University; Joanne Enticott, PhD, Monash University; Shajedur Rahman Shawon, PhD, Centre for Big Data Research in Health, UNSW Medicine; Helena Teede, MD, Monash University; Austria: Alexandra Kautzky-Willer, MD, Medizinische Universität Wien; Bangladesh: Arobindu Dash, MS, International University of Business, Agriculture & Technology; Brazil: Marilia Estevam Cornelio, PhD, University of Campinas; Marlus Karsten, Universidade do Estado de Santa Catarina (UDESC); Darlan Lauricio Matte, PhD, UDESC; Canada: Ahmed Abou-Setta, PhD, University of Manitoba; Shawn Aaron, PhD, Ottawa Hospital Research Institute; Angela Alberga, PhD, Concordia University; Tracie Barnett, PhD, McGill University; Silvana Barone, MD, Université de Montréal; Ariane Bélanger-Gravel, PhD, Université Laval; Sarah Bernard, PhD, Université Laval; Lisa Maureen Birch, PhD, Université Laval; Susan Bondy, PhD, University of Toronto, Dalla Lana School of Public Health; Linda Booij, PhD, Concordia University; Roxane Borgès Da Silva, PhD, Université de Montréal; Jean Bourbeau, MD, McGill University; Rachel Burns, PhD, Carleton University; Tavis Campbell, PhD, University of Calgary; Linda Carlson, PhD, University of Calgary; Kim Corace, PhD, University of Ottawa; Olivier Drouin, MD, CHU Sainte-Justine/Université de Montréal; Francine Ducharme, MD, Université de Montréal; Mohsen Farhadloo, Concordia University; Carl Falk, PhD, McGill University; Richard Fleet MD, PhD, Université Laval; Michel Fournier, MSc, Direction de la Santé Publique de Montréal; Gary Garber, MD, University of Ottawa/Public Health Ontario; Lise Gauvin, PhD, Université de Montréal; Jennifer Gordon, PhD, University of Regina; Roland Grad, MD, McGill University; Samir Gupta, MD, University of Toronto; Kim Hellemans, PhD, Carleton University; Catherine Herba PhD, UQAM; Heungsun Hwang, PhD, McGill University; Jack Jedwab, PhD, Canadian Institute for Identities and Migration and the Association for Canadian Studies; Keven Joyal-Desmarais, PhD, Concordia University; Lisa Kakinami, PhD, Concordia University; Eric Kennedy, PhD, York University; Sunmee Kim, PhD, University of Manitoba; Joanne Liu, PhD, McGill University; Colleen Norris, PhD, University of Alberta; Sandra Pelaez, PhD, Université de Montréal; Louise Pilote, MD, McGill University; Paul Poirier, MD, Université Laval; Justin Presseau, PhD, University of Ottawa; Eli Puterman, PhD, University of British Columbia; Joshua Rash, PhD, Memorial University; Paula AB Ribeiro, PhD, MBMC; Mohsen Sadatsafavi, PhD, University of British Columbia; Paramita Saha Chaudhuri, PhD, McGill University; Jovana Stojanovic, PhD, Concordia University; Eva Suarthana, MD, PhD, Université de Montréal/McGill University; Sze Man Tse, MD, CHU Sainte-Justine; Michael Vallis, PhD, Dalhousie University; Chile: Nicolás Bronfman Caceres, PhD, Universidad Andrés Bello; Manuel Ortiz, PhD, Universidad de La Frontera; Paula Beatriz Repetto, PhD, Universidad Católica de Chile; Colombia: Mariantonia Lemos-Hoyos, PhD, Universidad EAFIT; Cyprus: Angelos Kassianos, PhD, University of Cyprus; Denmark: Naja Hulvej Rod, PhD, University of Copenhagen; FRANCE: Mathieu Beraneck, PhD, Université de Paris; CNRS; Gregory Ninot, PhD, Université de Montpellier; Germany: Beate Ditzen, PhD, Heidelberg University; Thomas Kubiak, PhD, Mainz University; Ghana: Sam Codjoe MPhil,MSc, University of Ghana; Lily Kpobi, PhD, University of Ghana; Amos Laar, PhD, University of Ghana; India: Naorem Kiranmala Devi, PhD, University of Delhi; Sanjenbam Meitei, PhD, Manipur University; Suzanne Tanya Nethan, MDS, ICMR-National Institute of Cancer Prevention & Research; Lancelot Pinto, MD, PhD, Hinduja Hospital and Medical Research Centre; Kallur Nava Saraswathy, PhD, University of Delhi; Dheeraj Tumu, MD, WHO; Indonesia: Silviana Lestari, MD, PhD, Universitas Indonesia; Grace Wangge, MD, PhD, SEAMEO Regional Center for Food and Nutrition; Ireland: Molly Byrne, PhD, National University of Ireland, Galway; Hannah Durand, PhD, National University of Ireland, Galway; Jennifer McSharry, PhD, National University of Ireland, Galway; Oonagh Meade, PhD, National University of Ireland, Galway; Gerry Molloy, PhD, National University of Ireland, Galway; Chris Noone, PhD, National University of Ireland, Galway; Israel: Hagai Levine, MD, Hebrew University; Anat Zaidman-Zait, PhD, Tel-Aviv University; Italy: Stefania Boccia, PhD, Università Cattolica del Sacro Cuore; Ilda Hoxhaj, MD, Università Cattolica del Sacro Cuore, Stefania Paduano, MSc, PhD, University of Modena and Reggio Emilia; Valeria Raparelli, PhD, Sapienza, University of Rome; Drieda Zaçe, MD, MSc, PhDc, Università Cattolica del Sacro Cuore; Jordan: Ala'S Aburub, PhD, Isra University; Kenya: Daniel Akunga, PhD, Kenyatta University; Richard Ayah, PhD, University of Nairobi, School Public Health; Chris Barasa, MPH, University of Nairobi, School Public Health; Pamela Miloya Godia, PhD, University of Nairobi; Elizabeth W. Kimani-Murage, PhD, African Population and Health Research Center; Nicholas Mutuku, PhD, University of Kenya; Teresa Mwoma, PhD, Kenyatta University; Violet Naanyu, PhD, Moi University; Jackim Nyamari, PhD, Kenyatta University; Hildah Oburu, PhD, Kenyatta University; Joyce Olenja, PhD, University of Nairobi; Dismas Ongore, PhD, University of Nairobi; Abdhalah Ziraba, PhD, African Population and Health Research Center; Malawi: Chiwoza Bandawe, PhD, University of Malawi; Malaysia: Loh Siew Yim, PhD, Faculty of medicine, University of Malaya; New Zealand: Andrea Herbert, PhD, University of Canterbury; Daniela Liggett, PhD, University of Canterbury; Nigeria: Ademola Ajuwon, PhD, University of Ibadan; Pakistan: Nisar Ahmed Shar, PhD, CoPI-National Center in Big Data & Cloud Computing; Bilal Ahmed Usmani, PhD, NED University of Engineering and Technology; Peru: Rosario Mercedes Bartolini Martínez, PhD, Instituto de Investigacion Nutricional; Hilary Creed-Kanashiro, M.Phil., Instituto de Investigacion Nutricional; Portugal: Paula Simão, MD, S. Pneumologia de Matosinhos; Rwanda: Pierre Claver Rutayisire, PhD, University Rwanda; Saudi Arabia: Abu Zeeshan Bari, PhD, Taibah University; Slovakia: Iveta Nagyova, PhD, PJ Safarik University, UPJS; South Africa: Jason Bantjes, PhD, University of Stellenbosch; Brendon Barnes, PhD, University of Johannesburg; Bronwyne Coetzee, PhD, University of Stellenbosch; Ashraf Khagee, PhD, University of Stellenbosch; Tebogo Mothiba, PhD, University of Limpopo; Rizwana Roomaney, PhD, University of Stellenbosch; Leslie Swartz, PhD, University of Stellenbosch; South Korea: Juhee Cho, PhD, Sungkyunkwan University; Man-gyeong Lee, PhDc, Sungkyunkwan University; Sweden: Anne Berman, PhD, Karolinska Institutet; Nouha Saleh Stattin, MD, Karolinska Institutet; Switzerland: Susanne Fischer, PhD, University of Zurich; Taiwan: Debbie Hu, MD, MSc, Tainan Municipal Hospital; Turkey: Yasin Kara, MD, Kanuni Sultan Süleyman Training and Research Hospital, Istanbul; Ceprail Şimşek, MD Health Science University; Bilge Üzmezoğlu, MD, University of Health Science; Uganda: John Bosco Isunju, PhD, Makerere University School of Public Health; James Mugisha, PhD, University of Uganda; United Arab Emirates: Zahir Vally, PhD, United Arab Emirates University; United Kingdom: Lucie Byrne-Davis, PhD, University of Manchester; Paula Griffiths, PhD, Loughborough University; Joanne Hart, PhD, University of Manchester; Will Johnson, PhD, Loughborough University; Susan Michie, PhD, University College London; Nicola Paine, PhD, Loughborough University; Emily Petherick, PhD, Loughborough University; Lauren Sherar, PhD, Loughborough University; USA: Robert M. Bilder, PhD, ABPP-CN, University of California, Los Angeles; Matthew Burg, PhD, Yale; Susan Czajkowski, PhD, NIH, National Cancer Institute; Ken Freedland, PhD, Washington University; Sherri Sheinfeld Gorin, PhD, University of Michigan; Alison Holman, PhD, University of California, Irvine; Jiyoung Lee, PhD, University of Alabama; Gilberto Lopez ScD, MA, MPH, Arizona State University and University of Rochester Medical Center; Sylvie Naar, PhD, Florida State University; Michele Okun, PhD, University of Colorado, Colorado Springs; Lynda Powell, PhD, Rush University; Sarah Pressman, PhD,University of California, Irvine; Tracey Revenson, PhD, University of New York City; John Ruiz, PhD, University of Arizona; Sudha Sivaram, PhD, NIH, Center for Global Health; Johannes Thrul, PhD, Johns Hopkins; Claudia Trudel-Fitzgerald, PhD, Harvard T.H. Chan School of Public Health; Abehaw Yohannes, PhD, Azusa Pacific University. Students: Australia: Rhea Navani, BSc, Monash University; Kushnan Ranakombu, PhD, Monash University; Brazil: Daisuke Hayashi Neto, Unicamp; Canada: Tair Ben-Porat, PhD, Tel Aviv University; Anda Dragomir, University of Quebec at Montreal (UQAM) and CIUSSS-NIM; Amandine Gagnon-Hébert, BA, UQAM; Claudia Gemme, MSc, UQAM; Vincent Gosselin Boucher, University of Quebec at Montreal (UQAM) and CIUSSS-NIM; Mahrukh Jamil, Concordia University and CIUSSS-NIM; Lisa Maria Käfer, McGill

University; Ariany Marques Vieira, MSc, Concordia University; Tasfia Tasbih, Concordia University and CIUSSS-NIM; Maegan Trottier, University of Lethbridge; Robbie Woods, MSc, Concordia University; Reyhaneh Yousefi, Concordia University and CIUSSS-NIM; France: Tamila Roslyakova, Université de Montpellier; Germany: Lilli Priesterroth, Mainz University; Israel: Shirly Edelstein, Hebrew University, Hadassah School of Public Health; Tanya Goldfrad, Hebrew University-Hadassah School of Public Health; Ruth Snir, Hebrew University, Hadassah School of Public Health; Yifat Uri, Hebrew University, Hadassah School of Public Health; New Zealand: Mohsen Alyami, University of Auckland; Nigeria: Comfort Sanuade; Serbia: Katarina Vojvodic, University of Belgrade. Community Participants: Canada: Olivia Crescenzi; Kyle Warkentin; Denmark: Katya Grinko; India: Lalita Angne; Jigisha Jain; Nikita Mathur, Syncorp Clinical Research; Anagha Mithe; Sarah Nethan, Community Empowerment Lab.

Contributors iCARE Study conceptualisation and design: KL and SB; substudy conceptualisation and design: KL, SB, VG-B, JS, SG, MG, KJ-D, KS, SSG, PR, MV, KC and JP; survey design and administration: KL, SB, KS and VG-B; funding acquisition: KL and SB; data validation and analyses: KL, SB, JS, VG-B, PR and BV; manuscript drafting–original draft: KL; and review and editing: SB, VG-B, JS, SG, MG, KJ-D, KS, SSG, PR, BV, MV, KC and JP. KL acts as guarantor for the final manuscript.

Funding The International COVID-19 Awareness and Responses Evaluation (iCARE) study is supported by the Canadian Institutes of Health Research (CIHR: MM1-174903; MS3-173099; SMC-151518), the Canada Research Chairs Program (950-232522, Chair holder: Dr. Kim L. Lavoie), the Fonds de recherche du Québec - santé (FRQ-S: 251618 and 34757), the Fonds de recherche du Québec – Société et culture (FRQSC: 2019-SE1-252541), and the Ministère de l'Économie et de l'Innovation du Québec (2020-2022-COVID-19-PSOv2a-51754). Study sponsors had no role in the design of the database and data collection.

Competing interests KL is a member of the Canadian COVID-19 Expert Advisory Panel (Health Canada); has served on the advisory board or as a consultant for Schering-Plough, Takeda, AbbVie, Almirall, Janssen, GSK, Novartis, Boehringer Ingelheim (BI) and Sojecci; has received sponsorship for investigator-generated research grants from GlaxoSmithKline (GSK) and AbbVie, speaker fees from GSK, Astra-Zeneca, Astellas, Novartis, Takeda, AbbVie, Merck, Boehringer Ingelheim, Bayer, Pfizer, Xfacto and Air Liquide; and has received support for educational materials from Merck, none of which are related to the current article. MV has served on the advisory board for Diabetes Canada and has received sponsorship for investigator-generated research grants from Novo Nordisk, Abbott Diabetes Care and Bausch Health, and consultation and speaker fees from Abbott Diabetes Care, Novo Nordisk, Abbvie, Boehringer Ingelheim and Lifescan, none of which are related to the current article. JP is a member of the Ontario Immunization Advisory Committee (Public Health Ontario) and a member of the Ontario COVID-19 Science Advisory Table. SB is a member of the Health Canada COVID Alert Application Working Group; has served on the advisory board for Bayer and Sanofi; and has received sponsorship for investigator-generated research grants from GSK, Moderna and Abbvie, consultation fees from Schering-Plough, Merck, Astra Zeneca, Sygesa, Bayer, Sanofi, Lucilab and Respiplus, and speaker fees from Novartis, Respiplus and Janssen, none of which are related to the current article.

Patient and public involvement Patients and/or the public were involved in the design, conduct, reporting or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and the primary Research Ethics Board (REB) approval was obtained from the Comité d'Ethique de la Recherche du Centre Intégré Universitaire de Santé et de Services Sociaux du Nord-de-l'Île-de-Montréal (reference number 2020-2099/25-03-2020). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. The International COVID-19 Awareness and Responses Evaluation Study is an open access study. Data access procedures are available at https://mbmc-cmcm.ca/covid19/apl/. Planned analyses are logged at https://mbmc-cmcm.ca/covid19/apl/log/.

ORCID iDs
Kim Lavoie http://orcid.org/0000-0003-2606-1357
Vincent Gosselin-Boucher http://orcid.org/0000-0002-3030-6022
Jovana Stojanovic http://orcid.org/0000-0002-3984-5241
Samir Gupta http://orcid.org/0000-0002-7307-6247
Myriam Gagné http://orcid.org/0000-0002-0559-5731
Keven Joyal-Desmarais http://orcid.org/0000-0003-0657-8367
Sherri Sheinfeld Gorin http://orcid.org/0000-0002-5346-0997
Michael Vallis http://orcid.org/0000-0002-0165-5936
Justin Presseau http://orcid.org/0000-0002-2132-0703
Simon Bacon http://orcid.org/0000-0001-7075-0358

REFERENCES

1 Umakanthan S, Sahu P, Ranade AV. Origin, transmission, diagnosis and management of coronavirus disease 2019 (COVID-19). *Postgrad Med J* 2020;96:753–8.
2 Government of Canada. Vaccines for COVID-19: authorized vaccines, 2021. Available: https://wwwcanadaca/en/health-canada/services/drugs-health-products/covid19-industry/drugs-vaccines-treatments/vaccineshtml [Accessed 09-2021].
3 Francis AI, Ghany S, Gilkes T. Review of COVID-19 vaccine subtypes, efficacy and geographical distributions. *Postgrad Med J* 2021.
4 Gomes M, Corder R, King J. Individual variation in susceptibility or exposure to SARS-CoV-2 lowers the herd immunity threshold. *MedRxiv [Preprint]* 2020.
5 Centers for Disease Control and Prevention. Delta Variant: What We Know About the Science: U.S. Department of Health & Human Services, 2021. Available: https://www.cdc.gov/coronavirus/2019-ncov/variants/delta-variant.html [Accessed 09-2021].
6 Aschwanden C. Five reasons why COVID herd immunity is probably impossible. *Nature* 2021;591:520–2.
7 Kadkhoda K. Herd immunity to COVID-19. *Am J Clin Pathol* 2021:1–2.
8 MacDonald NE. Sage Working group on vaccine Hesitancy. vaccine hesitancy: definition, scope and determinants. *Vaccine* 2015;33:4161–4.
9 Szilagyi PG, Thomas K, Shah MD, *et al*. National Trends in the US Public's Likelihood of Getting a COVID-19 Vaccine—April 1 to December 8, 2020. *JAMA* 2021;325:396–8.
10 Biddle N, Edwards B, Gray M. Change in vaccine willingness in Australia: August 2020 to January 2021. *MedRxiv [Preprint]* 2021.
11 Crawshaw J KK, Castillo G, van Allen Z. Factors affecting COVID-19 vaccination acceptance and uptake among the general public: a living behavioural science evidence synthesis (V5, AUG 31st, 2021), 2021. Available: https://www.mcmasterforum.org/docs/default-source/product-documents/living-evidence-syntheses/covid-19-living-evidence-synthesis-4.5-factors-affecting-covid-vaccination-acceptance-and-uptake-among-the-general-public.pdf?sfvrsn=33dc4261_5 [Accessed 09-2021].
12 Larson HJ, Jarrett C, Eckersberger E, *et al*. Understanding vaccine hesitancy around vaccines and vaccination from a global perspective: a systematic review of published literature, 2007-2012. *Vaccine* 2014;32:2150–9.
13 Bacon SL, Lavoie KL, Boyle J, *et al*. International assessment of the link between COVID-19 related attitudes, concerns and behaviours in relation to public health policies: optimising policy strategies to improve health, economic and quality of life outcomes (the iCARE study). *BMJ Open* 2021;11:e046127.
14 Michie S, van Stralen MM, West R. The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implementation Science* 2011;6:42.
15 Rosenstock IM. The health belief model and preventive health behavior. *Health Educ Monogr* 1974;2:354–86.
16 Rosenstock IM, Strecher VJ, Becker MH. Social learning theory and the health belief model. *Health Educ Q* 1988;15:175–83.

17 Kirscht JP. The health belief model and predictions of health actions. In: Gochman DS, ed. *Health behavior: emerging research perspectives*. New York, NY: Plenum Press, 1988: 27–41p..
18 Lavoie K, Gosselin-Boucher V, Stojanovic J. Do COVID-19-related policy attitudes and concerns influence adherence to behavioural prevention strategies among Canadians? findings from the International assessment of COVID-19-related attitudes, concerns responses and impacts in relation to public health policies (iCARE) study. *Health Psychol*.
19 Ramshaw A. The complete guide to acceptable survey response rates, 2019. Available: https://www.genroe.com/blog/acceptable-survey-response-rate-2/11504 [Accessed 09-2021].
20 World Economic Forum. Fewer people say they would take a COVID-19 vaccine now than 3 months ago, 2020. Available: https://www.weforum.org/agenda/2020/11/fewer-people-say-they-would-take-a-covid-19-vaccine-now-than-3-months-ago/ [Accessed 09-2021].
21 Duquette N. Heard immunity: effective persuasion for a future COVID-19 vaccine. *SSRN Electronic Journal* 2020.
22 Thunstrom L, Ashworth M, Finnoff D, *et al*. Hesitancy towards a COVID-19 vaccine and prospects for herd immunity. *SSRN Electronic Journal* 2020;94.
23 Loomba S, de Figueiredo A, Piatek SJ, *et al*. Measuring the impact of COVID-19 vaccine misinformation on vaccination intent in the UK and USA. *Nat Hum Behav* 2021;5:337–48.
24 Callaghan T, Moghtaderi A, Lueck JA, *et al*. Correlates and disparities of COVID-19 vaccine hesitancy. *SSRN Journal* 2020.
25 Reiter PL, Pennell ML, Katz ML. Acceptability of a COVID-19 vaccine among adults in the United States: how many people would get vaccinated? *Vaccine* 2020;38:6500–7.
26 Malik AA, McFadden SM, Elharake J, *et al*. Determinants of COVID-19 vaccine acceptance in the US. *EClinicalMedicine* 2020;26:100495.
27 Edwards B, Biddle N, Gray M, *et al*. COVID-19 vaccine hesitancy and resistance: correlates in a nationally representative longitudinal survey of the Australian population. *PLoS One* 2021;16:e0248892.
28 Rhodes A, Hoq M, Measey M-A, *et al*. Intention to vaccinate against COVID-19 in Australia. *Lancet Infect Dis* 2021;21:e110.
29 Ward JK, Alleaume C, Peretti-Watel P, *et al*. The French public's attitudes to a future COVID-19 vaccine: The politicization of a public health issue. *Soc Sci Med* 2020;265:113414.
30 Graeber D, Schmidt-Petri C, Schröder C. Attitudes on voluntary and mandatory vaccination against COVID-19: evidence from Germany. *PLoS One* 2021;16:e0248372.
31 Peretti-Watel P, Seror V, Cortaredona S, *et al*. A future vaccination campaign against COVID-19 at risk of vaccine hesitancy and politicisation. *Lancet Infect Dis* 2020;20:769–70.
32 Galasso V, Pons V, Profeta P. Gender differences in COVID-19 related attitudes and behavior: evidence from a panel survey in eight OECD countries. *Proceedings of the National Academy of Sciences of the United States of American* 2020;117:27285–91.
33 Harris C, Jenkins M, Glaser D. Gender differences in risk assessment: why do women take fewer risks than men? *Judgement and Decision Making* 2006;1:48–63.
34 Flanagan KL, Fink AL, Plebanski M, *et al*. Sex and gender differences in the outcomes of vaccination over the life course. *Annu Rev Cell Dev Biol* 2017;33:577–99.
35 Fischinger S, Boudreau CM, Butler AL, *et al*. Sex differences in vaccine-induced humoral immunity. *Semin Immunopathol* 2019;41:239–49.
36 Townsel C, Moniz MH, Wagner AL, *et al*. COVID-19 vaccine hesitancy among reproductive-aged female tier 1A healthcare workers in a United States medical center. *Journal of Perinatology* 2021;41:2549–51.
37 Goncu Ayhan S, Oluklu D, Atalay A, *et al*. COVID-19 vaccine acceptance in pregnant women. *Intl J Gynecology & Obste* 2021;154:291–6.
38 Shimabukuro TT, Kim SY, Myers TR, *et al*. Preliminary findings of mRNA Covid-19 vaccine safety in pregnant persons. *N Engl J Med Overseas Ed* 2021;384:2273–82.
39 Yang XY, Gong RN, Sassine S, *et al*. Risk perception of COVID-19 infection and adherence to preventive measures among adolescents and young adults. *Children* 2020;7:311.
40 Snape MD, Viner RM. COVID-19 in children and young people. *Science* 2020;370:286–8.
41 Bhopal SS, Bagaria J, Olabi B, *et al*. Children and young people remain at low risk of COVID-19 mortality. *The Lancet Child & Adolescent Health* 2021;5:e12–13.
42 Government of Canada. COVID-19 daily epidemiological update, 2021. Available: https://health-infobasecanadaca/covid-19/epidemiological-summary-covid-19-caseshtml [Accessed 05-2021].
43 Sarlo C. A Critical Assessment of Canada's Official Poverty Line. Frasure Institute, 2018. Available: https://www.fraserinstitute.org/studies/critical-assessment-of-canadas-official-povertyline#:~:text=As%20of%the%latest%(2020,of%20%460%2C000%20to%20escape%20poverty [Accessed 09-2021].
44 Fisher KA, Bloomstone SJ, Walder J, *et al*. Attitudes Toward a Potential SARS-CoV-2 Vaccine : A Survey of U.S. Adults. *Ann Intern Med* 2020;173:964–73.
45 Williams L, Flowers P, McLeod J. Social patterning and stability of COVID-19 vaccination acceptance in Scotland: will those most at risk accept a vaccine? *medRxiv [Preprint]* 2020.
46 Lima G, Hwang H, Cha C. Public willingness to get vaccinated against COVID-19: how AI-Developed vaccines can affect acceptance. *arXiv [Preprint] arXiv* 2020:200608164.
47 Statistics Canada. Impacts on immigrants and people designated as visible minorities, 2020. Available: https://www150.statcan.gc.ca/n1/pub/11-631-x/2020004/s6-eng.htm [Accessed 09-2021].
48 Biasio LR. Vaccine hesitancy and health literacy. *Hum Vaccin Immunother* 2017;13:701–2.
49 Razai MS, Osama T, McKechnie DGJ, *et al*. Covid-19 vaccine hesitancy among ethnic minority groups. *BMJ* 2021;372:n513.
50 UK Government Scientific Advisory Group for Emergencies. Factors influencing covid-19 vaccine uptake among minority ethnic groups, 202017 December. Available: https://wwwgovuk/government/publications/factors-influencing-covid-19-vaccine-uptake-among-minority-ethnic-groups-17-december2020 [Accessed 09-2021].
51 Galvin G. Essential workers more Wary of getting vaccinated despite higher COVID-19 risk, 2021. Available: https://morningconsult.com/2021/02/03/essential-workers-more-wary-of-getting-vaccinated-despite-higher-covid-19-risk/ [Accessed 09-2021].
52 Dzieciolowska S, Hamel D, Gadio S, *et al*. Covid-19 vaccine acceptance, hesitancy, and refusal among Canadian healthcare workers: a multicenter survey. *Am J Infect Control* 2021;49:1152–7.
53 Gadoth A, Halbrook M, Martin-Blais R. Assessment of COVID-19 vaccine acceptance among healthcare workers in Los Angeles. *medRxiv [Preprint]* 2020.
54 Papagiannis D, Malli F, Raptis DG, *et al*. Assessment of knowledge, attitudes, and practices towards new coronavirus (SARS-CoV-2) of health care professionals in Greece before the outbreak period. *Int J Environ Res Public Health* 2020;17:4925–14.
55 Kumar R, Alabdulla M, Elhassan NM, *et al*. Qatar Healthcare Workers' COVID-19 Vaccine Hesitancy and Attitudes: A National Cross-Sectional Survey. *Front Public Health* 2021;9:727748.
56 Antoni MH, Cruess DG, Klimas N, *et al*. Increases in a marker of immune system reconstitution are predated by decreases in 24-h urinary cortisol output and depressed mood during a 10-week stress management intervention in symptomatic HIV-infected men. *J Psychosom Res* 2005;58:3–13.
57 Wang J, Jing R, Lai X, *et al*. Acceptance of COVID-19 vaccination during the COVID-19 pandemic in China. *Vaccines* 2020;8:482.
58 Faasse K, Newby J. Public perceptions of COVID-19 in Australia: perceived risk, knowledge, health-protective behaviors, and vaccine intentions. *Front Psychol* 2020;11.
59 Paul E, Steptoe A, Fancourt D. Anti-vaccine attitudes and risk factors for not agreeing to vaccination against COVID-19 amongst 32,361 UK adults: implications for public health communications. *SSRN Journal* 2020.
60 Dubé E, Gagnon D, Ouakki M, *et al*. Understanding vaccine hesitancy in Canada: results of a consultation study by the Canadian immunization research network. *PLoS One* 2016;11:e0156118.
61 Government of Canada. COVID-19 daily epidemiology update, 2021. Available: https://health-infobase.canada.ca/covid-19/epidemiological-summary-covid-19-cases.html.
62 Lin Y, Hu Z, Zhao Q, *et al*. Understanding COVID-19 vaccine demand and hesitancy: a nationwide online survey in China. *PLoS Negl Trop Dis* 2020;14:e0008961.
63 Head KJ, Kasting ML, Sturm LA, *et al*. A national survey assessing SARS-CoV-2 vaccination intentions: implications for future public health communication efforts. *Sci Commun* 2020;42:698–723.
64 Lackner CL, Wang CH. Demographic and psychological correlates of SARS-CoV-2 vaccination intentions in a sample of Canadian families. *medRxiv [Preprint]* 2020.
65 Underschultz JG, Barber P, Richard D. What drives resistance to public health measures in Canada's COVID-19 pandemic? An online survey of Canadians' knowledge, attitudes, and practices. *University of Toronto Medical Journal* 2021;98:35–40.
66 Leng A, Maitland E, Wang S, *et al*. Individual preferences for COVID-19 vaccination in China. *Vaccine* 2021;39:247–54.
67 Rosenman R, Tennekoon V, Hill LG. Measuring bias in self-reported data. *Int J Behav Healthc Res* 2011;2:320–32.