

Original research

Incidence of outbreak-associated COVID-19 cases by industry in Ontario, Canada, 1 April 2020–31 March 2021

Sarah A Buchan,^{1,2} Peter M Smith ,^{2,3} Christine Warren,⁴ Michelle Murti ,^{1,5} Cameron Mustard ,^{2,3} Jin Hee Kim,^{5,6} Sandya Menon,¹ Kevin A Brown,^{1,2} Trevor van Ingen,⁷ Brendan T Smith ,^{2,4}

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¹Health Protection, Public Health Ontario, Toronto, Ontario, Canada

²Epidemiology, Dalla Lana School of Public Health, University of Toronto, Toronto, Ontario, Canada

³Institute for Work & Health, Toronto, Ontario, Canada

⁴Health Promotion, Chronic Disease and Injury Prevention, Public Health Ontario, Toronto, Ontario, Canada

⁵Clinical Public Health, Dalla Lana School of Public Health, University of Toronto, Toronto, Ontario, Canada

⁶Environmental and Occupational Health, Public Health Ontario, Toronto, Ontario, Canada

⁷Analytic Services, Public Health Ontario, Toronto, Ontario, Canada

Correspondence to

Dr Sarah A Buchan, Health Protection, Public Health Ontario, Toronto, ON M5G 1M1, Canada; sarah.buchan@oahpp.ca

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ABSTRACT

Objectives The objective of our study was to estimate the rate of workplace outbreak-associated cases of COVID-19 by industry in labour market participants aged 15–69 years who reported working the majority of hours outside the home in Ontario, Canada.

Methods We conducted a population-based cross-sectional study of COVID-19 workplace outbreaks and associated cases reported in Ontario between 1 April 2020 and 31 March 2021. All outbreaks were manually classified into two-digit North American Industry Classification System codes. We obtained monthly denominator estimates from the Statistics Canada Labour Force Survey to estimate the incidence of outbreak-associated cases per 100 000 000 hours among individuals who reported the majority of hours were worked outside the home. We performed this analysis across industries and in three distinct time periods.

Results Overall, 12% of cases were attributed to workplace outbreaks among working-age adults across our study period. While incidence varied across the time periods, the five industries with the highest incidence rates across our study period were agriculture, healthcare and social assistance, food manufacturing, educational services, and transportation and warehousing.

Conclusions Certain industries have consistently increased the incidence of COVID-19 over the course of the pandemic. These results may assist in ongoing efforts to reduce transmission of COVID-19 by prioritising resources, as well as industry-specific guidance, vaccination and public health messaging.

INTRODUCTION

Understanding the role of workplace exposure to COVID-19, and differential risk by industry, is critical to reducing morbidity and mortality. Occupational risk is an important source of COVID-19 exposure and transmission.^{1 2} Elevated risk of COVID-19 has been documented among healthcare workers,³ given direct contact with patients with COVID-19.⁴ However, workplace outbreaks of COVID-19 have consistently been observed across many industries beyond healthcare, especially in essential services where work is unable to be done from home.⁵ A comprehensive analysis

Key messages

What is already known about this subject?

- Work is an important source of COVID-19 exposure and transmission, yet significant gaps exist in occupational surveillance for COVID-19.
- Healthcare is an industry of primary concern; however, workplace outbreaks of COVID-19 have consistently been observed across many industries beyond healthcare.
- An improved understanding of workplace outbreaks of COVID-19 is essential to designing equitable public health measures for reducing COVID-19-related risk.

What are the new findings?

- This study examines a population-based sample of all workplace outbreaks (N=5759) and their associated cases (N=35 168) across all industries between April 2020 and March 2021 in a working population aged 15–69 years.
- Workplace outbreak-associated cases accounted for 12% of all cases and 7% of hospitalisations during the study period.
- The incidence of COVID-19 was consistently higher in agriculture, healthcare and social assistance, food manufacturing, educational services, and transportation and warehousing over the three time periods examined in our study.
- Our findings were restricted to individuals reporting the majority of hours were worked outside the home, adding to the current literature by accounting for work disruption due to public health measures.

How might this impact on policy or clinical practice in the foreseeable future?

- Our study highlights industries where additional protections and public health measures may be required to reduce workplace outbreaks of COVID-19, as well as industries where rates of COVID-19 transmission were lower than those observed at the population level. Improved occupational surveillance may enhance the ability to effectively respond to COVID-19 and future pandemics.

of the distribution of workplace outbreaks across industries is important to understand the effectiveness and limitations of workplace infection prevention and control practices, as well to ensure equitable public health measures to reduce risk in workplaces and prevent ongoing spread in the community.

The location and frequency of workplace outbreaks will vary by region, depending on the prevalence of industries and community incidence of COVID-19.⁶ A number of occupational characteristics have been observed to increase COVID-19 risk at work, including physical proximity to others,⁷ exposure to disease⁸ and indoor ventilation; furthermore, protections in the workplace may vary by industry.⁹ In Ontario, an analysis of workplace outbreaks early in the pandemic (January–June 2020) found that 68% of outbreaks and 80% of cases belonged to manufacturing, agriculture and transportation warehousing after excluding hospital, congregate living, and education and childcare settings.¹⁰ Since this period, Ontario has experienced additional waves of COVID-19, accompanied by adjustments to public health measures that restricted operations at worksites in some industries. As such, it is critical to use accurate denominator data to estimate the risk of COVID-19 through work. Surveillance systems are often limited in their capture of occupational data^{11,12}; however, outbreak data present an opportunity to explore cases associated with reported outbreaks within workplaces to mitigate this limitation.

Understanding differences in COVID-19 incidence among workers in industries is required to understand risk and inform prevention practices. The objective of our study was to estimate the rate of workplace outbreak-associated cases of COVID-19 by industry in labour market participants aged 15–69 years who reported working the majority of hours outside the home in Ontario, Canada. We also aimed to estimate the proportion of cases in this age group that were associated with a workplace-associated outbreak.

METHODS

We conducted a population-based cross-sectional study of COVID-19 workplace outbreaks and associated cases reported in Ontario between 1 April 2020 and 31 March 2021. All outbreaks and cases in Ontario are entered into the Public Health Case and Contact Management Solution (CCM), the provincial reportable disease surveillance system, by one of Ontario's 34 local public health units (PHUs). We used monthly data from Ontario respondents to Statistics Canada's Labour Force Survey (LFS) to estimate the size of the Ontario workforce to quantify the population at risk from April 2020 through March 2021.¹³ The LFS is a monthly household survey that uses a rotating panel sample design consisting of six representative panels, where one panel is replaced each month allowing for efficient estimation of monthly changes in the Canadian labour force, including shifts in employment across industrial sectors, hours worked, labour force participation and unemployment rates. LFS respondents are representative of 98% of non-institutionalised Canadians aged 15 years and above, excluding persons living on reserves and other indigenous settlements, full-time members of the Canadian Armed Forces and institutionalised populations.¹³ In response to the COVID-19 pandemic, an LFS supplement was introduced in April 2020 to collect information on working arrangements, including working remotely and site-based work. Specifically, 'the location where the respondent worked the most hours in the previous week' was assessed, with potential responses being at home, at the worksite, outside of the home but not in a particular location and absent from work. We

excluded respondents who reported having worked the most hours at home and those who were absent from work for the full week, to better represent the population at risk of outbreak-associated COVID-19 at work. Questions in the LFS supplement are only asked of respondents aged 15–69 years, so we further restricted our sample to COVID-19 cases aged 15–69 years to focus on labour market participants. The Public Health Ontario Ethics Review Board determined that this project did not require research ethics committee approval as the activities described were considered public health practice and not research.

Outbreak definition and industry assignment

In Ontario, PHUs are responsible for declaring COVID-19 outbreaks based on provincial guidance regarding the assessment of risk of acquisition and transmission in a workplace. The outbreak definition varied by industry setting,¹⁴ with individual cases constituting an outbreak in long-term care homes (and childcare settings until 9 November 2020) or two cases occurring within 14 days with an epidemiological link in other settings.¹⁵ For hospitals, long-term care homes and education settings, outbreaks were classified on PHU entry using existing lookup tables available in CCM. All other outbreaks were reviewed retrospectively based on locations (address and outbreak name as entered by the PHU) to ensure consistency with data entry across PHUs and to assign two-digit (ie, sector) North American Industry Classification System (NAICS) industry codes based on a manual lookup.¹⁶ Classification was done by a single coder and reviewed by a secondary coder with discrepancies resolved through consensus. Based on reported outbreaks, 13 categories were examined in our study: agriculture, forestry, fishing and hunting; mining and utilities; construction; manufacturing—food; manufacturing—other; wholesale trade; retail trade; transportation and warehousing; educational services; healthcare and social assistance; accommodation and food services; public administration; and other service industries. Other service industries comprise other service industry groups which were unlikely to provide stable estimates due to the size of the workforce working outside of the home. Additional details on the NAICS and classification of industries are available in online supplemental appendix 1.

Workplace outbreak-associated cases

We restricted our primary sample to only include workplace outbreak-associated cases. All laboratory-confirmed (ie, those meeting provincial case definition¹⁷) COVID-19 cases and hospitalisations were obtained from CCM. For healthcare and congregate care/living settings, we included outbreak-associated cases in workers indicated by an occupational flag in CCM to exclude patients or residents. For the education industry, we included all non-students aged above 18 years or had an educational staff flag who were linked to a childcare, elementary or secondary school outbreak. Outbreak-associated cases from industries where public health measures restricted interactions with the public during the study period (eg, cancelling indoor dining in the food service industry, or curb-side pick-up only for retail stores) were retained as the workplace was the most likely source of acquisition for outbreak-associated cases. All other cases among the working-age population, defined as 'non-workplace outbreak-associated cases', were retained as a comparison group, but were not included in the primary analyses. This group included cases in the community, as well as outbreak-related cases in residents of congregate care/living and outbreak-related cases in settings where working status data were not available and transmission

was unlikely to be restricted to workers only—these included recreational fitness settings (eg, gyms), other recreational settings (eg, visual arts class) and places of worship.

Hours worked outside the home

We estimated person-time at risk of exposure to a workplace COVID-19 outbreak based on the number of hours worked outside the home in the past week at their main job as reported by LFS respondents. The actual weekly hours of work were multiplied by 52 and divided by 12 to estimate the monthly number of hours. Industry-specific total monthly hours worked outside the home were assessed according to 13 industry sectors (grouped based on NAICS codes collected in the LFS), matching the sectors described above. Estimates were generated using individual sample weights, provided by Statistics Canada with each monthly LFS. Weighting enables tabulation of hours worked that are population representative of Ontario, correcting for the stratified multistage design of LFS, including inverse probability of selection and accounting for non-response.¹³

Covariates

We distinguished dates of cases, outbreaks and hours worked outside the home across three time periods: 1 April–31 August 2020 (period 1), 1 September–31 December 2020 (period 2) and 1 January–31 March 2021 (period 3). These time periods coincided with changes to public health measures (ie, stay at home order)¹⁸ and the rise of prevalence of variants of concern, and allowed for adequate sample size to be obtained from the LFS based on the survey's sampling strategy.¹³ Demographic information on outbreak-associated cases included gender, age (10-year categories) and diagnosing PHU. Furthermore, quintiles of neighbourhood material deprivation and diversity (measured using the ethnic concentration dimension) were measured using the Ontario Marginalization Index.¹⁹

Statistical analyses

We examined COVID-19-related cases and hospitalisations across characteristics of workplace and to non-workplace-associated cases. Furthermore, we aggregated these outcomes by industry across three time periods. For each period, we estimated industry-specific incidence rates per 100 000 000 work hours and per 100 000 workers who reported that the majority of hours were worked outside the home.

We calculated SIR, and 95% CIs,²⁰ as the ratio of the workplace outbreak-associated COVID-19 incidence rate to the overall incidence rate in Ontarians aged 15–69 years (including both workplace outbreak and non-workplace outbreak cases), for each industry and time period. We estimated the overall rate by summing the number of COVID-19 cases in Ontario among those aged 15–69 years and dividing it by the sum of waking hours (assuming 16 hours of awake time per person per day multiplied by the Ontario population aged 15–69 years (N=10 724 408 persons) estimated from projection data for 2020 sourced from IntelliHEALTH Ontario).

We performed sensitivity analyses to (1) include an estimate of temporary foreign workers in agricultural settings who are captured in the case data but not in the LFS denominator,²¹ and (2) reclassify the hours of those self-employed (with employees) on farms to working outside the home (ie, to ensure their exposure to others was enumerated).

All analyses were conducted in R-Studio (V.1.2.5019).

RESULTS

Between 1 April 2020 and 31 March 2021, there were 282 539 COVID-19 cases reported in Ontarians aged 15–69 years.

Of these, 247 371 were excluded as they were non-workplace outbreak-associated cases (ie, cases not associated with an outbreak, residents of congregate care/living or not meeting workplace-associated outbreak definition; online supplemental appendices 2 and 3). Our final study population included 35 168 cases associated with 5759 workplace outbreaks.

The number of COVID-19 cases and hospitalisations across sociodemographic characteristics by workplace outbreak and non-workplace outbreak-associated cases are presented in [table 1](#). Overall, 12% of cases and 7% of hospitalisations were attributed to workplace outbreaks among working-age adults, with 2% and 3% workplace and non-workplace outbreak-associated cases requiring hospitalisation, respectively. Despite an increase in COVID-19 cases and hospitalisations occurring in periods 2 and 3 compared with period 1 overall, a lower percentage of workplace compared with non-workplace outbreak-associated cases and hospitalisation were observed. The proportion of workplace outbreak-associated cases was higher among females (14%) compared with males (11%), but hospitalisations were similar across gender. The proportion of workplace outbreak-associated cases differed by geography (ie, PHU), ranging from approximately 5% of all cases among the working population to 27% of all cases. An increasing number of workplace-associated cases and overall cases were observed with increasing neighbourhood diversity and deprivation. However, no differences were observed in the proportion of cases due to workplace outbreaks across different levels of deprivation, while the proportion of workplace outbreak cases was lowest among areas with the highest levels of diversity.

The number of workplace outbreak-associated COVID-19 outbreaks, cases and hospitalisations, and SIRs by industry and time period are presented in [table 2](#). An SIR greater than 1.0 indicates that there was a higher rate of COVID-19 cases per hour exposed in a given industry compared with what was observed in the overall working-age population, while an SIR less than 1.0 indicates a decreased rate. The majority of workplace-associated cases were attributed to select industries; these industries were consistent over time, but the distribution varied between periods and was impacted by public health measures. In period 1, excess workplace outbreak-associated cases (SIR) were observed in agriculture (24.9), healthcare and social assistance (9.3) and food manufacturing (5.0) industries. Similar trends were observed in periods 2 and 3, although to a lesser extent, with cases 2.4 and 4.3 times higher in agriculture, 2.6 and 2.2 times higher in healthcare and social assistance, and 2.6 and 2.4 times higher in food manufacturing industries. In addition, excess cases were observed in transportation and warehousing (period 2: 1.1; period 3: 1.5) and education (period 1: 1.2; period 3: 1.1) industries. The incidence of workplace outbreak-associated COVID-19 cases per 100 000 000 hours worked by industry and time period is presented in [figure 1](#).

The incidence of workplace outbreak-associated COVID-19 cases per 100 000 workers (as opposed to hours exposed) by industry and time period is presented in online supplemental appendix 4. The distribution of COVID-19 incidence rates was consistent across industries using both the number of workers and hours worked as denominators.

Sensitivity analyses

When we updated our results to account for the seasonal variation of temporary foreign workers in agricultural settings and for the home also being the work setting for self-employed agriculture workers, the incidence in the agricultural setting decreased

Table 1 Sociodemographic characteristics of COVID-19 cases and hospitalisations among those aged 15–69 years, reported 1 April 2020–31 March 2021 in workplace and non-workplace outbreak-associated cases in Ontario, Canada

	Cases				Hospitalisations			
	Workplace outbreak	Non-workplace outbreak	Proportion related to workplace outbreak	Proportion related to non-workplace outbreak	Workplace outbreak	Non-workplace outbreak	Proportion related to workplace outbreak	Proportion related to non-workplace outbreak
	N	N	%	%	N	N	%	%
Total (Ontario)	35 168	247 371	12%	88%	557	7376	7%	93%
Time period								
Period 1 (1 Apr–31 Aug 2020)	6648	22 721	23%	77%	187	1881	9%	91%
Period 2 (1 Sep–31 Dec 2020)	12 995	105 125	11%	89%	130	2205	6%	94%
Period 3 (1 Jan–31 Mar 2021)	15 525	119 525	11%	89%	240	3290	7%	93%
Gender								
Female	19 534	119 207	14%	86%	243	3050	7%	93%
Male	15 397	126 882	11%	89%	311	4305	7%	93%
Other*	237	1282	16%	84%	3	21	13%	88%
Age (in years)								
15–24	4245	52 581	7%	93%	9	239	4%	96%
25–34	8400	58 002	13%	87%	48	629	7%	93%
35–44	7544	43 380	15%	85%	72	839	8%	92%
45–54	8089	42 887	16%	84%	183	1567	10%	90%
55–64	6023	38 679	13%	87%	206	2593	7%	93%
65–69	867	11 842	7%	93%	39	1509	3%	97%
Material deprivation quintile †								
1—low	4419	36 358	11%	89%	57	831	6%	94%
2	5800	38 690	13%	87%	110	965	10%	90%
3	6765	45 369	13%	87%	115	1129	9%	91%
4	7424	49 634	13%	87%	115	1345	8%	92%
5—high	8607	58 644	13%	87%	145	2235	6%	94%
Missing	2153	14 284	13%	87%	15	369	4%	96%
Diversity quintile ‡								
1—low	2700	11 893	19%	81%	36	391	8%	92%
2	4045	17 161	19%	81%	74	532	12%	88%
3	4445	26 572	14%	86%	75	786	9%	91%
4	6550	48 028	12%	88%	116	1299	8%	92%
5—high	15 275	125 041	11%	89%	241	3497	6%	94%
Missing	2153	14 284	13%	87%	15	369	4%	96%
Public health unit								
Algoma District	16	179	8%	92%	1	1	50%	50%
Brant County	187	1609	10%	90%	1	30	3%	97%
Chatham-Kent	295	1021	22%	78%	2	22	8%	92%
City of Hamilton	1344	8733	13%	87%	23	328	7%	93%
City of Ottawa	1703	11 312	13%	87%	37	383	9%	91%
Durham Region	1592	9729	14%	86%	31	284	10%	90%
Eastern Ontario	275	2099	12%	88%	4	80	5%	95%
Grey Bruce	81	557	13%	87%	4	11	27%	73%
Haldimand-Norfolk	448	846	35%	65%	11	24	31%	69%
Haliburton, Kawartha, Pine Ridge	126	698	15%	85%	3	19	14%	86%
Halton Region	909	7381	11%	89%	15	152	9%	91%
Hastings and Prince Edward Counties	82	345	19%	81%	3	8	27%	73%
Huron Perth	186	837	18%	82%	1	15	6%	94%
Kingston, Frontenac, Lennox and Addington	121	618	16%	84%	3	7	30%	70%
Lambton County	235	1966	11%	89%	2	28	7%	93%
Leeds, Grenville and Lanark District	193	634	23%	77%	7	23	23%	77%
Middlesex-London	896	4978	15%	85%	7	174	4%	96%
Niagara Region	1748	5579	24%	76%	31	155	17%	83%
North Bay Parry Sound District	16	221	7%	93%	0	18	0%	100%

continued

Table 1 continued

	Cases				Hospitalisations			
	Workplace outbreak	Non-workplace outbreak	Proportion related to workplace outbreak	Proportion related to non-workplace outbreak	Workplace outbreak	Non-workplace outbreak	Proportion related to workplace outbreak	Proportion related to non-workplace outbreak
	N	N	%	%	N	N	%	%
Northwestern	26	506	5%	95%	1	26	4%	96%
Southwestern	498	1655	23%	77%	6	48	11%	89%
Peel Region	7272	51 759	12%	88%	74	933	7%	93%
Peterborough County-City	61	647	9%	91%	0	17	0%	100%
Porcupine	43	206	17%	83%	1	13	7%	93%
Renfrew County and District	85	233	27%	73%	0	5	0%	100%
Simcoe Muskoka District	1123	5150	18%	82%	35	171	17%	83%
Sudbury and District	203	865	19%	81%	3	34	8%	92%
Thunder Bay District	216	2029	10%	90%	3	95	3%	97%
Timiskaming	22	80	22%	78%	0	8	0%	100%
Toronto	7933	80 016	9%	91%	158	3013	5%	95%
Waterloo Region	1445	8221	15%	85%	16	237	6%	94%
Wellington-Dufferin-Guelph	852	3377	20%	80%	11	94	10%	90%
Windsor-Essex County	2724	8481	24%	76%	25	282	8%	92%
York Region	2212	24 804	8%	92%	38	638	6%	94%

*Includes individuals for whom gender was not reported or missing, as well as individuals reporting transgender or non-binary gender.

†Individuals residing in congregate care were not assigned to a quintile (4392 cases and 502 hospitalisations). Quintile 5 represents the highest quintile of deprivation or diversity. The material deprivation measure combines information on income, quality of housing, educational attainment and family structure characteristics to assess the ability of individuals and communities to access and attain basic material needs. The ethnic concentration dimension is based on the proportion of non-white and non-Indigenous residents and/or the proportion of immigrants who arrived in Canada within the past 5 years.

in all time periods (online supplemental appendix 5). However, the ranking of incidence compared with other industries did not change.

DISCUSSION

In a population-based study including all workplace outbreaks and their associated cases in Ontario, Canada, between April 2020 and March 2021, we observed that workplace outbreak-associated cases accounted for 12% of all cases and 7% of all hospitalisations in the working-age population. When broken down by industry, incidence rates were highest in healthcare and social assistance, food manufacturing, agriculture, other manufacturing, educational services, and transportation and warehousing. This reflects only cases linked to identified and reported workplace outbreaks and does not account for non-outbreak cases in workers or further spread within households related to index cases associated with workplace outbreaks; as such, the total number of cases resulting from workplace outbreaks is likely to be larger than what is presented in this study.^{10 22}

Our work expands on previous estimates for Ontario's first wave,¹⁰ for which denominator data were not available. In our updated results, we found a high incidence of outbreak-related cases in manufacturing (including food), agriculture, and transportation and warehousing industries as before, as well as in the education industry during periods that included time frames when schools had reopened for in-person learning. The overall COVID-19 incidence rate across industries was highest in the third period of our study, which encompassed the peak of the second wave and beginning of the third wave of COVID-19 in Ontario, driven by the rapid rise of the Alpha variant. This period also coincided with the roll-out of COVID-19 vaccines to all hospital and other congregate setting (ie, long-term care homes, retirement homes) staff, which may explain the comparatively smaller increase in rates of healthcare and social assistance

between periods 3 and 2 relative to other industries. Vaccines to other individuals aged 15–69 years were not broadly available in our study period.

The majority of published estimates report on occupations^{23–25} or specific industries of interest, particularly healthcare⁴ and food processing.^{26 27} Other studies have focused on ecological comparisons of rates in neighbourhoods by the proportion of 'essential workers',²⁸ but were unable to assess risk across occupations or industries. Few other papers have comprehensively estimated incidence across all industries, but those results have consistently identified food manufacturing, other manufacturing, and transportation and warehousing.^{29–31 29–31}

These studies excluded a combination of healthcare, congregate-living and education settings and included denominator data from 2019 or prior to estimate incidence within their industry classifications, which are unlikely to accurately reflect labour force participation during the pandemic period, given workplace closures and remote work (which varies by industry). However, similar to these studies, we identified manufacturing industries as having some of the highest rates of COVID-19, but separated food manufacturing from other manufacturing. Our results demonstrate higher incidence of outbreak-associated COVID-19 in food manufacturing relative to all other manufacturing and align with other studies that have identified outbreaks in food processing facilities.^{26 27} Factors that relate to a higher risk of COVID-19, including high-density settings, close proximity and prolonged duration of contact, may be particularly prevalent in manufacturing settings.³²

Comparisons to other studies are challenging due to differences in study methodology and data sources (eg, compensation claims,³³ time frames, use of occupational vs industry data^{23–25} and geography-specific restrictions). Furthermore, industry, occupation and other sociodemographic data on cases and contacts are limited in surveillance data. For example, we were

Table 2 COVID-19 cases and hospitalisations of workplace outbreak-associated cases and SIR for cases, by industry and period among workers aged 15–69 years in Ontario, Canada, reported 1 April 2020–31 March, 2021

Time period and industry	Workplace outbreaks			Cases		Hospitalisations		SIR in cases*
	N	N	%†	N	%†	N	%†	SIR (95% CI)
Period 1 (1 Apr–31 Aug 2020)								
Accommodation and food service	16	49	1%	4	2%	0.4		0.4 (0.3 to 0.5)
Agriculture	29	1339	20%	21	11%	24.9		24.9 (23.5 to 26.3)
Construction	11	43	1%	0	0%	0.1		0.1 (0.1 to 0.2)
Education	17	45	1%	0	0%	1.2		1.2 (0.9 to 1.6)
Healthcare and social assistance	549	4050	61%	130	70%	9.3		9.3 (9.0 to 9.6)
Manufacturing—food	32	474	7%	17	9%	5.0		5.0 (4.6 to 5.5)
Manufacturing—other	63	313	5%	6	3%	0.8		0.8 (0.7 to 0.9)
Mining and utilities	1	21	0%	1	1%	0.5		0.5 (0.3 to 0.7)
Other service industries	19	70	1%	1	1%	0.1		0.1 (0.1 to 0.2)
Public administration	5	32	0%	3	2%	0.2		0.2 (0.2 to 0.3)
Retail trade	16	42	1%	0	0%	0.1		0.1 (0.1 to 0.1)
Transportation and warehousing	29	164	2%	4	2%	0.8		0.8 (0.7 to 0.9)
Wholesale trade	3	6	0%	0	0%	0.1		0.1 (0 to 0.1)
Period 2 (1 Sep–31 Dec 2020)								
Accommodation and food service	114	528	4%	6	5%	0.6		0.6 (0.6 to 0.7)
Agriculture	26	532	4%	4	3%	2.4		2.4 (2.2 to 2.6)
Construction	58	192	1%	2	2%	0.1		0.1 (0.1 to 0.1)
Education	445	923	7%	8	6%	0.8		0.8 (0.8 to 0.9)
Healthcare and social assistance	1113	5862	45%	60	46%	2.6		2.6 (2.6 to 2.7)
Manufacturing—food	72	861	7%	5	4%	2.6		2.6 (2.4 to 2.8)
Manufacturing—other	214	1577	12%	15	12%	0.8		0.8 (0.7 to 0.8)
Mining and utilities	6	19	0%	0	0%	0.1		0.1 (0.1 to 0.1)
Other service industries	100	457	4%	7	5%	0.2		0.2 (0.2 to 0.2)
Public administration	31	130	1%	1	1%	0.3		0.3 (0.2 to 0.3)
Retail trade	96	528	4%	7	5%	0.3		0.3 (0.3 to 0.3)
Transportation and warehousing	64	1153	9%	12	9%	1.1		1.1 (1.0 to 1.1)
Wholesale trade	32	233	2%	3	2%	0.5		0.5 (0.4 to 0.5)
Period 3 (1 Jan–31 Mar 2021)								
Accommodation and food service	88	391	3%	9	4%	0.5		0.5 (0.5 to 0.6)
Agriculture	78	705	5%	9	4%	4.3		4.3 (4.0 to 4.6)
Construction	118	562	4%	6	3%	0.3		0.3 (0.3 to 0.4)
Education	484	1138	7%	20	8%	1.1		1.1 (1.1 to 1.2)
Healthcare and social assistance	1011	5471	35%	51	21%	2.2		2.2 (2.2 to 2.3)
Manufacturing—food	65	991	6%	27	11%	2.4		2.4 (2.2 to 2.5)
Manufacturing—other	267	2450	16%	56	23%	1.1		1.1 (1.0 to 1.1)
Mining and utilities	14	75	0%	1	0%	0.3		0.3 (0.2 to 0.4)
Other service industries	146	688	4%	19	8%	0.3		0.3 (0.3 to 0.3)
Public administration	53	376	2%	5	2%	0.7		0.7 (0.6 to 0.8)
Retail trade	128	718	5%	11	5%	0.3		0.3 (0.3 to 0.3)
Transportation and warehousing	106	1739	11%	22	9%	1.5		1.5 (1.4 to 1.5)
Wholesale trade	39	221	1%	4	2%	0.4		0.4 (0.3 to 0.4)

*SIR was estimated by the ratio of workplace outbreak-associated COVID-19 incidence rate (per 200 000 work hours) to the overall incidence rate (per 200 000 hours awake) in Ontarians aged 15–69 years.

†The proportion (%) of cases and hospitalisations represent the share of outcomes from each two-digit North American Industry Classification System 2017 industry within the designated time period.

unable to disentangle industry-specific risk from other factors in our data, such as occupational risk, socioeconomic and racial inequities, household size and financial barriers to isolate, all of which may be associated with an increased risk of COVID-19.³⁴ Improved occupational surveillance for COVID-19, along with the collection of other socioeconomic determinants,³⁵ would enhance capabilities to inform interventions that mitigate infection transmission risk while addressing inequities among

individuals, groups and industries disproportionately affected by non-pharmaceutical public health interventions.^{5 6 36}

Strengths and limitations

Our study is not without limitations. We restricted our analyses to workplace outbreak-associated cases; as a result, these should not be interpreted as overall rates of COVID-19 among workers. In addition, not all included outbreak-associated cases

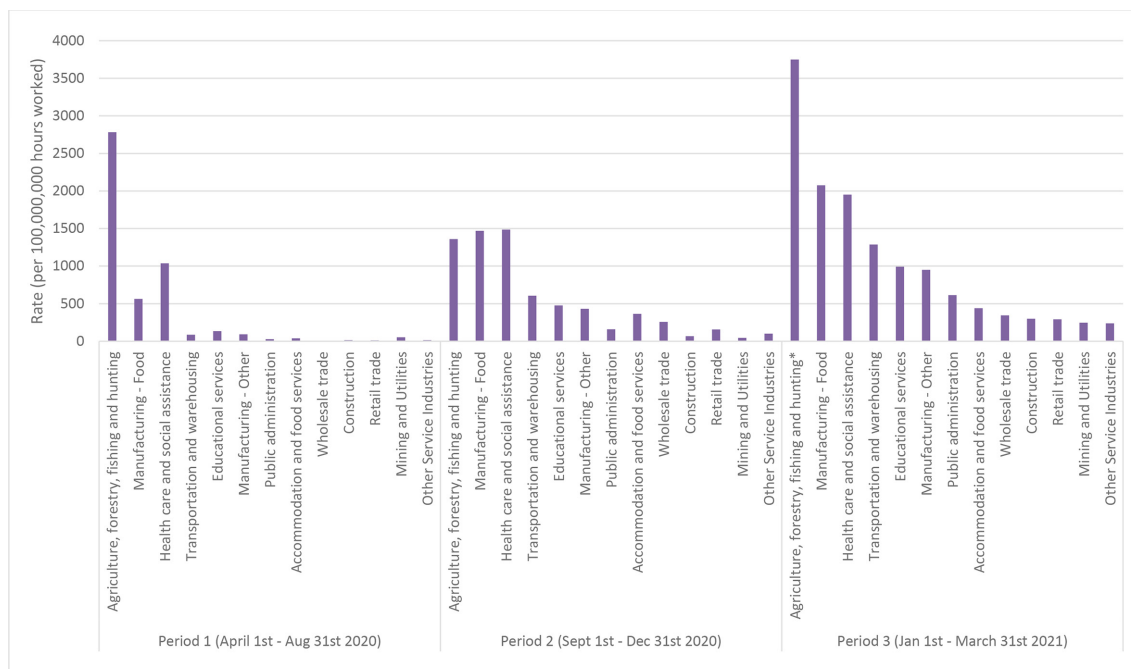


Figure 1 Cumulative case rate (per 100 000 000 hours worked outside the home) of COVID-19 among Ontario workers aged 15–69 years by industry and period.

were acquired in the workplace, or while on duty, we were unable to distinguish risks incurred in work areas versus work-related circumstances (eg, carpooling or breaks). There were also likely differences in declaring/managing outbreaks across the study period (eg, due to contact tracing capacity, access to testing for outbreaks) and by PHU. This would have impacted the overall number of cases linked to workplace outbreaks and their proportion of total cases. In addition, not all individuals will seek testing, which would result in underdetection; this behaviour could vary across industries.

Workplace outbreak guidance was issued in June 2020 and updated in February 2021 to a lower threshold for identifying contacts for testing and quarantine related to variants of concern; as such, there may be additional inconsistency across periods in our study.¹⁵ Furthermore, there may be differential identification of outbreaks across industries. First, enhanced testing initiatives (including funded testing programmes³⁷) implemented in some industries (ie, healthcare, education) may have increased case and outbreak identification. Second, outbreak definitions were not consistent across industries and some changed over time. For example, a single case constituted an outbreak in long-term care settings which may have inflated outbreak-associated cases in the healthcare relative to other industries, whereas an outbreak required two epidemiologically linked cases. Furthermore, in the agriculture industry, we were unable to distinguish infections acquired in the workplace from those due to co-habiting workers as many staff reside in provided accommodation. This factor may be a significant driver of the high incidence in this industry and may impact the generalisability of these results. We have underestimated the incidence in industries where settings were excluded, such as gyms and places of worship, where outbreaks were less likely to have been restricted to staff only based on what is known about transmission dynamics in these settings.^{38 39} Third, public health measures and interventions (eg, school closures, stay at home orders) changed over the study period⁴⁰ and would have impacted the likelihood of transmission in the workplace.

In addition, the LFS is only reflective of an individual's self-reported main job, which may have resulted in COVID-19 rates being overestimated in industries where part-time work is more prevalent. If an individual worked across industries, their case was assigned to the industry related to the outbreak, but this may not have aligned with the denominator data as they only reflect time in the main occupation. There may have been some misclassification related to outbreaks being classified manually into industry; however, as we reported outbreaks at the two-digit level, we believe this is minimal. Finally, to calculate the SIRs, we used 16 hours per day to estimate the number of hours a person may have been at risk of contracting COVID-19, assuming the risk is zero while sleeping (8 hours per day). Our estimate acknowledges that the risk of COVID-19 transmission across settings is a continuum, with few settings posing zero risk. Reducing the time (ie, 10 hours per day) would lead to smaller SIRs across industry groups than reported.

Our study also has several strengths. First, we were able to estimate the incidence of all workplace outbreak-associated cases, a limitation to previous studies that use general population cohorts (less representative and higher SES¹²) or only include information on specific settings. While this approach may not have captured all workplace-associated cases, declaration of an outbreak is an indication that workplace transmission was considered reasonable.¹⁵ By using a combination of risk factors in the provincial surveillance system, along with the manual classification of settings and industry, we created a comprehensive dataset of all workplace outbreak-associated cases. This has allowed us to examine industry-specific incidence, including comparisons between non-healthcare and healthcare industries, responding to the stated need to quantify the COVID-19 burden on all workers.⁵ Second, our analyses incorporate denominator data from 2020/2021 and are more reflective of the changes in the number of individuals actually employed and working outside of the home within an industry during the pandemic than those who rely on older estimates. This stratification mitigates concerns in comparing incidence by restrictions on certain

industries, as we have estimated incidence in those individuals who worked outside the home and could therefore be considered 'at-risk'.

Our results demonstrate that cases associated with workplace-outbreaks contributed to the burden of COVID-19 in working-age populations in Ontario, although a considerable proportion of COVID-19 cases in this group were not associated with workplace outbreaks. We have also shown that under varying circumstances of changing restrictions and policy guiding outbreak declaration/management, certain industries consistently had increased incidence of COVID-19 over the course of the pandemic. Given the variation in SIRs across industry groups, with many industry groups having SIRs less than one, there may be important findings across different industries with various levels of COVID-19 incidence which may help inform future interventions to reduce burden and transmission in these workplace settings. For instance, identification of higher risk industries can inform prioritisation of public health and labour interventions, such as the enforcement of hierarchy of control standards for reducing COVID-19 risk. Our results suggest the potential utility of field investigation data from outbreaks in these industries to further hone current guidance on infection prevention and control measures. These data may also help target industries at increased risk of outbreaks for inspections and enforcement of measures. As such, our results may assist in ongoing efforts to reduce transmission of COVID-19, by prioritising resources, as well as industry-specific guidance, vaccination and public health messaging.

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Contributors SAB, PMS and BTS designed the study. SAB, SM and TVI extracted surveillance data on cases from CCM and classified outbreaks by industry, while PMS extracted denominator data from the Labour Force Survey. CW conducted all the data analysis. SAB, CW and BTS drafted the manuscript. SAB, PMS, CW, MM, CM, JHK, SM, KAB, TVI and BTS all contributed to the interpretation of the data, revising the manuscript and final approval. SAB is responsible for the overall content as the guarantor of this work.

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Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval The Public Health Ontario Ethics Review Board determined that this project did not require research ethics committee approval as the activities described were considered public health practice and not research.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement No data are available. Public Health Ontario (PHO) cannot disclose the underlying data. Doing so would compromise individual privacy contrary to PHO's ethical and legal obligations. Restricted access to the data may be available under conditions prescribed by the Ontario Personal Health Information Protection Act, 2004, the Ontario Freedom of Information and Protection of Privacy Act, the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2 (2018)) and PHO privacy and ethics policies. Data are available for researchers who meet PHO's criteria for access to confidential data. Information about PHO's data access request process is available on-line at <https://www.publichealthontario.ca/en/data-and-analysis/using-data/data-requests>. Access to the anonymised microdata for the Labour Force Survey Supplement is available through Statistics Canada to accredited researchers and government employees for research purposes.

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ORCID iDs

Peter M Smith <http://orcid.org/0000-0001-8286-4563>

Michelle Murti <http://orcid.org/0000-0003-4649-6913>

Cameron Mustard <http://orcid.org/0000-0002-0747-8870>

Brendan T Smith <http://orcid.org/0000-0003-2785-1246>

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Supplementary Data

Supplementary Appendix 1: Supplementary methods for NAICS classification

The North American Industry Classification System (NAICS)-2017 is a hierarchical classification system developed by Canada, The United States, and Mexico [1]. For our study objective, we classified workplace outbreaks using the 2-digit NAICS industry sectors (N=20), with some modifications (see table below).

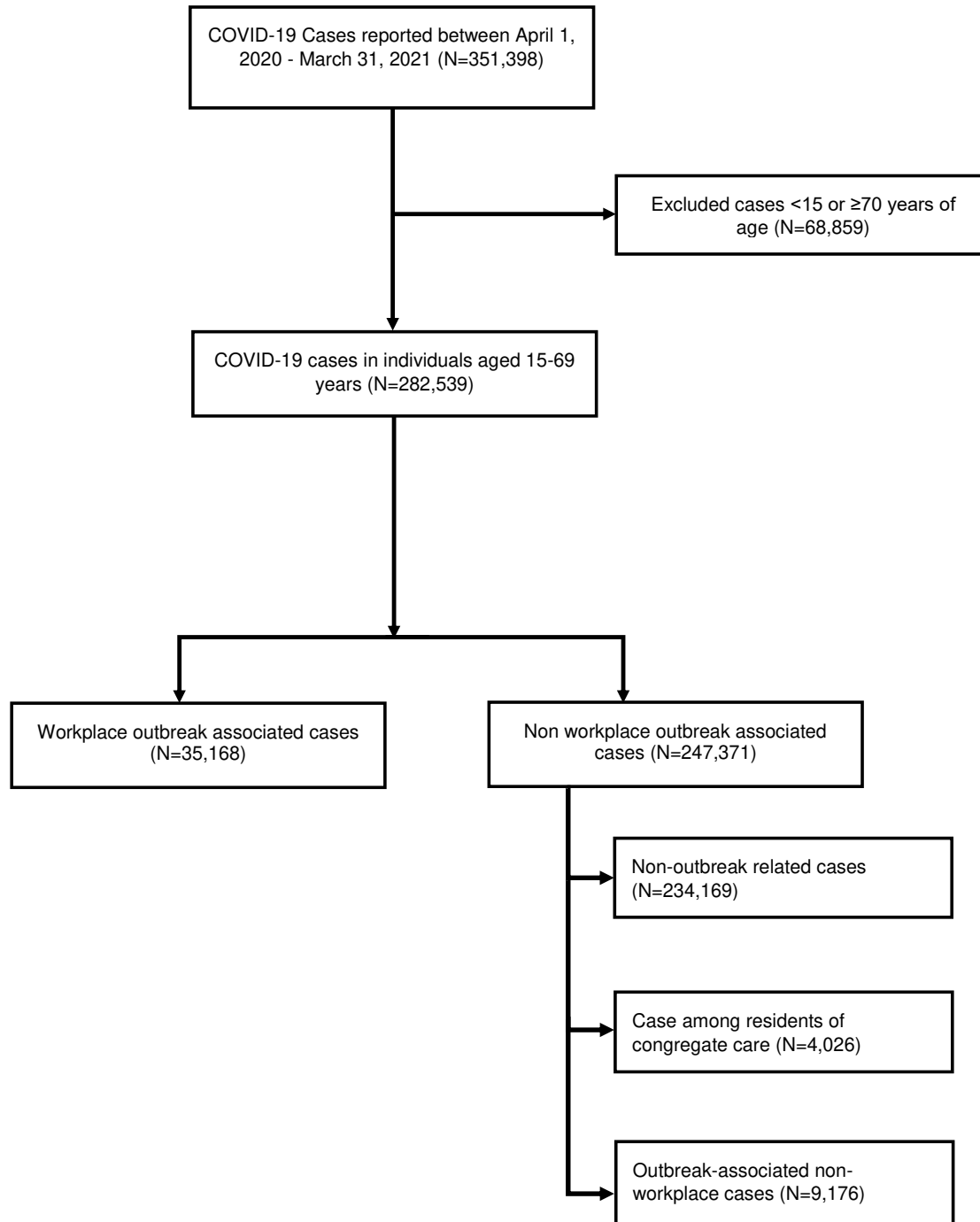
First, we separated the NAICS-2017 industry sector 31-33 - manufacturing into 2 distinct groups: food manufacturing (i.e., NAICS-2017 industry subsectors: 311 - food manufacturing and 312 - beverage and tobacco product manufacturing) and other manufacturing. Second, we combined sectors with few outbreaks, including 'mining and utilities' (i.e., NAICS-2017 industry sector codes: 21 - mining, quarrying, and oil and gas extraction and 22 - utilities) and 'other services industries' (i.e., NAICS-2017 industry sector codes: 51 - information and cultural, 52 - finance and insurance, 53 - real estate, rental and leasing, 54-professional, scientific and technical services, 55-management of companies and enterprises, 56- administrative and support, waste management and remediation services, 71 - arts, entertainment and recreation and 81 - other services (except public administration)). For consistency, we excluded workers from our denominators from industries that were ineligible for our workplace outbreak-associated case definition, including NAICS-2017 industry groups: 6116 - other schools and instruction, 7111 - performing arts companies, 7112 - spectator sports, 7113 - promoters (presenters) of performing arts, sports and similar events, 7114 - agents and managers for artists, athletes, entertainers and other public, 7115 - independent artists, writers and performers, 7131 - amusement parks and arcades 7132 - gambling industries, 7139 - other amusement and recreation industries, and 8131 - religious organizations. Overall, 13 sector categories were examined: agriculture, forestry, fishing and hunting; mining and utilities; construction; manufacturing – food; manufacturing – other; wholesale trade; retail trade; transportation and warehousing; educational services; health care and social assistance; accommodation and food services; public administration; and, other service industries.

North American Industry Classification System (NAICS) 2017 industry sectors and modifications for study objectives.

North American Industry Classification System (NAICS) 2017: 2-digit Industry Sector	Final Industry Sectors in Analysis (N=13)
11 Agriculture, forestry, fishing and hunting	Agriculture, forestry, fishing and hunting
21 Mining, quarrying, and oil and gas extraction	Mining and utilities
22 Utilities	Mining and utilities
23 Construction	Construction
31-33 Manufacturing	Manufacturing - food Includes: 311 - Food manufacturing and 312 - Beverage and tobacco product manufacturing
	Manufacturing - other
41 Wholesale trade	Wholesale trade
44-45 Retail trade	Retail trade

48-49 Transportation and warehousing	Transportation and warehousing
51 Information and cultural industries	Other service industries
52 Finance and insurance	Other service industries
53 Real estate and rental and leasing	Other service industries
54 Professional, scientific and technical services	Other service industries
55 Management of companies and enterprises	Other service industries
56 Administrative and support, waste management and remediation services	Other service industries
61 Educational services	Educational services Excludes: 6116 - other schools and instruction
62 Health care and social assistance	Health care and social assistance
71 Arts, entertainment and recreation	Other service industries Excludes: 7111 - performing arts companies, 7112 - spectator sports, 7113 - promoters (presenters) of performing arts, sports and similar events, 7114 - agents and managers for artists, athletes, entertainers and other public, 7115 - independent artists, writers and performers, 7131 - amusement parks and arcades 7132 - gambling industries, 7139 - other amusement and recreation industries
72 Accommodation and food services	Accommodation and food services
81 Other services (except public administration)	Other service industries Excludes: 8131 - religious organizations
91 Public administration	Public administration

Supplementary Appendix 2. Flow diagram of study cohort



Supplementary Appendix 3: Socio-demographic characteristics of case and hospitalizations workplace outbreak-associated cases, non-outbreak related cases, residents in congregate care cases and outbreak-associated non-workplace cases among 15-69 year olds in Ontario, Canada

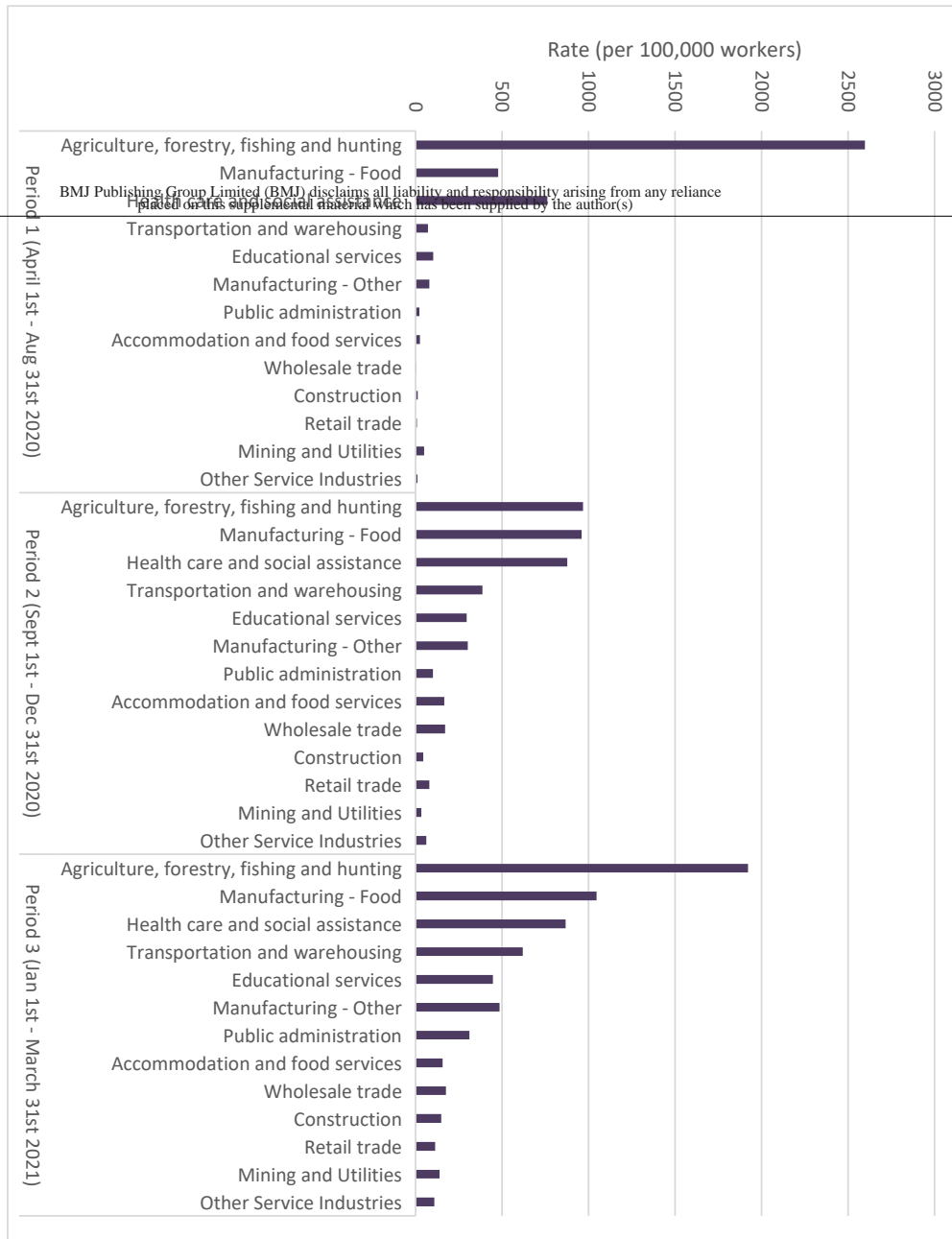
	Cases				Hospitalizations			
	Workplace outbreak-associated	Non-outbreak related	Residents in congregate care	Outbreak-associated non-workplace	Workplace outbreak-associated	Non-outbreak related	Residents in congregate care	Outbreak-associated non-workplace
Total (Ontario)	35,168	234,169	4,026	9,176	557	6,122	456	798
Time								
Period 1 (April 1st - Aug 31st 2020)	6,648	20,488	1,214	1,019	187	1,457	236	188
Period 2 (Sept 1st - Dec 31st 2020)	12,995	100,860	931	3,334	130	1,882	97	226
Period 3 (Jan 1st - March 31st 2021)	15,525	112,821	1,881	4,823	240	2,783	123	384
Gender								
Female	19,534	113,355	1,268	4,584	243	2,564	188	298
Male	15,397	119,668	2,721	4,493	311	3,540	268	497
Other*	237	1,146	37	99	3	18	0	3
Age (years)								
15-24	4,245	50,264	232	2,085	9	217	5	17
25-34	8,400	55,643	590	1,769	48	555	19	55
35-44	7,544	41,394	537	1,449	72	738	26	75
45-54	8,089	40,692	569	1,626	183	1,352	59	156
55-64	6,023	35,859	1,150	1,670	206	2,141	172	280
65-69	867	10,317	948	577	39	1,119	175	215
Material Deprivation Quintile**								
1 - low	4,419	34,990	8	1,360	57	731	0	100
2	5,800	37,155	6	1,529	110	846	1	118
3	6,765	43,960	4	1,405	115	1,007	1	121
4	7,424	48,008	6	1,620	115	1,187	0	158
5 - high	8,607	56,411	9	2,224	145	2,011	1	223
Missing	2,153	13,250	2	1,032	15	291	0	78

Diversity Quintile**								
1 - low	2,700	11,040	9	844	36	327	0	64
2	4,045	16,031	3	1,127	74	421	0	111
3	4,445	25,135	4	1,433	75	655	1	130
4	6,550	46,199	7	1,822	116	1,126	0	173
5 - high	15,275	122,119	10	2,912	241	3,235	2	242
Missing	2,153	13,250	2	1,032	15	291	0	78
Public Health Unit								
Algoma District	16	142	2	35	1	1	0	0
Brant County	187	1,518	19	72	1	24	1	5
Chatham-Kent	295	968	3	50	2	20	0	2
City Of Hamilton	1,344	7,998	208	527	23	213	33	82
City Of Ottawa	1,703	10,427	447	438	37	291	50	42
Durham Region	1,592	9,381	145	203	31	256	10	18
Eastern Ontario	275	1,962	33	104	4	66	3	11
Grey Bruce	81	535	5	17	4	10	0	1
Haldimand-Norfolk	448	797	14	35	11	24	0	0
Haliburton, Kawartha, Pine Ridge	126	630	22	46	3	17	2	0
Halton Region	909	6,882	292	207	15	130	12	10
Hastings & Prince Edward Counties	82	327	3	15	3	8	0	0
Huron Perth	186	780	33	24	1	14	0	1
Kingston, Frontenac, Lennox & Addington	121	571	1	46	3	6	0	1
Lambton County	235	1,819	56	91	2	25	1	2
Leeds, Grenville And Lanark District	193	547	16	71	7	20	0	3
Middlesex-London	896	4,456	97	425	7	127	11	36
Niagara Region	1,748	4,920	142	517	31	113	15	27
North Bay Parry Sound District	16	161	3	57	0	14	0	4
Northwestern	26	295	3	208	1	15	0	10
Southwestern	498	1,582	33	40	6	39	4	5
Peel Region	7,272	50,803	248	708	74	860	32	41

Peterborough County-City	61	558	7	82	0	15	1	1
Porcupine	43	181	14	11	1	9	3	1
Renfrew County And District	85	224	1	8	0	5	0	0
Simcoe Muskoka District	1,123	4,874	66	210	35	145	3	23
Sudbury And District	203	728	6	131	3	25	2	7
Thunder Bay District	216	1,415	159	455	3	71	1	23
Timiskaming	22	70	2	8	0	4	2	2
Toronto	7,933	76,322	1,360	2,334	158	2,520	192	301
Waterloo Region	1,445	7,576	112	533	16	178	22	37
Wellington-Dufferin-Guelph	852	3,107	44	226	11	78	5	11
Windsor-Essex County	2,724	7,851	295	335	25	227	29	26
York Region	2,212	23,762	135	907	38	552	21	65

*Includes individuals for which gender was not reported or missing, as well as individuals reporting transgender or non-binary gender

**Quintile 5 represents the highest quintile of deprivation or diversity. The material deprivation measure combines information on income, quality of housing, educational attainment and family structure characteristics to assess the ability of individuals and communities to access and attain basic material needs. The ethnic concentration dimension is based on the proportion of non-white and non-Indigenous residents and/or the proportion of immigrants that arrived in Canada within the past five years.



Supplementary Appendix 4: Cumulative case rate (per 100,000 workers) of COVID-19 among Ontario workers aged 15-69 by time and industry

Supplementary Appendix 5: Supporting data for Figure 1 and Supplementary Appendix 4

Time period & Industry	Cases	Total Number of Hours		Average Number of Workers	
		Total Number of Hours Worked (majority hours outside the home)	Case rate per 100,000,000 hours worked (majority hours outside the home)	Average number of workers (majority hours outside the home)	Case rate per 100,000 workers (majority hours outside the home)
Period 1 (April 1st - Aug 31st 2020)					
Agriculture, forestry, fishing and hunting	1,339	48,153,959	2,781*	51,556	2,597
Manufacturing - Food	474	84,207,299	563	99,273	477
Health care and social assistance	4,050	390,015,763	1,038	531,731	762
Transportation and warehousing	164	187,868,797	87	230,425	71
Educational services	45	33,429,083	135	44,098	102
Manufacturing - Other	313	341,111,765	92	392,149	80
Public administration	32	115,840,750	28	143,596	22
Accommodation and food services	49	123,507,904	40	193,549	25
Wholesale trade	6	104,561,653	6	125,528	5
Construction	43	293,157,284	15	346,412	12
Retail trade	42	377,679,497	11	548,037	8
Mining and Utilities	21	39,578,589	53	42,343	50
Other Service Industries	70	471,204,619	15	620,155	11
Period 2 (Sept 1st - Dec 31st 2020)					
Agriculture, forestry, fishing and hunting	532	39,126,580	1,360*	54,942	968
Manufacturing - Food	861	58,594,099	1,469	89,695	960
Health care and social assistance	5,862	394,230,318	1,487	668,834	876
Transportation and warehousing	1,153	190,001,785	607	298,357	386
Educational services	923	194,025,987	476	312,211	296
Manufacturing - Other	1,577	364,638,983	432	523,169	301
Public administration	130	81,801,155	159	128,973	101
Accommodation and food services	528	145,406,278	363	318,445	166

Wholesale trade	233	89,878,386	259	135,895	171
Construction	192	290,645,426	66	424,963	45
Retail trade	528	339,150,494	156	660,874	80
Mining and Utilities	19	41,960,750	45	56,759	33
Other Service Industries	457	450,104,813	102	741,174	62
Period 3 (Jan 1st - March 31st 2021)					
Agriculture, forestry, fishing and hunting	705	18,796,210	3,751*	36,672	1,922
Manufacturing - Food	991	47,740,439	2,076	94,744	1,046
Health care and social assistance	5,471	280,224,605	1,952	630,463	868
Transportation and warehousing	1,739	135,208,416	1,286	280,578	620
Educational services	1,138	114,756,384	992	254,875	446
Manufacturing - Other	2,450	257,680,749	951	504,841	485
Public administration	376	61,268,514	614	120,701	312
Accommodation and food services	391	89,073,950	439	249,135	157
Wholesale trade	221	64,267,322	344	125,874	176
Construction	562	187,336,542	300	377,017	149
Retail trade	718	245,766,795	292	629,478	114
Mining and Utilities	75	30,452,374	246	53,814	139
Other Service Industries	688	290,377,823	237	629,961	109

* Two sensitivity analyses related to the Agriculture, forestry, fishing and hunting industry were performed. 1) Accounting for temporary foreign workers (TFWs) decreased the COVID-19 incidence rates in the agriculture industry from 2,781 to 1,858 (period 1), 1360 to 927 (period 2), and from 3,751 to 2,208 (period 3) cases per 100,000,000 hours in those who worked mostly outside the home. 2) When we reclassified the hours of those self-employed (with employees) on farms to working outside the home (i.e., to ensure their exposure to others was enumerated), the incidence decreased across all time periods (to 2,275, 1,175, and 3,118 per 100,000,000 hours in periods 1-3, respectively).

Reference

- 1 Statistics Canada. North American Industry Classification System (NAICS) Canada 2017 Version 3.0. 2021. <https://www23.statcan.gc.ca/imdb/p3VD.pl?Function=getVD&TVD=1181553> (accessed 23 Jun 2021).