Original research

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

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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.

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.

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

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 disease[8] 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 definition[17]) 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 healthcare[4] 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

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

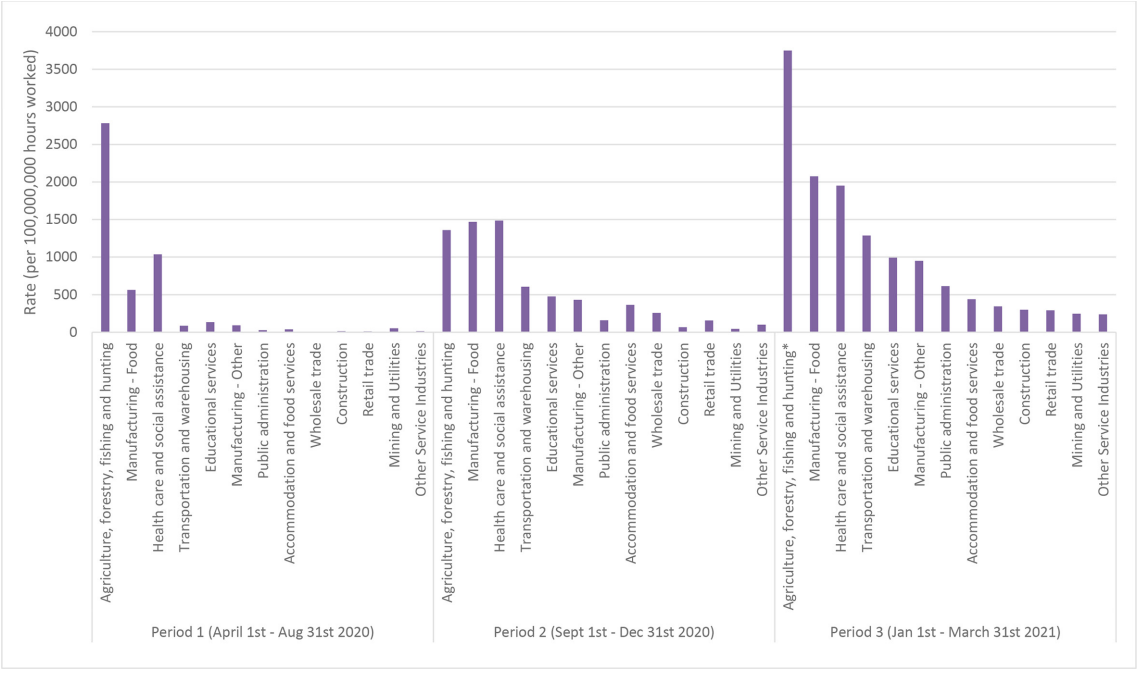

Figure 1 Cumulative case rate (per 100 000 000 hours worked outside the home) of COVID-19 among Ontario workers aged 15–69 years by industry and period.

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 programmes[37]) 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-habitating 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 period[40] 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 SES[12]) 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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Patient consent for publication Not applicable.

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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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REFERENCES

1 United Kingdom Office for National Statistics. *Statistical bulletin:Coronavirus (COVID-19) related deaths by occupation, England and Wales:deaths registered up to and including 20 April 2020*, 2020.
2 Burdorf A, Porru F, Rugulies R. The COVID-19 (coronavirus) pandemic: consequences for occupational health. *Scand J Work Environ Health* 2020;46:229–30.
3 Schwartz KL, Achonu C, Buchan SA, *et al*. Epidemiology, clinical characteristics, household transmission, and lethality of severe acute respiratory syndrome coronavirus-2 infection among healthcare workers in Ontario, Canada. *PLoS One* 2020;15:e0244477.
4 Gholami M, Fawad I, Shadan S, *et al*. COVID-19 and healthcare workers: a systematic review and meta-analysis. *Int J Infect Dis* 2021;104:335–46.
5 Carlsten C, Gulati M, Hines S, *et al*. COVID-19 as an occupational disease. *Am J Ind Med* 2021;64:227–37.
6 Sim MR. The COVID-19 pandemic: major risks to healthcare and other workers on the front line. *Occup Environ Med* 2020;77:281–2.
7 European Centre for Disease Prevention and Control. COVID-19 clusters and outbreaks in occupational settings in the EU/EEA and the UK, 2020. Available: https://www.ecdc.europa.eu/en/publications-data/covid-19-clusters-and-outbreaks-occupational-settings-eueea-and-uk [Accessed 23 Jun 2021].
8 Baker MG, Peckham TK, Seixas NS. Estimating the burden of United States workers exposed to infection or disease: a key factor in containing risk of COVID-19 infection. *PLoS One* 2020;15:e0232452.
9 Smith PM, Smith BT, Warren C, *et al*. The prevalence and correlates of workplace infection control practices in Canada between July and September 2020. *Health Rep* 2021;32:16–27.
10 Murti M, Achonu C, Smith BT, *et al*. COVID-19 workplace outbreaks by industry sector and their associated household transmission, Ontario, Canada, January to June, 2020. *J Occup Environ Med* 2021;63:574–80.
11 De Matteis S. COVID-19: are not all workers 'essential'? *Occup Environ Med* 2021;78:305–6.
12 Kromhout H. Learning from a global pandemic. *Occup Environ Med* 2020;77:587–8.
13 Statistics Canada. Guide to the labour force survey 2020. statistics Canada, 2020. Available: https://www150.statcan.gc.ca/n1/pub/71-543-g/71-543-g2020001-eng.htm [Accessed 23 Jun 2021].
14 Ministry of Health. COVID-19 guidance for the health sector. Toronto, ON, 2021. Available: https://www.health.gov.on.ca/en/pro/programs/publichealth/coronavirus/2019_guidance.aspx [Accessed 23 Jun 2021].
15 Ministry of Health. COVID-19 guidance: workplace outbreaks. Toronto, ON, 2020. Available: https://www.health.gov.on.ca/en/pro/programs/publichealth/coronavirus/docs/2019_workplace_outbreak_guidance.pdf [Accessed 23 Jun 2021].
16 Statistics Canada. North American industry classification system (NAICS) Canada 2017 version 3.0, 2021. Available: https://www23.statcan.gc.ca/imdb/p3VD.pl?Function=getVD&TVD=1181553 [Accessed 23 Jun 2021].
17 Ministry of Health. Case definition – coronavirus disease (COVID-19). Toronto, on, 2021. Available: https://www.health.gov.on.ca/en/pro/programs/publichealth/coronavirus/docs/2019_case_definition.pdf [Accessed 23 Jun 2021].
18 Government of Ontario. Ontario Declares second provincial emergency to address COVID-19 crisis and save lives, 2021. Available: https://news.ontario.ca/en/release/59922/ontario-declares-second-provincial-emergency-to-address-covid-19-crisis-and-save-lives
19 Matheson FI, van Ingen T. *2016 Ontario marginalization index*. Toronto, ON: St. Michael's Hospital, 2018. https://www.publichealthontario.ca/en/data-and-analysis/health-equity/ontario-marginalization-index
20 Rothman KJ, Greenland S, Lash TL. *Modern epidemiology*. Third edition. Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins, 2008.
21 Statistics Canada. COVID-19 disruptions and agriculture: temporary foreign workers, 2020. Available: https://www150.statcan.gc.ca/n1/pub/45-28-0001/2020001/article/00002-eng.htm [Accessed 23 Jun 2021].
22 Tibebu S A, Brown K, Daneman N. Household secondary attack rate of COVID-19 by household size and index case characteristics. *medRxiv*2021:2021.02.23.21252287.

23 Mutambudzi M, Niedwiedz C, Macdonald EB, *et al*. Occupation and risk of severe COVID-19: prospective cohort study of 120 075 UK Biobank participants. *Occup Environ Med* 2020:oemed-2020-106731.
24 Chen Y-H, Glymour M, Riley A, *et al*. Excess mortality associated with the COVID-19 pandemic among Californians 18-65 years of age, by occupational sector and occupation: March through November 2020. *PLoS One* 2021;16:e0252454.
25 Nafilyan V, Pawelek P, Ayoubkhani D. Occupation and COVID-19 mortality in England: a national linked data study of 14.3 million adults. *medRxiv*2021.
26 Dyal JW, Grant MP, Broadwater K, *et al*. COVID-19 among workers in meat and poultry processing facilities — 19 states, April 2020. *MMWR Morb Mortal Wkly Rep* 2020;69:mmwr.mm6918e3.
27 Waltenburg MA, Rose CE, Victoroff T, *et al*. Coronavirus disease among workers in food processing, food manufacturing, and agriculture workplaces. *Emerg Infect Dis* 2021;27:243–9.
28 Rao A, Ma H, Moloney G, *et al*. A disproportionate epidemic: COVID-19 cases and deaths among essential workers in Toronto, Canada. *Ann Epidemiol* 2021;63:63–7.
29 Bui DP, McCaffrey K, Friedrichs M, *et al*. Racial and Ethnic Disparities Among COVID-19 Cases in Workplace Outbreaks by Industry Sector - Utah, March 6-June 5, 2020. *MMWR Morb Mortal Wkly Rep* 2020;69:1133–8.
30 Contreras Z, Ngo V, Pulido M, *et al*. Industry sectors highly affected by worksite outbreaks of coronavirus disease, Los Angeles County, California, USA, March 19-September 30, 2020. *Emerg Infect Dis* 2021;27:1769–75.
31 Chen Y, Aldridge T, *et al*, UK COVID-19 National Core Studies Consortium,. COVID-19 outbreak rates and infection attack rates associated with the workplace: a descriptive epidemiological study. *medRxiv*2021:2021.05.06.21256757.
32 Center for Disease Control and Prevention. Manufacturing workers and employers interim guidance from CDC and the occupational safety and health administration (OSHA), 2021. Available: https://www.cdc.gov/coronavirus/2019-ncov/community/guidance-manufacturing-workers-employers.html#exposure-risk [Accessed 23 Jun 2021].
33 Marinaccio A, Boccuni F, Rondinone BM, *et al*. Occupational factors in the COVID-19 pandemic in Italy: compensation claims applications support establishing an occupational surveillance system. *Occup Environ Med* 2020;77:818–21.
34 van Ingen T, Akingbola S, Brown KA. Neighbourhood-level risk factors of COVID-19 incidence and mortality. *medRxiv*2021:2021.01.27.21250618.
35 Khalatbari-Soltani S, Cumming RC, Delpierre C, *et al*. Importance of collecting data on socioeconomic determinants from the early stage of the COVID-19 outbreak onwards. *J Epidemiol Community Health* 2020;74:620–3.
36 Klein A, Smith E. Explaining the economic impact of COVID-19: core industries and the Hispanic workforce. 1-18, 2021. Available: https://digitalscholarship.unlv.edu/brookings_policybriefs_reports/2 [Accessed 12 Oct 2021].
37 Government of Ontario. Ontario deploys rapid tests to more essential workplaces and settings, 2021. Available: https://news.ontario.ca/en/release/60337/ontario-deploys-rapid-tests-to-more-essential-workplaces-and-settings [Accessed 23 Jun 2021].
38 Groves LM, Usagawa L, Elm J, *et al*. Community Transmission of SARS-CoV-2 at Three Fitness Facilities - Hawaii, June-July 2020. *MMWR Morb Mortal Wkly Rep* 2021;70:316–20.
39 Katelaris AL, Wells J, Clark P, *et al*. Epidemiologic evidence for airborne transmission of SARS-CoV-2 during church singing, Australia, 2020. *Emerg Infect Dis* 2021;27:1677–80.
40 Canadian Institute for Health Information. *COVID-19 intervention scan — data tables*. Ottawa, ON: CIHI, 2021.