History of Concussion and Risk of Severe Maternal Mental Illness:

A Population-Based Cohort Study

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Abstract

Objective: To evaluate the relationship between a predelivery history of concussion and risk of severe maternal mental illness.

Methods: We conducted a population-based cohort study of birthing people with a singleton livebirth accrued between 2007 and 2017 with follow-up to 2021 in Ontario, Canada. The primary outcome was severe maternal mental illness, defined as a psychiatric emergency department visit, psychiatric hospital admission, or self-harm or suicide in the 14 years after delivery. Cox proportional hazards regression generated adjusted hazard ratios (aHRs) and 95% confidence intervals (CIs) comparing those with a history of a health care encounter for concussion between database inception and the index delivery date to those without a recorded health care encounter for concussion, adjusted for maternal age, parity, neighborhood income quintile, rural residence, immigration status, chronic conditions, history of interpersonal violence, and history of mental illness. Results were also stratified by history of mental illness.

Results: There were n = 18,064 birthing people with a history of concussion and n = 736,689 without a history of concussion. Those with a history of concussion had an increased risk of severe maternal mental illness compared to those without this history (14.7 vs 7.9 per 1,000 person-years; aHR 1.25, 95% CI, 1.20–1.31). After stratification by predelivery history of mental illness, the association was strongest in individuals with no mental illness history (aHR 1.33, 95% CI, 1.23–1.44).

Conclusion: These findings indicate the need for early identification and screening of birthing people with a history of concussion, as well as ongoing long-term supports using trauma-informed approaches to prevent adverse psychiatric outcomes.

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Maternal mental illness is common, with an estimated prevalence of 25% in birthing people who have children aged 0–16 years.[1] Maternal mental illness has a negative impact on the affected individual and their offspring.[2–4] Severe mental illness outcomes, including psychiatric emergency department visits, psychiatric hospital admissions, and self-harm or suicide, affect only 1% of birthing people but have significant negative impacts on individuals and families.[5,6] There are several known risk factors for severe maternal mental illness, including history of mental illness,[7] lack of social support,[8] and history of abuse or violence[9]; however, many birthing people experience severe mental illness outcomes without these risk factors.[5] Most available research on maternal mental illness focuses on the postpartum period.[5,10] Less information is available on long-term outcomes beyond the first year postpartum.[1]

Concussion, the most common form of traumatic brain injury (TBI), is a risk factor for mental illness in the general population,[11–15] including severe outcomes even years after the concussion.[16] Concussion is a term for a set of symptoms that develop after an acute brain injury, including impaired balance and cognition.[17] Concussion disrupts brain function and has the potential to cause long-term physical health concerns,[18] sleep disturbances,[19] and decreased cognitive functioning.[20] About 15%–25% of birthing people report a history of concussion.[21] One study found an increased risk for postpartum complications, including depression, among birthing people with a history of moderate to severe TBI vs those without TBI.[22] However, no studies, to our knowledge, have examined the impact of concussion

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Clinical Points

- Concussion has been associated with mental illness in the general population, but this is the first study to examine how a predelivery history of concussion impacts serious maternal mental illness risk.
- Health care providers should consider prevention of concussion in people with reproductive capacity, antenatal screening for a history of concussion, and delivery of trauma-informed care for those with a history of concussion who develop mental illness after the birth of a child.

on long-term severe maternal mental illness. This is an important gap; concussion may increase the risk of maternal mental illness via an interaction between parenting stressors such as poor sleep and noise and injury-related difficulties such as diminished cognitive and executive functioning.[23–25]

Our objective was, therefore, to examine the association between a predelivery history of concussion and long-term risk of severe maternal mental illness. We hypothesized that concussion would be associated with elevated risk of severe maternal mental illness and that this association would be moderated by mental illness history.

METHODS

Study Design and Data Sources

This was a population-based cohort study using Ontario, Canada health administrative data accessed from the Institute of Clinical Evaluative Sciences (ICES). This research was part of the first author's Master's thesis.[26] The datasets, described in Supplementary Table 1, were linked using unique encoded identifiers and analyzed at ICES. ICES is a prescribed entity under Ontario's *Personal Health Information Protection Act* (PHIPA).[27] Section 45 of PHIPA authorizes ICES to collect personal health information, without consent, for analyses that inform health care system management, planning, and evaluation. The use of the data in this project was authorized under section 45 and approved by ICES' Privacy and Legal Office. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2013. All procedures involving human subjects/patients were approved by the University of Toronto Research Ethics Board (application # 42750).

Study Population

The cohort included all birthing people with a singleton livebirth between April 1, 2007, and March 31, 2017, excluding those ineligible for Ontario health insurance in the 2 years before delivery. Fewer than 1% of those living in Ontario are ineligible for the Ontario Health Insurance Plan (OHIP); they mainly include those who are new immigrants or nonstatus (ie, students, temporary migrant workers, and newcomers without immigration status).[28] We excluded individuals with a history of TBI other than concussion or unspecified head injury,[13] and those admitted to the hospital within 2 days of the concussion encounter. The latter exclusion was made because these individuals would likely have more severe TBI,[16] and we wanted to focus on concussion, as it is the most common form of head injury and may have less comprehensive follow-up than severe TBI as it does not typically require hospital admission. To handle clustering of multiple pregnancies to the same person, 1 pregnancy was randomly selected. In this remaining cohort, those with a history of unspecified head injury were excluded from primary analyses.[29]

The exposure of interest was a history of a concussion-related health care encounter (without hospital admission) before the index pregnancy's delivery date. Concussions were identified in ≥1 outpatient visits (OHIP billing code: 850) or emergency department visits (*International Classification of Diseases, Ninth Revision* [ICD-9], physician billing code for emergency department visits prior to 2002: 850; *ICD-10* diagnostic code for emergency department visits in the National Ambulatory Care Reporting System after 2002: S06.0).[16,29,30] The concussion diagnosis code could be in any field and did not need to be the primary diagnosis position, given that a person could be seen for polytrauma where the concussion was not the most acute condition at the health care encounter. Those without an encounter for concussion or unspecified head injury from database inception to the delivery date were the unexposed.

In additional analyses, concussion exposure was subclassified by proximity of the most recent concussion health care encounter to the delivery: ≥5 years prior to conception, 2–5 years prior to conception, or <2 years prior to conception and up to delivery.

In sensitivity analyses, those with unspecified head injury codes were included in the exposed group to address the potential misclassification that may occur wherein those with a concussion may have been coded as having an unspecified head injury.[29]

Outcome

The primary outcome was a composite measure of severe maternal mental illness, defined as any psychiatric emergency department visit, psychiatric hospital admission, or self-harm or suicide between the day after delivery and March 31, 2021 (Supplementary Table 2). This provided a follow-up period of 4–14 years, with a

median of 8.54 years for the total cohort. Secondary outcomes were defined as follows: (1) each of psychiatric emergency department visits, psychiatric hospital admissions, and self-harm or suicide, separately, and (2) for psychiatric emergency department visits and hospital admissions, the specific diagnosis (ie, psychotic, depressive and other moods, anxiety and related, or substance and alcohol use disorders) (Supplementary Table 3).

Covariates

Confounders were age, parity, neighborhood income quintile, rurality, immigration status (Immigration, Refugees, and Citizenship Canada Permanent Residents Database), stable and unstable chronic conditions (Johns Hopkins Adjusted Clinical Groups v. 10.0),[31] predelivery history of assault resulting in an emergency department visit, and predelivery history of mental illness. Predelivery history of mental illness was divided into (1) no history of mental illness in pregnancy or 5 years before conception, (2) history of outpatient care for mental illness in pregnancy or 2 years before conception without a history of acute care for mental illness in pregnancy or 5 years before conception, and (3) history of acute care for mental illness in pregnancy or 5 years before conception. (History of acute care included psychiatric emergency department visits, psychiatric hospital admissions, and self-harm.)

Pregnancy and child variables were measured to describe the cohort and were not adjusted for in the main analyses since they might be mediators (Supplementary Figure 1).[5,22] Pregnancy variables were pregnancy-induced hypertension, gestational diabetes, instrumental delivery, and caesarean delivery. Child variables were preterm birth <37 weeks, small for gestational age <10th percentile, neonatal intensive care unit admission, and child mortality.

Statistical Analysis

All statistical analyses were performed using SAS software, version 9.4 (SAS Institute Inc, Cary, NC, USA). The characteristics of birthing people with and without a history of concussion were described and compared using standardized differences.[32]

The outcomes were displayed as the number of events per 1,000 person-years of follow-up. Cox proportional hazards regression was used to estimate the hazard ratio (HR) and 95% CI for severe maternal mental illness, comparing birthing people with a predelivery history of concussion to those without such a history. Participants were censored at death, loss of OHIP eligibility, or March 31, 2021, whichever came first. Additional analyses examined each element of the composite and specific psychiatric diagnoses within acute health care encounters separately. Adjusted HRs (aHRs) were produced controlling for maternal age, parity, neighborhood income quintile, rurality, immigration status, chronic conditions, history of assault, and history of mental illness. Due to the known association between a history of mental illness and both concussion and recurrence of mental illness after delivery,[14,33] an interaction term between history of concussion and history of mental illness was assessed, with statistically significant interaction terms followed by analyses stratified by history of mental illness.

The proportional hazards assumption was assessed by visualizing the cumulative incidence function, log-negative-log of survival by log time, and log-negative-log of survival by time graphs and by assessing the concussion-time interaction in the Cox proportional hazards regression model.[34] No major departures were visualized in the exposure-outcome relationship and the concussion-time interaction variable resulted in a *P* value of .81, supporting the proportionality of the hazards of serious maternal mental illness over the follow-up period.

Several sensitivity analyses were performed: (1) concussion exposure was examined by proximity of the concussion health care encounter to delivery; (2) concussion exposure was limited to those with a concussion health care encounter in the 5 years before conception up to delivery to ensure an equal lookback period for the cohort; (3) those with unspecified head injury codes were added to the concussion group to address misclassification of concussion miscoded as unspecified head injury[29]; (4) observations with concussion or TBI after delivery were excluded to ensure results were due to *predelivery* concussion; (5) the follow-up period was truncated to end on March 12, 2020, to account for possible changes in health care use during the COVID-19 pandemic[35]; (6) pregnancy and child variables were added to the multivariable models; and (7) an E-value was calculated to assess the minimum magnitude of association an unmeasured confounder must have with the exposure and outcome to bring the HR to the null.[36]

RESULTS

There were 1,288,480 singleton livebirths between April 1, 2007, and March 31, 2017 (Supplementary Figure 1). After exclusions, 1,178,248 deliveries to 806,330 unique people met the inclusion criteria. Of the final cohort, 18,064 (2.2%) had a predelivery history of concussion, 51,577 (6.4%) had a predelivery history of unspecified head injury, and 736,689 (91.4%) had no predelivery history of concussion or unspecified head injury. Birthing people with a predelivery history of concussion were more likely than those without such a history to live in a rural area, be long-term residents, and have a history of assault or mental illness. There were no

Table 1.

Baseline Characteristics of Women With and Without a Predelivery History of Concussion, Ontario, Canada, 2007–2017[a]

Variables	Predelivery history of concussion N = 18,064	No predelivery history of concussion N = 736,689	Standardized difference
Baseline characteristics			
Maternal age at delivery; mean (SD), y	29.1 (5.7)	30.9 (5.4)	**0.31**
13–24	4,008 (22.2%)	92,575 (12.6%)	**0.26**
25–34	10,807 (59.8%)	454,894 (61.7%)	0.04
35–44	3,215 (17.8%)	187,124 (25.4%)	**0.19**
45–54	34 (0.2%)	2,096 (0.3%)	0.02
Primiparous	10,028 (55.5%)	343,926 (46.7%)	**0.18**
Neighborhood income quintile[b]			
Q1 (lowest)	3,676 (20.3%)	157,602 (21.4%)	0.03
Q2	3,664 (20.3%)	147,073 (20.0%)	0.01
Q3	3,751 (20.8%)	152,483 (20.7%)	0.00
Q4	3,860 (21.4%)	155,646 (21.1%)	0.01
Q5 (highest)	3,051 (16.9%)	121,322 (16.5%)	0.01
Missing	62 (0.3%)	2,563 (0.3%)	0.00
Rural residence[c]	2,456 (13.6%)	65,544 (8.9%)	**0.15**
Missing	12 (0.1%)	337 (0.0%)	0.01
Immigration status			
Refugee	36 (0.2%)	5,906 (0.8%)	0.09
Nonrefugee immigrant	261 (1.4%)	65,838 (8.9%)	**0.34**
Long-term resident	17,767 (98.4%)	664,945 (90.3%)	**0.35**
Comorbidities[d]			
Stable chronic conditions	7,647 (42.3%)	310,542 (42.2%)	0.00
Unstable chronic conditions	4,885 (27.0%)	170,713 (23.2%)	0.09
History of assault	606 (3.4%)	7,042 (1.0%)	**0.17**
Mental illness history[e]			
No history of mental illness	10,712 (59.3%)	511,550 (69.4%)	**0.21**
Outpatient care for mental illness	5,411 (30.0%)	188,307 (25.6%)	**0.10**
Acute care for mental illness	1,941 (10.7%)	36,832 (5.0%)	**0.21**
Pregnancy, labor and delivery, and child characteristics			
Serious pregnancy-induced hypertension	81 (0.4%)	2,227 (0.3%)	0.02
Gestational diabetes	564 (3.1%)	34,890 (4.7%)	0.08
Instrumental delivery	1,804 (10.0%)	73,572 (10.0%)	0.00
Caesarean section	5,052 (28.0%)	214,703 (29.1%)	0.03
Preterm birth <37 wk gestation	1,306 (7.2%)	46,894 (6.4%)	0.03
Small for gestational age[f]	2,156 (11.9%)	95,247 (12.9%)	0.03
Neonatal intensive care unit admission	2,278 (12.6%)	82,436 (11.2%)	0.04
Child mortality	53 (0.3%)	2,307 (0.3%)	0.00

[a]All data are presented as number (%) unless otherwise specified. Bold standardized difference indicate a clinically meaningful difference of 0.10 or greater.
[b]Neighborhood income quintile was calculated by linking postal code at delivery to dissemination area income from the most recent census.
[c]Rural residence indicates communities with fewer than 10,000 individuals, according to the most recent census.
[d]Stable chronic conditions indicate diagnoses with low complication risk, and unstable chronic conditions indicate an increased risk of complications and increased resource use over a longer period of time.
[e]No history of mental illness was defined as no history of outpatient care for mental illness in the 2 y prior to conception until delivery and no history of acute care for mental illness in the 5 y prior to conception until delivery; outpatient care for mental illness was defined as a history of outpatient care for mental illness in the 2 y prior to conception until delivery, but no history of acute care for mental illness in the 5 y prior to conception until delivery; and acute care for mental illness was defined as a psychiatric emergency department visit, psychiatric hospital admission, or self-harm in the 5 y prior to conception until delivery.
[f]Small for gestational age was calculated based on gestational age at birth compared to provincial sex-specific birth weight percentiles, with those having a birthweight less than the 10th percentile for gestational age being small for gestational age.
Abbreviation: Q = quintile.

notable differences in other variables including pregnancy and child characteristics (Table 1).

The results of the primary analysis are shown in Table 2. Overall, 2,033 (11.3%) of the 18,064 observations with a predelivery history of concussion experienced severe maternal mental illness (14.7 per 1,000 person-years), compared to 49,928 (6.8%) of the 736,689 observations without a predelivery history of concussion (7.9 per 1,000) (HR 1.82, 95% CI, 1.74–1.90). These results remained statistically significant after adjustment, with an aHR of 1.25 (95% CI, 1.20–1.31). After stratification by predelivery history of mental illness, the association was strongest in individuals with no mental illness history (aHR 1.33, 95% CI, 1.23–1.44), followed by those with a history of outpatient care for mental illness (aHR 1.30, 95% CI,

Table 2.

Unadjusted and Adjusted Association Between a History of Concussion and any Severe Maternal Mental Illness[a]

Stratum	History of concussion	Number with outcome	Incidence per 1,000 person-years (95%CI)	HR (95%CI)	aHR (95%CI)
Total cohort	No (N = 736,689)	49,928	7.9 (7.9–8.0)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 18,064)	2,033	14.7 (14.0–15.3)	1.82 (1.74–1.90)	1.25 (1.20–1.31)
No history of mental illness	No (N = 511,550)	19,645	4.9 (4.9–5.0)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 10,712)	688	8.2 (7.6–8.8)	1.65 (1.53–1.78)	1.33 (1.23–1.44)
History of outpatient care for mental illness	No (N = 188,307)	16,450	9.9 (9.8–10.1)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 5,411)	642	15.0 (13.9–16.2)	1.48 (1.37–1.60)	1.30 (1.20–1.40)
History of acute care for mental illness	No (N = 36,832)	11,746	46.3 (45.5–47.1)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 1,941)	703	59.4 (55.1–63.9)	1.24 (1.15–1.33)	1.14 (1.06–1.24)

[a]HR adjusted for maternal age at delivery, parity, neighborhood income quintile, rural residence, immigration status, stable and unstable chronic conditions, history of assault, and history of mental illness (in unstratified model).
Abbreviations: HR = hazard ratio, aHR = adjusted hazard ratio.

Table 3.

Secondary Analysis: Unadjusted and Adjusted Association Between a History of Concussion and Severe Maternal Mental Illness, According to Each Element of the Composite[a]

Stratum	Outcome	History of concussion	Number with outcome	Incidence per 1,000 person-years (95%CI)	HR (95%CI)	aHR (95%CI)
Total cohort	Psychiatric emergency department visit	No (N = 736,689)	44,930	7.1 (7.0–7.2)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 18,064)	1,851	13.3 (12.7–13.9)	1.84 (1.76–1.93)	1.26 (1.20–1.32)
	Psychiatric hospital admission	No (N = 736,689)	12,740	2.0 (1.9–2.0)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 18,064)	537	3.7 (3.4–4.0)	1.86 (1.70–2.02)	1.19 (1.09–1.30)
	Self-harm or suicide	No (N = 736,689)	4,749	0.7 (0.7–0.7)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 18,064)	214	1.4 (1.3–1.7)	1.99 (1.73–2.28)	1.18 (1.02–1.35)
No history of mental illness	Psychiatric emergency department visit	No (N = 511,550)	19,645	4.5 (4.4–4.5)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 10,712)	631	7.5 (6.9–8.1)	1.67 (1.54–1.81)	1.34 (1.24–1.46)
	Psychiatric hospital admission	No (N = 511,550)	4,254	0.9 (0.9–1.0)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 10,712)	135	1.6 (1.3–1.8)	1.65 (1.39–1.95)	1.31 (1.10–1.55)
	Self-harm or suicide	No (N = 511,550)	1,693	0.4 (0.4–0.4)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 10,712)	41	0.5 (0.3–0.6)	1.25 (0.92–1.70)	0.93 (0.69–1.28)
History of outpatient care for mental illness	Psychiatric emergency department visit	No (N = 188,307)	14,652	8.8 (8.7–8.9)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 5,411)	580	13.5 (12.4–14.6)	1.51 (1.39–1.64)	1.30 (1.20–1.42)
	Psychiatric hospital admission	No (N = 188,307)	4,197	2.4 (2.4–2.5)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 5,411)	159	3.5 (3.0–4.1)	1.44 (1.22–1.68)	1.26 (1.07–1.47)
	Self-harm or suicide	No (N = 188,307)	1,349	0.8 (0.7–0.8)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 5,411)	62	1.4 (1.0–1.7)	1.75 (1.36–2.26)	1.44 (1.12–1.86)
History of acute care for mental illness	Psychiatric emergency department visit	No (N = 36,832)	10,633	40.6 (39.8–41.4)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 1,941)	640	52.1 (48.2–56.2)	1.24 (1.15–1.35)	1.14 (1.05–1.24)
	Psychiatric hospital admission	No (N = 36,832)	4,289	14.4 (14.0–14.8)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 1,941)	243	17.0 (15.0–19.2)	1.15 (1.01–1.31)	1.09 (0.95–1.24)
	Self-harm or suicide	No (N = 36,832)	1,707	5.4 (5.2–5.7)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 1,941)	111	7.4 (6.1–8.8)	1.34 (1.10–1.62)	1.16 (0.95–1.41)

[a]HR adjusted for maternal age at delivery, parity, neighborhood income quintile, rural residence, immigration status, stable and unstable chronic conditions, history of assault, and history of mental illness (in unstratified models).
Abbreviations: HR = hazard ratio, aHR = adjusted hazard ratio.

1.20–1.40) and with a history of acute care for mental illness (aHR 1.14, 95% CI, 1.06–1.24) (interaction $P < .0001$).

Results of the secondary outcomes, including each element of the composite (Table 3) and psychiatric diagnosis at the acute health care encounter (Table 4),

Table 4.

Secondary Analysis: Unadjusted and Adjusted Association Between a History of Concussion and Severe Maternal Mental Illness, by Specific Psychiatric Diagnosis in Emergency Department Visits and Hospitalizations[a]

Stratum	Mental illness diagnosis	History of concussion	Number with outcome	Incidence per 1,000 person-years (95%CI)	HR (95%CI)	aHR (95%CI)
Total cohort	Psychotic	No (N = 736,689)	2,525	0.4 (0.4–0.4)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 18,064)	76	0.5 (0.4–0.6)	1.33 (1.06–1.67)	0.89 (0.70–1.11)
	Depressive and other mood	No (N = 736,689)	14,319	2.2 (2.2–2.2)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 18,064)	611	4.2 (3.9–4.5)	1.86 (1.71–2.01)	1.22 (1.13–1.33)
	Anxiety and related	No (N = 736,689)	30,516	4.8 (4.7–4.8)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 18,064)	1,234	8.6 (8.2–9.1)	1.80 (1.70–1.90)	1.26 (1.19–1.34)
	Alcohol or substance use	No (N = 736,689)	10,646	1.6 (1.6–1.7)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 18,064)	479	3.3 (3.0–3.6)	2.00 (1.83–2.19)	1.16 (1.06–1.27)
No history of mental illness	Psychotic	No (N = 511,550)	887	0.2 (0.2–0.2)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 10,712)	17	0.2 (0.1–0.3)	1.01 (0.62–1.62)	0.90 (0.56–1.45)
	Depressive and other mood	No (N = 511,550)	4,963	1.1 (1.1–1.1)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 10,712)	170	2.0 (1.7–2.3)	1.75 (1.50–2.04)	1.39 (1.19–1.62)
	Anxiety and related	No (N = 511,550)	13,558	3.1 (3.0–3.1)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 10,712)	412	4.8 (4.4–5.3)	1.58 (1.43–1.74)	1.28 (1.16–1.42)
	Alcohol or substance use	No (N = 511,550)	3,813	0.8 (0.8–0.9)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 10,712)	134	1.5 (1.3–1.8)	1.85 (1.56–2.20)	1.29 (1.08–1.53)
History of outpatient care for mental illness	Psychotic	No (N = 188,307)	680	0.4 (0.4–0.4)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 5,411)	21	0.5 (0.3–0.7)	1.18 (0.77–1.82)	1.08 (0.70–1.67)
	Depressive and other mood	No (N = 188,307)	5,047	2.9 (2.9–3.0)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 5,411)	190	4.2 (3.7–4.9)	1.41 (1.22–1.63)	1.23 (1.07–1.43)
	Anxiety and related	No (N = 188,307)	9,902	5.9 (5.7–6.0)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 5,411)	389	8.8 (8.0–9.7)	1.49 (1.35–1.65)	1.31 (1.18–1.45)
	Alcohol or substance use	No (N = 188,307)	3,121	1.8 (1.7–1.9)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 5,411)	136	3.0 (2.5–3.5)	1.66 (1.40–1.98)	1.32 (1.11–1.56)
History of acute care for mental illness	Psychotic	No (N = 36,832)	958	3.0 (2.8–3.2)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 1,941)	38	2.5 (1.8–3.3)	0.80 (0.58–1.11)	0.80 (0.57–1.10)
	Depressive and other mood	No (N = 36,832)	4,309	14.5 (14.1–15.0)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 1,941)	251	17.7 (15.6–20.0)	1.18 (1.04–1.34)	1.12 (0.98–1.27)
	Anxiety and related	No (N = 36,832)	7,058	24.8 (24.3–25.4)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 1,941)	433	32.3 (29.3–35.4)	1.27 (1.15–1.40)	1.19 (1.08–1.32)
	Alcohol or substance use	No (N = 36,832)	3,712	12.2 (11.9–12.6)	1.00 (Referent)	1.00 (Referent)
		Yes (N = 1,941)	209	14.3 (12.5–16.4)	1.15 (1.00–1.32)	1.01 (0.88–1.17)

[a]HR adjusted for maternal age at delivery, parity, neighborhood income quintile, rural residence, immigration status, stable and unstable chronic conditions, history of assault, and history of mental illness (in unstratified models).
Abbreviations: HR = hazard ratio, aHR = adjusted hazard ratio.

were similar, with the exception of psychotic disorders, which had a nonsignificant aHR. Results stratified by mental illness history were mostly similar, with some exceptions possibly due to lower statistical power.

In sensitivity analyses examining proximity of the concussion health care encounter to delivery, aHRs were elevated for distal, mid, and proximal history of concussion (Supplementary Table 4). Analyses restricting the lookback to 5 years preconception (Supplementary Table 5), including unspecified head injuries in the concussion group (Supplementary Table 6), excluding those with postdelivery concussion or TBI (Supplementary Table 7), truncating follow-up prior to the COVID-19 pandemic (Supplementary Table 8), and including pregnancy and child variables (Supplementary Table 9) showed similar results. Finally, the E-value for the aHR for the primary analyses was 1.81 for the point estimate and 1.69 for the lower bound of the 95% CI.

DISCUSSION

In this large, population-based study in Ontario, Canada, we found that a predelivery history of concussion was associated with an increased risk of severe maternal

mental illness. The relative increase in risk for those with concussion was greater among those with no history of mental illness than among those with a predelivery history of mental illness. Results were consistent across additional and sensitivity analyses. These results have critical clinical implications for the prevention of concussion in people with reproductive capacity, antenatal screening for a history of concussion, and delivery of trauma-informed care for those with a history of concussion who develop mental illness after the birth of a child.

Previous Research

This research aligns with previous research in pediatric populations,[12,13] professional athletes,[11] and veterans[37] that also showed an increased risk of mental illness, including serious outcomes such as psychiatric emergency department visits, psychiatric hospital admissions, self-harm, and suicide, even years after concussion.[11–16] Only 1 study examined postpartum mental illness, finding an increased risk of postpartum depression following TBI; however, neither concussion nor long-term maternal mental health outcomes were examined.[22] Our sensitivity analyses also align with previous research showing that the observed association is not unduly influenced by misclassification of concussion as unspecified head injury.[29] Sensitivity analyses further adjusting for pregnancy and child variables, as well as omitting concussion or TBI after delivery, support the unique impact of predelivery concussion, and no other trauma, on serious maternal mental illness. The current study therefore contributes new data by showing a strong relation between a history of concussion and long-term risk of severe maternal mental illness.

Potential Mechanisms

There is considerable literature to support the biological plausibility of an association between concussion and severe maternal mental illness. Concussion can lead to neurotransmitter, blood flow, neuronal, and inflammatory changes,[38] poor sleep quality,[39] and long-term cognitive impairment.[40] Each of these factors could lead to the development of mental illness.[41,42] Pregnancy, labor and birth, and parenting may add complexity to the relationship between concussion and mental illness. Research has shown that people with TBI, including concussion, have light and sound sensitivities and a resulting increase in fatigue.[23,24] Sleep is also integral to healing following a head injury[25] but may be compromised among parents of young children. Not only does a history of concussion have the potential to make parenting more difficult due to neurological deficits and sensitivities,[23–25,43] but the demands of parenting could also worsen concussion symptoms, including increasing the long-term risk of mental illness.[44]

Strengths and Limitations

This population-based cohort study was the first study to examine the relation between a predelivery history of concussion and serious maternal mental illness outcomes and has many strengths. A relatively large sample size provided enough statistical power to stratify the cohort by mental illness history. We were able to capture outpatient concussion health care encounters, which research has shown make up the majority of concussion health care encounters.[30]

However, there is likely geographical and provider heterogeneity in concussion diagnosis, indicating the need for consistent diagnosis guidelines. We were unable to distinguish between health care encounters for new concussion vs ongoing management of prior concussion in order to capture the number of concussions. This is an important limitation because there is a potential dose-response effect of the number of concussions on mental illness risk.[11] The data also do not capture the occurrence of concussions where no health care was sought, or care was sought outside of Ontario. Therefore, it is possible that there are observations in the unexposed group who had a history of concussion. Finally, we excluded individuals admitted to the hospital following a concussion health care encounter to exclude more severe head injuries potentially misclassified as concussion. Theoretically, this exclusion would dilute our findings, as a more severe TBI would be expected to have an even stronger association with severe maternal mental illness.

There are confounders that are not captured in Ontario health administrative data (eg, race/ethnicity, education level, health practices). This limitation speaks to the importance of collecting data on these contextual factors in health administrative data in the future. However, the large E-value indicated that a strong association would be needed between an unmeasured confounder and both concussion and severe maternal mental illness to attenuate the results.

Finally, we were unable to examine the specific mechanisms underlying the observed association, and it is possible other factors that lie along the causal pathway between concussion and severe maternal mental illness explain the results. More research is needed to address these mechanisms to assist in our understanding of this relationship and prevent development of serious maternal mental illness.

Conclusion

Concussion in reproductive-aged people is common,[30] and our findings show the potential long-term effect of concussion on severe mental health outcomes in an important population group. The importance of concussion prevention for all people with reproductive capacity is integral and requires awareness of their long-term risk of

severe mental illness. Screening for a history of concussion should also be a part of routine antenatal and postnatal care, enabling adequate supports to be arranged for postdelivery care as a means of preventing maternal mental illness. Such supports could include sleep relief to aid in concussion healing[25] and plans to address light and sound sensitivities common after concussion.[23,24] As a high-risk group, birthing people with a history of concussion could also benefit from ongoing screening for mental illness by their primary care provider in the months and years after childbirth. Last, those with a history of concussion and maternal mental illness may benefit from trauma-informed mental health care, as routine care has the potential to trigger memories of traumatic experience and exacerbate symptoms of mental illness.[45] Together, these clinical considerations could address the association between predelivery history of concussion and severe maternal mental illness and potentially decrease the incidence of these important outcomes.

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Supplementary Material: Available at Psychiatrist.com.

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Supplementary Material

Article Title: History of Concussion and Risk of Severe Maternal Mental Illness: A Population-Based Cohort Study

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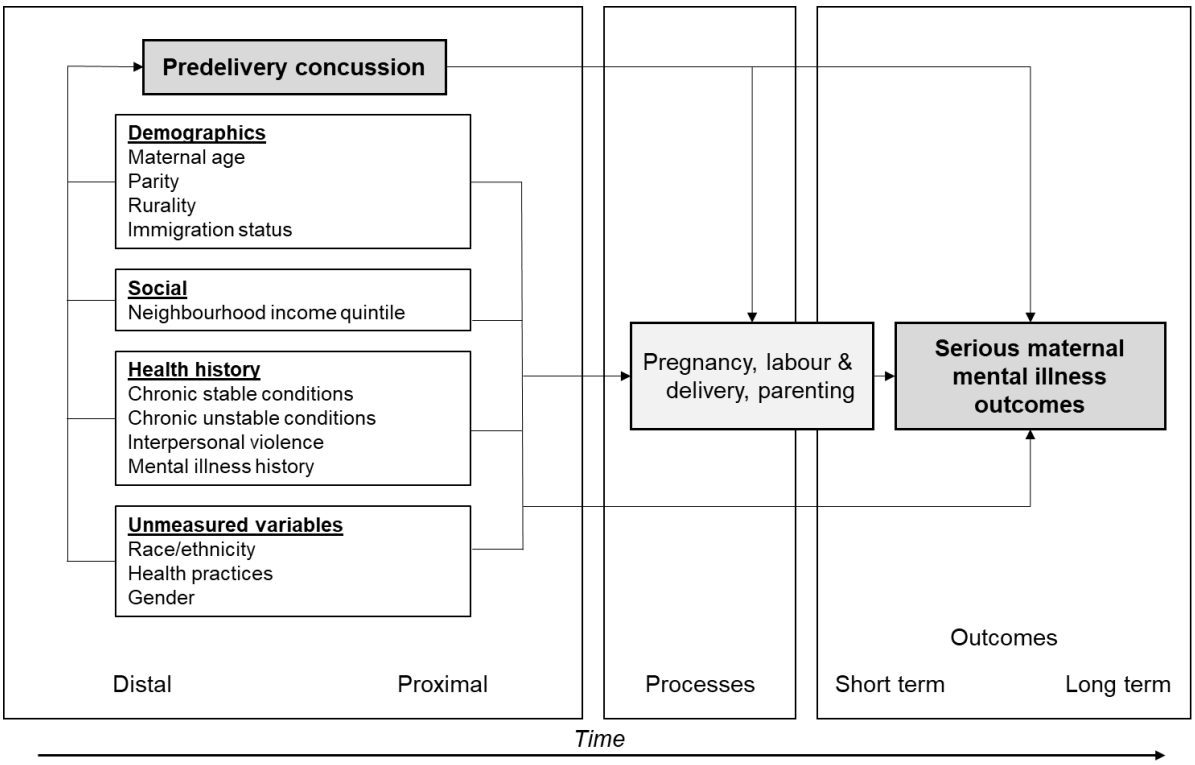
LIST OF SUPPLEMENTARY MATERIAL FOR THE ARTICLE

The Journal of Clinical Psychiatry

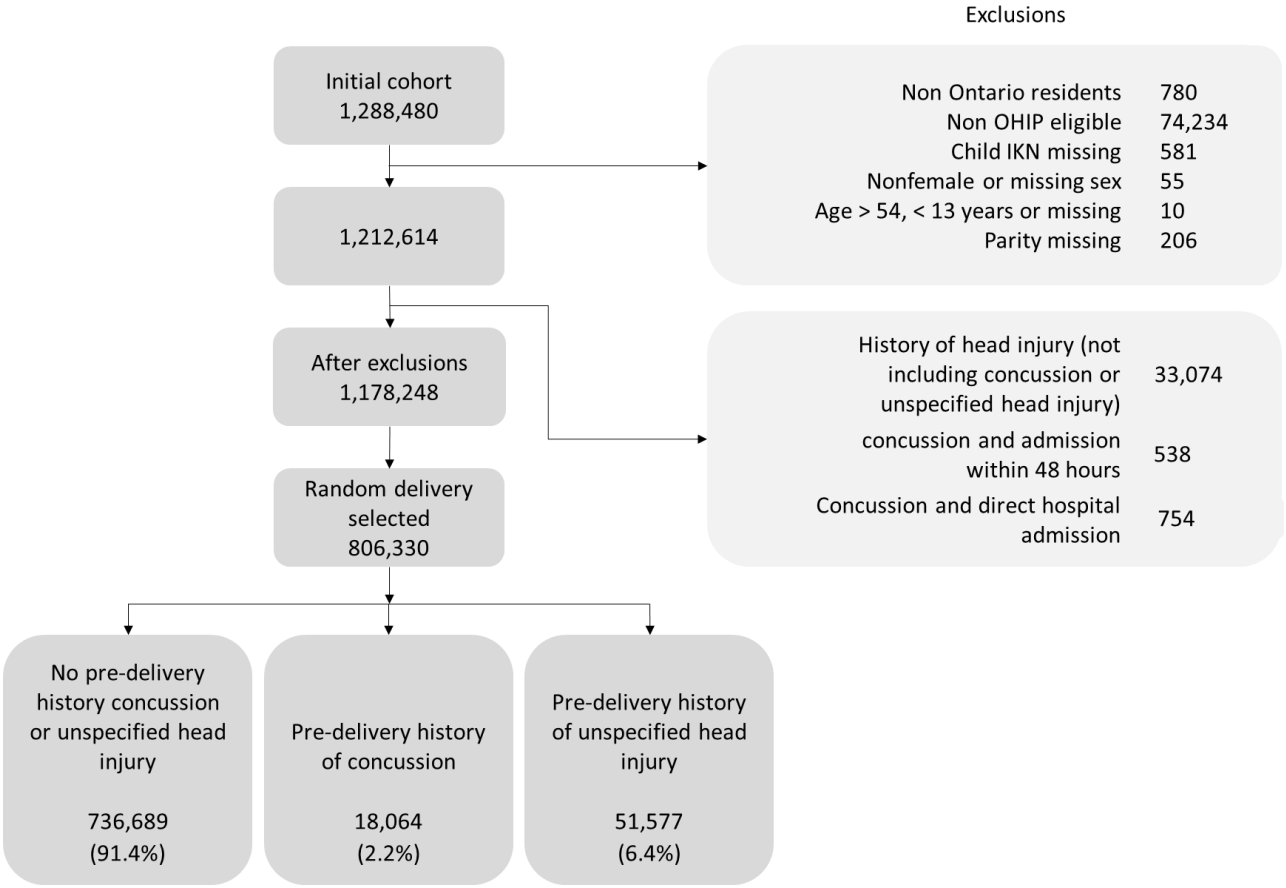
DISCLAIMER

Supplementary Figure 1: Conceptual model



Supplementary Figure 2: Cohort creation flow diagram

This figure displays the creation of the final cohort after exclusions and selection of one random delivery per mother. The right of the figure displays the exclusion criteria including the number excluded per criterion. The final cohort is displayed in the three boxes in the bottom left of the figure: those without a pre-delivery history of concussion or unspecified head injury, those with a pre-delivery history of concussion only, and those with a pre-delivery history of unspecified head injury.



Supplementary Table 1: Health administrative databases and descriptions.

Databases	Description	Variables for this study	Availability
Canadian Institute for Health Information Discharge Abstract Database (CIHI-DAD)	Contains information on hospital admissions, including clinical, demographic, and administrative information	**Baseline characteristics**: stable and unstable chronic conditions, history of hospital admission for mental illness	April 1988 onward
		Pregnancy characteristics: hospital admissions for pregnancy-induced hypertension, gestational diabetes	
		Child characteristics: NICU admission	
		Outcome: hospital admissions for mental illness	
		Sensitivity analysis: concussion or TBI following delivery	
Mother-baby dataset (MOMBABY)	Links maternal and child CIHI-DAD records	**Delivery admission information**: delivery date, maternal age, parity, mode of delivery, gestational age at delivery date, child sex, birthweight, small for gestational age	April 1988 onward
Census	Contains information on population size, neighbourhood income quintile which is linked to the RPDB	**Baseline characteristics**: neighbourhood income quintile, rural residence	1991, 1996, 2001, 2006, 2011, 2016
Immigration, Refugees and Citizenship Canada Permanent Residents Database (IRCC)	Contains information from immigration application records	**Baseline characteristics**: refugee, non-refugee immigrant, and long-term resident status	January 1985 onward
National Ambulatory Care Reporting System (NACRS)	Contains information on emergency department visits, including clinical, demographic, and administrative information	**Baseline characteristics**: stable and unstable chronic conditions, history of assault, history of ED visit for mental illness	2002 onward
		Pregnancy characteristics: ED visits for pregnancy-induced hypertension, gestational diabetes	
		Exposure: ED visit for concussion	
		Outcome: ED visits for mental illness, self-harm	
		Sensitivity analysis: concussion or TBI following delivery	
Ontario Health Insurance Plan (OHIP) database	Contains information from claims paid for by the Ontario Health Insurance Plan, including outpatient physician visits.	**Baseline characteristics**: stable and unstable chronic conditions, history of outpatient visit for mental illness	July 1991 onwards
		Pregnancy characteristics: outpatient visits for pregnancy-induced hypertension, gestational diabetes	
		Exposure: outpatient visits for concussion, ED visits for concussion prior to 2002 using OHIP macro for ED visits.	
		Sensitivity analysis: concussion or TBI following delivery	
		Censoring: Loss of OHIP eligibility	
Ontario Mental Health Reporting System	Contains information on hospital admissions for	**Baseline characteristics**: adult hospital admissions for mental illness	October 2005 onward

Databases	Description	Variables for this study	Availability
(OMHRS)	adults to mental health designated beds	**Outcome**: adult hospital admissions for mental illness	
Ontario Registrar General Database (ORGD)	Contains information on all deaths registered in Ontario	**Outcome:** Death by suicide **Censoring**: Death not by suicide	December 1990 onward
Registered Persons Database (RPDB)	Contains demographic information which is linked to Census data	**Baseline characteristics**: Postal code at delivery for ascertainment of neighbourhood income quintile, rural residence	April 1991 onward

Abbreviations: NICU: neonatal intensive care unit, TBI: traumatic brain injury, ED: emergency department.

Supplementary Table 2: Diagnostic codes for severe maternal mental illness.

Outcome	ICD-10 codes (CIHI-DAD/NACRS)	DSM-IV codes (OMHRS)	DSM-V codes (OMHRS post 2016/2017)
Psychiatric emergency department visit or hospitalization	F06.0-F06.4, F07.0, F10-21, F22-F29, F30.x, F31.x, F32, F33, F34.1, F34.8, F34.9, F38, F39, F32.x, F33.x, F34.0, F34.1, F40-F43, F45.2, F53.0, F53.1, F55, F60-F63, F68, F69, F93.1, F93.0-F93.2, F94.0-F94.2	291.x (excl. 291.82), 292.x (excl. 292.85), 293.83, 295.x, 296.0x, 296.2x, 296.3x, 296.4x, 296.5x, 296.6x, 296.7, 296.80, 297.x, 298.x, 300, 300.0x, 300.2x, 300.3x, 300.4x, 301.0, 301.13, 301.20, 301.22, 301.4, 301.50, 301.6, 301.7, 301.81, 301.82, 301.83, 301.9, 303.x, 304.x, 305.x, 308.3x, 309.0x, 309.24, 309.28, 309.3x, 309.4x, 309.8x, 309.9x, 311.x, PROVDX = 4 - 7, 15	291.x, 292.x, 293.81/82, 293.84, 295.x, 296.0x, 296.2x, 296.3x, 296.4x, 296.5x, 296.6x, 296.7x, 296.8x, 296.9x, 297.x, 298.x, 300, 300.0x, 300.2x, 300.3x, 300.4x, 300.7x, 301, 301.0x, 301.13, 301.2x, 301.4x, 301.5x, 301.6x, 301.7x, 301.81-3, 301.89, 301.9x, 303.x, 304.x, 305.x, 308.3x, 309, 309.0x, 309.21, 309.24, 309.28, 309.3x, 309.4x, 309.81, 309.89, 309.9x, 310.1, 311.x, 312.31, 312.39, 313.23, 313.89, 625.4x, PROVDX = 2, 3, 4, 5 – 7, 16, 18
Self-harm	DX10CODE2-10 = X60-X84, Y10-Y19, Y28 (with or without a psychiatric diagnosis)		
Suicide	Cause of death = suicide in ORGD		

Abbreviations: ICD: International Classification of Disease, CIHI-DAD: Canadian Institute for Health Information Discharge Abstract Database, NACRS: National Ambulatory Care Reporting System, DSM: Diagnostic and Statistical Manual of Mental Disorders, OMHRS: Ontario Mental Health Reporting System, ED: emergency department, ORGD: Ontario Registrar General Database.

Supplementary Table 3: Diagnostic codes for each psychiatric diagnosis, recorded in emergency department visits and hospital admissions.

Outcome	ICD-10 codes (CIHI-DAD/NACRS)	DSM-IV codes (OMHRS)	DSM-V codes (OMHRS post 2016/2017)
Psychotic disorders	F06.0-F06.2, F20, F22-F29, F53.1	295.x, 297.x, 298.x. Provisional=5	293.81/82, 295.x, 297.x, 298.x. Provisional=2
Depressive and other mood disorders	F06.3, F30.x, F31.x, F32, F33, F34.1, F34.8, F34.9, F38, F39, F53.0, F32.x, F33.x, F34.0, F34.1, F53.8 and 53.9 (was 53.0)	293.83, 296.0x, 296.2x, 296.3x, 296.4x, 296.5x, 296.6x, 296.7, 296.80, 300.4x, 301.13, 311.x. Provisional=6	296.0x, 296.2x, 296.3x, 296.4x, 296.5x, 296.6x, 296.7x, 296.8x, 296.9x, 300.4x, 301.13, 311.x, 625.4x. Provisional=3 or 4
Anxiety and related disorders	F06.4, F40-F43, F45.2, F63.3, F93.1, F93.0-F93.2, F94.0-F94.2	300, 300.0x, 300.2x, 300.3x, 308.3x, 309.0x, 309.24, 309.28, 309.3x, 309.4x, 309.8x, 309.9x. Provisional=7, 15	293.84, 300, 300.0x, 300.2x, 300.3x, 300.7x, 308.3x, 309, 309.0x, 309.21, 309.24, 309.28, 309.3x, 309.4x, 309.81, 309.89, 309.9x, 312.39, 313.23, 313.89, 698.4x. Provisional=5-7
Alcohol and substance use disorders	F10-19, F55, F63	291.x (excl. 291.82), 292.x (excl. 292.85), 303.x, 304.x, 305.x. Provisional=4	291.x, 292.x, 303.x, 304.x, 305.x, 312.31. Provisional=16

Abbreviations: ICD: International Classification of Disease, CIHI-DAD: Canadian Institute for Health Information Discharge Abstract Database, NACRS: National Ambulatory Care Reporting System, DSM: Diagnostic and Statistical Manual of Mental Disorders, OMHRS: Ontario Mental Health Reporting System, ne: not equal to, ORGD: Ontario Registrar General Database.

Supplementary Table 4: Unadjusted and adjusted associations between a history of concussion and severe maternal mental illness, by proximity of concussion health care encounter.

Stratum	History of concussion	Number with outcome	Incidence per 1,000 person years (95% CI)	HR (95% CI)	aHR (95% CI)
Total cohort	No (N = 736,689)	49,928	7.9 (7.9-8.0)	1.00 (Referent)	1.00 (Referent)
	Yes > 5 years (N = 12,955)	1,325	13.0 (12.3-13.7)	1.61 (1.53-1.70)	1.22 (1.15-1.28)
	Yes 2-5 years (N = 2,718)	370	18.5 (16.7-20.5)	2.29(2.06-2.53)	1.30 (1.17-1.44)
	Yes < 2 years (N = 2,391)	338	20.5 (18.4-22.8)	2.50 (2.25-2.79)	1.37 (1.23-1.52)
No mental illness history	No (N = 511,550)	21,732	4.9 (4.9-5.0)	1.00 (Referent)	1.00 (Referent)
	Yes > 5 years (N = 7,952)	479	7.5 (6.9-8.2)	1.51 (1.38-1.66)	1.25 (1.14-1.37)
	Yes 2-5 years (N = 1,493)	112	9.9 (8.2-11.9)	2.00 (1.66-2.41)	1.51 (1.25-1.83)
	Yes < 2 years (N = 1,267)	97	10.6 (8.7-12.9)	2.13 (1.75-2.60)	1.64 (1.34-2.00)
Outpatient care for mental illness history	No (N = 188,307)	16,450	9.9 (9.8-10.1)	1.00 (Referent)	1.00 (Referent)
	Yes > 5 years (N = 3,855)	434	13.8 (12.6-15.2)	1.37 (1.25-1.51)	1.22 (1.11-1.34)
	Yes 2-5 years (N = 798)	103	16.9 (13.9-20.4)	1.67 (1.37-2.02)	1.40 (1.15-1.70)
	Yes < 2 years (N = 758)	105	19.9 (16.4-24.0)	1.94 (1.60-2.35)	1.59 (1.31-1.93)
Acute care for mental illness history	No (N = 36,832)	11,746	46.3 (45.5-47.1)	1.00 (Referent)	1.00 (Referent)
	Yes > 5 years (N = 1,148)	412	57.4 (52.1-63.2)	1.21 (1.09-1.33)	1.15 (1.04-1.27)
	Yes 2-5 years (N = 427)	155	59.6 (50.8-69.6)	1.24 (1.05-1.45)	1.13 (0.96-1.32)
	Yes < 2 years (N = 366)	136	65.9 (55.5-77.7)	1.33 (1.13-1.58)	1.15 (0.97-1.36)

HR adjusted for: maternal age at delivery, parity, neighbourhood income quintile, rural residence, immigration status, stable and unstable chronic conditions, history of assault, and history of mental illness (in unstratified models).
Abbreviations: HR: hazard ratio, aHR: adjusted hazard ratio, CI: confidence interval.

Supplementary Table 5: Unadjusted and adjusted associations between a history of concussion and severe maternal mental illness, with restricted 5-year concussion lookback period.

Stratum	History of concussion in pregnancy or the 5 years before conception	Number with outcome	Incidence per 1,000 person years (95% CI)	HR (95% CI)	aHR (95% CI)
Total cohort	No (N = 749,644)	51,253	8.0 (7.9-8.1)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 5,109)	708	19.4 (18.1-20.9)	2.36 (2.19-2.54)	1.33 (1.23-1.43)
No mental illness history	No (N = 519,502)	22,211	5.0 (4.9-5.0)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 2,760)	209	10.3 (8.9-11.7)	2.04 (1.78-2.34)	1.56 (1.36-1.79)
Outpatient care for mental illness history	No (N = 192,162)	16,884	10.0 (9.9-10.2)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 1,556)	208	18.3 (15.9-20.9)	1.78 (1.55-2.04)	1.48 (1.29-1.70)
Acute care for mental illness history	No (N = 37,980)	12,158	46.6 (45.8-47.4)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 793)	291	62.4 (55.5-69.9)	1.27 (1.13-1.43)	1.13 (1.01-1.28)

HR adjusted for: maternal age at delivery, parity, neighbourhood income quintile, rural residence, immigration status, stable and unstable chronic conditions, history of assault, and history of mental illness (in unstratified models).
Abbreviations: HR: hazard ratio, aHR: adjusted hazard ratio, CI: confidence interval.

Supplementary Table 6: Unadjusted and adjusted associations between a history of concussion or unspecified head injury and severe maternal mental illness.

Stratum	History of concussion or unspecified head injury	Number with outcome	Incidence per 1,000 person years (95% CI)	HR (95% CI)	aHR (95% CI)
Total cohort	No (N =736,689)	49,928	7.9 (7.9-8.0)	1.00 (Referent)	1.00 (Referent)
	Concussion only (N = 18,064)	2,033	14.7 (14.0-15.3)	1.82 (1.74-1.90)	1.25 (1.20-1.31)
	Concussion or unspecified head injury (N = 69,641)	10,025	19.1 (18.7-19.4)	2.36 (2.31-2.41)	1.34 (1.31-1.37)
No mental illness history	No (N =511,550)	21,732	4.9 (4.9-5.0)	1.00 (Referent)	1.00 (Referent)
	Concussion only (N = 10,712)	688	8.2 (7.6-8.8)	1.65 (1.53-1.78)	1.33 (1.23-1.44)
	Concussion or unspecified head injury (N = 39,412)	3,173	10.3 (9.9-10.7)	2.07 (1.99-2.15)	1.46 (1.40-1.52)
Outpatient care for mental illness history	No (N =188,307)	16,450	9.9 (9.8-10.1)	1.00 (Referent)	1.00 (Referent)
	Concussion only (N = 5,411)	642	15.0 (13.9-16.2)	1.48 (1.37-1.60)	1.30 (1.20-1.40)
	Concussion or unspecified head injury (N = 20,322)	2,849	18.0 (17.3-18.7)	1.77 (1.71-1.85)	1.39 (1.33-1.45)
Acute care for mental illness history	No (N =36,832)	11,746	46.3 (45.5-47.1)	1.00 (Referent)	1.00 (Referent)
	Concussion only (N = 1,941)	703	59.4 (55.1-63.9)	1.24 (1.15-1.33)	1.14 (1.06-1.24)
	Concussion or unspecified head injury (N = 9,907)	4,003	67.3 (65.3-69.4)	1.40 (1.35-1.45)	1.21 (1.16-1.25)

HR adjusted for: maternal age at delivery, parity, neighbourhood income quintile, rural residence, immigration status, stable and unstable chronic conditions, history of assault, and history of mental illness (in unstratified models).
Abbreviations: HR: hazard ratio, aHR: adjusted hazard ratio, CI: confidence interval.

Supplementary Table 7: Unadjusted and adjusted associations between a history of concussion and severe maternal mental illness, after excluding those with concussion or TBI after delivery.

Stratum	History of concussion	Number with outcome	Incidence per 1,000 person years (95% CI)	HR (95% CI)	aHR (95% CI)
Total cohort	No (N = 700,718)	46,588	7.8 (7.7-7.9)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 16,246)	1,839	14.8 (14.1-15.5)	1.85 (1.76-1.94)	1.27 (1.21-1.33)
No mental illness history	No (N = 490,009)	20,357	4.9 (4.8-4.9)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 9,858)	617	8.1 (7.5-8.7)	1.64 (1.52-1.78)	1.33 (1.23-1.44)
Outpatient care for mental illness history	No (N = 176,895)	15,296	9.9 (9.8-10.1)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 4,864)	581	15.3 (14.1-16.6)	1.51 (1.39-1.64)	1.32 (1.21-1.43)
Acute care for mental illness history	No (N = 33,814)	10,935	47.8 (16.9-48.7)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 1,704)	641	63.5 (58.7-68.5)	1.27 (1.18-1.38)	1.17 (1.08-1.27)

HR adjusted for: maternal age at delivery, parity, neighbourhood income quintile, rural residence, immigration status, stable and unstable chronic conditions, history of assault, and history of mental illness (in unstratified models).
Abbreviations: HR: hazard ratio, aHR: adjusted hazard ratio, CI: confidence interval, TBI: traumatic brain injury.

Supplementary Table 8: Unadjusted and adjusted associations between a history of concussion and severe maternal mental illness, when ending follow-up prior to the COVID-19 pandemic.

Stratum	History of concussion	Number with outcome	Incidence per 1,000 person years (95% CI)	HR (95% CI)	aHR (95% CI)
Total cohort	No (N = 736,689)	45,885	8.2 (8.1-8.3)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 18,064)	1,868	15.3 (14.6-16.0)	1.84 (1.76-1.93)	1.26 (1.20-1.32)
No history of mental illness	No (N = 511,550)	19,673	5.0 (5.0-5.1)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 10,712)	619	8.4 (7.8-9.1)	1.66 (1.53-1.80)	1.33 (1.23-1.45)
History of outpatient care for mental illness	No (N = 188,307)	15,186	10.3 (10.1-10.4)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 5,411)	589	15.6 (14.3-16.9)	1.50 (1.38-1.63)	1.30 (1.20-1.42)
History of acute care for mental illness	No (N = 36,832)	11,026	48.3(47.4-49.2)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 1,941)	660	62.4(57.8-67.4)	1.25 (1.15-1.35)	1.16 (1.07-1.25)

HR adjusted for: maternal age at delivery, parity, neighbourhood income quintile, rural residence, immigration status, stable and unstable chronic conditions, history of assault, and history of mental illness (in unstratified models).
Abbreviations: HR: hazard ratio, aHR: adjusted hazard ratio, CI: confidence interval

Supplementary Table 9: Unadjusted and adjusted associations between a history of concussion and severe maternal mental illness, including pregnancy and child characteristics in multivariable analyses.

Stratum	History of concussion	Number with outcome	Incidence per 1,000 person years (95% CI)	HR (95% CI)	aHR (95% CI)
Total cohort	No (N = 736,689)	49,928	7.9 (7.9-8.0)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 18,064)	2,033	14.7 (14.0-15.3)	1.82 (1.74-1.90)	1.25 (1.19-1.31)
No history of mental illness	No (N = 511,550)	19,645	4.9 (4.9-5.0)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 10,712)	688	8.2 (7.6-8.8)	1.65 (1.53-1.78)	1.33 (1.23-1.43)
History of outpatient care for mental illness	No (N = 188,307)	16,450	9.9 (9.8-10.1)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 5,411)	642	15.0 (13.9-16.2)	1.48 (1.37-1.60)	1.29 (1.19-1.40)
History of acute care for mental illness	No (N = 36,832)	11,746	46.3 (45.5-47.1)	1.00 (Referent)	1.00 (Referent)
	Yes (N = 1,941)	703	59.4 (55.1-63.9)	1.24(1.15-1.33)	1.14 (1.05-1.23)

HR adjusted for: maternal age at delivery, parity, neighbourhood income quintile, rural residence, immigration status, stable and unstable chronic conditions, history of assault, history of mental illness (in unstratified models), serious pregnancy-induced hypertension, gestational diabetes, instrumental delivery, caesarean section, preterm birth <37 weeks gestation, small for gestational age, neonatal intensive care unit admission, and child mortality.
Abbreviations: HR: hazard ratio, aHR: adjusted hazard ratio, CI: confidence interval