CLINICAL RESEARCH STUDY

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COVID Vaccine Hesitancy and Risk of a Traffic Crash

Donald A. Redelmeier, MD, FRCPC, MSHSR, FACP,[a,b,c,d,e] **Jonathan Wang, MMASc,**[b,c] **Deva Thiruchelvam, MSc**[a,c]

[a]Evaluative Clinical Sciences, Sunnybrook Research Institute, Toronto, Ont, Canada; [b]Department of Medicine, University of Toronto, Ont, Canada; [c]Institute for Clinical Evaluative Sciences (ICES), Toronto, Ont, Canada; [d]Division of General Internal Medicine; [e]Center for Leading Injury Prevention Practice Education & Research, Sunnybrook Health Sciences Centre, Toronto, Ont, Canada.

ABSTRACT

BACKGROUND: Coronavirus disease (COVID) vaccine hesitancy is a reflection of psychology that might also contribute to traffic safety. We tested whether COVID vaccination was associated with the risks of a traffic crash.

METHODS: We conducted a population-based longitudinal cohort analysis of adults and determined COVID vaccination status through linkages to individual electronic medical records. Traffic crashes requiring emergency medical care were subsequently identified by multicenter outcome ascertainment of all hospitals in the region over a 1-month follow-up interval (178 separate centers).

RESULTS: A total of 11,270,763 individuals were included, of whom 16% had not received a COVID vaccine and 84% had received a COVID vaccine. The cohort accounted for 6682 traffic crashes during follow-up. Unvaccinated individuals accounted for 1682 traffic crashes (25%), equal to a 72% increased relative risk compared with those vaccinated (95% confidence interval, 63-82; $P < 0.001$). The increased traffic risks among unvaccinated individuals extended to diverse subgroups, was similar to the relative risk associated with sleep apnea, and was equal to a 48% increase after adjustment for age, sex, home location, socioeconomic status, and medical diagnoses (95% confidence interval, 40-57; $P < 0.001$). The increased risks extended across the spectrum of crash severity, appeared similar for Pfizer, Moderna, or other vaccines, and were validated in supplementary analyses of crossover cases, propensity scores, and additional controls.

CONCLUSIONS: These data suggest that COVID vaccine hesitancy is associated with significant increased risks of a traffic crash. An awareness of these risks might help to encourage more COVID vaccination.

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KEYWORDS: COVID-19; Human factors; Judgment and reasoning; Motor vehicle accident; Traffic crash; Vaccine hesitancy

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Authorship: The lead author (DAR) had full access to all the data in the study, takes responsibility for the integrity of the data, and is accountable for the accuracy of the analysis. Other contributions include: Conceptualization (DAR, JW, DT), data curation (DAR, DT), formal analysis (DAR, JW, DT), funding acquisition (DAR, JW), investigation (DAR, JW, DT), methodology (DAR, JW, DT), project administration (DAR, JW), resources (DAR, JW), software (nil), supervision (DAR), validation (DAR, JW, DT), visualization (DAR, JW, DT), original draft (DAR), and revisions (DAR, JW, DT). The protocol was approved by the Sunnybrook Research Ethics board and conducted using privacy safeguards at the Institute for Clinical Evaluative Sciences. Parts of this material are based on data compiled by CIHI; however, the analyses, conclusions, and statements expressed are those of the authors and not necessarily those of CIHI. Study participants contributed in important ways to this research yet it was not feasible to directly involve individuals in study design or conduct. Members of the public provided feedback on study results and earlier presentations of this material.

Data Availability: The study dataset is held securely in coded form at the Institute for Clinical Evaluative Sciences (ICES). While legal data sharing agreements between ICES and data providers (eg, health care organizations and government) prohibit ICES from making the dataset publicly available, access may be granted to those who meet criteria for confidential access, available at www.ices.on.ca/DAS (email das@ices.on.ca). The full dataset creation plan and analytic code are available from the authors upon request, understanding that the computer programs might rely upon coding templates or macros that are unique to ICES.

Requests for reprints should be addressed to Donald A. Redelmeier, MD, Sunnybrook Health Sciences Centre, G-151 2075 Bayview Ave, Toronto, ON M4N 3M5, Canada.

E-mail address: dar@ices.on.ca

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INTRODUCTION

Motor vehicle traffic crashes are a common cause of sudden death, brain injury, spinal damage, skeletal fractures, chronic pain, and other disabling conditions. Crash risks occur as a complication of several diseases including alcohol misuse, sleep apnea, and diabetes.[1] Crashes also occur in patients with controlled hypertension, prior cancer, or no disease at all.[2] The proximate causes of most crashes are human behaviors including speeding, inattention, tailgating, impairment, improper passing, disobeying a signal, failing to yield right-of-way, or other infractions.[3] These behaviors might partially reflect health consciousness, safety mindedness, community spirit, or other psychological characteristics that are difficult to measure in a systematic manner.[4,5]

Coronavirus disease (COVID) vaccine hesitancy is defined by the World Health Organization as a delay in acceptance or refusal of vaccination against an important contagious disease despite supply (distribution), access (availability), and awareness (albeit with possible misinformation).[6,7] Vaccine hesitancy or confidence is not new; for example, the original polio vaccine required multifactorial efforts, including celebrity endorsements (eg, the publicized injection for Elvis Presley in 1956).[8-10] Vaccination preferences mayalso reflect past misadventures (eg, the ill-advised swine-flu vaccine mandate by Gerald Ford in 1976).[11] Vaccine hesitancy in regions of wide availability, however, can be contentious due to conflicting values, fallible self-report, cognitive blind spots, or other behavioral issues.[12-17]

COVID vaccination is an objective, available, important, authenticated, and timely indicator of human behavior—albeit in a domain separate from motor vehicle traffic crashes. Whether COVID vaccination is associated with increased traffic risks, however, has not been tested and might seem surprising.[18] Simple immune activation against a coronavirus, for example, has no direct effect on traffic behavior or the risk of a motor vehicle crash.[19] Instead, we theorized that individual adults who tend to resist public health recommendations might also neglect basic road safety guidelines.[20-23] The study question was "Does COVID vaccine hesitancy correlate with the risks of a serious traffic crash?"

CLINICAL SIGNIFICANCE

- Coronavirus disease (COVID) vaccination uptake has stalled despite being safe, effective, and free.
- COVID vaccine hesitancy is associated with increased traffic risks.
- The risks in unvaccinated adults apply to differing patients and severe events.
- The traffic risks are comparable with the risks with sleep apnea.
- Physicians counseling patients who decline COVID vaccination could consider safety reminders to mitigate traffic risks.

METHODS

Study Setting

Ontario is the most populous province of Canada, with 14,789,778 residents in 2021.[24] The yearly crash risk was 2% for an average adult (minor incidents included), the minimum driving age was 16 years, and novice drivers initially received beginner licenses.[3] The COVID vaccine became available in winter 2020, doses were widely delivered to adults by spring 2021, and uptake had plateaued in summer 2021.[25,26] The 4 vaccines were Pfizer-BioNTech (approved December 9, 2020), Moderna (December 23, 2020), AstraZeneca (February 26, 2021), and Johnson & Johnson (March 5, 2021).[27-29] Vaccination was free to all, supported by popular community outreach, accompanied by public campaigns, and connected to a central registration system (COVAXON).[30]

Vaccination Status

We identified individuals using encrypted identifiers from official government registries.[31] We included adults age 18 years or more on July 31, 2021 to ensure that each was eligible for a regular driver's license and a COVID vaccine.[32] This population-based approach was fully comprehensive, with the exception of excluding cases marked as invalid, containing faulty identifiers, or missing a birthdate.[33-35] We also excluded those living elsewhere (home address), having no earlier activity (record gap), or who were not alive (death database). COVID vaccination status was based on the COVAXON database, with further details on product (manufacturer), date of first dose (earlier or later), and completeness (1 or 2 doses).[36,37] The study was registered in advance, approved by the Sunnybrook Research Ethics Board, and conducted using Institute for Clinical Evaluative Sciences safeguards.

Additional Characteristics

Information on age (years), sex (binary), home location (urban, rural), and socioeconomic status (quintile) was based on demographic databases.[38,39] Linked health care records were used to identify past diagnoses (International Classification of Diseases, Ninth Revision) and access to care (clinic contacts, emergency visits, hospital admissions) based on the preceding year.[40,41] We directed specific attention to diseases associated with traffic risks, including alcohol misuse, sleep apnea, diabetes, depression, and dementia.[42,43] For interest, we also checked for a past diagnosis of hypertension, cancer, and COVID infection. The available databases lacked information on driver skill, functional status, personality traits, traffic infractions, political affiliation, and self-identified ethnicity.[44]

Table 1 Baseline Characteristics

Variable		COVID Vaccination: Yes (n = 9,425,473)	COVID Vaccination: No (n = 1,845,290)
Demographic			
Age (years)			
	18-39	3,040,343 (32.3%)	938,310 (50.8%)
	40-64	3,987,941 (42.3%)	684,712 (37.1%)
	≥65	2,397,189 (25.4%)	222,268 (12.0%)
Sex			
	Male	4,505,555 (47.8%)	928,543 (50.3%)
	Female	4,919,918 (52.2%)	916,747 (49.7%)
Home			
	Urban	8,464,905 (89.8%)	1,619,385 (87.8%)
	Rural	960,568 (10.2%)	225,905 (12.2%)
Socioeconomic status*			
	Higher	3,956,080 (42.0%)	620,654 (33.6%)
	Middle	1,913,588 (20.3%)	366,488 (19.9%)
	Lower	3,555,805 (37.7%)	858,148 (46.5%)
Diagnoses†			
Alcohol misuse‡	Yes	37,118 (0.4%)	13,522 (0.7%)
Sleep apnea§	Yes	507,054 (5.4%)	80,454 (4.4%)
Diabetes‖	Yes	987,422 (10.5%)	109,995 (6.0%)
Depression¶	Yes	1,181,992 (12.5%)	262,915 (14.2%)
Dementia**	Yes	151,776 (1.6%)	11,522 (0.6%)
Hypertension††	Yes	1,069,601 (11.3%)	123,536 (6.7%)
Cancer‡‡	Yes	654,151 (6.9%)	75,226 (4.1%)
COVID infection§§	Yes	390,928 (4.1%)	64,696 (3.5%)
General†			
Clinic contacts	≥3	6,283,552 (66.7%)	1,116,778 (60.5%)
Emergency visit	Yes	1,891,240 (20.1%)	475,786 (25.8%)
Hospital admission	Yes	477,873 (5.1%)	107,175 (5.8%)

*Based on home neighborhood, missing data coded as lower.
†Based on previous year.
‡Code 303.
§Code 786.
‖Code 250.
¶Code 300.
**Code 290.
††Code 401.
‡‡Codes 140 to 208.
§§Code 080.

Traffic Crashes

We identified serious traffic crashes during the subsequent month based on emergency care throughout the region (178 individual hospitals).[45] This definition reflected incidents sending a patient to an emergency department as a driver, passenger, or pedestrian (codes V00-V69).[46] Additional crash characteristics included time (morning, afternoon, night), day (weekend, weekday), ambulance involvement (yes, no), and triage severity score (higher, lower).[47] In each case we also determined whether the patient was admitted (yes, no) and final status (dead, alive).[45,46,48-50] Due to privacy restrictions we did not link to insurance records (financial costs from vehicle damage) or police records (deaths at the scene prior to reaching hospital).

Other Outcomes

Our study was not a randomized trial and we selected additional outcomes to check for a difference where a difference was anticipated (positive control) and no difference where no difference was anticipated (negative control).[51] Specifically, we replicated methods by focusing instead on emergency care for COVID pneumonia as an alternative outcome (positive control). The rationale was that a lack of COVID vaccination, in theory, would be associated with an increased risk of subsequent COVID infection. Similarly, we tested emergency care for uncomplicated constipation (negative control). The rationale was that uncomplicated constipation is a frequent and distinct medical disorder among diverse patients unrelated to COVID vaccination or COVID infection.

Statistical Analysis

The main analysis evaluated emergency visits for individuals injured in traffic crashes. The primary comparison used the chi-square test to analyze those who had not received a COVID vaccine relative to those who had received a COVID vaccine. Odds ratios were used for relative risk estimates, with no censoring for interval deaths (accounting for deaths at the scene and censoring for interval deaths yielded nearly identical results). Stratified analyses assessed

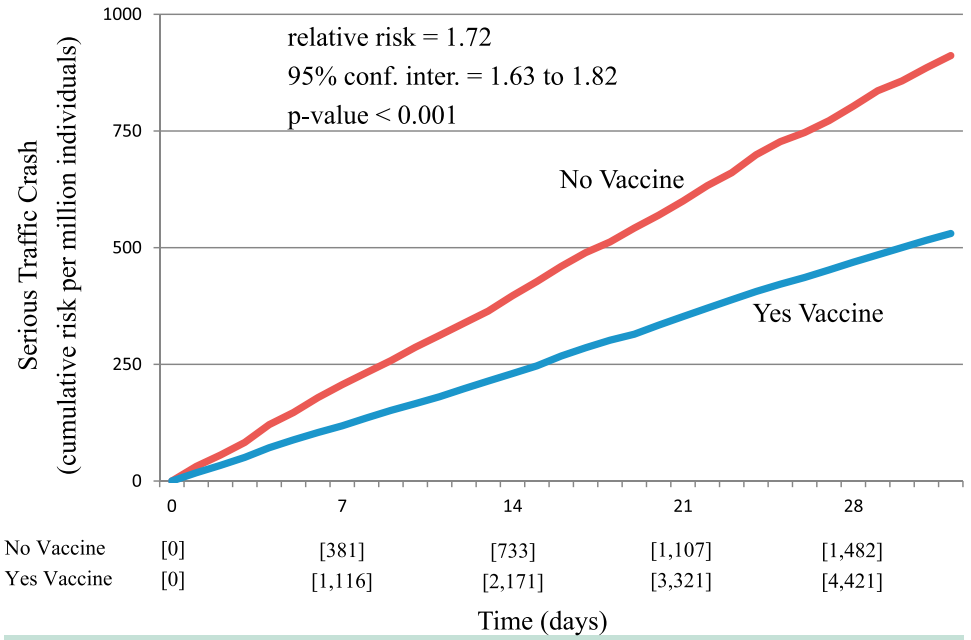

Figure 1 Cumulative incidence plots of absolute risk of a serious traffic crash. X-axis shows days following start of follow-up. Y-axis shows cumulative incidence of events per million individuals. Blue line denotes those vaccinated against coronavirus disease (COVID) and red line denotes those not vaccinated against COVID. Counts in square brackets indicate cumulative total patients in each group with an event at corresponding time. Relative risk ratio based on logistic regression model. Results show substantial incidence of serious traffic crashes that is increased for those who are not vaccinated relative to those who are vaccinated.

differences according to individual characteristics, with special attention to a diagnosis of alcohol misuse. The analysis was then replicated for patients diagnosed with subsequent COVID pneumonia (positive control) and patients diagnosed with uncomplicated constipation (negative control).

Secondary analyses explored further nuances to check the robustness of a potential association between COVID vaccination and traffic crash risks. We used multivariable logistic regression analysis to test the strength of association after accounting for baseline demographic and diagnostic predictors. Prespecified subgroup analyses were used to check for replication according to specific vaccine, recency of first dose, and completeness of vaccination. Similarly, subtype analyses were used to examine whether the association extended across the spectrum of crash severity. In addition, a sensitivity analysis was conducted to account for crossover patients who eventually received a vaccination during the 1-month follow-up interval.

Two more supplementary sets of analyses were conducted in a post hoc manner after examining results from the primary analysis. The first analyses tested a propensity score approach as an alternative method to adjust for observed baseline individual differences. Individual patients were pair matched one-to-one based on age (within 5 years), sex (binary), location (binary), socioeconomic status (quintile), and propensity score of specific diagnosis (total = 8). The second analyses tested additional negative controls to validate statistics and check for a further lack of difference in unrelated outcomes. The 4 separate additional emergency outcomes were a fall, a water transportation incident, appendicitis, and conjunctivitis (Appendix, available online). Study reporting followed the Strengthening the Reporting of Observational Studies in Epidemiology guideline (STROBE checklist).

RESULTS

Overview

A total of 11,270,763 adults were identified. Overall, 9,425,473 (84%) had received a COVID vaccine and 1,845,290 (16%) had not received a COVID vaccine at study baseline (July 31, 2021). The 2 groups spanned a diverse range of demographics, with comparable general health care utilization (Table 1). The largest relative differences were that those who had not received a COVID vaccine were more likely to be younger, living in a rural area, and below the middle socioeconomic quintile. Those who had not received a vaccine also were more likely to have a diagnosis of alcohol misuse or depression and less likely to have a diagnosis of sleep apnea, diabetes, cancer, or dementia. About 4% had a past COVID diagnosis, with no major imbalance between the 2 groups.

Traffic Crashes

A total of 6682 individuals required emergency care for a serious traffic crash during the subsequent month of follow-up. This rate averaged over 200 individuals per day and was comparable with population norms for high-income countries. Patients who had not received a COVID vaccine accounted for 1682 crashes (25% of total crashes), equal to an absolute risk of 912 per million. Patients who had received a COVID vaccine accounted for 5000 crashes (75% of total crashes), equal to an absolute risk of 530 per million. The difference corresponded to a relative risk of 1.72 for patients who had not received the COVID vaccine (95% confidence interval, 1.63-1.82; $P < 0.001$). The risk of a traffic crash was proportional with time for both groups (Figure 1).

Consistency for Subgroups

The association between a lack of COVID vaccination and increased traffic risks extended to important subgroups. The pattern was apparent for younger and middle-aged adults,

Characteristic	Total Crashes	Risk with Vaccine	Risk with No Vaccine
Age 18-39 years	3,255	701	1198
Age 40-64 years	2,548	517	711
Age ≥ 65 years	879	337	319
Men	3,875	619	1168
Women	2,807	449	651
Urban home	5,963	530	913
Rural home	719	537	899
Higher SES	2,534	513	815
Middle SES	1,276	506	840
Lower SES	2,872	564	1011
Alcoholism-yes	91	1616	2293
Alcoholism-no	6,591	526	901
Sleep apnea-yes	416	647	1094
Sleep apnea-no	6,266	524	903
Diabetes-yes	507	451	564
Diabetes-no	6,175	540	934
Depression-yes	1,244	758	1324
Depression-no	5,438	498	843
Dementia-yes	38	184	868
Dementia–no	6,644	536	912
Hypertension-yes	464	380	469
Hypertension-no	6,218	550	943
Cancer-yes	343	451	638
Cancer-no	6,339	536	923
COVID infection-yes	311	660	819
COVID infection-no	6,371	525	915
Total Cohort	6,682	530	912

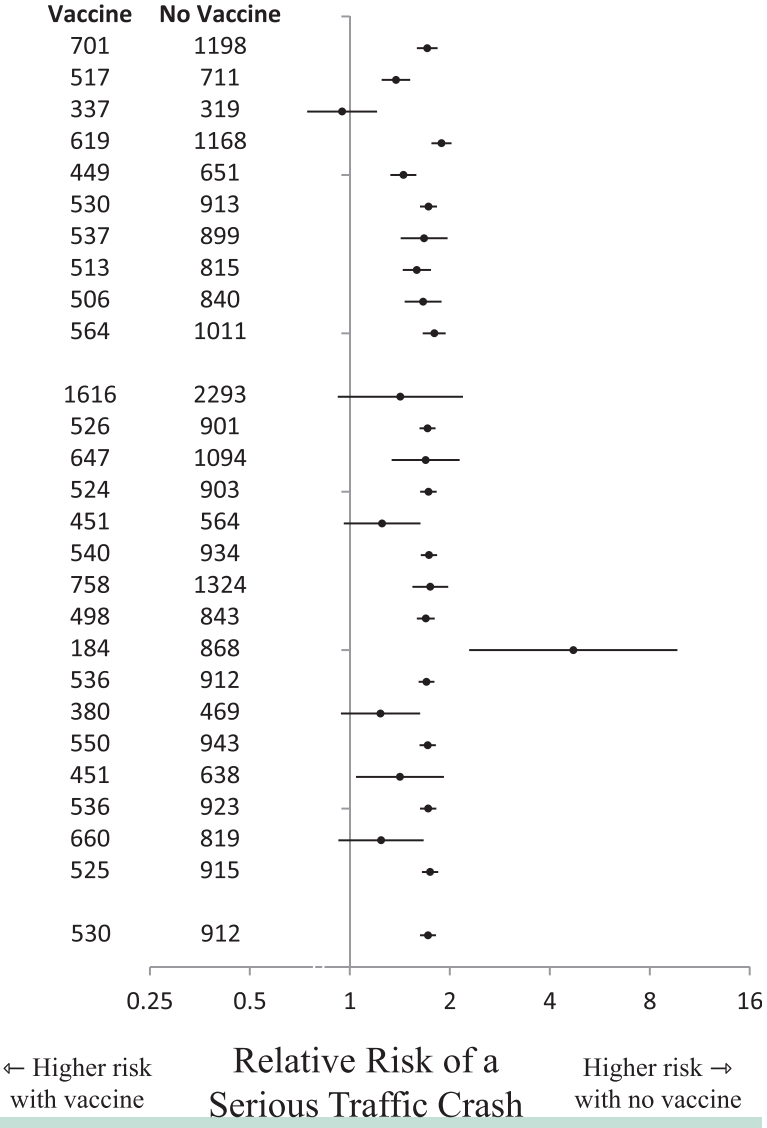

Figure 2 Forest plot of relative risk of a serious traffic crash in different subgroups. Relative risk compares unvaccinated adults with vaccinated adults for each estimate. In each subgroup, counts show total crashes along with absolute crash risk for those vaccinated and for those not vaccinated (events per million). Circles denote relative risk estimate and horizontal lines denote 95% confidence interval. Null association shown as a relative risk of 1.00 on logarithmic axis. Summary data for total cohort at bottom. Findings show substantial counts, increased relative risk for those unvaccinated, and most subgroups overlapping main analysis. High outlier of unvaccinated patients with dementia potentially attributable to chance.

men and women, those in urban and rural locations, and across the range of socioeconomic status (Figure 2). The smallest relative risk was for adults older than 65 years. The results persisted after stratifying for a diagnosis of alcohol misuse or other specific diagnosis. Stratified analyses based on total clinic contacts, emergency visits, and prior admissions also yielded findings consistent with the primary analysis (Appendix). All subgroups with at least 1000 total crashes showed a significant finding replicating the primary analysis. No subgroup showed a significant opposite association.

Additional Predictors of Crash Risk

The baseline risk of a traffic crash was also related to other individual characteristics (Table 2). In accord with past studies, the risk was greater for younger than older adults, more for men than women, and higher for those with lower socioeconomic status. Living in a rural location was not associated with a large difference in risk in either univariable or multivariable analysis. A diagnosis of alcohol misuse was a substantial risk factor, sleep apnea or depression were modest risk factors, and a past diagnosis of COVID infection was an equivocal risk factor. Adjustment for all measured individual characteristics suggested a relative risk of 1.48 for individuals who had not received a COVID vaccine (95% confidence interval, 1.40-1.57; $P < 0.001$).

Secondary Analyses

The increased traffic crash risks among those who had not received a COVID vaccine applied across diverse analyses (Table 3). The increased risk extended to patients who required ambulance transport, had higher triage severity, and needed hospital admission. The increased risk was accentuated in analyses distinguishing earlier rather than later vaccine timing and distinguishing those with 2 rather than 1 dose. The risk was similar for the Pfizer, Moderna, or other vaccines. As expected, the risk of subsequent COVID pneumonia was increased for those who had not received a COVID vaccine, whereas the risk of constipation was unrelated to the COVID vaccine. Results were further validated in analyses of those eventually vaccinated during follow-up, those matched by propensity scores, and those with additional outcomes (Appendix).

DISCUSSION

We studied millions of adults and found that COVID vaccine hesitancy was associated with significant increased traffic risks. The increased risks included adults with diverse characteristics who spanned the range of socioeconomic status and home locations. The increased risks extended across the spectrum of crash severity, including cases requiring ambulance transport and acute hospitalization. The magnitude of estimated risk was substantial and similar to the relative risk associated with sleep apnea, less than associated with alcohol misuse, and greater than associated with diabetes. A relative risk of this magnitude, furthermore, exceeds the safety gains from modern automobile engineering advances and also imposes risks on other road users.[43,52]

Our research agrees with past studies about psychology contributing to traffic risks.[53,54] One of the earliest studies evaluated taxi drivers and observed a 7-times greater frequency of personality disorders among those with multiple crashes compared with those with no crashes.[55] A study of young drivers identified a near doubling of crash incidents associated with an aggressive personality pattern.[56] A psychometric analysis of motorcycle riders found that personal temperament was the largest predictor of crash involvement.[57] The weaknesses of past studies include small sample sizes, fallible self-report, cross-sectional designs, low outcome counts, and narrow generalizability.[58,59] We are

Table 2 Predictors of Traffic Crash Risk

	Basic Analysis*		Adjusted Analysis†	
	Relative Risk	Confidence Interval	Relative Risk	Confidence Interval
No COVID vaccination	1.72	1.63-1.82	1.48	1.40-1.57
Younger age (<40 y)	1.50	1.43-1.58	1.40	1.33-1.48
Older age (≥65 y)	0.62	0.57-0.66	0.67	0.62-0.73
Male sex	1.48	1.41-1.56	1.50	1.43-1.57
Rural home	1.03	0.95-1.11	1.06	0.98-1.15
Higher socioeconomic status‡	0.99	0.93-1.06	1.01	0.94-1.08
Lower socioeconomic status‡	1.16	1.09-1.24	1.13	1.06-1.21
Alcohol misuse	3.06	2.49-3.77	2.25	1.83-2.78
Sleep apnea	1.21	1.09-1.33	1.32	1.19-1.46
Diabetes	0.76	0.70-0.83	0.98	0.90-1.08
Depression	1.56	1.46-1.66	1.53	1.44-1.63
Dementia	0.39	0.28-0.54	0.59	0.43-0.82
Hypertension	0.63	0.57-0.69	0.82	0.74-0.90
Cancer	0.78	0.70-0.87	1.01	0.90-1.13
COVID infection	1.16	1.03-1.30	1.11	0.99-1.25

*No adjustments for baseline differences.
†Adjusted for other differences through regression model.
‡Referent is middle socioeconomic status.

Table 3 Secondary Analyses

		Total Events	Risk with Vaccine*	Risk with No Vaccine*	Relative Risk†	Confidence Interval
Primary analysis		6682	530	912	1.72	1.63-1.82
Crash details						
Involvement						
	Driver	2856	218	434	1.99	1.83-2.16
	Passenger	1189	92	175	1.91	1.68-2.17
	Pedestrian	2637	221	303	1.38	1.25-1.51
Time‡						
	Morning	1490	123	178	1.45	1.28-1.64
	Afternoon	3589	292	455	1.56	1.45-1.69
	Night	1603	116	278	2.41	2.17-2.67
Day						
	Weekend	2142	172	285	1.66	1.51-1.84
	Weekday	4540	359	627	1.75	1.63-1.87
Ambulance transport						
	Yes	2657	207	381	1.84	1.69-2.00
	No	4025	323	531	1.64	1.53-1.77
Triage severity§						
	Higher	1838	137	297	2.17	1.96-2.39
	Lower	4844	394	615	1.56	1.46-1.67
Hospital admission						
	Yes	550	42	82	1.97	1.64-2.38
	No	6132	489	828	1.69	1.60-1.80
Outcome§						
	Alive	6674	530	909	1.72	1.62-1.81
	Dead	8	0.42	2.17	5.11	1.28-20.43
Vaccine details						
Timing‖	Earlier¶	3901	457	912	2.00	1.88-2.13
	Later¶	4463	609	912	1.50	1.41-1.59
Completeness‖	Two doses	5895	505	912	1.81	1.71-1.91
	One dose	2469	725	912	1.26	1.16-1.37
Specific type‖	Pfizer	5190	523	912	1.74	1.64-1.85
	Moderna	2718	558	912	1.63	1.51-1.77
	Other**	2138	528	912	1.73	1.56 tp 1.92
Validation analysis						
Eventual vaccination		6682	534	939	1.76	1.66-1.86
Propensity matched		2899	661	911	1.38	1.28-1.49
Other outcomes††						
COVID pneumonia		5358	303	1354	4.47	4.23-4.74
Constipation		2985	263	272	1.03	0.94-1.14
Fall		28,805	2598	2337	0.90	0.87-0.93
Water craft‡‡		462	40	44	1.10	0.87-1.40
Appendicitis		1164	101	115	1.14	0.98-1.32
Conjunctivitis		1677	149	150	1.01	0.89-1.15

*Risk is crash rate per million individuals.
†Calculated from logistic regression.
‡Morning 4 AM to 11:59 AM, afternoon 12 noon to 7:59 PM, night is remainder.
§Based on Canadian Triage Severity Score, higher is 1 or 2, lower is remainder.
‖Denotes control group for each sub-analysis based on first dose.
¶Earlier is prior to May 1, 2021, later is after May 1, 2021.
**AstraZeneca or Johnson & Johnson.
††Supplementary details in accompanying appendix.
‡‡Transportation incident on waterway not roadway.

aware of no past study testing COVID vaccination and traffic risks.

A limitation of our study is that correlation does not mean causality because our data do not explore potential causes of vaccine hesitancy or risky driving.[60] One possibility relates to a distrust of government or belief in freedom that contributes to both vaccination preferences and increased traffic risks.[61] A different explanation might be misconceptions of everyday risks, faith in natural protection, antipathy toward regulation, chronic poverty, exposure

to misinformation, insufficient resources, or other personal beliefs.[62] Alternative factors could include political identity, negative past experiences, limited health literacy, or social networks that lead to misgivings around public health guidelines.[63,64] These subjective unknowns remain topics for more research.

Another limitation of our study is the lack of direct data on driving exposure in different groups. A 100% increase in driving distance, however, is unlikely to explain the magnitude of traffic risks observed in this study.[65] A difference in driving distance would also not explain why the increased risks extended to pedestrians, why the increased risks were not lower in urban locations, and why the increased risks were not higher on weekends (when discretionary driving is common).[66] To be sure, physical factors such as vehicle speed and distance are controlled by the driver and part of the mechanism that ultimately results in a traffic crash. These physical unknowns do not change the importance of our study for estimating prognosis.

Our study has other limitations. The analysis does not correct for barriers in access to care or risk compensation that each bias results in the contrary direction.[67] The analysis does not include minor crashes that do not lead to emergency care or deaths at the scene prior to reaching the hospital (Appendix).[68] The data do not examine the long-term recovery, quality of life, and insurance costs for those who survive initial injuries. Many vehicle factors remain unexplored, including speed, spacing, configuration, location, weather, and distances driven. The study does not test the reliability of COVID vaccination as a proxy for COVID vaccine hesitancy. The available data do not examine long-term trends, test at-fault liability, or assess measurement error that biases results toward the null.[58] These uncertainties are further opportunities for future science.[10]

The current findings can help address 4 common misunderstandings.[69] We show the high numbers and the diverse profile of adults who are not vaccinated (Table 1), contrary to claims that COVID vaccine hesitancy is concentrated in men, in poverty, and in rural regions. We validate that vaccination is associated with large reductions in subsequent COVID pneumonia (Table 3), contrary to claims that industry-funded trials are misleading. We document that traffic crashes have continued unabated during the COVID pandemic (Figure 1), contrary to claims that social distancing would lead to fewer traffic fatalities or that one pandemic somehow might replace another. We verify that traffic crashes disproportionately involve those in poverty (Table 2), contrary to claims that traffic safety is unrelated to health disparities.

Our findings have direct relevance by highlighting how injury risks have continued despite the COVID pandemic.[70] Primary care physicians who wish to help patients avoid becoming traffic statistics, for example, could take the opportunity to stress standard safety reminders such as wearing a seatbelt, obeying speed limits, and never driving drunk.[1,71] The observed risks are sufficiently large that paramedics, emergency staff, and other first responders should be aware that unvaccinated patients are overrepresented in the aftermath of a traffic crash.[72,73] The observed risks might also justify changes to driver insurance policies in the future.[74] Together, the findings suggest that unvaccinated adults need to be careful indoors with other people and outside with surrounding traffic.

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References

1. Redelmeier DA, Yarnell CJ, Thiruchelvam D, Tibshirani RJ. Physicians' warnings for unfit drivers and the risk of trauma from road crashes. *N Engl J Med* 2012;367(13):1228–36.
2. National Highway Traffic Safety Administration. *Traffic Safety Facts 2019*. Washington, DC: US Department of Transportation; 2021. Available at: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813141 [Accessed June 9, 2022
3. Ontario Ministry of Transportation. *Ontario Road Safety Annual Report 2018*. Toronto: Government of Ontario; 2021. Available at: https://files.ontario.ca/mto-2/mto-orsar-2018-en-2021-11-18.pdf [Accessed June 9, 2022
4. Adavikottu A, Velaga NR. Analysis of factors influencing aggressive driver behavior and crash involvement. *Traffic Inj Prev* 2021;22(suppl 1):S21–6.
5. Redelmeier DA, Najeeb U, Etchells EE. Understanding patient personality in medical care: five-factor model. *J Gen Intern Med* 2021;36 (7):2111–4.
6. MacDonald NE, SAGE Working Group on Vaccine Hesitancy. Vaccine hesitancy: definition, scope and determinants. *Vaccine* 2015;33 (34):4161–4.
7. Dror AA, Eisenbach N, Taiber S, et al. Vaccine hesitancy: the next challenge in the fight against COVID-19. *Eur J Epidemiol* 2020;35 (8):775–9.
8. Dudley MZ, Privor-Dumm L, Dubé È, MacDonald NE. Words matter: vaccine hesitancy, vaccine demand, vaccine confidence, herd immunity and mandatory vaccination. *Vaccine* 2020;38(4):709–11.
9. Hershfield H, Brody I. How Elvis got Americans to accept the polio vaccine. *Scientific American*. January 18, 2021. Available at: https://www.scientificamerican.com/article/how-elvis-got-americans-to-accept-the-polio-vaccine/. Accessed June 9, 2022.
10. Sehgal NKR. Impact of Vax-a-Million Lottery on COVID-19 vaccination rates in Ohio. *Am J Med* 2021;134(11):1424–6.
11. Fineberg HV. Swine flu of 1976: lessons from the past. An interview with Dr Harvey V Fineberg. *Bull World Health Organ* 2009;87 (6):414–5.
12. Nisbett RE, Wilson TD. Telling more than we can know: verbal reports on mental processes. *Psychol Rev* 1977;84(3):231–59.
13. Hall L, Johansson P, Strandberg T. Lifting the veil of morality: choice blindness and attitude reversals on a self-transforming survey. *PLoS One* 2012;7(9):e45457.
14. Krumpal I. Determinants of social desirability bias in sensitive surveys: a literature review. *Qual Quant* 2013;47:2025–47.
15. Lambooij MS, Harmsen IA, Veldwijk J, et al. Consistency between stated and revealed preferences: a discrete choice experiment and a

behavioural experiment on vaccination behaviour compared. *BMC Med Res Methodol* 2015;15:19.
16. Arena R, Pronk NP, Laddu D, et al. Mapping one million COVID-19 deaths and unhealthy lifestyle behaviors in the United States: recognizing the syndemic pattern and taking action. *Am J Med* 2022;135 (11):1288–95.
17. Murphy J, Vallières F, Bentall RP, et al. Psychological characteristics associated with COVID-19 vaccine hesitancy and resistance in Ireland and the United Kingdom. *Nat Commun* 2021;12(1):29.
18. Redelmeier DA, Shafir E. Pitfalls of judgment during the COVID-19 pandemic. *Lancet Public Health* 2020;5(6):e306–8.
19. Forchette L, Sebastian W, Liu T. A comprehensive review of COVID-19 virology, vaccines, variants, and therapeutics. *Curr Med Sci* 2021;41(6):1037–51.
20. Norris FH, Matthews BA, Riad JK. Characterological, situational, and behavioral risk factors for motor vehicle accidents: a prospective examination. *Accid Anal Prev* 2000;32(4):505–15.
21. Shrank WH, Patrick AR, Brookhart MA. Healthy user and related biases in observational studies of preventive interventions: a primer for physicians. *J Gen Intern Med* 2011;26(5):546–50.
22. Rosenbaum L. Escaping Catch-22 — overcoming Covid vaccine hesitancy. *N Engl J Med* 2021;384(14):1367–71.
23. Fendrich SJ, Balachandran M, Patel MS. Association between behavioral phenotypes and sustained use of smartphones and wearable devices to remotely monitor physical activity. *Sci Rep* 2021;11(1):21501.
24. Government of Ontario. Ontario demographic quarterly: highlights of first quarter. 2021. Available at: https://www.ontario.ca/page/ontario-demographic-quarterly-highlights-first-quarter. Accessed June 9, 2022.
25. Ipsos. Global attitudes on a COVID-19 vaccine. World Economic Forum, 2021. Available at: https://www.ipsos.com/en-ca/global-attitudes-covid-19-vaccine-january-2021. Accessed June 9, 2022.
26. Tang X, Gelband H, Nagelkerke N, et al. COVID-19 vaccination intention during early vaccine rollout in Canada: a nationwide online survey. *Lancet Reg Health Am* 2021;2:100055.
27. Government of Canada. Canada's COVID-19 vaccine supply and donation strategy. 2021. Available at: https://www.canada.ca/en/public-health/services/diseases/coronavirus-disease-covid-19/vaccines/supply-donation.html. Accessed June 9, 2022.
28. Government of Ontario. COVID-19 Vaccine Distribution Plan. 2021. Available at: https://files.ontario.ca/moh-covid-19-vaccine-distribution-plan-en-2021-02-19.pdf. Accessed June 9, 2022.
29. Government of Canada. Drug and vaccine authorizations for COVID-19: List of authorized drugs, vaccines and expanded indications. 2022. Available at: https://www.canada.ca/en/health-canada/services/drugs-health-products/covid19-industry/drugs-vaccines-treatments/authorization/list-drugs.html. Accessed June 9, 2022.
30. ICES. ICES COVID-19 Dashboard. 2021. Available at: https://www.ices.on.ca/DAS/AHRQ/COVID-19-Dashboard. Accessed June 9, 2022.
31. Iron K, Zagorski BM, Sykora K, Manuel DG. *Living and Dying in Ontario: An Opportunity for Improved Health Information*. Toronto: Institute for Clinical Evaluative Sciences; 2008 [ICES Investigative Report.
32. Public Health Ontario. Surveillance report: COVID-19 vaccine uptake in Ontario: December 14, 2020 to May 23, 2022. [Page 5]. Available at: https://www.publichealthontario.ca/-/media/documents/ncov/epi/covid-19-vaccine-uptake-ontario-epi-summary.pdf?la=en. Accessed June 9, 2022.
33. Williams JI, Young W. A summary of studies on the quality of health care administrative databases in Canada:eds. In: Goel V, Williams JI, Anderson GM, Blackstien-Hirsch P, Fooks C, Naylor CD, eds. *Patterns of Health Care in Ontario: The ICES Practice Atlas*, Ottawa: Canadian Medical Association; 1996:339–45.
34. eds. In: Tu JV, Penfold SP, McColgan P, Laupacis A, eds. *Access to Health Services in Ontario: ICES Atlas*, Toronto: Institute for Clinical Evaluative Sciences; 2006.
35. Juurlink D, Preyra C, Croxford R, et al. *Canadian Institute for Health Information Discharge Abstract Database: a validation study*. Toronto: Institute for Clinical Evaluative Sciences; 2006.
36. Chung H, He S, Nasreen S, et al. Effectiveness of BNT162b2 and mRNA-1273 covid-19 vaccines against symptomatic SARS-CoV-2 infection and severe covid-19 outcomes in Ontario, Canada: test negative design study. *BMJ* 2021;374:n1943.
37. Leung G, Verma A. Epidemiological study of COVID-19 fatalities and vaccine uptake: insight from a public health database in Ontario, Canada. *Cureus.* 2021;13(7):e16160.
38. Yarnell CJ, Thiruchelvam D, Redelmeier DA. Risks of serious injury with testosterone treatment. *Am J Med* 2021;134(1):84–94.e6.
39. Redelmeier DA, Ng K, Thiruchelvam D, Shafir E. Association of socioeconomic status with medical assistance in dying: a case-control analysis. *BMJ Open* 2021;11(5):e043547.
40. Government of Ontario. Medical services — claims history database. Ontario Ministry of Health and Long-Term Care, IntelliHEALTH ONTARIO. Available at: https://intellihealth.moh.gov.on.ca/. Accessed June 9, 2022.
41. Macpherson AK, Schull M, Manuel D, Cernat G, Redelmeier DA, Laupacis A. *Injuries in Ontario: ICES Atlas*. Toronto: Institute for Clinical Evaluative Sciences; 2005.
42. World Health Organization. *International Statistical Classification of Diseases and Related Health Problems*. Geneva, Switzerland: World Health Organization; 2010.
43. Redelmeier DA, Tien HC. Medical interventions to reduce motor vehicle collisions. *CMAJ* 2014;186(2):118–24.
44. Sehgal AR. Lifetime risk of death from firearm injuries, drug overdoses, and motor vehicle accidents in the United States. *Am J Med* 2020;133(10):1162–1167.e1.
45. Schull MJ, Hatcher CM, Guttmann A, et al. *Development of a Consensus on Evidence-Based Quality of Care Indicators for Canadian Emergency Departments. ICES Investigative Report*. Toronto: Institute for Clinical Evaluative Sciences; 2010.
46. Canadian Institute for Health Information (CIHI). *CIHI Data Quality Study of Emergency Department Visits for 2004-2005: volume II of IV: Main Study Findings*. Ottawa: CIHI; 2008.
47. Bullard MJ, Musgrave E, Warren D, et al. Revisions to the Canadian Emergency Department Triage and Acuity Scale (CTAS) guidelines 2016. *CJEM* 2017;19(S2):S18–27.
48. Scales DC, Guan J, Martin CM, Redelmeier DA. Administrative data accurately identified intensive care unit admissions in Ontario. *J Clin Epidemiol* 2006;59(8):802–7.
49. Wodchis WP, Bushmeneva K, Nikitovic M, McKillop I. *Guidelines on Person-Level Costing Using Administrative Databases in Ontario*. Toronto, Canada: Health System Performance Research Network; 2013 [Working Paper Series. Volume 1.
50. Wodchis WP, Austin PC, Henry DA. A 3-year study of high-cost users of health care. *CMAJ* 2016;188(3):182–8.
51. Prasad V, Jena AB. Prespecified falsification end points: can they validate true observational associations? *JAMA* 2013;309(3):241–2.
52. Evans L. *Traffic Safety*. Bloomfield Hills, Mich: Science Serving Society; 2004.
53. Nabi H, Rachid Salmi L, Lafont S, Chiron M, Zins M, Lagarde E. Attitudes associated with behavioral predictors of serious road traffic crashes: results from the GAZEL cohort. *Inj Prev* 2007;13(1):26–31.
54. Nunn J, Erdogan M, Green RS. The prevalence of alcohol-related trauma recidivism: a systematic review. *Injury* 2016;47(3):551–8.
55. Tillmann WA, Hobbs GE. The accident-prone automobile driver; a study of the psychiatric and social background. *Am J Psychiatry* 1949;106(5):321–31.
56. Gulliver P, Begg D. Personality factors as predictors of persistent risky driving behavior and crash involvement among young adults. *Inj Prev* 2007;13(6):376–81.
57. Cheng ASK, Ng TCK, Lee HC. A comparison of the hazard perception ability of accident-involved and accident-free motorcycle riders. *Accid Anal Prev* 2011;43(4):1464–71.

58. Redelmeier DA, Yarnell CJ. Lethal misconceptions: interpretation and bias in studies of traffic deaths. *J Clin Epidemiol* 2012;65(5):467–73.
59. Brown TG, Ouimet MC, Eldeb M, et al. Personality,executive control, and neurobiological characteristics associated with different forms of risky driving. *PLoS One* 2016;11(2):e0150227.
60. Bullock J, Lane JE, Shults FL. What causes COVID-19 vaccine hesitancy? Ignorance and the lack of bliss in the United Kingdom. *Humanit Soc Sci Commun* 2022;9(1):1–7.
61. Kirzinger A, Sparks G, Brodie M. KFF COVID-19 vaccine monitor: in their own words, six months later. Kaiser Family Foundation, July 13, 2021. Available at: https://www.kff.org/coronavirus-covid-19/poll-finding/kff-covid-19-vaccine-monitor-in-their-own-words-six-months-later/. Accessed June 9, 2022.
62. Rosenbaum L. No cure without care — soothing science skepticism. N Engl J M*ed* 2021;384(15):1462–5.
63. Johnson NF, Velásquez N, Restrepo NJ, et al. The online competition between pro- and anti-vaccination views. *Nature* 2020;582(7811):230–3.
64. Angus Reid Institute. Dwindling group of unvaccinated cite 'personal freedom' and 'health concerns' as main reasons for dodging the jab. November 3, 2021. Available at: https://angusreid.org/canada-unvaccinated-freedom-reasons/. Accessed June 9, 2022.
65. Redelmeier DA. The fallacy of interpreting deaths and driving distances. *Med Decis Making* 2014;34(8):940–3.
66. Redelmeier DA, Zipursky JS. Pedestrian deaths during the COVID-19 pandemic [online ahead of print]. *Am J Lifestyle Med*. Published online November 26, 2021. Available at: https://journals.sagepub.com/doi/10.1177/15598276211058378. Accessed November 15, 2022.
67. Trogen B, Caplan A. Risk compensation and COVID-19 vaccines. *Ann Intern Med* 2021;174(6):858–9.
68. Rojas Castro MY, Orriols L, Basha Sakr D, et al. A web-based prospective cohort study of home, leisure, school and sports injuries in France: a descriptive analysis. *Inj Epidemiol* 2021;8(1):50.
69. Hitti FL, Weissman D. Debunking mRNA Vaccine Misconceptions-An Overview for Medical Professionals. *Am J Med* 2021;134(6):703–4.
70. National Highway Traffic Safety Administration. Early estimate of motor vehicle traffic fatalities in 2020. Washington DC: United States Department of Transportation. Available at: https://www.nhtsa.gov/press-releases/2020-fatality-data-show-increased-traffic-fatalities-during-pandemic. Accessed June 9, 2022.
71. Redelmeier DA, McLellan BA. Modern medicine is neglecting road traffic crashes. *PLoS Med* 2013;10(6):e1001463.
72. Bledsoe BE, Sweeney RJ, Berkeley RP, Cole KT, Forred WJ, Johnson LD. EMS provider compliance with infection control recommendations is suboptimal. *Prehosp Emerg Care* 2014;18(2):290–4.
73. Prezant DJ, Zeig-Owens R, Schwartz T, et al. Medical leave associated with COVID-19 among emergency medical system responders and firefighters in New York City. *JAMA Netw Open* 2020;3(7):e2016094.
74. Weisburd S. Identifying moral hazard in car insurance contracts. *Rev Econ Stat* 2015;97(2):301–13.

SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amjmed.2022.11.002.

APPENDIX: COVID VACCINE HESITANCY AND RISK OF A TRAFFIC CRASH

Table of Contents:

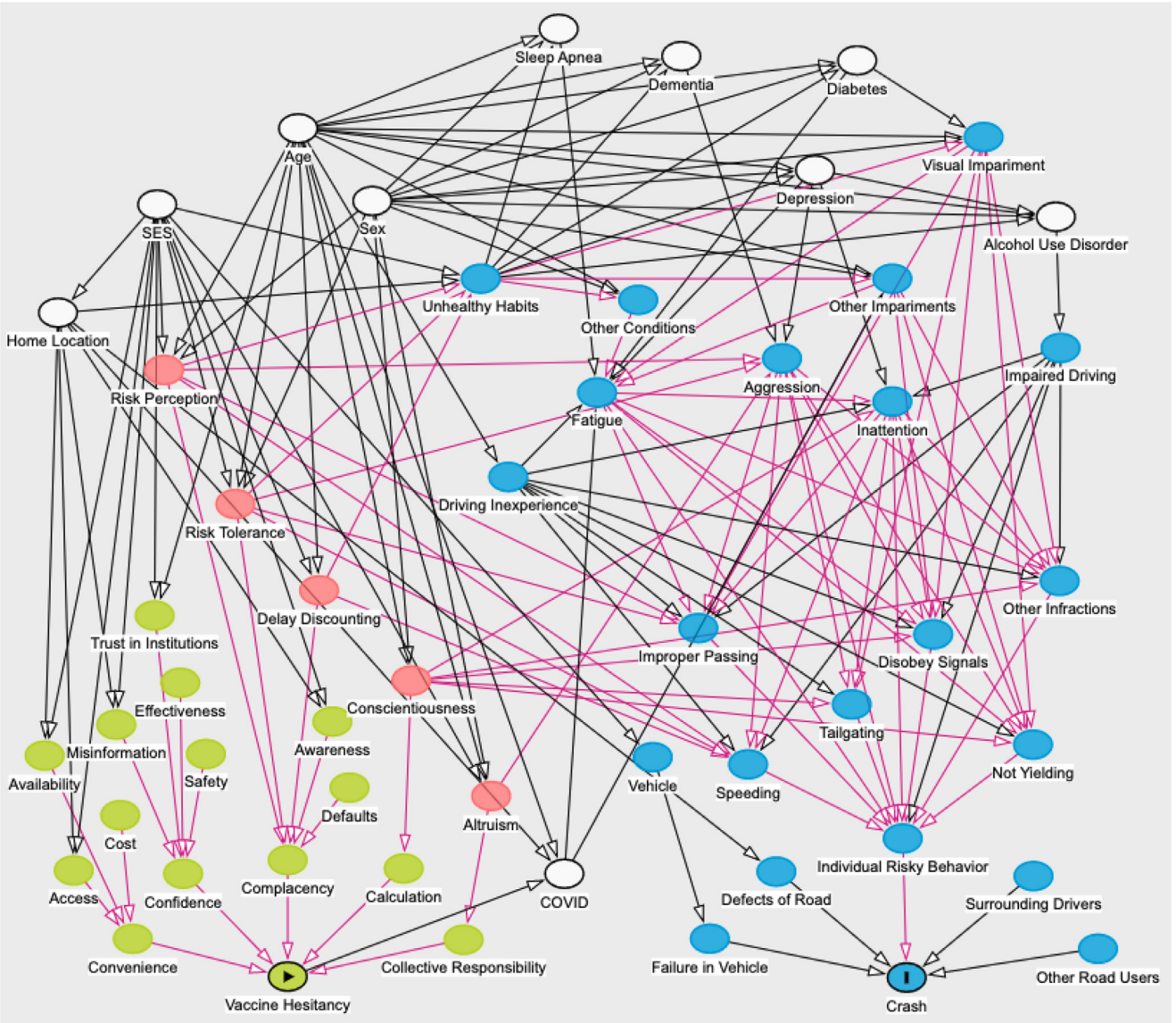
§1 Research in Context

Evidence prior to this study: We searched MEDLINE, PsychInfo, Scopus, and Google Scholar on December 31, 2021 with no language or date restrictions. The search terms for MEDLINE were ("vaccines" OR "immunization") AND ("traffic accidents" OR "automobile driving"). The search terms for other databases were adapted as appropriate (details on request). Only 3 surveys examined the association of vaccination with traffic crash risks. One survey (n = 104,594) correlated previous influenza vaccinations with driving safety and detected a significant inverse association (individuals who had not received an influenza vaccination were 15% more likely to report risky driving). Two other survey studies (n = 348 and n = 654) assessed general attitudes toward public health and also found clustering of risks (individuals who reported risk-taking tendencies were 39% less likely to be coronavirus disease (COVID) vaccinated and 41% less likely to follow COVID public health instructions). No studies used validated longitudinal analysis to compare objective vaccination status with actual traffic crash risks.

Added value of this study: This is the first population-based longitudinal cohort study to examine an adult's COVID vaccination status and subsequent traffic crash risk. The analysis of over 10 million adults found the risk of a serious traffic crash was significantly higher for adults who had not received a COVID vaccine compared with adults who had received a COVID vaccine. The increased traffic risk associated with COVID vaccine hesitancy persisted in relevant subgroups stratifying for age, sex, home location, socioeconomic status, medical diagnoses, and access to care. The relative risk was similar to the relative risk associated with sleep apnea, less than the risk associated with alcohol misuse, and greater than the risk associated with diabetes. The increased risk was primarily explained by events when driving at night. The increased risk extended across differing degrees of crash severity, was more prominent in analyses based on 2 doses rather than 1 dose, and similar for the Pfizer, Moderna, or other COVID vaccines.

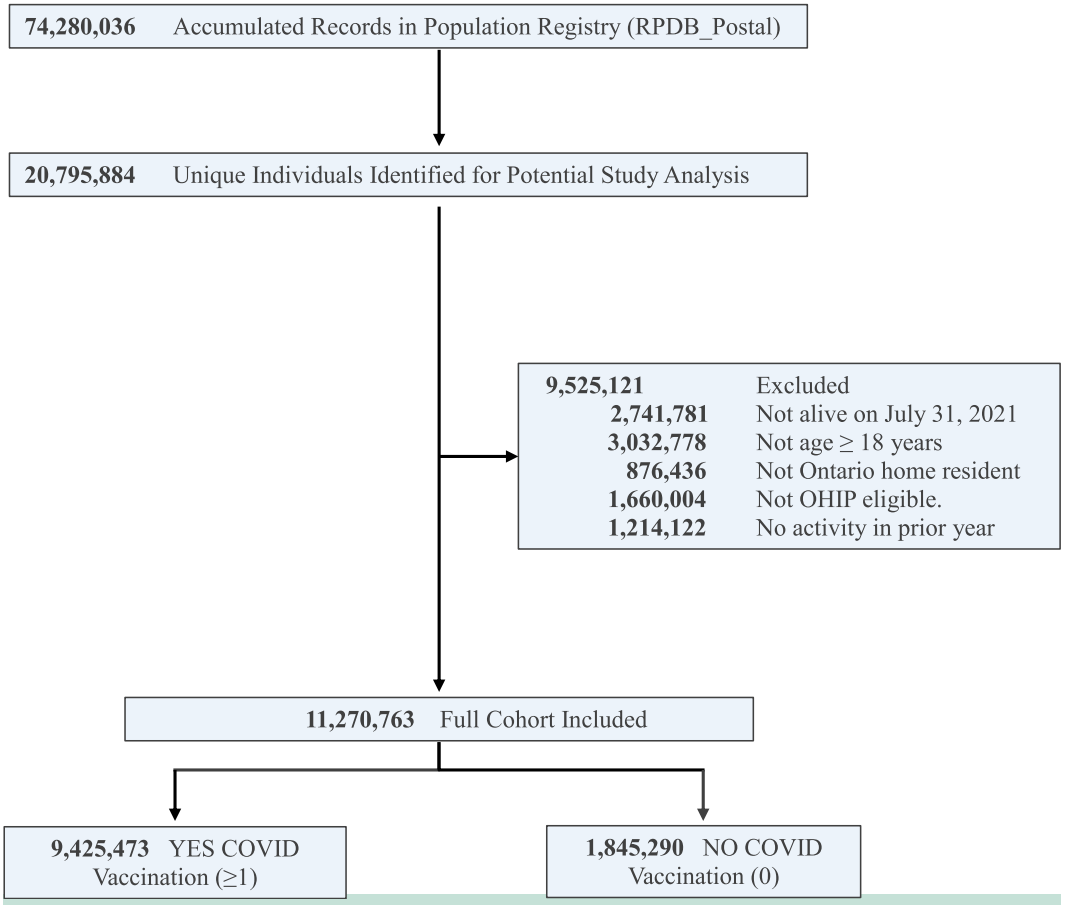
Implications of all available evidence: COVID vaccine hesitancy is associated with an increased risk of a traffic crash. A direct effect from immunization is unlikely; instead, diverse psychological factors contribute to vaccine willingness and driving safety (eg, both entail inconveniences advocated by authorities to protect the community). Traffic crashes have continued during the COVID pandemic, implying that physicians have a responsibility to counsel at-risk patients in primary care. In addition, COVID vaccine status might be considered for regions that prioritize road safety, such as those that mandate physicians to warn risky drivers and report to vehicle licensing agencies. Prehospital care providers need to also be aware that unvaccinated adults are overrepresented in the aftermath of a traffic crash, thereby justifying maintaining adherence to COVID precautions at the frenzied crash scene. In addition, the clustering of risks imposed on others might indirectly promote new strategies to promote COVID vaccination.

§2 Directed Acyclic Graph



Footnote: Directerd Acyclic Graph of possible causal pathways relevant to vaccine hesitancy and traffic risks. The diagram displays measured factors (white), unmeasured ancestors of vaccine hesitancy (green), unmeasured ancestors of traffic risks (blue), and unmeasured ancestors to both vaccine hesitancy and traffic risks (pink). Causal pathways denoted as closed (black lines) or open (magenta lines). Specific causal pathways based on literature review, direct clinical experience (Canada's largest trauma center), and expert consultation (International Traffic Medicine Association).

§3 Description of Patient Flows



OHIP = Ontario Health Insurance Plan.

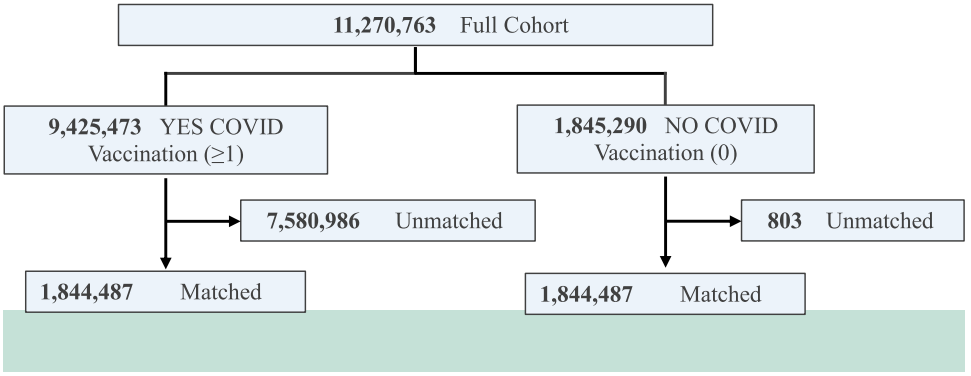
§4 Additional Negative Controls

	ICD 10 Codes	Total Events
Positive Control		
COVID pneumonia	U07	5358
Negative Control		
Constipation	K95	2985
Falls	W00 to W19	28,805
Appendicitis	K35 to K38	1164
Conjunctivitis	H10 to H13	1677
Water transportation	V90 to V94	462

COVID = coronavirus disease; ICD = International Classification of Diseases.

§5 Additional Propensity Score Analyses: General and Stringent

The purpose of the first propensity score analysis was to retain a large sample size when matching an unvaccinated individual 1-to-1 with a vaccinated individual and accounting for baseline demographic characteristics and individual diseases.

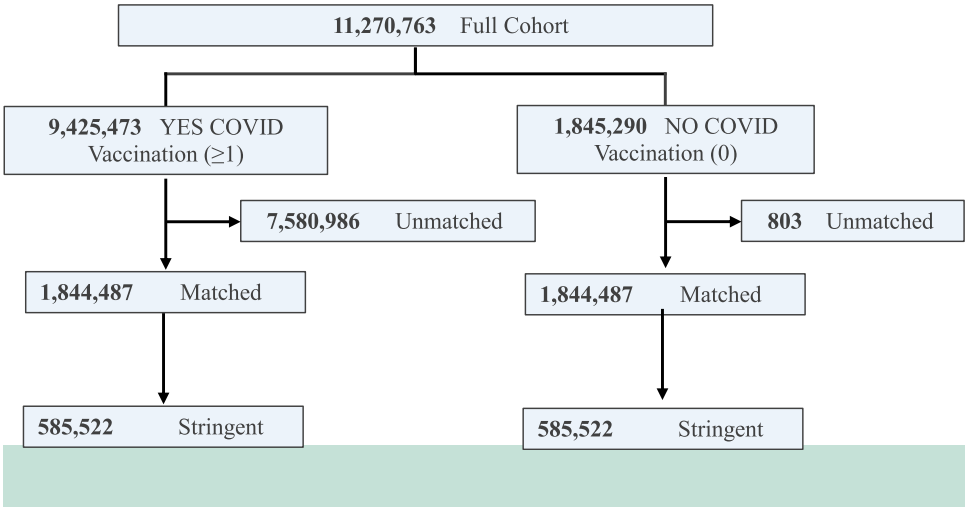


Analysis of General Matched Cohort Pairs

		Unvaccinated Control	
		YES CRASH	NO CRASH
Vaccinated Individual	YES CRASH	3	1216
	NO CRASH	1677	1,841,591

Total individuals = 3,688,974; total pairs = 1,844,487; total crashes = 2899; odds ratio = 1.38; 95% confidence interval, 1.28-1.44; *P*-value < 0.001.

The purpose of the second propensity score analysis was to be stringent when matching an unvaccinated individual 1-to-1 with a vaccinated individual and excluding cases where any person had a medical diagnosis.



Analysis of Stringent Matched Cohort Pairs

		Unvaccinated Control	
		YES CRASH	NO CRASH
Vaccinated individual	YES CRASH	X	42X
	NO CRASH	68X	584,41X

"X" denotes single digit suppression for privacy regulations; total individuals = 1,171,044; total pairs = 585,522; total crashes = 1111; odds ratio = 1.63; 95% confidence interval, 1.45-1.85; *P*-value < 0.001.

§6 Additional Stratified Analysis

	Total Events	Risk with Vaccine*	Risk with No Vaccine*	Relative Risk†	Confidence Interval
Primary analysis	6682	530	912	1.72	1.63-1.82
Health care‡					
Clinic contacts ≥3	4620	562	975	1.74	1.62-1.86
Clinic contacts ≤2	2062	468	814	1.74	1.58-1.92
Emergency visit yes	2298	834	1515	1.82	1.67-1.99
Emergency visit no	4384	454	702	1.55	1.44-1.66
Hospital admit yes	363	582	793	1.36	1.07-1.74
Hospital admit no	6319	528	919	1.74	1.65-1.84

*Risk is crash rate per million individuals.
†Calculated from logistic regression.
‡Based on previous year.

§7 Accounting for Scene Deaths

The study examined serious traffic crashes based on emergency care throughout the region and thereby did not include deaths at the scene. In turn, we considered extreme assumptions to examine how results might change based on these missing deaths. Specifically, traffic statistics for this setting (602 total deaths in Ontario, 2018) suggested that 50 total deaths might have occurred in our study during follow-up (602/12). Taking into account the 8 deaths that were included, therefore, we estimated potentially 42 total deaths at the scene (50−8).

Making an extreme assumption and assigning all these deaths to the vaccinated group yielded minimal changes to final results. In particular, the observed event count increased from a total of 5000 crashes to 5042 crashes, equivalent to an absolute risk of 535 per million (rather than 530 per million). This observed absolute risk was still substantially lower than the observed risk of 912 per million in the unvaccinated group. These results suggested that extreme assumptions about the deaths at the scene make minimal difference to final estimates of relative risk.

§8 Accounting for Later Vaccinations

The study examined vaccination status based on records on July 31, 2021 and did not include possible later vaccination that might have eventually occurred. In turn, we retrieved information on these subsequent vaccinations and considered extreme assumptions to examine how results might change based on the crossover cases. Specifically, we found 219,740 individuals who were eventually vaccinated from the cohort of 1,8450,290 who had been classified as unvaccinated. These individuals accounted for 155 total traffic crashes during follow-up.

Making an extreme assumption and assigning all individuals to the vaccinated group yielded minimal changes to final results. In particular, the observed event count increased from a total of 5000 crashes to 5155 crashes, equivalent to an absolute risk of 534 per million (rather than 530 per million). This observed absolute risk was still substantially lower than the recalculated risk of 939 per million in the unvaccinated group. These results suggested that extreme assumptions about possible eventual vaccination during follow-up make minimal difference to final estimates of relative risk.