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Risk of premature mortality due to smoking, alcohol use, obesity and physical activity varies by income: A population-based cohort study

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ABSTRACT

Background: Premature deaths are a strong population health indicator. There is a persistent and widening pattern of income inequities for premature mortality. We sought to understand the combined effect of health behaviours and income on premature mortality in a large population-based cohort.

Methods: We analyzed a cohort of 121,197 adults in the 2005–2014 Canadian Community Health Surveys, linked to vital statistics data to ascertain deaths for up to 5 years following baseline. Information on household income quintile and mortality-relevant risk factors (smoking status, alcohol use, body mass index (BMI), and physical activity) was captured from the survey. Hazard ratios (HR) for combined income-risk factor groups were estimated using Cox proportional hazards models. Stratified Cox models were used to identify quintile-specific HR for each risk factor.

Results: For each risk factor, HR of premature mortality was highest in the lowest-income, highest-risk group. Additionally, an income gradient was seen for premature mortality HR for every exposure level of each risk factor. In the stratified models, risk factor HRs did not vary meaningfully between income groups. All findings were consistent in the unadjusted and adjusted models.

Conclusion: These findings highlight the need for targeted strategies to reduce health inequities and more careful attention to how policies and interventions are distributed at the population level. This includes targeting and tailoring resources to those in lower income groups who disproportionately experience premature mortality risk to prevent further widening health inequities.

1. Background

The most prominent and prevalent risk factors that impact population health include smoking, obesity, physical inactivity, and unhealthy alcohol consumption. These risk factors are some of the most prevalent unhealthy behaviours in Canada and other high-income countries and hence are the focus of most chronic disease prevention strategies (Bauer, Briss, Goodman, & Bowman, 2014; Ng, Freeman, & Fleming, 2014; Stringhini et al., 2017). Several studies have shown how these risk factors influence overall, premature and amenable mortality (deRuiter, Cairney, Leatherdale, & Faulkner, 2016; Hallal et al., 2012; Ng, Fleming, et al., 2014; Ng, Freeman, & Fleming, 2014; Rosella et al., 2019). Because of their well-recognized influence on population health outcomes (Flegal, Kit, Orpana, & Graubard, 2013; Muller et al., 2016; Thun et al., 2013) they are a target for public health. Interventions and policies that improve these health behaviours reduce the risk of all-cause and premature mortality as well as the incidence of major chronic disease (Khaw et al., 2008; Loef & Walach, 2012; Manuel et al., 2016).

Disparities related to income and other indicators of socioeconomic position (SEP) are well established for population health outcomes and, specifically premature mortality. Studies consistently show that individuals with lower SEP are more likely to die prematurely than those with higher SEP (Buajitti, Frank, Watson, Kornas, & Rosella, 2020). In addition, recent studies have shown that income and SEP-related inequities in premature mortality are widening in several countries in North America and Europe (Bor, Cohen, & Galea, 2017; Hajizadeh,

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Mitnitski, & Rockwood, 2016; Krieger et al., 2008; Mackenbach et al., 2016). In Canada, income inequalities in premature mortality have widened dramatically in recent decades, and declines in premature mortality over time may have stalled or even reversed in the most disadvantaged groups (Shahidi, Parnia, & Siddiqi, 2020a). These mortality inequalities have been linked to unequal access to health care services and public health interventions and underlying inequalities in health status and mortality risk factors.

Health behaviours, including smoking, obesity, physical inactivity, and unhealthy alcohol consumption, are highly implicated in these trends. Health behaviours vary considerably by SEP, and have been the target of extensive public health and health system efforts (Hiscock, Bauld, Amos, Fidler, & Munafò, 2012a, 2012b). For example, tobacco control policies have made remarkable progress at reducing both the prevalence of smoking and frequency of use and Canada has lower smoking rates than other high-income countries, including the US; however, these improvements have been concentrated among highly educated groups (Corsi et al., 2014; Reid, Hammond, & Driezen, 2010).

Widening socioeconomic inequalities in mortality risk factors are cause for major concern, particularly since income inequality in Canada continues to rise (Heisz, 2016). While income inequality in Canada is lower than in the US, it is behind many other OECD countries. Since the 1980s, poverty and income inequality have continued to increase as social assistance and housing affordability lag behind wage growth, with dangerous consequences for social determinants of health (Bryant, Raphael, Schrecker, & Labonté, 2010).

While it is well recognized that efforts to improve population health must address both socioeconomic disparities and promote healthy behaviour, it is less clear how these factors intersect. Therefore, the objective of this study is to examine how the major risk factors, smoking, obesity, unhealthy alcohol consumption, and physical activity, vary according to income among a large population-based cohort linked to a single health system.

We draw upon two conceptual frameworks to conceptualize this project and to guide our analyses and interpretation. The first is the World Health Organization (WHO) Social Determinant of Health Framework (World Health Organization, 2008), which articulates how a wide range of social and economic factors, including education, income, employment, housing, and social support networks, influence health outcomes. The second is the ecosocial model of health (Krieger, 2001), which postulates that multiple factors shape behaviours and health at many levels of influence from the inter/intrapersonal, extending toward institutions, communities, and overarching policy. Interpreting the joint impact of income and risk factors on premature mortality involves recognizing both theoretical constructs. Importantly, this framing allows us to consider the effects of risk factors in the context of income gradients; by considering these features together, we can more comprehensively understand the distribution of premature mortality risk in the population and better understand where intervention may be needed to mitigate premature mortality inequalities and support progress towards improved population health.

2. Methods

2.1. Study population

Our study population was made up of respondents to the Canadian Community Health Survey (CCHS), a cross-sectional survey of community-dwelling Canadian residents. The CCHS survey methodology has been described in detail elsewhere (Beland, 2002). In summary, the CCHS program consists of a repeated cross-sectional survey conducted in 2-year interview cycles. A combination of stratified cluster sampling (of households) and random digit dialling is used to identify survey households from which individual respondents are randomly selected. These respondents answer questions about their sociodemographic characteristics, health status and well-being, health-relevant behaviours, and health care utilization and need. Statistics Canada provides survey weights with CCHS data such that the weighted CCHS respondent population for each 2-year survey cycle is representative of 98% of non-institutionalized Canadian residents aged 12 or older.

Survey responses were linked to health administrative data from Ontario's single-payer health insurance program (OHIP) using unique encoded identifiers and analyzed at ICES, an independent, non-profit research institute authorized to collect and use Ontario health care data for health system evaluation and improvement. We included CCHS respondents in our study population if they participated in the CCHS between January 1, 2005 and December 31, 2014, were between the ages of 18 and 69 at the interview date, and consented to have their responses linked to health administrative data for follow-up. Overall consent rates are high, at approximately 85% across cycles, and CCHS sampling weights (which we used) account for non-consenters as well as non-response (Sanmartin et al., 2016). We excluded respondents who had been captured by a previous CCHS cycle, to prevent duplicate responses. We also excluded those who could not be linked at ICES or had irreconcilable data inconsistencies (e.g., death date prior to interview date).

To create our study cohort, we pooled CCHS respondents across the five survey cycles captured (2005/06 to 2013/14). To account for this pooling, we restricted it to first-time respondents, normalized the Statistics Canada survey weights to account for aggregation, and adjusted it for the survey cycle in all regression analyses.

2.2. Variables

Sociodemographic information were captured from CCHS responses and the linked health administrative data and were chosen according to the socio-ecological model of health (Krieger, 2001). Specifically, age group and sex were captured from the Registered Persons' Database, a population registry based on health card information for Ontario residents eligible for OHIP at any point since 1992. Marital status (married/common law or other), education (less than secondary, secondary, or more than secondary school), immigration status (recent immigrant (<10 years), long-term immigrant (10+ years), or Canadian-born), and household income quintile were based on self-reported information from the CCHS survey. The neighbourhood income quintile was derived by linking self-reported postal code information to income information from the nearest-year Canadian census at the Dissemination Area level. The selection of our socioeconomic variables was also informed by the World Health Organization (WHO) Social Determinant of Health Framework (World Health Organization, 2008).

The main risk factors of focus were identified using self-reported CCHS data. Smoking status was categorized as heavy (1+ packs per day), light (<1 pack per day), former heavy, former light, and non-smoker. Alcohol use was derived using sex-specific cutoffs based on the number of drinks consumed weekly; categories used included heavy (>22 drinks per week for males, >15 for females), moderate (4–21 per week for males, 3–14 for females), light (1–3 for males, 1–2 for females), and non-drinker (no drinks in the past 12 months). Body mass index (BMI) was calculated from self-reported weight and height and categorized into underweight (<18.5 kg/m^2), normal weight (18.5–24.9), overweight (25–29.9), and obese (30+). Physical activity level was measured based on energy expenditures associated with self-reported leisure time activities and categorized into inactive (<1.5 kcal per kg per day), moderately active (1.5–3 kcal per kg per day), and active (>3 kcal per kg per day) groups. We also captured self-reported health (excellent, very good, good, fair, or poor) from the CCHS questionnaire. We used mode imputation to fill in missing values for risk factors.

CCHS respondents were followed up for premature mortality for up to 5 years from the interview date. Deaths were identified using vital statistics information from RPDB. The age cutoff of 75 for premature mortality is consistent with the accepted definition used in Canada (Buajitti et al., 2019; Shahidi, Parnia, & Siddiqi, 2020b).

2.3. Statistical analysis

We calculated descriptive statistics for all cohort characteristics (sociodemographic and risk factors) by premature mortality status and the cohort overall. We also calculated risk factor prevalence by household income quintile.

To assess the joint effects of household income group and risk factors, we used Cox proportional hazards models to estimate hazard ratios (HR) for 5-year premature mortality. Cox models used time since survey interview as the time scale; censoring took place at death, age 75 birthday, or 5 years since CCHS interview date.

To limit the number of joint exposure categories while preserving meaningful differences between groups, we collapsed income quintiles into three household income categories: low income (quintile 1), middle income (quintiles 2 and 3), and high income (quintiles 4 and 5). We then created joint exposure variables with every combination of household income and each risk factor category (i.e. income and smoking, income and alcohol, income and BMI, and income and physical activity). We included the joint exposure variables in separate unadjusted and adjusted Cox models to quantify joint effects separately for each risk factor. Adjusted models included age group, sex, and CCHS cycle.

We also used the joint exposure groups to create survival plots of 5-year premature mortality for combined income-risk factor categories.

All analyses were based on the weighted CCHS population, which uses complex survey weights to account for the sampling design of the CCHS and results in a population-representative sample. Confidence intervals for hazard ratios were estimated using balanced repeated replication on CCHS bootstrap weights (n = 500) provided by Statistics Canada (Thomas & Wannell, 2009).

2.4. Supplementary analyses

We conducted several supplementary analyses to more comprehensively describe the associations between risk factors, income, and premature mortality. First, we fit stratified Cox models for each risk factor by household income quintile to assess the independent effects of risk factors across income groups. Models were used to estimate unadjusted and adjusted hazard ratios for each income quintile and the study cohort. As before, adjusted models included age group, sex, and CCHS cycle. Additionally, we fit an income-adjusted Cox model in the pooled (unstratified) cohort, adjusting for age group, sex, CCHS cycle, and household income quintile. For all Cox models, the proportional hazards assumption was assessed based on visual inspection of Schoenfeld residual plots (Hess, 1995).

We also stratified our primary (joint effects) models by sex to ascertain whether associations between income, risk factors, and premature mortality differed between males and females.

Finally, we conducted two sensitivity analyses to see whether our

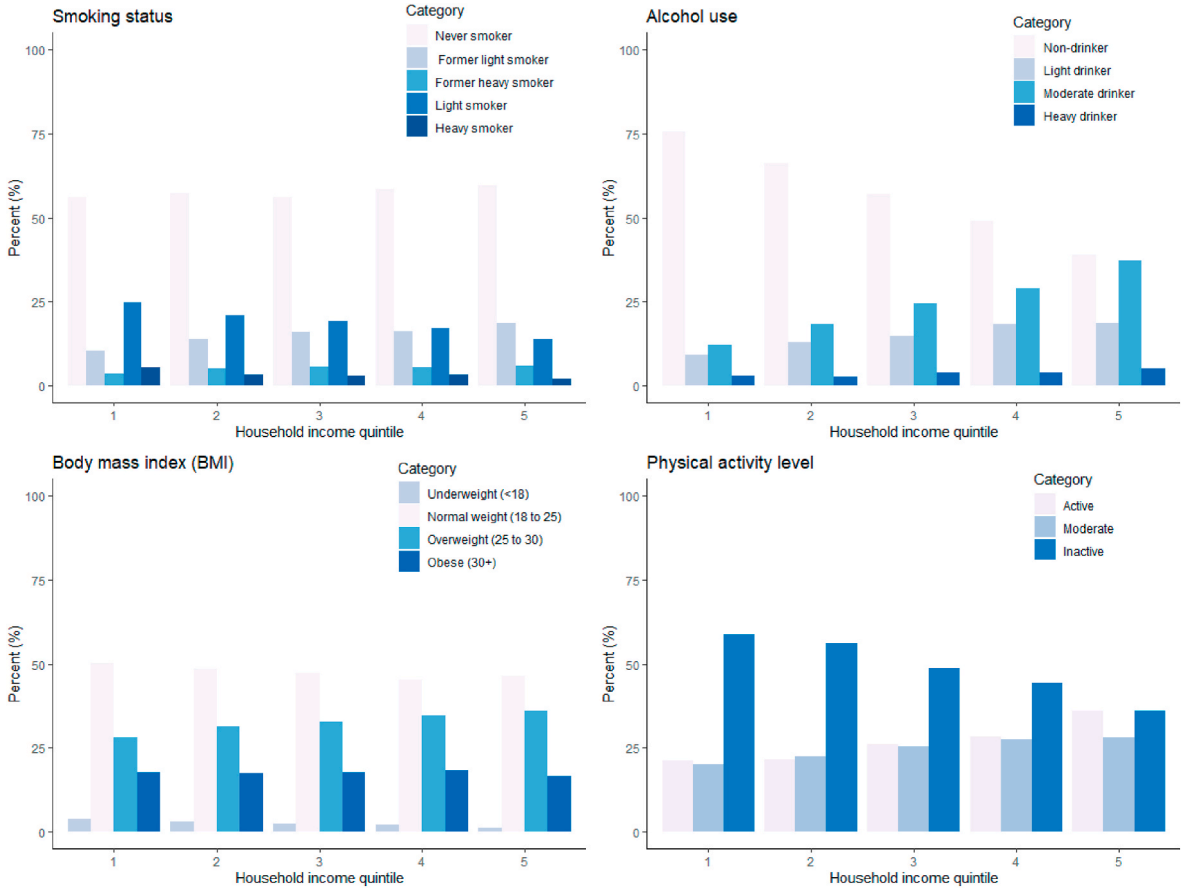

Fig. 1. Prevalence (weighted %[1]) of smoking[2], alcohol use[3], body mass index (BMI)[4] and physical activity[5] by household income quintile, Ontario CCHS respondents 2005 to 2014 (unweighted n = 121,197).

[1]Weighted using survey weights provided by Statistics Canada.

[2]Heavy smoking defined as 1 or more packs per day; light smoking <1 pack per day.

[3]For males, heavy drinking defined as >22 per week; moderate drinking 4–21 drinks per week; light drinking 1–3 drinks per week. For females, heavy drinking defined as >15 drinks per week; moderate drinking 3–14 drinks per week; light drinking 1–2 drinks per week. Non-drinker defined as no drinks in the past 12 months.

[4]BMI calculated as kg/m^2 based on self-reported height and weight.

[5]Inactive defined as <1.5 kcal per kg per day of leisure time activities; moderately active 1.5–3 kcal per kg per day; active >3 kcal per kg per day.

results were robust to categorization choices. First, we recategorized our joint income-risk factor exposure groups to include all five income quintiles separately (rather than low, middle, and high-income groups). Second, we reclassified BMI using correction factors to account for self-reporting bias in height and weight measures (Connor Gorber, Shields, Tremblay, & McDowell, 2008). Unadjusted and adjusted models were fit for both sensitivity analyses as in the original joint effects models.

3. Results

3.1. Cohort description

We identified 167,442 CCHS responses from Ontario residents between 2005 and 2014 survey years. After excluding records for data inconsistencies and age ineligibility (Figure A1), our final study cohort included 121,197 CCHS respondents aged 18 to 69 at the interview date. Before mode imputation, missingness was highest for BMI, with 4.1 percent missing.

Table 1 shows the sociodemographic and risk factor characteristics of the study cohort. Cohort characteristics according to premature mortality status are reported in the Supplement (Table A1). Table 2 reports the rates of premature mortality (per 1000) according to the cohort characteristics. Those who died prematurely within five years of the interview date were more likely to be male, older age, and Canadian-born. Decedents were also likely to have less education and belong to lower income groups for both household and neighbourhood income. Smoking (both current and former), heavy drinking, obesity, and physical inactivity were more prevalent among those who died prematurely compared to those who did not.

3.2. Premature mortality risk factors by household income group

Fig. 1 shows the prevalence of mortality-relevant risk factors according to household income quintile. The underlying data and overall population prevalence for each risk factor are shown in the appendices (Table A2).

Current smoking (heavy or light) was more prevalent among lower income compared to higher income (heavy 5.3% Q1 versus 2.0% Q5; light 24.7% versus 14.0%), whereas former smoking (heavy or light) and non-smoking was more prevalent among higher income groups (heavy 3.5% Q1 versus 5.8% Q5; light 10.4% versus 18.5%; never 56.1% versus 59.7%). Alcohol use (light, moderate or heavy drinking) was higher with increasing income (light 9.3% Q1 versus 18.7% Q5; moderate 12.2% versus 37.3%; heavy 2.9% versus 5.0%). Low-income groups were more likely to be non-drinkers in the past 12 months (75.6% Q1 versus 39.0% Q5). For BMI, both underweight and obesity were less prevalent among the highest income group (underweight 3.9% Q1 versus 1.1% Q5; obesity 17.7% versus 16.5%), while the prevalence of overweight increased with increasing income (28.1% Q1 versus 36.0% Q5). Physical inactivity was highest among the lowest income group and increased with decreasing income (58.8% Q1 versus 36.0% Q5). Higher-income groups were more likely to be moderately active (28.1% Q5 versus 20.0% Q1) or active (35.9% versus 21.1%).

3.3. Joint effects of income and premature mortality risk factors

Table 3 shows the hazard ratios and 95% confidence intervals from the joint effects Cox proportional models, which we fit separately for each risk factor (smoking, alcohol, BMI, and physical activity). The proportional hazards assumption was met for each joint effects model.

For each risk factor, the hazard of 5-year premature mortality was highest in the low-income, highest-risk group (i.e. low-income heavy smokers, low-income heavy drinkers, low-income obese, and low-income physically inactive). Generally speaking, hazard ratios decreased with increasing income (low to middle to high) and increasing risk (e.g. active to moderately active to inactive). Furthermore, an income gradient was observed for premature mortality within each risk factor category. These patterns persisted with adjustment for age group, sex, and CCHS cycle.

Some joint effects HRs were inconsistent with this general pattern. For example, for alcohol use, elevated hazards of premature mortality were seen only among low-income and middle-income heavy drinkers. In contrast, light and moderate drinking had null or protective associations (relative to non-drinking) for middle- and high-income groups. Similarly, overweight BMI had null or protective associations with

Table 1
Weighted[a] cohort characteristics at CCHS interview date, Ontario CCHS respondents 2005 to 2014 (Unweighted n = 121,197).

Cohort variables		Weighted %[a]
Sex	Female	50.6
	Male	49.4
Age group	18–29	23.7
	30–39	19.3
	40–49	22.5
	50–59	20.3
	60–69	14.3
Marital status	Married or common-law	63.8
	Other	36.2
Self-rated health	Excellent	22.7
	Very Good	39.2
	Good	27.6
	Fair	7.6
	Poor	2.9
Immigration status	Recent immigrant (<10 years)	8.5
	Long-term immigrant (10+ years)	23.7
	Canadian-born	67.8
Education level	Less than secondary	3.8
	Secondary school	9.8
	More than secondary	86.5
Household income quintile	1 (lowest income)	16.6
	2	17.4
	3	18.1
	4	19.7
	5 (highest income)	20.7
	Missing	7.5
Neighbourhood income quintile[b]	1 (lowest income)	19.2
	2	19.1
	3	19.9
	4	20.9
	5 (highest income)	20.9
Smoking status[c]	Heavy smoker	3.2
	Light smoker	18.9
	Former heavy smoker	5.0
	Former light smoker	14.9
	Never smoker	58.0
Alcohol use[d]	Heavy drinker	3.7
	Moderate drinker	24.5
	Light drinker	14.8
	Never drinker	57.0
Body mass index (BMI)[e]	Under weight (<18.5)	2.5
	Normal weight (18.5–25)	47.7
	Overweight (25–30)	32.5
	Obese (>30)	17.2
Physical activity level[f]	Inactive	48.3
	Moderate	24.6
	Active	27.1

[a] Weighted using survey weights provided by Statistics Canada.
[b] Based on median household income in the census Dissemination Area.
[c] Heavy smoking defined as 1 or more packs per day; light smoking <1 pack per day.
[d] For males, heavy drinking defined as >22 per week; moderate drinking 4–21 drinks per week; light drinking 1–3 drinks per week. For females, heavy drinking defined as >15 drinks per week; moderate drinking 3–14 drinks per week; light drinking 1–2 drinks per week. Non-drinker defined as no drinks in the past 12 months.
[e] BMI calculated as kg/m^2 based on self-reported height and weight.
[f] Inactive defined as <1.5 kcal per kg per day of leisure time activities; moderately active 1.5–3 kcal per kg per day; active >3 kcal per kg per day.

Table 2
Premature mortality status within 5 years of interview date, by cohort characteristics, Ontario CCHS respondents 2005 to 2014 (Unweighted n = 121,197).

Cohort variables		Deaths per 1000
Sex	Female	10.8
	Male	17.7
Age group	18–29	2.1
	30–39	3.0
	40–49	9.7
	50–59	21.1
	60–69	46.9
Marital status	Married or common-law	14.1
	Other	14.5
Self-rated health	Excellent	5.0
	Very Good	7.6
	Good	14.9
	Fair	27.2
	Poor	110.5
Immigration status	Recent immigrant (<10 years)	1.9
	Long-term immigrant (10+ years)	15.9
	Canadian-born	15.2
Education level	Less than secondary	44.1
	Secondary school	20.8
	More than secondary	12.2
Household income quintile	1 (lowest income)	25.3
	2	16.1
	3	13.9
	4	10.4
	5 (highest income)	7.4
Neighbourhood income quintile[a]	1 (lowest income)	19.5
	2	15.9
	3	13.1
	4	12.2
	5 (highest income)	11.0
Smoking status[b]	Heavy smoker	48.6
	Light smoker	20.2
	Former heavy smoker	38.8
	Former light smoker	15.7
	Never smoker	7.9
Alcohol use[c]	Heavy drinker	19.6
	Moderate drinker	12.3
	Light drinker	10.6
	Never drinker	15.6
Body mass index (BMI)[d]	Underweight (<18.5)	19.3
	Normal weight (18.5–25)	12.4
	Overweight (25–30)	12.4
	Obese (>30)	21.9
Physical activity level[e]	Inactive	19.0
	Moderate	11.5
	Active	8.3

[a] Based on median household income in the census Dissemination Area.
[b] Heavy smoking defined as 1 or more packs per day; light smoking <1 pack per day.
[c] For males, heavy drinking defined as >22 per week; moderate drinking 4–21 drinks per week; light drinking 1–3 drinks per week. For females, heavy drinking defined as >15 drinks per week; moderate drinking 3–14 drinks per week; light drinking 1–2 drinks per week. Non-drinker defined as no drinks in the past 12 months.
[d] BMI calculated as kg/m^2 based on self-reported height and weight.
[e] Inactive defined as <1.5 kcal per kg per day of leisure time activities; moderately active 1.5–3 kcal per kg per day; active >3 kcal per kg per day.

premature mortality relative to normal BMI. These findings were consistent in both unadjusted and adjusted models.

Survival plots showing the full 5-year premature mortality for income quintiles overall and for each income-risk factor group are available in the Supplement (Figures A.2 to A.6). Results were consistent with the unadjusted joint-effects Cox models, with survival being poorest for the low-income, highest risk group for each risk factor.

Table 3
Weighted[a] hazard ratio (HR) for 5-year premature mortality, joint effects of household income group and mortality risk factors, Ontario CCHS respondents 2005 to 2014 (unweighted n = 121,197).

HR (95% CI)		Household income group		
		Low	Middle	High
Unadjusted model				
Smoking status[b]	Heavy smoker	15.56 (10.92, 22.16)	9.35 (6.76, 12.93)	4.23 (2.81, 6.37)
	Light smoker	5.93 (4.54, 7.74)	3.60 (2.63, 4.93)	2.43 (1.75, 3.36)
	Former heavy smoker	15.54 (11.22, 21.53)	7.43 (5.52, 9.98)	4.63 (3.27, 6.56)
	Former light smoker	4.48 (3.30, 6.10)	3.33 (2.34, 4.74)	1.69 (1.22, 2.33)
	Never smoker	2.47 (1.74, 3.51)	1.52 (1.17, 1.97)	1.00 (ref)
Alcohol use[c]	Heavy drinker	5.93 (3.98, 8.83)	1.58 (0.96, 2.60)	0.77 (0.46, 1.27)
	Moderate drinker	3.10 (1.90, 5.06)	1.33 (1.03, 1.72)	0.64 (0.48, 0.86)
	Light drinker	1.44 (0.87, 2.40)	1.29 (0.86, 1.94)	0.55 (0.40, 0.76)
	Never drinker	2.08 (1.70, 2.54)	1.33 (1.07, 1.64)	1.00 (ref)
Body mass index (BMI)[d]	Under weight (<18.5)	4.93 (2.83, 8.56)	2.30 (1.24, 4.26)	1.61 (0.83, 3.12)
	Normal weight (18.5–25)	3.38 (2.55, 4.46)	2.15 (1.63, 2.84)	1.00 (ref)
	Overweight (25–30)	3.47 (2.59, 4.67)	2.03 (1.58, 2.60)	1.42 (1.07, 1.86)
	Obese (>30)	6.20 (4.57, 8.40)	3.42 (2.63, 4.44)	2.29 (1.70, 3.08)
Physical activity level[e]	Inactive	6.14 (4.69, 8.04)	3.86 (2.89, 5.16)	2.69 (2.02, 3.58)
	Moderate	4.40 (2.90, 6.67)	2.54 (1.83, 3.54)	1.56 (1.08, 2.25)
	Active	3.56 (2.14, 5.94)	1.97 (1.43, 2.70)	1.00 (ref)
Adjusted model (adjusted for age group, sex, and CCHS cycle)				
Smoking status[b]	Heavy smoker	12.1 (8.49, 17.25)	7.07 (5.10, 9.79)	3.27 (2.17, 4.95)
	Light smoker	6.72 (5.15, 8.76)	4.01 (2.93, 5.48)	2.68 (1.94, 3.7)
	Former heavy smoker	7.53 (5.46, 10.38)	3.53 (2.62, 4.74)	2.33 (1.64, 3.31)
	Former light smoker	3.10 (2.27, 4.22)	2.27 (1.58, 3.24)	1.18 (0.86, 1.63)
	Never smoker	2.75 (1.91, 3.95)	1.59 (1.23, 2.06)	1.00 (ref)
Alcohol use[c]	Heavy drinker	6.12 (4.14, 9.04)	1.48 (0.89, 2.45)	0.73 (0.44, 1.22)
	Moderate drinker	2.88 (1.77, 4.67)	1.10 (0.85, 1.42)	0.53 (0.39, 0.71)
	Light drinker	1.33 (0.79, 2.24)	1.16 (0.77, 1.74)	0.49 (0.35, 0.69)
	Never drinker	2.24 (1.83, 2.76)	1.37 (1.10, 1.70)	1.00 (ref)
Body mass index (BMI)[d]	Under weight (<18.5)	8.27 (4.65, 14.73)	3.69 (1.93, 7.06)	3.39 (1.74, 6.60)
	Normal weight (18.5–25)	3.67 (2.77, 4.87)	2.19 (1.66, 2.89)	1.00 (ref)
	Overweight (25–30)	2.52 (1.88, 3.39)	1.37 (1.07, 1.76)	0.94 (0.71, 1.24)
	Obese (>30)	4.58 (3.38, 6.22)	2.37 (1.82, 3.08)	1.46 (1.08, 1.97)
Physical activity level[e]	Inactive	6.36 (4.83, 8.37)	3.64 (2.72, 4.88)	2.44 (1.82, 3.27)
	Moderate	4.61 (3.04, 7.00)	2.53 (1.81, 3.53)	1.45 (1.00, 2.10)
	Active	4.31 (2.56, 7.28)	2.12 (1.54, 2.92)	1.00 (ref)

[a] Weighted using survey weights provided by Statistics Canada.
[b] Heavy smoking defined as 1 or more packs per day; light smoking <1 pack per day.

[c] For males, heavy drinking defined as >22 per week; moderate drinking 4–21 drinks per week; light drinking 1–3 drinks per week. For females, heavy drinking defined as >15 drinks per week; moderate drinking 3–14 drinks per week; light drinking 1–2 drinks per week. Non-drinker defined as no drinks in the past 12 months.

[d] BMI calculated as kg/m^2 based on self-reported height and weight.

[e] Inactive defined as <1.5 kcal per kg per day of leisure time activities; moderately active 1.5–3 kcal per kg per day; active >3 kcal per kg per day.

3.4. Supplementary analyses

Table 4 shows hazard ratios and 95% confidence intervals for each risk factor (smoking, alcohol, BMI, and physical activity) overall and stratified by household income quintile. The proportional hazards assumption was met for all models. In general, associations between the risk factors and premature mortality did not vary meaningfully by income quintile. For most risk factor categories, hazard ratios were similar across income groups and with hazard ratios in the overall cohort. Point estimates for smoking and alcohol use categories were notably lower for the highest income group (quintile 5) compared to the lowest income group (quintile 1), in both unadjusted and adjusted models. However, confidence intervals overlapped substantially between stratified models, and the models fit on the overall cohort data for all models. One exception to this trend was seen for heavy drinking, which was not associated with premature mortality in the overall cohort or for income quintiles 2 to 5, but was associated with an increased hazard of premature mortality in the lowest income quintile only (Unadjusted HR 2.86, 95%CI 1.93–4.23; Adjusted HR 2.73, 95%CI 1.82–4.11).

For the overall model, Table 4 also shows the results with the income quintile included as a covariate in the model. This maximally-adjusted model showed generally similar findings as before. Hazard ratios for most categories were slightly attenuated compared to the adjusted model, with exceptions for heavy drinkers (Income-adjusted HR 1.40, 95%CI 1.07, 1.83; Adjusted HR 1.20, 95%CI 0.92, 1.57) and underweight BMI (Income-adjusted HR 2.25, 95%CI 1.92, 3.32; adjusted HR 1.79, 95%CI 0.25, 13.09).

Table A.3 in the Supplement shows the hazard ratios and 95% confidence intervals for joint effects Cox proportional hazards models, fit separately for males and females. The findings did not change after stratifying for sex, and there was a substantial overlap of 95% confidence intervals between males and females for the income group-risk factor categories.

3.5. Sensitivity analyses

Table A3 in the Supplement shows the results of recategorizing our income-risk factor groups using all five income quintiles rather than grouping into low-, middle-, and high-income. The same patterns of joint effects HRs were seen when using quintile measures. Table A4 shows the results of reclassifying BMI using correction equations to account for self-reporting of weight and height. Neither sensitivity analysis had any meaningful impact on the direction or magnitude of associations with premature mortality for any risk factor, which suggests that our findings are robust to our categorization choices.

4. Discussion

In this large population-based cohort, we found important income differences in how smoking, BMI, physical inactivity, and alcohol consumption were related to premature mortality. The magnitude of the premature mortality risk for the highest risk factors and the lowest levels of income was staggering. Furthermore, we demonstrate that the risk factor burden among those with lower income is substantially higher.

Given that the inequities for smoking, obesity, physical activity and alcohol consumption are increasing over time and that low income is an established risk factor for premature mortality, further widening of the inequities seen in premature mortality is likely. The results emphasize the importance of reducing risk factors in the population, specifically low income populations, to prevent premature mortality inequities from widening even further. The findings further clarify that it is important to consider how both impact population health and the need to consider health equity as a basis for all efforts to improve population health. Aligned with the ecosocial model of health, our findings emphasize the cumulative impact of factors operating across behavioural and socioeconomic dimensions (Krieger, 2001).

Our findings for alcohol use may be somewhat counterintuitive. We found somewhat protective effects of light and moderate drinking compared to non-drinkers among higher income groups. This is most likely related to patterns of abstinence; our alcohol use indicator was based on drinking in the past 12 months, and the never-drinker category includes those with a history of drinking and those who choose to abstain for health-related reasons. Importantly, our findings are consistent with other analyses of CCHS data (Ng, Sutradhar, Yao, Wodchis, & Rosella, 2020; Rosella et al., 2019).

The importance of the findings is greater given the rising inequities in premature mortality observed worldwide. Although there is widespread attention to the need to reduce health inequities, worrying trends in recent years suggest that action is not reaching those in the lowest-income groups in the same way. There are well-established SEP disparities in the major population risk factors. For example, smoking prevalence is higher among disadvantaged groups, and disadvantaged smokers may face higher exposure to tobacco's harms (Hiscock et al., 2012a, 2012b). People with low SEP show greater susceptibility to the damaging effects of alcohol (Jones, Bates, McCoy, & Bellis, 2015). Those with higher SEP have been shown to engage in greater leisure physical activity (Gidlow, Johnston, Crone, Ellis, & James, 2006), and low SEP has been shown in reviews to be associated with higher levels of obesity (Mohammed et al., 2019). Furthermore, the disparities in risk factors, like premature mortality, appear to be increasing over time. For example, widening socioeconomic inequities in smoking cessation and initiation rates result in wider SES gradients in smoking rates.(Corsi et al., 2014; Nagelhout et al., 2012). It is important to emphasize that in line with our theoretical ecosocial model, underlying these disparities in risk factors and premature mortality is a critical role of social injustice and structural inequities in health outcomes.

These findings support the idea of proportionate universalism to reduce health inequities in premature mortality, which clarifies that in addition to population-wide approaches, there must be targeted attention to lower socioeconomic groups (Carey & Crammond, 2017; Marmot et al., 2010). Addressing health-promoting behaviours and strategies requires much more consideration than just greater attention. It requires more substantial policy action and tailored strategies that address the structural factors causing health disparities. Further, our findings align closely with the WHO Social Determinants of Health (World Health Organization, 2008) in demonstrating the importance of economic factors in an important population health outcome, such as premature mortality. As emphasized in the framework, in order to address these socioeconomic disparities, action is needed across sectors and must include tackling both the structural determinants as well as targeted interventions. Even interventions that are designed to address behavioural risk factors must be viewed in the lens of these structures in order to have a population health impact.

We wish to acknowledge some limitations to keep in mind when interpreting the results of this study. Several limitations are related to the CCHS survey data. First, these data are self-reported behavioural measures, which may be subject to misclassification. This could have led to residual confounding and potentially underestimated the risk factors due to social desirability bias. Secondly, the survey data were collected at a single point in time, and therefore, we were not able to update risk factor information over time. Thirdly, our physical activity measure was based on leisure-time activity, and therefore, we do not incorporate activity from work or active travel. As a result, we may not have

Table 4
Weighted[a] hazard ratio (HR) for 5-year premature mortality, mortality risk factors (smoking status, alcohol use, body mass index (BMI), and physical activity level), Ontario CCHS respondents 2005 to 2014, stratified by household income quintile (unweighted n = 121,197).

HR (95% CI)		Household income quintile					
		1 (lowest)	2	3	4	5 (highest)	Overall
Unadjusted model							
Smoking status[b]	Heavy smoker	6.31 (4.17, 9.53)	5.76 (3.62, 9.17)	6.63 (4.02, 10.94)	3.63 (1.98, 6.64)	5.10 (2.88, 9.02)	6.30 (5.10, 7.79)
	Light smoker	2.40 (1.65, 3.51)	2.15 (1.29, 3.58)	2.65 (1.89, 3.73)	3.23 (2.09, 4.98)	1.41 (0.83, 2.39)	2.59 (2.15, 3.12)
	Former heavy smoker	6.30 (4.24, 9.36)	2.80 (1.87, 4.19)	5.52 (3.56, 8.54)	5.98 (3.59, 9.95)	3.41 (2.15, 5.39)	5.03 (4.12, 6.15)
	Former light smoker	1.82 (1.20, 2.75)	1.13 (0.73, 1.73)	2.37 (1.42, 3.98)	1.76 (1.06, 2.93)	1.63 (1.04, 2.55)	2.01 (1.60, 2.51)
	Never smoker	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Alcohol use[c]	Heavy drinker	2.86 (1.93, 4.23)	1.76 (0.83, 3.76)	0.8 (0.43, 1.49)	0.61 (0.33, 1.13)	1.03 (0.46, 2.30)	1.25 (0.97, 1.62)
	Moderate drinker	1.49 (0.93, 2.39)	0.93 (0.62, 1.41)	1.09 (0.79, 1.52)	0.64 (0.41, 1.00)	0.70 (0.48, 1.04)	0.79 (0.61, 1.02)
	Light drinker	0.69 (0.42, 1.14)	1.00 (0.58, 1.70)	0.98 (0.52, 1.82)	0.43 (0.28, 0.66)	0.76 (0.47, 1.24)	0.68 (0.55, 0.84)
	Never drinker	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Body mass index (BMI)[d]	Under weight (<18.5)	1.46 (0.83, 2.57)	0.72 (0.36, 1.43)	1.63 (0.59, 4.47)	1.24 (0.44, 3.46)	2.23 (0.50, 9.94)	1.56 (1.08, 2.26)
	Normal weight (18.5–25)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
	Overweight (25–30)	1.03 (0.76, 1.39)	0.84 (0.57, 1.24)	1.08 (0.74, 1.57)	1.37 (0.93, 2.02)	1.48 (1.00, 2.18)	0.99 (0.85, 1.17)
	Obese (>30)	1.84 (1.34, 2.51)	1.48 (1.01, 2.17)	1.74 (1.20, 2.52)	2.29 (1.50, 3.49)	2.22 (1.44, 3.43)	1.77 (1.50, 2.08)
Physical activity level[e]	Inactive	1.72 (1.07, 2.79)	1.61 (1.12, 2.32)	2.37 (1.65, 3.41)	3.09 (2.07, 4.63)	2.19 (1.43, 3.35)	2.30 (1.90, 2.80)
	Moderate	1.24 (0.70, 2.17)	1.16 (0.73, 1.85)	1.44 (0.91, 2.27)	1.74 (1.01, 2.99)	1.38 (0.86, 2.21)	1.39 (1.10, 1.75)
	Active	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Adjusted model (adjusted for age group, sex, and CCHS cycle)							
Smoking status[b]	Heavy smoker	4.31 (2.79, 6.66)	4.00 (2.48, 6.44)	5.05 (3.05, 8.38)	2.83 (1.55, 5.16)	3.92 (2.20, 6.98)	4.81 (3.89, 5.95)
	Light smoker	2.43 (1.64, 3.60)	2.18 (1.32, 3.59)	3.02 (2.13, 4.27)	3.46 (2.24, 5.36)	1.59 (0.93, 2.71)	2.83 (2.35, 3.42)
	Former heavy smoker	2.80 (1.87, 4.19)	1.77 (1.09, 2.85)	2.57 (1.66, 3.98)	2.84 (1.69, 4.77)	1.85 (1.17, 2.94)	2.36 (1.92, 2.91)
	Former light smoker	1.13 (0.73, 1.73)	1.25 (0.77, 2.04)	1.57 (0.93, 2.64)	1.26 (0.77, 2.06)	1.15 (0.73, 1.82)	1.33 (1.06, 1.67)
	Never smoker	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Alcohol use[c]	Heavy drinker	2.73 (1.82, 4.11)	1.47 (0.67, 3.23)	0.78 (0.41, 1.47)	0.57 (0.30, 1.09)	1.03 (0.46, 2.31)	1.20 (0.92, 1.57)
	Moderate drinker	1.31 (0.82, 2.07)	0.72 (0.47, 1.09)	0.88 (0.62, 1.24)	0.54 (0.35, 0.85)	0.60 (0.40, 0.89)	0.63 (0.52, 0.77)
	Light drinker	0.61 (0.36, 1.01)	0.81 (0.47, 1.39)	0.89 (0.48, 1.64)	0.41 (0.26, 0.63)	0.68 (0.41, 1.12)	0.6 (0.48, 0.74)
	Never drinker	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Body mass index (BMI)[d]	Under weight (<18.5)	2.29 (1.27, 4.13)	1.09 (0.53, 2.22)	2.86 (1.02, 8.06)	2.67 (0.91, 7.85)	3.19 (0.75, 13.62)	1.79 (0.25, 13.09)
	Normal weight (18.5–25)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
	Overweight (25–30)	0.68 (0.50, 0.92)	0.54 (0.37, 0.79)	0.72 (0.48, 1.08)	0.95 (0.64, 1.41)	1.06 (0.69, 1.61)	0.61 (0.31, 1.22)
	Obese (>30)	1.24 (0.90, 1.69)	0.99 (0.68, 1.44)	1.16 (0.79, 1.71)	1.52 (0.97, 2.38)	1.54 (0.95, 2.49)	1.40 (0.7, 2.79)
Physical activity level[e]	Inactive	1.46 (0.91, 2.35)	1.44 (1.00, 2.07)	2.04 (1.41, 2.95)	2.93 (1.92, 4.47)	1.89 (1.23, 2.91)	2.06 (1.69, 2.50)
	Moderate	1.07 (0.61, 1.87)	1.12 (0.69, 1.82)	1.29 (0.81, 2.05)	1.66 (0.94, 2.91)	1.25 (0.78, 2.00)	1.26 (1.01, 1.59)
	Active	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Income-adjusted model (adjusted for age group, sex, CCHS cycle, and household income quintile)							
Smoking status[b]	Heavy smoker	–	–	–	–	–	4.10 (3.30, 5.10)
	Light smoker	–	–	–	–	–	2.55 (2.11, 3.10)
	Former heavy smoker	–	–	–	–	–	2.42 (1.97, 2.97)
	Former light smoker	–	–	–	–	–	1.39 (1.10, 1.76)
	Never smoker	–	–	–	–	–	1.00 (ref)
Alcohol use[c]	Heavy drinker	–	–	–	–	–	1.40 (1.07, 1.83)
	Moderate drinker	–	–	–	–	–	0.80 (0.66, 0.98)
	Light drinker	–	–	–	–	–	0.71 (0.57, 0.89)
	Never drinker	–	–	–	–	–	1.00 (ref)
Body mass index (BMI)[d]	Under weight (<18.5)	–	–	–	–	–	2.25 (1.52, 3.32)
	Normal weight (18.5–25)	–	–	–	–	–	1.00 (ref)
	Overweight (25–30)	–	–	–	–	–	0.68 (0.58, 0.81)
	Obese (>30)	–	–	–	–	–	1.19 (1.01, 1.40)
Physical activity level[e]	Inactive	–	–	–	–	–	1.79 (1.46, 2.19)
	Moderate	–	–	–	–	–	1.23 (0.98, 1.54)
	Active	–	–	–	–	–	1.00 (ref)

[a] Weighted using survey weights provided by Statistics Canada.
[b] Heavy smoking defined as 1 or more packs per day; light smoking <1 pack per day.
[c] For males, heavy drinking defined as >22 per week; moderate drinking 4–21 drinks per week; light drinking 1–3 drinks per week. For females, heavy drinking defined as >15 drinks per week; moderate drinking 3–14 drinks per week; light drinking 1–2 drinks per week. Non-drinker defined as no drinks in the past 12 months.
[d] BMI calculated as kg/m^2 based on self-reported height and weight.
[e] Inactive defined as <1.5 kcal per kg per day of leisure time activities; moderately active 1.5–3 kcal per kg per day; active >3 kcal per kg per day.

captured the totality of implications for physical activity in the population.

In addition to the data limitations, our analytic approach has some potential limitations. In several cases, we grouped continuous survey responses into categories. While these categories were carefully chosen to align with Canadian and international guidelines for health risks, the categorization assumes homogeneity of within-group risk and thus limits our ability to understand how mortality risk might vary within those groups. Also, we limited our analysis to within five years of the survey date. This choice was made to ensure equal follow-up for all CCHS respondents but limits our ability to assess longer-term mortality trends and potential latent risk factor effects.

5. Conclusion

These findings point to the need for targeted strategies to reduce health inequities and more careful attention to how policies and interventions are distributed at the population level. This includes targeting and tailoring resources to lower-income groups with disproportionate experience of premature mortality risk. Reducing disparities and improving health-related behaviours are important public health goals that must be considered more intentionally. Interventions that aim to improve access to healthcare, education, and employment opportunities together with tailored strategies to support environments for healthy behaviours, are needed.

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Data sharing

The dataset used in this study is held securely in coded format at the Institute for Clinical Evaluative Sciences (ICES). Although data sharing agreements prohibit ICES from making the dataset publicly available, access may be granted to those who meet the conditions for confidential access, available at www.ices.on.ca/Data-Services.

CRediT authorship contribution statement

Laura C. Rosella: Conceptualization, Investigation, Methodology, Supervision, Writing – original draft. **Emmalin Buajitti:** Data curation, Formal analysis, Methodology, Software, Visualization, Writing – review & editing.

Declaration of competing interest

All authors have no competing interests to declare.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

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