Original article

Population risk and burden of health behavioral–related all-cause, premature, and amenable deaths in Ontario, Canada: Canadian Community Health Survey–linked mortality files

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ABSTRACT

Purpose: To examine the association of all-cause and premature mortality with four modifiable lifestyle behaviors and quantify the burden of behavioral-related premature death in Ontario, Canada.
Methods: We analyzed a cohort of 149,262 adults in the 2000–2010 Canadian Community Health Surveys, linked to vital statistics data to ascertain deaths until December 31, 2015. The strength of the association between behaviors (smoking, body mass index, physical inactivity, and alcohol consumption) and all-cause and premature mortality was estimated using sex-specific Cox proportional hazards models. We estimated the proportion of deaths from causes amenable to the health system by behavior.
Results: After full adjustment, hazard ratios (95% confidence interval) for premature mortality were significantly increased for heavy smokers versus nonsmokers [males: 5.48 (4.55–6.60); females 4.45 (3.49–5.66)]; obese class III versus normal weight [males: 2.47 (1.76–3.48); females: 1.73 (1.29–2.31)]; and physically inactive versus active [males: 1.25 (1.07–1.45); females: 1.70 (1.41–2.04)]. In both sexes, a disproportionate burden of amenable deaths were experienced by heavy smokers, severely obese, physically inactive, and heavy drinkers.
Conclusions: The findings emphasize the importance of prevention to reduce the prevalence of risk behaviors that contribute to a large burden of premature deaths that are amenable to the health system.

Introduction

Patterns of health behaviors are among the determinants that influence mortality in a population, and by its extension, population health [1,2]. Smoking, obesity, physical inactivity, and alcohol consumption are some of the most prevalent unhealthy behaviors in Canada and other high-income countries [3–6]. Females are generally more likely to engage in healthier lifestyle behaviors than men [7], although there is evidence of gender convergence in smoking and alcohol consumption patterns [8–10]. Sex differences are also observed in mortality in that females generally have lower rates than males for all-cause and certain causes of death [11,12]; however, more recent trends show that the female mortality advantage is narrowing in high-income countries [13,14]. The contribution of health behaviors to the sex differences observed in mortality is not fully understood, in part, because information on lifestyle and behavioral history before death are not routinely collected in death certificates [15].

It is known that healthy behaviors reduce the risk of mortality [16–18]. Smoking, alcohol consumption, and obesity are among the most important risk factors for all-cause and premature death [19–21]. Moreover, gender differences in smoking and alcohol have

been suggested to be important causes of the sex differences in mortality [22,23].

An important function of health systems is to improve population health, in part, by reducing the prevalence of underlying risk factors for disease and death. Amenable mortality is closely linked to premature mortality but focuses specifically on causes of death that may be prevented through timely and appropriate health system intervention [24]. Measuring how modifiable health behaviors contribute to amenable mortality is important for informing opportunities in which the health system can reduce premature mortality, particularly from causes in which existing public health interventions exist.

This population-based study is among a few that have linked death certificates to population health surveys to examine the role of modifiable health behaviors on mortality [16,17,20,25–27]. Specifically, we examine gender differences in the risks associated with smoking, obesity, physical inactivity, and alcohol consumption on all-cause and premature death. We also quantify gender differences in the burden of behavioral-related premature deaths that are amenable to health system intervention, in a large representative sample of Canadians that live in the province of Ontario.

Methods

This cohort study used the Canadian Community Health Survey (CCHS)–linked mortality files, accessed at the ICES. This study was approved by the Research Ethics Boards at the University of Toronto and Sunnybrook Health Sciences Centre.

Data sources

The study cohort was created by linking respondents from five cycles of the CCHS [i.e., cycles 1.1 (2000), 2.1 (2003), 3.1 (2005), 07/08, 09/10] to death records obtained from the Office of the Registrar General-Deaths (ORG-D). The Registered Persons Database is the central population registry file for individuals who have ever received a health card number for the province's universal health care system and permits linkage with data holdings held at the ICES, including a 96.5% linkage rate with the ORG-D [28].

The CCHS is a cross-sectional survey administered by Statistics Canada that collects self-reported health-related data, including health behavioral information, and is representative of 98% of the Canadian population aged 12 years and older living in private dwellings. Excluded from the CCHS sampling frame are individuals living on Indian Reserves, Canadian Forces Bases, and some remote areas. The detailed survey methodology of the CCHS is described elsewhere [29]. The ORG-D contains information on all deaths registered in Ontario from January 1, 1990, including cause of death, coded using the International Classification of Disease 9th and 10th revision, with Canadian Enhancements. The ORG-D was used to identify CCHS respondents that died after their interview date. We captured comorbidity burden for the 2 years before interview date using the Johns Hopkins ACG System and linked health administrative databases: the Discharge Abstract Database, which contains patient-level data from all hospital discharges, and the Ontario Health Insurance Plan claims database, which contains patient-level billing claims for all physician encounters.

Study cohort

The combined CCHS cohort, with linkage to Registered Persons Database, consisted of 168,276 respondents from Ontario, Canada. We excluded individuals whose age at time of interview was less than 18 years ($n = 16,140$), women who reported being pregnant ($n = 1401$), subsequent records for respondents who appeared in

multiple cycles ($n = 1465$), and records where the death date occurred before CCHS interview date ($n = 8$). After exclusions, a total of 149,262 CCHS respondents were retained for the analysis.

Mortality outcomes

The primary outcomes were all-cause mortality, premature mortality, and amenable mortality. Premature deaths were classified as a death from any cause that occurred before the age of 75 years, this upper age limit is consistent with definitions for premature mortality applied in Canada and other countries [30–32], and it is assumed that deaths before the age of 75 years are more likely be avoidable than at older ages. Established classification lists were used to identify premature deaths (<75 years) from causes that are considered amenable to existing public health intervention or in the presence of timely and quality medical care [24,33,34] (see Appendix A for complete list). Follow-up time was calculated from CCHS interview date to death date or end of follow-up (December 31, 2015).

Exposure variables

The current analysis focused on four modifiable lifestyle behaviors derived from the CCHS, which are among the most prevalent risk behaviors in the Canadian population [3]: smoking, unhealthy body mass index (BMI), physical inactivity, and alcohol consumption. The CCHS questions used to define each behavioral risk factor can be found in Appendix B.

Smoking status was categorized as current heavy smoker (≥1 pack [25 cigarettes]/day), current light smoker (<1 pack [25 cigarettes]/day), former heavy smoker (≥1 pack [25 cigarettes]/day), former light smoker (<1 pack [25 cigarettes]/day), and nonsmoker (never smoker or former occasional smoker with <100 lifetime cigarettes).

BMI was calculated by dividing self-reported body weight by the square of body height (kg/m^2) and classified according to the international standard [35]: underweight (<18.5 kg per m^2), normal weight (18.5–24.9 kg per m^2), overweight (25.0–29.9 kg per m^2), obesity class I (30.0–34.9 kg per m^2), obesity class II (35.0–39.9 kg per m^2), and obesity class III (≥40.0 kg per m^2).

Physical activity was measured by the average daily energy expended for leisure time activities, calculated by multiplying the number of times engaged in each type of activity in the past year, average duration of participation in hours, and metabolic equivalent of task value assigned to each activity [36]. Respondents were categorized as being inactive (0–1.4 kcal per kg/day), moderately inactive (1.5–3.0 kcal per kg/day), and active (≥3.0 kcal per kg/day).

Alcohol consumption was categorized according to gender-specific cutoffs adapted from previous research [16] for the number of alcoholic drinks consumed in the previous week: heavy drinker (≥21 [men] or ≥14 [women] drinks or bingeing behavior on a weekly basis [≥5 drinks on any occasion]), moderate drinker (4–21 [men] or 3–14 [women] drinks), light drinker (1–3 [men] or 1–2 [women] drinks), and nondrinker (did not consume alcohol in the last 12 months or drinks less than weekly).

Covariates

Household income quintile and age were captured from the CCHS. Age at interview was classified as a cubic spline with 5 knots placed at the 5th, 27.5th, 50th, 72.5th, and 95th centiles. Comorbidity was adjusted for by calculating Aggregated Diagnosis Groups (ADG) scores, which categorizes individuals illnesses based on severity and likelihood of persistence [37].

Statistical analysis

All analyses were stratified by sex given that there are significant differences in behavioral risk factor patterns and mortality between males and females [13,38]. X^2 and *t* tests were used to assess differences in key characteristics between sexes in our study cohort. The CCHS cycles were combined using the pooled approach [39].

We used unadjusted and adjusted Cox proportional hazards regression to examine the hazards of all-cause and premature death in relation to smoking, BMI, physical activity, and alcohol consumption. Premature mortality models were restricted to individuals who were aged less than 75 years at interview date, and survival over the follow-up period was modeled up to age 75 years, after which the individual was censored. Analyses were adjusted for sociodemographic covariates (household income and age) and comorbidity (ADG scores). Given that premature mortality is an age-specific subset of all-cause mortality, we did not adjust for age in models in our primary analysis examining the hazards of premature death but did include age-adjusted premature mortality as a supplementary analysis (results presented in Appendix C).

We examined the sex-specific burden of premature deaths across each behavioral risk factor by calculating the proportion of those who died from amenable causes of death. This analysis was restricted to deaths that occurred up until December 31, 2013, as information on cause of death was not available for the two most recent years.

All analyses were weighted using sampling weights provided by Statistics Canada to adjust for the complex sampling design of the CCHS and to produce estimates reflecting the Ontario population. Weighted 95% confidence intervals (CIs) were calculated using bootstrap weights applied using the balanced repeated replication approach for standard error estimation. All analyses were conducted using the SAS statistical software, version 9.4.

Results

Weighted sex-specific characteristics for the cohort are presented in Table 1. At interview, females were slightly older, more likely to reside in low-income households, and had a greater comorbidity burden than males. Relative to females, unhealthy behaviors were more prevalent among males, with a larger proportion reporting being a current or former smoker, overweight, and a heavy or moderate drinker. In contrast, physical inactivity was more common among females than males. Within the cohort, 8188 males and 8741 females died during the follow-up period, with an average follow-up time of 5.5 (males) and 5.8 (females) years. The mean age at death was 73.8 (SD, 0.27) years among males and 77.5 (SD, 0.27) years among females.

Lifestyle behaviors on all-cause and premature mortality

Tables 2 and 3 presents the sex-specific Cox proportional weighted hazards associated with each behavior on all-cause mortality and premature mortality, respectively.

Associations with smoking status

Among the behaviors examined, smoking had the highest risk of all-cause mortality and premature mortality, in both males and females, with a step-wise increase by smoking status (former vs. current) and frequency (heavy vs. light). After full adjustment for health behaviors, age, income, and ADG scores, heavy smoking increased the hazard of all-cause death by 4.19-fold in males (CI: 3.74—4.71) and 3.89-fold in females (CI: 3.41—4.44), relative to not

Table 1
Sex-specific weighted* distribution of characteristics in the combined (2000—2010) Canadian Community Health Survey cohort ($n = 149{,}262$)[‡]

Characteristic	Males % (95% CI), $n = 68{,}242$	Females % (95% CI), $n = 81{,}020$
Age at interview, y, mean (SD)	44.96 (0.10)	46.51 (0.10)
18—24	13.49 (13.00, 13.98)	11.83 (11.42, 12.24)
25—34	16.85 (16.37, 17.32)	16.17 (15.72, 16.61)
35—44	21.93 (21.40, 22.46)	20.98 (20.47, 21.50)
45—54	18.88 (18.35, 19.41)	19.36 (18.82, 19.90)
55—64	14.26 (13.83, 14.68)	14.01 (13.61, 14.40)
65—74	8.92 (8.63, 9.21)	9.71 (9.42, 10.01)
75—85	5.00 (4.80, 5.21)	6.68 (6.44, 6.92)
>85	0.67 (0.60, 0.74)	1.26 (1.17, 1.36)
Household income		
Q1 (lowest)	9.84 (9.42, 10.27)	12.94 (12.52, 13.37)
Q2	11.41 (10.99, 11.83)	13.29 (12.86, 13.72)
Q3	16.40 (15.95, 16.86)	16.75 (16.33, 17.17)
Q4	23.42 (22.91, 23.93)	21.15 (20.68, 21.62)
Q5 (highest)	28.09 (27.55, 28.63)	21.59 (21.12, 22.06)
Missing	10.83 (10.35, 11.32)	14.28 (13.77, 14.78)
ADG score[‡]		
Mean (SD)	4.04 (0.02)	5.56 (0.02)
Smoking status		
Heavy smoker	5.20 (4.95, 5.46)	2.58 (2.41, 2.74)
Light smoker	19.88 (19.36, 20.40)	16.35 (15.93, 16.77)
Former heavy smoker	8.78 (8.47, 9.09)	4.20 (4.01, 4.40)
Former light smoker	17.11 (16.65, 17.56)	14.92 (14.53, 15.31)
Nonsmoker	45.21 (44.57, 45.85)	58.65 (58.07, 59.23)
Missing	3.82 (3.57, 4.06)	3.30 (3.09, 3.50)
Body mass index category		
Underweight	1.27 (1.10, 1.45)	4.15 (3.89, 4.41)
Normal weight	39.80 (39.17, 40.44)	50.55 (49.94, 51.16)
Overweight	40.33 (39.71, 40.96)	26.20 (25.68, 26.72)
Obesity class I	13.13 (12.72, 13.54)	10.08 (9.74, 10.43)
Obesity class II	2.82 (2.63, 3.01)	3.22 (3.03, 3.42)
Obesity class III	1.00 (0.87, 1.13)	1.64 (1.50, 1.78)
Missing	1.63 (1.44, 1.82)	4.16 (3.88, 4.43)
Physical activity		
Inactive	46.11 (45.47, 46.74)	53.37 (52.77, 53.98)
Moderately active	23.38 (22.86, 23.91)	23.91 (23.41, 24.41)
Active	26.87 (26.31, 27.43)	20.33 (19.87, 20.80)
Missing	3.64 (3.39, 3.89)	2.39 (2.15, 2.62)
Alcohol consumption		
Heavy drinker	11.85 (11.46, 12.24)	3.70 (3.48, 3.92)
Moderate drinker	24.95 (24.41, 25.48)	17.02 (16.59, 17.45)
Light drinker	16.17 (15.70, 16.65)	11.03 (10.67, 11.38)
Nondrinker	45.49 (44.85, 46.13)	67.35 (66.80, 67.90)
Missing	1.54 (1.39, 1.69)	0.90 (0.80, 1.01)

* Numbers are weighted percentages using bootstrap weights by Statistics Canada, unless specified otherwise.

[†] Mean ADG score—a weighted score based on John Hopkins Aggregated Diagnosis Groups (ADG).

[‡] *P*'s for difference between groups are from the *t* test (continuous variable) or χ^2 test (binary, categorical variable) as appropriate. Individual *P*'s were not reported as all variable differences between males and females were significant from these tests at $P < .01$.

smoking. In the fully adjusted premature mortality model, heavy smokers experienced a 5.48- (males, CI: 4.55—6.60) and 4.45-fold (females, CI: 3.49—5.66) increase in premature death, followed by former heavy smokers, light smokers, and former light smokers.

Associations with unhealthy BMI

In comparison to normal weight, in the fully adjusted model, a j-shaped relationship was observed for the hazards of all-cause mortality and BMI groups outside the normal range, with the highest sex-specific hazards associated with obesity class III males (HR 2.11, CI: 1.65—2.70) and underweight females (HR 1.65, CI: 1.46—1.85). In both sexes, those who were overweight experienced a 12% (males, HR 0.88, CI: 0.82—0.94) and 17% (females, HR 0.83, CI:

Table 2
Weighted unadjusted and adjusted sex-specific hazard ratios (HRs)[*] for the association between health behaviors and all-cause mortality

Variable	Unadjusted[†], HR (95% CI)		Adjusted[‡], HR (95% CI)		Fully adjusted[§], HR (95% CI)	
	Male	Female	Male	Female	Male	Female
Smoking						
Heavy smoker	**2.64** (2.36—2.94)	**1.89** (1.66—2.15)	**2.69** (2.41—3.00)	**1.96** (1.72—2.23)	**4.19** (3.74—4.71)	**3.89** (3.41—4.44)
Light smoker	**1.34** (1.23—1.46)	1.01 (0.93—1.09)	**1.41** (1.30—1.54)	**1.10** (1.02—1.19)	**2.51** (2.29—2.75)	**2.32** (2.14—2.51)
Former heavy smoker	**3.90** (3.59—4.23)	**2.05** (1.85—2.27)	**4.25** (3.91—4.62)	**2.41** (2.17—2.67)	**1.54** (1.42—1.67)	**1.79** (1.62—1.99)
Former light smoker	**2.81** (2.61—3.03)	**1.40** (1.30—1.50)	**3.11** (2.88—3.35)	**1.64** (1.52—1.76)	**1.32** (1.22—1.43)	**1.36** (1.27—1.47)
Nonsmoker	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
Missing	**2.41** (2.11—2.75)	**1.64** (1.44—1.87)	**2.25** (1.97—2.57)	**1.78** (1.56—2.02)	1.11 (0.97—1.26)	**1.19** (1.05—1.36)
BMI						
Underweight	**1.76** (1.46—2.13)	**1.59** (1.41—1.79)	**1.76** (1.45—2.13)	**1.49** (1.33—1.68)	**2.08** (1.72—2.52)	**1.65** (1.46—1.85)
Normal weight	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
Overweight	**0.93** (0.88—0.99)	**1.21** (1.14—1.29)	**0.85** (0.80—0.90)	**1.09** (1.02—1.16)	**0.88** (0.82—0.94)	**0.83** (0.78—0.89)
Obesity class I	1.03 (0.95—1.13)	**1.36** (1.24—1.48)	**0.83** (0.76—0.91)	**1.10** (1.01—1.20)	1.07 (0.98—1.17)	0.92 (0.85—1.01)
Obesity class II	**1.20** (1.02—1.40)	**1.30** (1.13—1.51)	0.89 (0.76—1.05)	0.95 (0.82—1.10)	**1.24** (1.06—1.46)	1.06 (0.91—1.23)
Obesity class III	**1.43** (1.12—1.83)	**1.34** (1.10—1.64)	1.14 (0.89—1.46)	0.94 (0.77—1.14)	**2.11** (1.65—2.70)	**1.43** (1.17—1.75)
Missing	**3.57** (3.11—4.11)	**2.11** (1.89—2.35)	**1.67** (1.43—1.94)	1.11 (0.99—1.25)	**0.85** (0.73—1.00)	1.05 (0.93—1.19)
Physical activity						
Inactive	**1.85** (1.72—2.00)	**2.64** (2.41—2.89)	**1.70** (1.57—1.84)	**2.52** (2.30—2.76)	**1.29** (1.19—1.39)	**1.45** (1.32—1.59)
Moderately active	**1.34** (1.22—1.47)	**1.33** (1.20—1.48)	**1.27** (1.16—1.39)	**1.31** (1.17—1.46)	1.03 (0.94—1.13)	1.03 (0.93—1.15)
Active	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
Missing	**5.51** (4.98—6.11)	**8.34** (7.38—9.42)	**4.26** (3.82—4.76)	**8.14** (7.15—9.27)	**2.20** (1.97—2.47)	**2.51** (2.19—2.87)
Alcohol consumption						
Heavy drinker	**0.65** (0.57—0.74)	0.91 (0.75—1.11)	**0.64** (0.56—0.73)	0.90 (0.74—1.10)	1.08 (0.95—1.23)	**1.56** (1.29—1.90)
Moderate drinker	1.04 (0.95—1.14)	1.02 (0.91—1.15)	0.99 (0.90—1.08)	1.04 (0.92—1.17)	**0.85** (0.78—0.93)	0.94 (0.83—1.06)
Light drinker	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
Nondrinker	**1.38** (1.27—1.49)	**1.57** (1.42—1.73)	**1.35** (1.24—1.46)	**1.45** (1.32—1.60)	**1.12** (1.03—1.21)	**1.29** (1.17—1.42)
Missing	**1.57** (1.28—1.94)	**1.54** (1.17—2.05)	**1.37** (1.11—1.68)	1.31 (0.99—1.73)	0.88 (0.72—1.09)	1.01 (0.76—1.34)

[*] HRs calculated using Cox proportional hazards regression. Bolded values indicate significantly different from reference category ($P < .05$).
[†] Unadjusted univariate analysis.
[‡] Adjusted for all covariates in the table.
[§] Fully adjusted for all covariates in the table, age, income quintile, and ADG scores.

0.78—0.89) reduced risk of all-cause mortality, compared with those with normal weight.

Obesity was associated with an increased risk of premature death in both males and females, as compared with normal weight. After full adjustment, the hazards of premature death were greatest for obesity class III males (HR 2.47, CI: 1.76—3.48) and females (HR 1.73, CI: 1.29—2.31), whereas the effect of overweight was not significantly associated with premature mortality in both sexes.

Associations with physical inactivity

Physical inactivity increased the risk of both all-cause and premature mortality in males and females, relative to physically active individuals. In the fully adjusted model, being inactive increased the hazard of all-cause mortality by 1.29-fold in males (CI: 1.19—1.39) and 1.45-fold in females (CI: 1.32—1.59) and increased the hazard of premature mortality by 1.25-fold in males (CI: 1.07—1.45) and 1.70-fold in females (CI: 1.41—2.04). Moderate physical activity was associated with a significantly higher risk of premature death among females only (HR 1.33, CI: 1.07—1.65).

Associations with alcohol consumption

The association of alcohol consumption on all-cause mortality differed between sexes in the fully adjusted model. Specifically, compared with light drinkers, there was a significantly higher risk of all-cause mortality associated with female heavy drinkers (HR 1.56, CI: 1.29—1.90) and nondrinkers (males, HR 1.12, CI: 1.03—1.21; females, HR 1.29, CI: 1.17—1.42), whereas a 15% reduction (HR 0.85, CI: 0.78—0.93) in risk was observed among male moderate drinkers.

Alcohol consumption had no significant association with premature mortality in either males or females after adjusting for health behaviors, income, and ADGs.

Sex differences in health behavioral risk of mortality

The fully adjusted sex-specific behavioral hazards associated with all-cause and premature mortality are plotted in Figure 1. In both sexes, the risk associated with each unhealthy behavior was higher for premature mortality than all-cause mortality, with the exception of alcohol consumption categories (both sexes) and comparable hazards for underweight and physical inactivity (males only). For most unhealthy behavior categories, the magnitude of risk for all-cause and premature death was higher among males than females. An exception to this pattern was observed for heavy alcohol consumption (on all-cause death), physical inactivity (on premature death), and former heavy smoking (on both all-cause and premature death), in which the risks were more elevated among females than males.

Behavioral-related amenable mortality burden

Table 4 shows the sex-specific distribution of amenable deaths ($n = 1347$ in males and $n = 1144$ in females) and nonamenable deaths ($n = 5739$ in males and $n = 6302$ in females) by behavior. Among the total premature deaths in males ($n = 2809$) and females ($n = 2117$), almost half were due to amenable causes (weighted percentages were 45.8% and 51.0%, respectively).

The prevalence of amenable deaths incrementally increased by smoking frequency, with the greatest burden experienced by heavy smokers (males: 49.28%; females: 46.52%). The proportion of amenable deaths increased with excess BMI, with the highest prevalence among decedents who were obesity class III (males:

Table 3
Weighted unadjusted and adjusted sex-specific hazard ratios (HRs)* for the association between health behaviors and premature mortality

Variable	Unadjusted[†], HR (95% CI)		Income adjusted[‡], HR (95% CI)		Fully adjusted[§], HR (95% CI)	
	Male	Female	Male	Female	Male	Female
Smoking						
Heavy smoker	**5.93** (4.95–7.10)	**5.32** (4.25–6.65)	**5.56** (4.61–6.69)	**4.93** (3.90–6.22)	**5.48** (4.55–6.60)	**4.45** (3.49–5.66)
Light smoker	**2.48** (2.07–2.97)	**2.18** (1.84–2.57)	**2.46** (2.04–2.95)	**2.28** (1.94–2.68)	**2.47** (2.06–2.97)	**2.21** (1.87–2.61)
Former heavy smoker	**4.61** (3.83–5.55)	**3.42** (2.79–4.19)	**4.55** (3.73–5.54)	**3.58** (2.91–4.41)	**3.72** (3.05–4.53)	**3.35** (2.72–4.11)
Former light smoker	**2.72** (2.26–3.29)	**1.98** (1.65–2.38)	**2.88** (2.36–3.50)	**2.26** (1.87–2.74)	**2.54** (2.08–3.11)	**2.14** (1.78–2.59)
Nonsmoker	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
Missing	**1.70** (1.24–2.34)	**1.84** (1.20–2.82)	**1.66** (1.20–2.29)	**2.02** (1.32–3.11)	**1.56** (1.14–2.15)	**1.95** (1.26–3.00)
BMI						
Underweight	**2.15** (1.29–3.61)	**1.38** (1.03–1.86)	**1.96** (1.17–3.27)	1.31 (0.98–1.76)	**1.98** (1.18–3.32)	1.30 (0.97–1.74)
Normal weight	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
Overweight	**1.18** (1.02–1.36)	**1.37** (1.16–1.60)	**1.16** (1.00–1.34)	**1.23** (1.04–1.44)	1.11 (0.96–1.29)	1.18 (0.99–1.39)
Obesity class I	**1.60** (1.34–1.91)	**1.85** (1.55–2.20)	**1.39** (1.15–1.67)	**1.47** (1.23–1.75)	**1.26** (1.05–1.53)	**1.33** (1.12–1.59)
Obesity class II	**2.15** (1.66–2.78)	**2.21** (1.66–2.93)	**1.68** (1.31–2.15)	**1.66** (1.25–2.19)	**1.54** (1.20–1.98)	**1.47** (1.11–1.94)
Obesity class III	**3.14** (2.24–4.39)	**2.98** (2.23–3.99)	**2.66** (1.90–3.73)	**1.99** (1.48–2.66)	**2.47** (1.76–3.48)	**1.73** (1.29–2.31)
Missing	**2.14** (1.50–3.04)	**2.55** (1.86–3.49)	1.02 (0.69–1.52)	**1.62** (1.18–2.23)	0.99 (0.66–1.49)	**1.55** (1.11–2.16)
Physical activity						
Inactive	**1.65** (1.42–1.91)	**1.98** (1.65–2.37)	**1.30** (1.11–1.52)	**1.74** (1.45–2.09)	**1.25** (1.07–1.45)	**1.70** (1.41–2.04)
Moderately active	1.19 (1.01–1.41)	**1.35** (1.09–1.67)	1.11 (0.94–1.31)	**1.32** (1.07–1.64)	1.06 (0.90–1.26)	**1.33** (1.07–1.65)
Active	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
Missing	**3.79** (2.93–4.91)	**5.13** (3.49–7.54)	**3.27** (2.48–4.31)	**5.03** (3.43–7.37)	**2.99** (2.26–3.95)	**4.61** (3.07–6.92)
Alcohol consumption						
Heavy drinker	1.07 (0.86–1.32)	1.39 (0.86–2.26)	0.84 (0.67–1.05)	1.03 (0.64–1.66)	0.91 (0.73–1.13)	1.05 (0.65–1.69)
Moderate drinker	1.03 (0.84–1.26)	0.92 (0.70–1.19)	0.97 (0.79–1.19)	0.91 (0.70–1.19)	0.99 (0.81–1.22)	0.93 (0.71–1.21)
Light drinker	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
Nondrinker	**1.41** (1.18–1.69)	**1.27** (1.01–1.60)	1.20 (0.99–1.45)	1.08 (0.86–1.35)	1.14 (0.95–1.37)	1.02 (0.81–1.29)
Missing	**1.79** (1.18–2.71)	1.22 (0.68–2.18)	1.50 (0.99–2.25)	0.96 (0.53–1.73)	**1.52** (1.01–2.28)	0.96 (0.53–1.72)

* HRs calculated using Cox proportional hazards regression. Bolded values indicate significantly different from reference category (*P* < .05).
† Unadjusted univariate analysis.
‡ Adjusted for all covariates in the table.
§ Fully adjusted for all covariates in the table, income quintile, and ADG scores.

39.59%; females: 37.81%). Across alcohol consumption categories, the greatest burden of amenable deaths was concentrated among heavy drinkers (males, 32.21%; females, 34.79%). The proportion of physically inactive decedents who died from amenable causes was 20.87% in males and 16.48% in females, which was slightly lower than the proportion of amenable deaths among physically active individuals (males, 23.08%; females, 22.87%).

Discussion

We have shown that mortality in a large population-based sample is associated with patterns of smoking, BMI, physical inactivity, and alcohol consumption. Generally, the magnitude of the risk associated with most unhealthy behaviors was more pronounced in males than females and higher for premature mortality than all-cause mortality. We have also demonstrated that in both sexes, a large portion of premature deaths are amenable to health system intervention, with the largest burden experienced by heavy smokers, such that almost half of deaths in heavy smokers were considered amendable, followed by obesity class III (almost 40% amenable), heavy drinkers (about one-third amenable), and the physically inactive (about one-fifth amenable). The results emphasize important targets for health system intervention in that a substantial burden of amenable deaths occurred among those with unhealthy behaviors. Although unhealthy behaviors are modifiable, they are shaped by income, living conditions, the built environment, and other complex factors that are challenging to address, given that political, economic, and social forces shape policy decisions [40]. This analysis is strengthened by linkages of mortality data with population survey data, which allowed for the creation of a provincially representative cohort with information on each decedent's cause of death and their health behavioral history. Few jurisdictions have access to similar data linkages for

studying the underlying behavioral determinants of death at the population level.

Our findings of a stepwise increasing risk of all-cause and premature death with smoking status (current, former) and frequency (heavy, light) are similar to findings from other cohort studies [19,20,41]. Smoking patterns are also important causes of the narrowing gender gap and narrowing observed in mortality [22,23]. Our results illustrate gender commonalities in smoking-related deaths in that among the risk behaviors examined, in both sexes, current heavy smoking was the most important contributor (and current light smoking the fourth leading contributor) to the burden of premature deaths that are amenable to the health system. This confirms that a large burden of amenable mortality could be avoided by public health and medical care efforts focused on tobacco cessation and preventing smoking uptake.

The graded increase in the all-cause and premature mortality risks associated with increasing obesity and lowering physical activity levels is consistent with previous evidence [16,17,21,27]. Our findings of a slightly reduced risk for all-cause mortality in overweight individuals have been observed in other research [21,27]; further research to examine the mortality patterns among overweight individuals using multiple indicators for body fat is warranted, particularly, because a limitation of BMI is that it does not distinguish between fat and muscle mass [42].

We found a slightly larger burden of amenable deaths observed among physically active than inactive individuals. It is possible that physically active individuals who died from amenable causes exhibited other types of risky behaviors that are associated with mortality [3,43]; the impact of co-occurring risk behaviors on the amenable mortality burden can be explored in future research. Given that the prevalence of obesity is steadily increasing [44] and the majority of the general population continues to be physically inactive [3], strategies focused on reducing weights and increasing
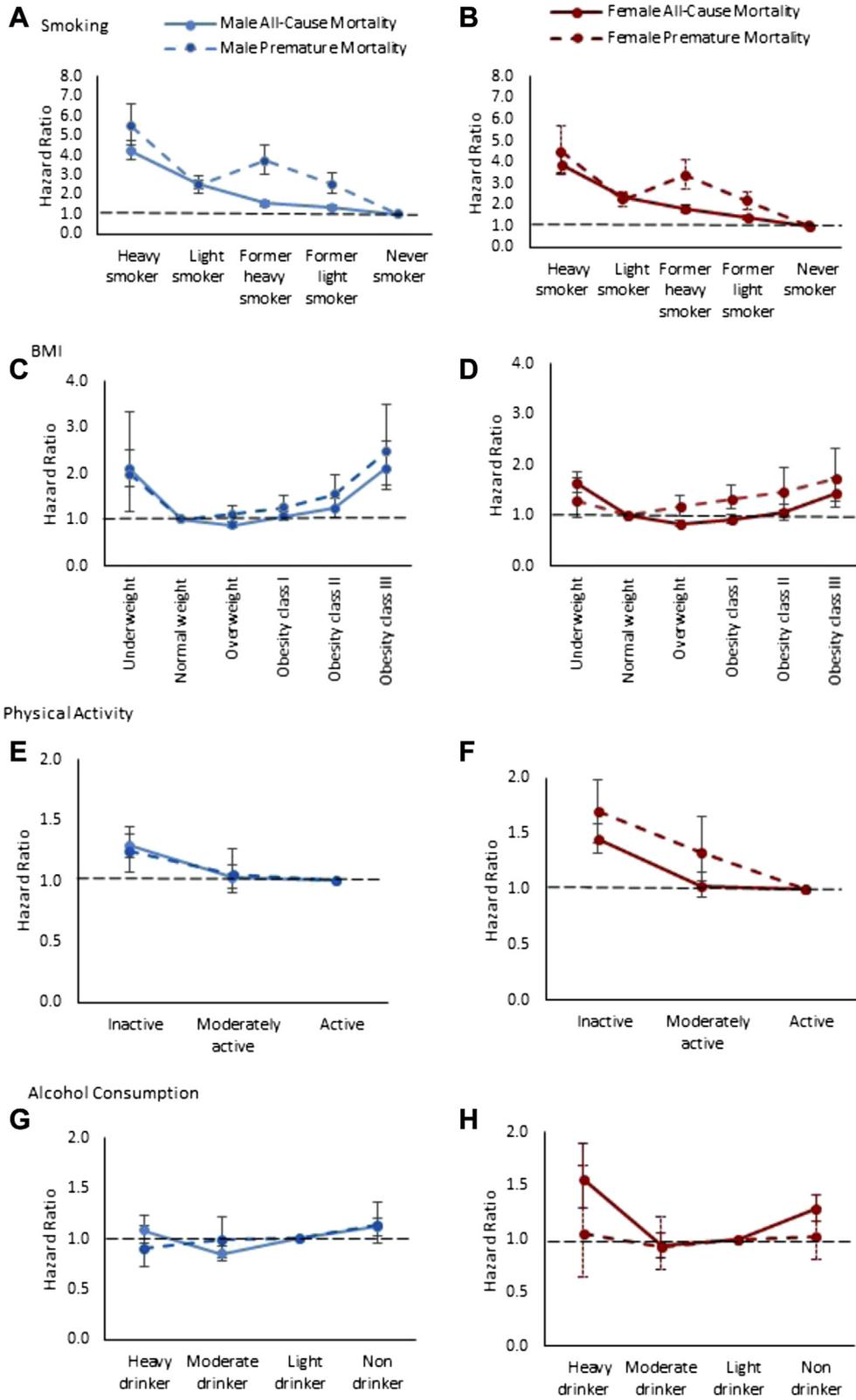
Fig. 1. Fully adjusted hazard ratios for all-cause and premature death according to health behavior and sex. (A) smoking, males; (B) smoking, females; (C) BMI , males; (D) BMI, females; (E) physical activity, males; (F) physical activity, females; (G) alcohol consumption, males; (H) alcohol consumption, females. Error bars represent 95% confidence intervals.

physical activity levels represent appropriate targets with potential to curb the amenable mortality burden. Targeting these strategies to entire population will benefit, which is key to having impact on reducing premature deaths.

Relative to light drinkers, nondrinking (both sexes) and heavy alcohol consumption (females) were associated with a higher risk of all-cause mortality, whereas moderate drinking had a protective association among males. A similar pattern in alcohol drinking and

Table 4
Weighted[*] proportion (%) of amenable and nonamenable deaths in Ontario from 2000 to 2013 in males (n = 7109) and females (n = 7446), according to behavioral characteristics in the combined 2000–2010 CCHS cohort

Characteristic before death	Total deaths	Premature deaths	Males						
			Amenable deaths (<75 years old)			Nonamenable deaths (<75 years old), n = 1462	Nonamenable deaths (≥75 years old), n = 4277	Total amenable deaths, n = 1347	Total nonamenable deaths, n = 5739
			Public health, n = 515	Medical care, n = 338	Both (IHD), n = 494				
Total deaths	7109	2809	7.71	5.18	7.36	23.94	55.57	20.25	79.51
Smoking									
Heavy smoker	593	473	25.17	8.08	16.03	35.23	15.38	49.28	50.61
Light smoker	1069	694	16.83	7.81	13.40	32.02	29.91	38.04	61.93
Former heavy smoker	1536	533	5.53	4.44	7.92	20.46	61.09	17.89	81.55
Former light smoker	1892	515	4.53	3.87	4.41	19.10	67.95	12.81	87.05
Never smoker	1595	515	2.28	5.07	4.56	25.61	62.27	11.91	87.88
BMI									
Underweight	143	48	15.84	10.41	†	16.03	53.72	30.26	69.75
Normal weight	2769	905	8.65	2.92	5.16	20.24	62.88	16.73	83.12
Overweight	2647	1066	6.00	6.45	7.98	25.99	53.12	20.43	79.11
Obesity class I	927	482	8.92	6.92	10.68	32.69	40.63	26.52	73.32
Obesity class II	230	160	10.12	10.92	17.13	28.02	33.81	38.17	61.83
Obesity class III	103	82	6.89	11.11	21.59	45.26	15.16	39.59	60.42
Physical activity									
Inactive	3892	1517	7.70	4.94	8.23	23.71	55.19	20.87	78.90
Moderately active	1368	572	7.19	5.08	7.62	26.05	53.76	19.89	79.81
Active	1170	541	9.99	6.90	6.19	30.12	46.68	23.08	76.80
Alcohol consumption									
Heavy drinker	546	373	18.60	5.55	8.06	39.82	27.54	32.21	67.36
Moderate drinker	1624	586	8.15	3.68	6.36	23.50	58.15	18.19	81.65
Light drinker	941	363	5.84	5.35	5.23	26.55	56.65	16.42	83.20
Non-drinker	3835	1428	6.79	5.78	8.16	21.37	57.69	20.73	79.06
			Females						
			Amenable deaths (<75 years old)			Nonamenable deaths (<75 years old), n = 1033	Nonamenable deaths (≥75 years old), n = 5269	Total amenable deaths, n = 1144	Total nonamenable deaths, n = 6302
			Public health, n = 458	Medical care, n = 466	Both (IHD), n = 220				
Total deaths	7446	2117	6.31	7.83	3.08	16.53	65.92	17.22	82.42
Smoking									
Heavy smoker	370	244	21.74	16.90	7.88	24.58	28.81	46.52	53.39
Light smoker	1134	574	14.74	9.72	7.60	23.95	43.74	32.06	67.69
Former heavy smoker	652	241	13.14	6.07	4.23	16.10	60.32	23.44	76.42
Former light smoker	1439	396	6.81	7.60	2.34	15.96	66.80	16.75	82.76
Nonsmoker	3491	654	1.39	6.21	1.57	14.72	75.74	9.17	90.46
BMI									
Underweight	452	110	8.29	5.33	1.75	12.00	72.29	15.37	84.29
Normal weight	3249	817	7.13	6.85	1.56	15.07	69.10	15.54	84.17
Overweight	2100	598	5.55	7.27	4.44	16.21	66.12	17.26	82.33
Obesity class I	871	309	6.11	9.96	4.60	18.33	60.50	20.67	78.83
Obesity class II	258	126	3.93	13.79	4.11	28.18	49.67	21.83	77.85
Obesity class III	152	106	11.89	22.21	3.71	35.36	26.62	37.81	61.98
Physical activity									
Inactive	5269	1393	6.21	7.20	3.07	15.36	67.79	16.48	83.15
Moderately active	1160	434	9.01	10.48	3.31	21.72	54.90	22.80	76.62
Active	692	279	7.73	9.96	5.18	22.42	54.72	22.87	77.14
Alcohol consumption									
Heavy drinker	139	88	20.11	9.03	5.65	35.29	29.29	34.79	64.58
Moderate drinker	879	300	8.19	6.97	2.90	18.03	63.47	18.06	81.50
Light drinker	573	199	7.11	10.92	2.67	22.51	56.80	20.70	79.31
Never drinker	5802	1567	5.47	7.66	3.07	15.08	68.37	16.20	83.45

IHD = ischemic heart disease, considered amenable to both public health and medical care.
[*] Numbers presented are unweighted and percentages are weighted to account for complex survey design unless indicated otherwise. Row percentages do not total 100% where missing values are not reported.
[†] Suppressed value, cell size ≤ 5 crude deaths or value can be used to recalculate suppressed cell.

all-cause mortality has been shown among adults in the United States [45]. The observed elevated risks among nondrinkers could be related to abstaining from alcohol due to health problems or potential misclassification of respondents as nondrinkers given that the CCHS questions assess drinking behavior for the past week. Although alcohol consumption was not significantly associated with premature death in the follow-up period of our study, a graded increase in the proportion of alcohol-related amenable deaths was observed in both sexes. These findings further support efforts by the public health and medical care system to promote low-risk drinking patterns which have potential to reduce amenable mortality.

There are some notable limitations to acknowledge when interpreting the results of this study. First was the use of self-reported behavioral measures that are subject to social desirability and over-reporting of healthy behaviors [46]. In addition, the

cross-sectional nature of the CCHS limited behavioral information for a single point in time (at interview date); therefore, any change in behaviors over time was not captured. It is important to recognize that measuring these types of health behaviors at the population level is currently difficult to achieve any other way. Limited national surveys, such as the Canadian Health Measures Survey, collect information on direct physical measures, including height, weight, and physical activity; however, these cohorts were not linked to health administrative and vital statistics mortality data at the time of this study. Future efforts to better harness data from electronic medical records and linkages with data on direct physical measures may offer a more objective means by which to overcome the challenges with self-reported data. With respect to physical activity, we were only able to capture leisure-time physical activity based on the questions, which does not account for potential gains from physical activity at the workplace, home, or through active travel. This may have resulted in an underestimate on the benefits form physical activity, particularly, among those who have less means to participate in leisure time activity. Although established classification lists were used to define amenable mortality, capturing conditions, such as treatable cancers, infections, diabetes, and cardiovascular disease, other causes of death that may be viewed as amenable, such as poisonings, were not included, which may have resulted in an under-reporting of the true amenable mortality burden. Finally, potential premature deaths within the cohort that occurred after the study follow-up period were not captured. Consequently, it is possible that our findings underestimate the true risk and burden of behavioral-related deaths in Ontario.

Conclusions

Our findings indicate that smoking, obesity, and physical inactivity are persistent risk factors for all-cause and premature mortality in both males and females in Ontario. These risky health behaviors, along with alcohol consumption, account for a large burden of premature deaths that are amenable to health system intervention. The findings emphasize the importance of integrated efforts by the public health and medical care system to prevent and modify risky behaviors in the population.

Acknowledgments

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Appendix

Appendix A
List of causes of deaths amenable to medical care and public health intervention

Cause	ICD-9 code	Age group (y)
Deaths amenable to both medical care & public health		
Ischemic heart disease	410–414, 429.2	35–74
Deaths amenable to medical care		
Intestinal infection	001–009	0–14
Tuberculosis	010–018, 137	0–74
Diphtheria	032	0–74
Whooping cough	033	0–14
Tetanus	037	0–74
Septicemia	038	0–74
Poliomyelitis	045	0–74
Measles	055	1–14
Syphilis	090–097	0–74
Other bacterial infections	019–031, 034, 320–322, 381–383, 390–392, 680–686, 711	0–74
Female breast cancer	174	25–74
Cervical cancer	180	15–74
Other uterine cancers	179, 182	15–74
Testicular cancer	186	0–74
Hodgkin's disease	201	0–74
Leukemia	204–208	0–14
Diseases of the thyroid	240–246	0–74
Diabetes mellitus	250	0–74
Deficiency anemia	280, 281	0–74
Epilepsy	345	0–74
Active rheumatic fever	390–392	0–74
Chronic rheumatic heart disease	393–398	0–74
Hypertensive disease	401–405	35–74
Cerebrovascular disease	430–438	35–74
Influenza	487	0–74
Pneumonia	480–483, 485–486	0–74
Other acute respiratory infections	460–466	1–14
Asthma	493	0–49
Peptic ulcer	531–534	0–74
Appendicitis	540–543	0–74
Abdominal hernia	550–553	0–74
Ileus without hernia	560	0–74
Cholelithiasis, cholecystitis, and cholangitis	574–575.1, 576.1	0–74
Nephritis and nephrosis	580–589	0–74
Infections of the urinary system	590, 595	0–74
Hyperplasia of the prostate	600	0–74
Complications of pregnancy	630–676	0–74
Osteomyelitis and periostitis	730	0–74
Congenital cardiovascular anomalies	745–747	0–74
Congenital digestive anomalies	750–751	0–74
Perinatal conditions, excluding still births*	760–779	0–74
Misadventures to patients during surgical and medical care	E870–876, E878–879	0–74
Deaths amenable to public health		
HIV	042	0–74
Lung cancer	162	0–74
Skin cancer	173	0–74
Chronic obstructive pulmonary disease	490–492, 496	0–74
Cirrhosis of the liver	571	0–74
Motor vehicle accidents	E810–825	0–74

Appendix B
Definitions for exposure variables

Risk factor	CCHS survey question(s) used to define risk factor variable	Type
Body mass index	BMI/self-report	Derived
	Height (meters)/self-report	Collected
	Weight (kilograms)/self-report	Collected
Smoking Status	Type of smoker	Derived
	How many cigarettes do you smoke each day now? (daily smokers)	Collected
	On days that you smoke, how many cigarettes do you usually smoke? (occasional smokers)	Collected
	How many cigarettes did you usually smoke each day? (former daily smokers)	Collected
	In your lifetime, have you smoked a total of 100 or more cigarettes (about 4 packs)?	Collected
Physical activity	Daily energy expenditure in leisure time physical activities in the past 3 months expressed as Metabolic Equivalent of Task (MET) (kcal/kg/day). Energy expenditure calculated using the frequency and duration per session of physical activity and MET value of the activity. Respondents reported duration of each activity as <15 min; 16–30 min; 31–60 min; >60 min. Activities assessed included walking for exercise (MET = 3), gardening or yard work (MET = 3), swimming (MET = 3), bicycling (MET = 4), popular or social dance (MET = 3), home exercises (MET = 3), ice hockey (MET = 6), ice skating (MET = 4), in-line skating or rollerblading (MET = 5), jogging or running (MET = 9.5), golfing (MET = 4), exercise class or aerobics (MET = 4), downhill skiing or snowboarding (MET = 4), bowling (MET = 2), baseball or softball (MET = 3), tennis (MET = 4), weight-training (MET = 3), fishing (MET = 3), volleyball (MET = 5), basketball (MET = 6), soccer (MET = 5), and other (MET = 4).	Derived
Alcohol Consumption	During the past 12 months, have you had a drink of beer, wine, liquor, or any other alcoholic beverage?	Collected
	During the past 12 months, how often did you drink alcoholic beverages?	Collected
	How often in the past 12 months have you had 5 or more drinks on one occasion?	Collected
	Number of drinks—past week	Derived
	Starting with yesterday, that is [day name], how many drinks did you have—Monday	Collected
	Starting with yesterday, that is [day name], how many drinks did you have—Tuesday	Collected
	Starting with yesterday, that is [day name], how many drinks did you have—Wednesday	Collected
	Starting with yesterday, that is [day name], how many drinks did you have—Thursday	Collected
	Starting with yesterday, that is [day name], how many drinks did you have—Friday	Collected
	Starting with yesterday, that is [day name], how many drinks did you have—Saturday	Collected
	Starting with yesterday, that is [day name], how many drinks did you have—Sunday	Collected

Appendix C
Sensitivity analysis adjusting for age and other covariates for the association between health behaviors and premature mortality

Variable	Fully adjusted with age[†], HR[*] (95% CI)	
	Male	Female
Smoking		
Heavy smoker	**4.89** (4.24–5.63)	**4.22** (3.56–4.99)
Light smoker	**2.80** (2.48–3.17)	**2.61** (2.31–2.95)
Former heavy smoker	**1.94** (1.69–2.23)	**2.07** (1.73–2.47)
Former light smoker	**1.55** (1.36–1.77)	**1.64** (1.43–1.87)
Nonsmoker	1.00 (ref.)	1.00 (ref.)
Missing	1.04 (0.80–1.35)	**1.47** (1.14–1.90)
BMI		
Underweight	**2.62** (1.97–3.48)	**1.80** (1.43–2.26)
Normal weight	1.00 (ref.)	1.00 (ref.)
Overweight	0.96 (0.87–1.06)	**0.88** (0.78–0.99)
Obesity class I	**1.14** (1.01–1.29)	1.00 (0.86–1.15)
Obesity class II	**1.38** (1.13–1.69)	1.20 (0.97–1.49)
Obesity class III	**2.43** (1.85–3.19)	**1.58** (1.23–2.02)
Missing	0.84 (0.60–1.18)	**1.53** (1.25–1.87)
Physical activity		
Inactive	1.11 (0.99–1.24)	**1.44** (1.25–1.67)
Moderately active	0.98 (0.85–1.11)	1.17 (0.99–1.38)
Active	1.00 (ref.)	1.00 (ref.)
Missing	**2.50** (2.09–2.99)	**2.93** (2.30–3.75)
Alcohol consumption		
Heavy drinker	1.14 (0.96–1.35)	**1.61** (1.24–2.09)
Moderate drinker	0.89 (0.77–1.03)	0.84 (0.69–1.02)
Light drinker	1.00 (ref.)	1.00 (ref.)
Nondrinker	**1.19** (1.05–1.36)	1.14 (0.98–1.34)
Missing	1.32 (0.96–1.80)	0.80 (0.48–1.34)

[*] HRs Hazard ratios calculated using Cox proportional hazards regression. Bolded values indicate significantly different from reference category ($P < .05$).

[†] Fully adjusted for all covariates in the table, life stress, age, income quintile, and ADG scores.