Chronic diseases associated with mortality in British Columbia, Canada during the 2021 western North America extreme heat event

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February 9, 2023

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Key Points

- British Columbia experienced an unprecedented extreme heat event (EHE) in summer 2021 associated with a 95% increase in population mortality
- Deaths during the EHE and previous years were compared with respect to chronic diseases present at time of death
- Schizophrenia was most strongly associated with higher risk of death during the EHE

Abstract

Western North America experienced an unprecedented extreme heat event (EHE) in 2021, characterized by high temperatures and reduced air quality. There were approximately 740 excess deaths during the EHE in the province of British Columbia, making it one of the deadliest weather events in Canadian history. It is important to understand who is at risk of death during EHEs so that appropriate public health interventions can be developed. This study compares 1614 deaths from 25 June – 02 July 2021 with 6524 deaths on the same dates from 2012-2020 to examine differences in the prevalence of 26 chronic diseases between the two groups. Conditional logistic regression was used to estimate the odds ratio (OR) for each chronic disease, adjusted for age, sex, and all other diseases, and conditioned on geographic area. The OR [95% confidence interval] for schizophrenia among all EHE deaths was 3.07 [2.39, 3.94], and was larger than the ORs for other conditions. Chronic kidney disease and ischemic heart disease were also significantly increased among all EHE deaths, with ORs of 1.36 [1.18, 1.56] and 1.18 [1.00, 1.38], respectively. Chronic diseases associated with EHE mortality were somewhat different for deaths attributed to extreme heat, deaths with an unknown/pending cause, and non-heat-related deaths. Schizophrenia was the only condition associated with significantly increased odds of EHE mortality in all three subgroups. These results confirm the role of mental illness in EHE risk and provide further impetus for interventions that target specific groups of high-risk individuals based on underlying chronic conditions.

Plain Language Summary

Western North America experienced the most severe extreme heat event (EHE) ever recorded in the region during the summer of 2021. There were approximately 740 more deaths than usual in British Columbia (BC), Canada during the EHE, which made it one of the deadliest weather events in Canadian history. This study compares people who died during the EHE with people who died at the same time of year in other years to identify differences between the two groups with respect to 26 chronic diseases. We found that people with schizophrenia had the most significantly elevated risk of death during the EHE. People with chronic kidney disease and ischemic heart disease were also at increased risk. This information will be used to help develop programs that support people at higher risk during future EHEs.

Index terms

Impacts of climate change: Human health, Public health, Climate impact, Extreme events, Health impact

Keywords

Extreme heat; mortality; chronic disease; vital statistics; administrative data; air quality

1.0 Introduction

Individual extreme heat events (EHEs) can be associated with hundreds to thousands of excess deaths (Kovats & Hajat, 2008), with the most severe example being the approximately 70,000 excess deaths across Europe in the summer of 2003 (Robine et al., 2008). The frequency and intensity of EHEs are expected to increase in the coming decades because of climate change, and global temperature extremes have already become more frequent since the 1950s (Ebi et al., 2021; IPCC, 2021). Consequently, it is essential to understand who is at risk of dying during EHEs to help develop interventions to prevent future heat-related mortality.

Susceptibility to the health effects of high temperatures varies between individuals. For example, older adults have an increased risk of death because thermoregulation and the ability to recognize thermal stimuli deteriorate with age (Ebi et al., 2021; Kenny et al., 2018). Other factors associated with an increased risk include pre-existing cardiovascular disease (Ebi et al., 2021) and mental illness (J. Liu et al., 2021) as well as material deprivation (Kovats & Hajat, 2008) and social isolation (Kenny et al., 2019). Age, cardiovascular disease, respiratory disease, and diabetes are often cited as primary risk factors for heat-related illness or death and are generally referenced in public health messaging (Centers for Disease Control and Prevention, 2017; Ebi et al., 2021; Kenny et al., 2018). However, the risk of heat-related death varies over space and time as community characteristics, adaptation strategies, behaviors, and socio-demographics change. Further, EHEs may also co-occur with other environmental stressors such as high levels of ground-level ozone and particulate matter from wildfires (Rahman et al., 2022). Therefore, it is important to understand factors associated with the risk of death during specific EHEs to develop more targeted strategies to protect the health of susceptible populations in different regions.

Western North America experienced an unprecedented EHE in late June 2021, which was rapidly attributed to climate change (Philip et al., 2021). During this event, there was a 95% increase in population mortality across British Columbia (BC), Canada, equivalent to approximately 740 excess deaths, making it one of the deadliest weather events in Canadian history (Henderson et al., 2021). Early research from the BC Centre for Disease Control (BCCDC) found that community deaths in greater Vancouver were associated with neighborhood deprivation and decreased neighborhood greenness (Henderson, McLean, et al., 2022). In this follow-up study, we aim to assess the relationship between chronic diseases and the risk of death during the 2021 EHE. We compare all adults who died in BC during the EHE with all adults who died on the same dates in the previous nine years to examine differences in the prevalence of 26 chronic diseases between the two groups.

2.0 Methods

2.1 Study context

The province of BC is located on the west coast of Canada. It spans nearly one million km^2 and had a 2021 population of approximately 5.2 million people (Government of British Columbia, 2021). The climate in BC is generally temperate, and most homes do not have air conditioning, especially in more densely populated southern coastal areas (BC Hydro, 2020).

The 2021 EHE was caused by a high-pressure system known as a 'heat dome' (Philip et al., 2022) and was characterized primarily by unprecedented high temperatures, and secondarily by increased concentrations of ground-level ozone (O_3) and fine particulate matter ($PM_{2.5}$) in many regions (Table S1). Specifically, this event resulted in daily high temperatures 10-20°C above seasonal norms across the province (Figure 1; Table S1) and it happened following the summer solstice, when daylight ranges from ˜16 to ˜19 hours, south to north (Henderson, McLean, et al., 2022; Slattery, 2016; Philip et al. 2022). More than half of the provincial population (˜3.05 million) lives in the greater Vancouver region, where more than half of the deaths occurred (Figure 2). This area was under an air quality advisory during the EHE because of high ground-level O_3 concentrations (Henderson, McLean, et al., 2022). We consider the overall impact of the EHE period in this study, which includes the effects of both extreme heat and increased air pollution.

2.2 Study design

This study compares adults who died during the EHE with adults who died during more typical summer weather to identify differences between the two groups with respect to 26 chronic diseases. The EHE period was defined as 25 June – 02 July 2021 because this is when there was statistically significant excess daily mortality (Figure 1). Statistical significance was determined using the Public Health Intelligence for Disease Outbreak (PHIDO) algorithm, which compares observed daily mortality counts with the expected range based on a model using data from the past five years (Henderson et al., 2021). The PHIDO method was developed by BCCDC, and is similar to other anomaly detection techniques such as the Farrington method (Salmon et al., 2016). The typical weather period was defined as 25 June – 02 July from 2012-2020, so that comparator deaths were drawn from the same dates as the EHE deaths. We used data from 2012 onward to ensure that we included at least four typical weather deaths for each EHE death in the analyses. Using an approximate 4:1 ratio maximized statistical power while minimizing the time between the EHE and typical weather groups (Foppa & Spiegelman, 1997; Gordis, 2014).

2.3 The COVID-19 Data Library

During the COVID-19 pandemic, BC established the COVID-19 Data Library (Wilton et al., 2022) to support rapid public health informatics. This platform facilitates individual-level linkage between multiple administrative databases. BC has a single-payer healthcare system, and health records are captured in different datasets for every individual covered by the provincial Medical Services Plan. Datasets are linkable by a unique and anonymous patient master key. The BCCDC obtained authorization from the BC Ministry of Health to use the COVID-19 Data Library to generate evidence about the public health impacts of the EHE.

2.4 Mortality

Deaths were extracted from BC vital statistics records in the COVID-19 Data Library. Each record includes one underlying cause of death, age, sex, and geographic health unit of residence. The underlying cause of death is coded by the BC Vital Statistics Agency (BCVSA) according to the 10^{th} revision of the International Classification of Diseases (ICD-10), based on information from the certificate of death. Deaths among children (<18 years) were excluded from the study because the BC Coroners Service (BCCS) reported that all heat-related deaths during the 2021 EHE occurred among adults (BC Coroners Service, 2022a). Deaths missing information on age, sex, or location were also excluded.

2.5 Chronic disease registries

The BC Ministry of Health maintains 26 administrative chronic disease registries based on individual patterns of healthcare usage. They reflect the prevalence of conditions such as asthma, heart disease, and diabetes. Each registry has different publicly available inclusion criteria (BCCDC, 2022). All registries are updated annually at the end of the BC fiscal year (31 March), with a 1-year lag period. As such, data for this study were available to 31 March 2020. To ensure comparability between the EHE and typical weather deaths, we matched all deaths to the chronic disease registries that ended on 31 March of the year prior to the death.

Individuals with multiple chronic diseases are included in multiple registries. We linked each death in the EHE and typical weather groups with all 26 registries to capture chronic conditions for each decedent at the time of death. The underlying cause of death in the vital statistics data is independent of the information derived from the chronic disease registries. As such, the cause of death may not reflect any of the chronic conditions of the decedent at the time of death. Registries were excluded if they were associated with <1% of EHE deaths or if they were collinear with another registry ([?] 85% overlap).

2.6 Statistical analyses

We compared EHE deaths with typical weather deaths using conditional logistic regression. Models were conditioned on geographic health unit (N=16) of residence (Government of British Columbia, 2022) so EHE deaths were compared with others in the same area (Figure 2). We report odds ratios (ORs) to quantify the association between EHE mortality and each chronic disease adjusted for age, sex, and all other chronic diseases (Eq.1). The supplementary appendix includes results for each chronic disease adjusted for age and sex, but not the other chronic diseases (Table S2).

Eq.1. $EHE\ Death \mid Geographic\ Health\ Unit = \text{Chronic Disease}_1 + \text{Chronic Disease}_2 + \ldots + \text{Chronic Disease}_{21} + Age + Sex$

Decedents were also classified by their total number of chronic diseases (maximum 10+) to assess the overall burden of disease effects. Conditional logistic regression was used to estimate the OR for EHE mortality associated with the number of chronic diseases, with 0 as the reference category (Eq.2).

Eq.2. $EHE\ Death \mid Geographic\ Health\ Unit = Number\ of\ Comorbidities + Age + Sex$

2.7 Subgroup analysis

The BC Coroners Service (BCCS) investigates all unattended deaths, public deaths, deaths among children, and deaths otherwise reported by healthcare providers or the public. For all such deaths, the BC Vital Statistics Agency (BCVSA) must receive the coroner's certificate of death before assigning the underlying cause of death in the vital statistics data. There are often long reporting delays (months or years) between the two agencies, and BCVSA assigns the ICD-10 code R99 as the underlying cause of death while it is waiting to receive a coroner's certificate of death. BCCS investigated hundreds of deaths that occurred during the EHE and reported that 562 were due to extreme heat from 25 June – 02 July 2021. The role of extreme heat was assessed using a protocol to review the physical and circumstantial evidence available for each case (BC Coroners Service, 2022a).

When BCVSA receives a coroner's certificate indicating death due to extreme heat, it codes X30 as the underlying cause of death. BCVSA cannot code X30 for certificates of death completed by anyone other than a coroner. When it receives a certificate of death indicating extreme heat from another source, it forwards the case to the BCCS for investigation. We extracted the vital statistics data for the study on 30 November 2022. At this time, BCVSA had not yet received all the EHE death certificates from BCCS, so some of the heat-related deaths were coded as X30 and others were still coded as R99. To assess how chronic diseases varied among heat-related deaths (X30), deaths with a pending or unknown underlying cause (R99), and non-heat-related deaths (not X30 or R99), we reran regression models separately for each of the three subgroups.

3.0 Results

3.1 Description

There were 1649 deaths during the EHE (25 June – July 02, 2021) and 6700 deaths during the typical weather period (25 June – July 02, 2012-2020). We included 1614 EHE deaths and 6524 typical weather deaths after omitting 67 children (8 EHE; 59 typical weather), 95 deaths with missing location data (12 EHE; 83 typical weather), and 49 deaths with missing demographic information (15 EHE; 34 typical weather). During the EHE, there were 280 heat-related deaths (X30), 382 deaths with information still pending from BCCS (R99), and 952 non-heat-related deaths (not X30 or R99, Figure 3). More detailed information on cause of death for the entire study population is available in the supplementary materials (Figure S1). The mean annual number (range) of typical weather deaths was 725 (618-824). One typical weather death had extreme heat (X30) as the underlying cause, and 129 (2-50 per year) had an unknown or pending (R99) cause of death.

Overall, the age and sex distributions of the EHE and typical weather deaths were similar. The EHE group had higher proportions of decedents with schizophrenia, chronic kidney disease, diabetes, and depression than the typical weather group, as well as a higher total number of chronic diseases. The EHE group also had lower proportions of decedents with angina, dementia, and osteoporosis. Within the EHE group, there were some clear differences between the heat-related (X30), pending (R99), and non-heat-related (not X30 or R99) subgroups (Table 1).

We included 21 of the 26 chronic disease registries in conditional logistic regression. Juvenile arthritis was excluded because no children were included in this study (juvenile arthritis diagnoses require patients to be [?] 15 years old). We removed multiple sclerosis and hemorrhagic stroke because <1% of EHE decedents had these conditions. Hospitalized stroke and mood/anxiety disorders were collinear with ischemic stroke and depression, respectively. All cases of ischemic stroke (N = 481) were also categorized as hospitalized stroke (N = 539), and all cases of depression (N = 3557) were also categorized as mood/anxiety disorder (N = 4124). In both cases, we excluded the higher-level category (i.e., hospitalized stroke, mood/anxiety disorder) because the lower-level category (i.e., ischemic stroke, depression) represented a more specific condition.

Table 1. Descriptive statistics. Demographics and chronic diseases among the extreme heat event (EHE) deaths and the typical weather comparison group. The EHE deaths are further subdivided into heat-related (ICD-10 code X30), pending (ICD-10 code R99), and non-heat-related subgroups (ICD-10 code not X30 or R99).

	Extreme Heat Event (EHE)	Extreme Heat Event (EHE)	Extreme
	All causes (N=1614)	**Heat-related (N=280)**	**Pending (**
Demographics			
Mean Age (SD)	76.4 (14.6)	74.9 (13.5)	70.4 (15.2)
Male	52.4%	49.6%	55.8%
Chronic disease presence			
Acute Myocardial Infarction	9.4%	7.1%	7.3%
Angina	12.4%	11.4%	7.1%
Asthma	18.8%	21.4%	16.8%
Chronic Kidney Disease	27.1%	28.2%	21.5%
Chronic Obstructive Pulmonary Disease	25.7%	28.2%	25.1%
Dementia	16.6%	12.9%	7.6%
Depression	46.9%	59.6%	51.8%
Diabetes	34.0%	39.6%	28.3%
Epilepsy	2.8%	2.1%	4.2%
Gout	10.1%	9.3%	8.4%
Heart Failure	25.0%	22.1%	18.3%
Hospitalized Transient Ischemic Attack	1.9%	1.07%	1.05%
Hypertension	69.5%	68.9%	61.5%
Ischemic Heart Disease	33.5%	31.4%	25.4%
Ischemic Stroke	7.0%	5.0%	4.5%
Osteoarthritis	35.9%	30.7%	30.9%
Osteoporosis	19.0%	20.7%	14.9%
Parkinsonism	2.9%	3.6%	0.8%
Rheumatoid Arthritis	4.5%	3.6%	4.2%
Schizophrenia	8.3%	13.2%	15.7%
Substance Use Disorder	17.7%	21.4%	28.3%
Number of Comorbidities			
Mean (SD)	4.3 (2.6)	4.4 (2.4)	3.8 (2.5)
0	5.8%	4.3%	8.4%
1	9.2%	7.5%	10.2%
2	12.1%	11.4%	14.1%
3	14.6%	11.8%	16.2%
4	15.6%	21.8%	15.4%
5	11.6%	12.5%	13.9%
6	10.3%	9.6%	6.5%
7	8.5%	9.6%	5.8%
8	5.0%	4.6%	4.2%
9	3.8%	5.4%	1.6%
10+	3.3%	1.4%	3.7%

3.2 Specific chronic diseases

When all EHE deaths were compared with all typical weather deaths, the OR [95% confidence interval] for those with schizophrenia was 3.07 [2.39, 3.94]. EHE deaths were also significantly increased among those with chronic kidney disease and ischemic heart disease with ORs of 1.36 [1.18, 1.56] and 1.18 [1.00, 1.38], respectively. The effect estimates for most chronic diseases were null (Figure 4; Table S2). However, there were several conditions for which the odds of mortality were significantly lower among EHE deaths, including angina, hospitalized transient ischemic attack, dementia, and osteoporosis. For example, the OR was 0.74 [0.63, 0.87] for dementia and 0.58 [0.47, 0.71] for angina (Figure 4; Table S2).

3.3 Burden of chronic disease

The odds of EHE mortality were higher among those with more chronic diseases (Figure 5; Table S3). The ORs were higher than 1.0 for those with 3 or more chronic diseases, and most were statistically significant. However, there was no clear trend of increasing ORs with increasing burden of chronic disease; most estimates for 3 or more chronic diseases were similar. The ORs were null for those with 1 and 2 chronic diseases.

3.4 Subgroup analysis

3.4.1 Heat-related deaths

When the 280 deaths already classified as heat-related (X30) were compared with all typical weather deaths, odds of EHE mortality were significantly increased among those with schizophrenia, chronic kidney disease, depression, and diabetes (Figure 5A; Table S2). The ORs were 3.99 [2.62, 6.08] for schizophrenia, 1.45 [1.07, 1.96] for chronic kidney disease, 1.86 [1.42, 2.44] for depression, and 1.42 [1.08, 1.86] for diabetes. The ORs were significantly less than 1.0 for those with angina and dementia. The ORs were increased for those with 4 or more chronic diseases (Figure 5B; Table S3).

3.4.2 Deaths with pending cause (R99)

When the 382 deaths with pending cause (R99) were compared with all typical weather deaths, the odds of death during the EHE were significantly increased for those with schizophrenia, substance use disorder, and chronic obstructive pulmonary disease (Figure 5A; Table S2). The ORs were 4.95 [3.46, 7.09] for schizophrenia, 1.51 [1.14, 2.01] for substance use disorder, and 1.33 [1.01, 1.75] for chronic obstructive pulmonary disease. The ORs were significantly less than 1.0 for those with dementia and angina. There was no clear effect of higher chronic disease burden in this group (Figure 5B; Table S3).

3.4.3 Non-heat-related deaths (not X30 or R99)

When the 952 non-heat-related (not X30 or R99) deaths were compared with all typical weather deaths, the odds of EHE mortality were significantly increased among those with schizophrenia, ischemic stroke, chronic kidney disease, and ischemic heart disease (Figure 5A; Table S2). The ORs were 1.66 [1.14, 2.43] for schizophrenia, 1.39 [1.07, 1.80] for ischemic stroke, 1.39 [1.17, 1.64] for chronic kidney disease, 1.25 [1.03, 1.52], and for ischemic heart disease. The ORs were significantly decreased among those with angina and osteoporosis, and generally elevated for those with 6 or more chronic diseases (Figure 5B; Table S3).

4.0 Discussion

4.1 Summary

When deaths during the 2021 EHE were compared with deaths during previous years, there was a pronounced increase in odds of death for those with schizophrenia. This increase was observed among all deaths and the three EHE subgroups: heat-related (X30) deaths, deaths with pending cause (R99), and non-heat-related deaths (not X30 or R99). We also found that odds of EHE mortality were increased for those with chronic kidney disease and ischemic heart disease among all EHE deaths. While chronic kidney disease was increased among the heat-related (X30) and non-heat-related subgroups (not X30 or R99), ischemic heart disease was only increased in the non-heat-related subgroup (not X30 or R99). Depression and diabetes were associated with increased odds of EHE mortality among heat-related deaths (X30), substance use disorder and chronic obstructive pulmonary disease were associated with increased odds among deaths with pending cause (R99), and ischemic stroke was increased among non-heat-related deaths (not X30 or R99). Having 3 or more chronic diseases was also associated with increased odds of EHE death, though the odds did not increase with an increasing number of diseases. Finally, the odds of EHE mortality were significantly lower among those with angina, hospitalized transient ischemic attack, dementia, and osteoporosis.

4.2 Chronic diseases and increased odds of death during the EHE

4.2.1 Specific chronic diseases

Schizophrenia was the most strongly associated with the odds of EHE death after adjusting for the other 20 chronic diseases. This aligns with a growing number of studies reporting an increased risk of death among those with mental illness during EHEs (J. Liu et al., 2021; Lõhmus, 2018). For example, Hansen et al. (2008) found that the rate of deaths attributed to schizophrenia-type disorders was doubled (Incidence Rate Ratio = 2.08) during heat wave periods (daily max temperature [?]35 for at least 3 consecutive days) compared with non-heat wave periods in Adelaide, Australia from 1993-2004. We report an OR of 3.07 [2.39, 3.94] for administrative diagnosis of schizophrenia among all-cause EHE deaths in BC. The relationship between increased risk of death and mental illness is not fully understood and is likely the result of a complex set of interacting factors. Some people with schizophrenia may lack insight into their own health status, and thus may not perceive and respond to overheating (J. Liu et al., 2021). Schizophrenia is also treated with antipsychotic medications that can affect thermoregulation (Lohmus, 2018). Furthermore, the condition is associated with stigmatization, social isolation, economic marginalization, and coincident substance use disorder, all of which are independent risk factors for EHE mortality (Henderson, McLean, et al., 2022; J. Liu et al., 2021; Raphael et al., 2020; Semenza et al., 1996).

While subgroup analyses showed that people with schizophrenia were at increased odds of EHE mortality regardless of the cause of death, cause-specific associations with depression and substance use disorder may indicate more nuanced links to mental illness. Specifically, the odds of heat-related death (X30) were increased among those with depression. Like schizophrenia, depression is treated with medications that can affect thermoregulation and is associated with stigmatization, social isolation, and lower-socioeconomic status (Lohmus, 2018). Along with the results for schizophrenia, this suggests that mental illness is an important risk factor for heat-related mortality.

Our results also suggest that substance use disorder was associated with increased odds of EHE mortality among deaths with pending underlying cause (R99). Many of these deaths may be due to the ongoing toxic drug supply crises in BC (BC Coroners Service, 2022b). Substance use disorder has been previously associated with increased hot weather mortality (J. Liu et al., 2021; Wilson et al., 2013). Acute intoxication during EHEs may impair decision-making, and different substances (e.g., cocaine) can affect physiological susceptibility to heat (Bohnert et al., 2010). Long-term substance use is associated with health impacts that may increase the risk of EHE death (Ebi et al., 2021) such as alcoholic cardiomyopathy (Maisch, 2016). Further, mental illness and substance use disorder often co-occur, and may overlap to increase heat-related mortality risks (Brady & Sinha, 2005). For instance, 144 (47%) of all 309 decedents with schizophrenia in this study also had substance use disorder.

The association between chronic kidney disease and increased odds of EHE mortality aligns with previous research. For example, in Adelaide, Australia, hospital admissions for renal disease and acute renal failure were heightened during heat wave periods (A. L. Hansen et al., 2008), and the risk of same-day mortality among hemodialysis patients with end-stage renal disease was increased by 31% [1%, 70%] during EHEs in three USA cities from 2017 – 2019 (Remigio et al., 2019). This is quite consistent with our OR estimate of 1.36 [1.18, 1.56]. Associations between EHE mortality and kidney disease may be linked to increased sweat production, fluid loss, and dehydration during hot weather. For instance, as the body becomes dehydrated, the blood volume decreases putting strain on the kidneys, which may increase the risk of renal damage and failure (Ebi et al., 2021). Although pre-existing kidney problems may exacerbate this risk, chronic kidney disease is also associated with other conditions, such as heart disease, which may also increase the risk of death during EHEs (Ebi et al., 2021; Gansevoort et al., 2013). Indeed, we report increased odds of EHE mortality among those with ischemic heart disease and ischemic stroke. This is unsurprising because cardiovascular conditions are among the most widely recognized risk factors for heat-related mortality (Ebi et al., 2021) and are often referenced in public health messaging about extreme heat (Centers for Disease Control and Prevention, 2017).

Finally, consistent with previous studies, the OR for diabetes was increased among EHE deaths with a heat-related cause of death (X30). For example, a recent meta-analysis reported a pooled risk ratio of 1.18 [1.13, 1.25] for diabetes-related death during hot weather across more than twenty studies (Moon, 2021). This is somewhat lower than the OR of 1.42 [1.08, 1.86] we report for administrative diagnosis of diabetes among heat-related EHE deaths. The association between diabetes and hot weather mortality may be explained by findings that diabetes can affect the physiological capacity to dissipate heat by decreasing cutaneous blood flow and sweating (Kenny et al., 2016). However, these impacts depend on how well the disease is managed, how long someone has lived with diabetes, and their aerobic fitness (Kenny et al., 2016).

4.2.2 Burden of chronic disease

The odds of EHE mortality were higher for those with 3 or more chronic diseases but did not increase markedly for those with a higher number of chronic diseases. Previous research has also found higher risk among those with a higher burden of chronic disease. For example, a study of nearly 200,000 people in Germany found that dementia was associated with higher risk of death during hot weather, and that risk increased among those needing more care (Fritze, 2020). Similarly, Foroni et al. (2007) found that elderly persons living in Modena, Italy during a hot weather period in 2003 were more likely to die if they; (1) had a higher comorbidity score, (2) were more likely to use public health services, (3) took more medications, (4) were more likely to have been admitted to the hospital in the previous year, and (5) were more likely to have cognitive impairments or other disability. Together, these results indicate that individuals with more pre-existing conditions and with poorer overall health may have been at increased risk of death during the 2021 EHE in BC.

4.3 Chronic diseases and decreased odds of death during the EHE

Angina, hospitalized transient ischemic attack, dementia, and osteoporosis were associated with significantly lower odds of mortality during the EHE. This was surprising because some of these factors have been previously linked to increased heat susceptibility (Ebi et al., 2021; Fritze, 2020). For example, as previously mentioned, cardiovascular conditions are among the most widely recognized risk factors for heat-related mortality (Ebi et al., 2021), and dementia was associated with an 11% increase in the risk of death during periods of high ambient temperatures between 2004 – 2010 across Germany (Fritze, 2020). Our results may be inconsistent with other studies due to the case-only design or because these individuals may have received heightened care during the EHE, such as an increased frequency of health checks (Kafeety et al., 2020) and increased use of air conditioning. This is supported by BCCS reports (BC Coroners Service, 2022a) that most heat-related deaths occurred inside of private residences and not in health care settings where the frailest individuals may have been housed. However, more detailed investigations are required to better interpret these results.

4.4 Non-heat-related deaths

The distribution of chronic diseases among the non-heat-related (not X30 or R99) EHE deaths was similar to the typical weather deaths. However, the odds of non-heat-related death during the EHE were still increased for those with schizophrenia, chronic kidney disease, ischemic stroke, and ischemic heart disease, suggesting that deaths with non-heat-related causes were still affected by the EHE. For example, decedents with ischemic heart disease may have been coded with a cardiovascular cause of death. However, exposure to extreme heat increases the oxygen demand of the heart as the body cools itself by redistributing blood flow to the skin. As a result, those with ischemic heart disease are at a heightened risk of experiencing cardiovascular events during hot weather because the disease causes a reduction in blood flow and oxygen delivery to the heart (Ebi et al., 2021). Despite these deaths being related to heat exposure, they may have been coded with non-heat-related causes.

There may also be unidentified heat-related deaths (X30) included in the non-heat-related group. Only deaths reported to BCCS had the opportunity to be attributed to heat exposure, and approximately 50% of deaths during the EHE were not investigated by BCCS (BC Coroners Service, 2021; 2022a). Furthermore, there were an estimated 740 excess deaths during the 8-day EHE (Henderson et al., 2021), but BCCS only attributed 562 deaths to extreme heat during this period, suggesting that the non-heat-related group may include unidentified heat-related deaths. Under-attribution of heat-related deaths in vital statistics data is a widely recognized concern (Henderson, Lamothe, et al., 2022).

4.5 Limitations of this study

This study had important limitations. First, this is a case-only study comparing individuals who died during the EHE with those who died before the EHE. The reported effect estimates cannot be interpreted as risk and protective factors as could be done for a case-control study comparing EHE deaths with EHE survivors. Instead, an increased odds ratio indicates that the prevalence of a specific condition was higher among those who died during the EHE compared with those who died during more typical summer conditions. Second, typical weather deaths were drawn from the 2012-2020 period, and may not reflect the deaths that would have occurred in 2021 in the absence of the EHE. Changes in population demographics and therapeutics may lead to different point prevalence of the chronic diseases we examined over time.

Third, we were not able to fully separate deaths from heat-related and non-heat-related causes during the EHE because of reporting delays between BCCS and BCVSA. However, most studies of EHE mortality cannot do any such subgroup analyses because heat-related deaths often go unrecognized and unattributed in vital statistics data (Henderson, Lamothe, et al., 2022). In comparison, the health impacts of the 2021 EHE in BC were recognized early in the event, prompting the BCCS to remind clinicians to report potentially-heat-related deaths. As a result, many excess deaths during the EHE were attributed to extreme heat (BC Coroners Service, 2022a). This study represents an important advancement over prior work because it was able to examine the prevalence of chronic diseases separately among heat-related deaths, deaths with pending causes, and non-heat-related deaths.

Finally, we were not able to separate the effects of air pollution from those of heat. However, BC experienced long periods of very poor air quality in July 2017 due to extreme wildfire smoke, and there was no substantive increase in excess mortality (Figure 1; Table S1). In nearby Washington state, poor air quality from wildfire events has been associated with a 4.4% increase in all-cause mortality (Y. Liu et al., 2021), which is substantially lower than the 95% increase in daily mortality observed during this EHE. However, the effects of air pollution and heat may also interact to increase the overall risk of death. For example, approximately 2000 of 11000 excess deaths during a 2010 heat wave in Russia were attributed to an interaction between wildfire smoke and high temperatures (Shaposhnikov et al., 2014). During the 2021 EHE in BC, high ground-level O_3 concentrations in greater Vancouver (Henderson, McLean, et al., 2022) and higher concentrations of $PM_{2.5}$ throughout the province (Table S1), likely contributed to the increased deaths with pending cause (R99) among those with chronic obstructive pulmonary disease. While such deaths might eventually be coded with a non-heat-related cause, air pollution concentrations were increased by the hot weather, such that these deaths were still associated with the overall event (Henderson, McLean, et al., 2022).

4.6 Conclusion and future directions

We found that schizophrenia was most strongly associated with the odds of death during the 2021 EHE in BC. Other chronic diseases associated with increased odds of death were chronic kidney disease and ischemic heart disease, as well as a higher overall burden of diseases. The BCCS reported that most heat-related deaths occurred inside private residences, often among those who lived alone in multi-unit buildings without functioning air conditioning (BC Coroners Service, 2022a). While we do not have individual-level information on socioeconomic status, our previous study on this EHE showed a doubling of odds in the most deprived urban communities (Henderson, McLean, et al., 2022).

Together, these details paint a stark picture of those who were likely at the highest risk: people with mental and physical illnesses and disabilities who were economically and socially marginalized. These results, based on relatively rapid case-only analyses, should now be confirmed and extended with more detailed analyses in a case-control design. Our future work will compare individuals who died during the EHE with similar individuals who survived matched on age, sex, geographic region, setting (e.g., long-term care, emergency room, community), and other indicators using the same data platform. This will allow further examination of specific chronic diseases, the burden of chronic disease, and other potential risk factors such as dispensed pharmaceuticals.

As with our first analysis on this EHE (Henderson, McLean, et al., 2022) we undertook this rapid case-only study to generate actionable evidence for public health policy and practice. These studies suggest that some interventions should be directed to those with severe mental illness, finding ways to reach susceptible people in their homes. Public health should partner with organizations that serve such populations to facilitate outreach before, during, and after EHEs (Kafeety et al., 2020). In the short-term, targeted interventions should focus on health checks during hot weather and rapid transition to indoor environments with safe temperatures. Longer-term interventions are also necessary to mitigate the future risks of climate change, including changes to building codes (Crawford, 2022) and strategies that promote passive cooling through construction and urban design (Kenny et al., 2018).

Acknowledgements

We acknowledge the assistance of Provincial Health Services Authority, BC Ministry of Health and regional health authorities involved in data access, procurement, and management. We gratefully acknowledge the residents of British Columbia whose data are integrated into the British Columbia COVID-19 Data Library. Data source citations are available in Table S4. All inferences, opinions, and conclusions drawn in this manuscript are those of the authors, and do not reflect the opinions or policies of the Data Stewards. We would also like to thank Melissa Gorman and Liv Yoon for their review and feedback on the original manuscript. We would like to recognize the financial support provided by Health Canada (MOA #4500439523).

Competing interest statement

The authors have no conflicts of interest to declare.

Ethics approval

The British Columbia Centre for Disease Control (BCCDC) is a public health agency with the mandate to perform applied analytics to support policy and practice in British Columbia under the Public Health Act. The BCCDC obtained authorization from the BC Ministry of Health to use the COVID-19 Data Library to generate evidence about the impacts of the EHE, and the Ministry of Health has reviewed the manuscript to ensure its consistency with data governance policies.

Open research

The data (Table S4) supporting this study are available from the British Columbia Ministry of Health to support public health response and are not accessible to the public or research community. Requirements and mechanisms for accessing the data vary between BC government ministries, health sector partners, researchers, and other organizations or individuals. Use is governed by legislation, government policies, professional codes of ethics, and standards of practice. For detailed information on how to request access to this data see BC government (2023). All analysis was carried out in R version 4.2.0 (R Core Team, 2022) and RStudio version 2022.2.3.492 (RStudio Team, 2022).

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Figure 1. Daily counts of mortality (bars) and the population-weighted maximum daily temperature (blue line) for 2021 (top left) and 2012-2020. Bars are colored corresponding to their statistical deviation from the expected daily number of deaths (black line) calculated using the Public Health Intelligence for Disease Outbreak (PHIDO) algorithm which is used by the British Columbia Centre for Disease Control to detect anomalies. The extreme heat event (EHE) was defined as the period when there was significant excess mortality (orange and red bars) in the province (25 June – 02 July 2021).

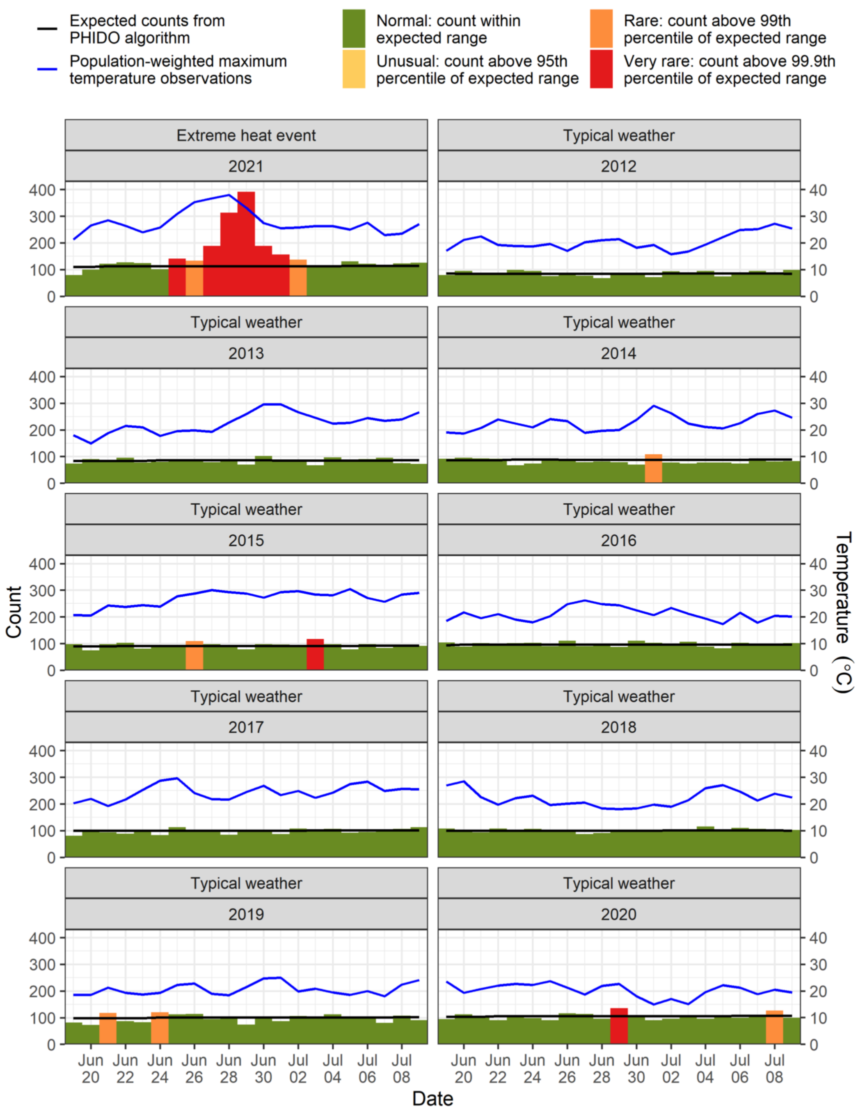


Figure 2. Maps of the extreme heat event (EHE) deaths across the 16 health service delivery areas (HSDAs) of British Columbia, Canada. The left (A) shows the crude adult mortality rate per 100,000 population. The right (B) shows the percentage of total EHE deaths in each HSDA. Deaths occurred throughout the province but were concentrated in the greater Vancouver area (insets).

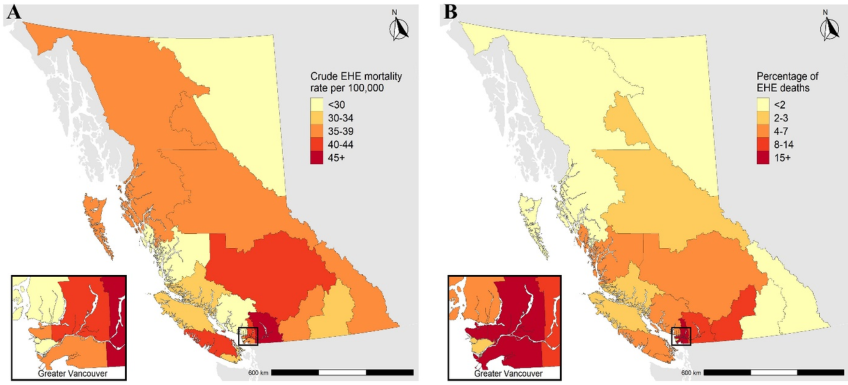


Figure 3. Flow chart of extreme heat event (EHE, 25 June – 02 July 2021) and typical weather deaths included in the study. The BC Coroners Service (BCCS) investigated hundreds of deaths during the EHE (818 the week of 25 June – 01 July and 333 the week of 02 – 08 July). At the time of study, BCCS had not yet submitted 398 certificates of death to the BC Vital Statistics Agency, and those deaths had the ICD-10 code R99 (cause unknown or pending) as their underlying cause in the vital statistics data. Of the deaths certificates that BCCS had submitted, 284 were coded as X30 (extreme heat). BCCS has reported 562 heat-related deaths from 25 June – 02 July 202, but there is no way to assess which 278 deaths will eventually be coded as X30 and which 120 will have non-heat-related causes of death. The BCCS certificate of death can take months or years to submit, depending on the investigation. The X30, R99, and non-heat-related numbers here differ slightly from the numbers in Table 1 because excluded deaths are shown as the last step.

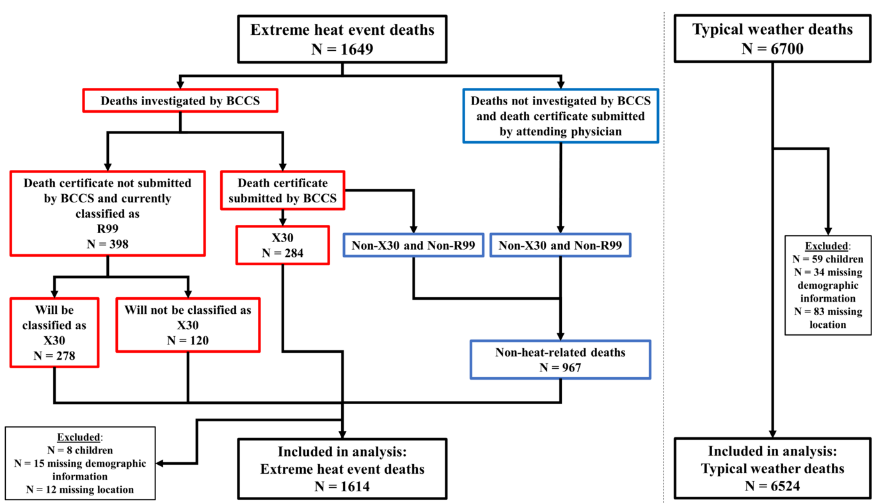


Figure 4. Chronic diseases and odds of mortality during the 2021 extreme heat event (EHE). Odds ratios (ORs) and 95% confidence intervals, derived from conditional logistic regression, for each chronic disease (adjusted for age, sex, and all other chronic diseases) among all EHE deaths compared with typical weather deaths. The chronic diseases are ordered from top to bottom by the OR point estimates.

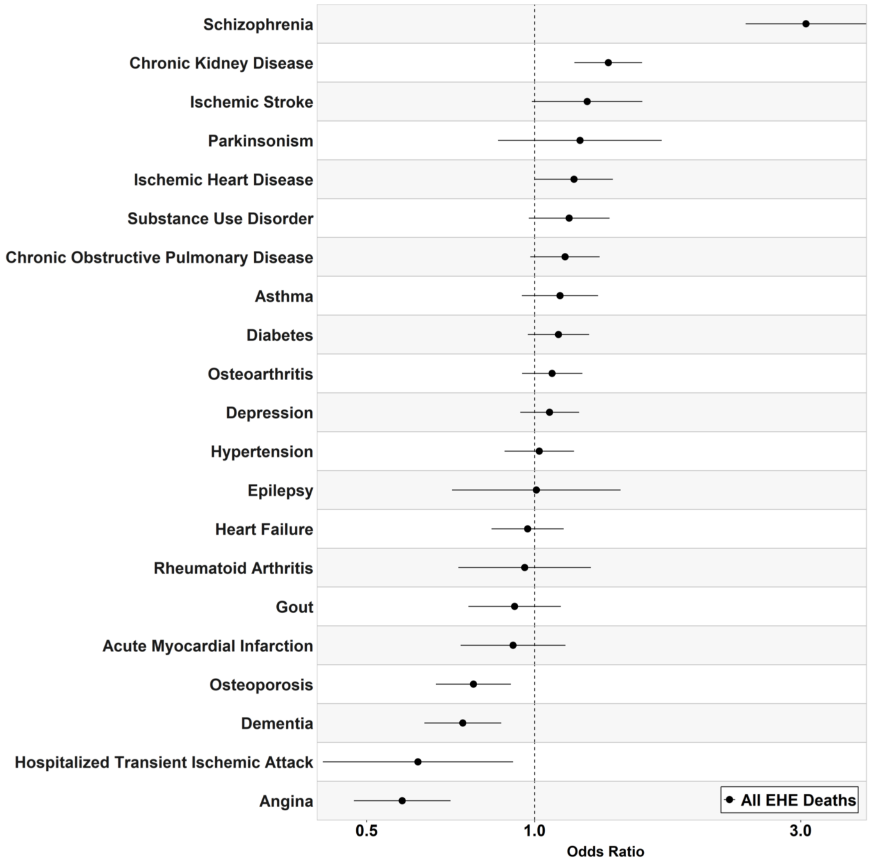


Figure 5. Burden of chronic diseases and odds of mortality during the 2021 extreme heat event (EHE) . Odds ratios (ORs) and 95% confidence intervals, derived from conditional logistic regression, for the total number of chronic diseases per person among all EHE deaths compared with typical weather deaths. Those with 0 chronic diseases were used as the reference category.

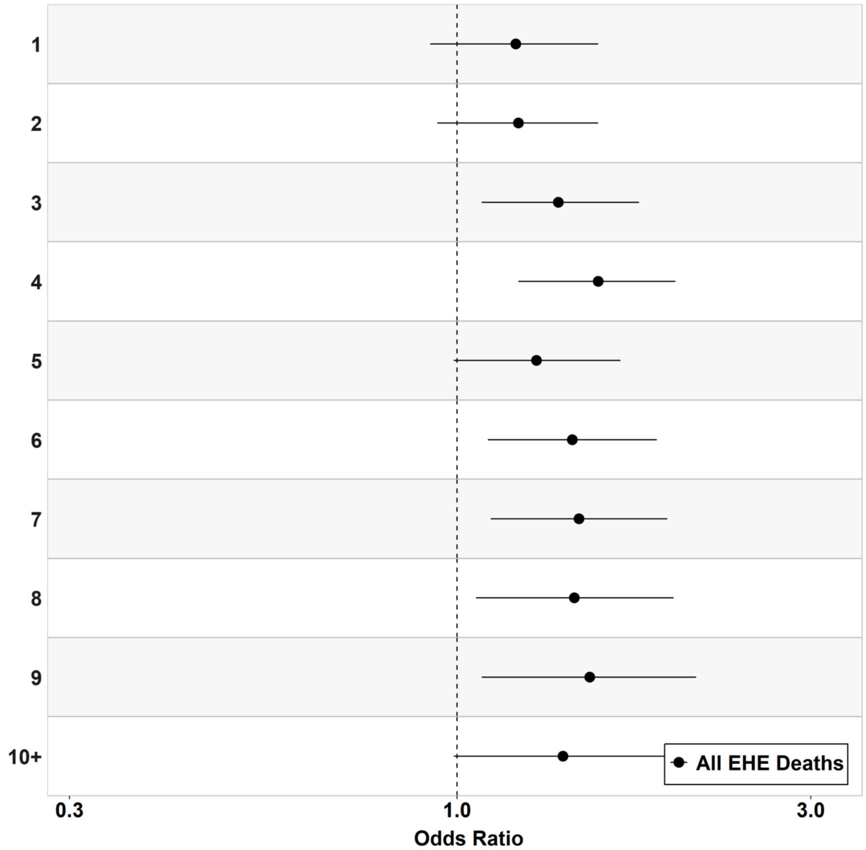
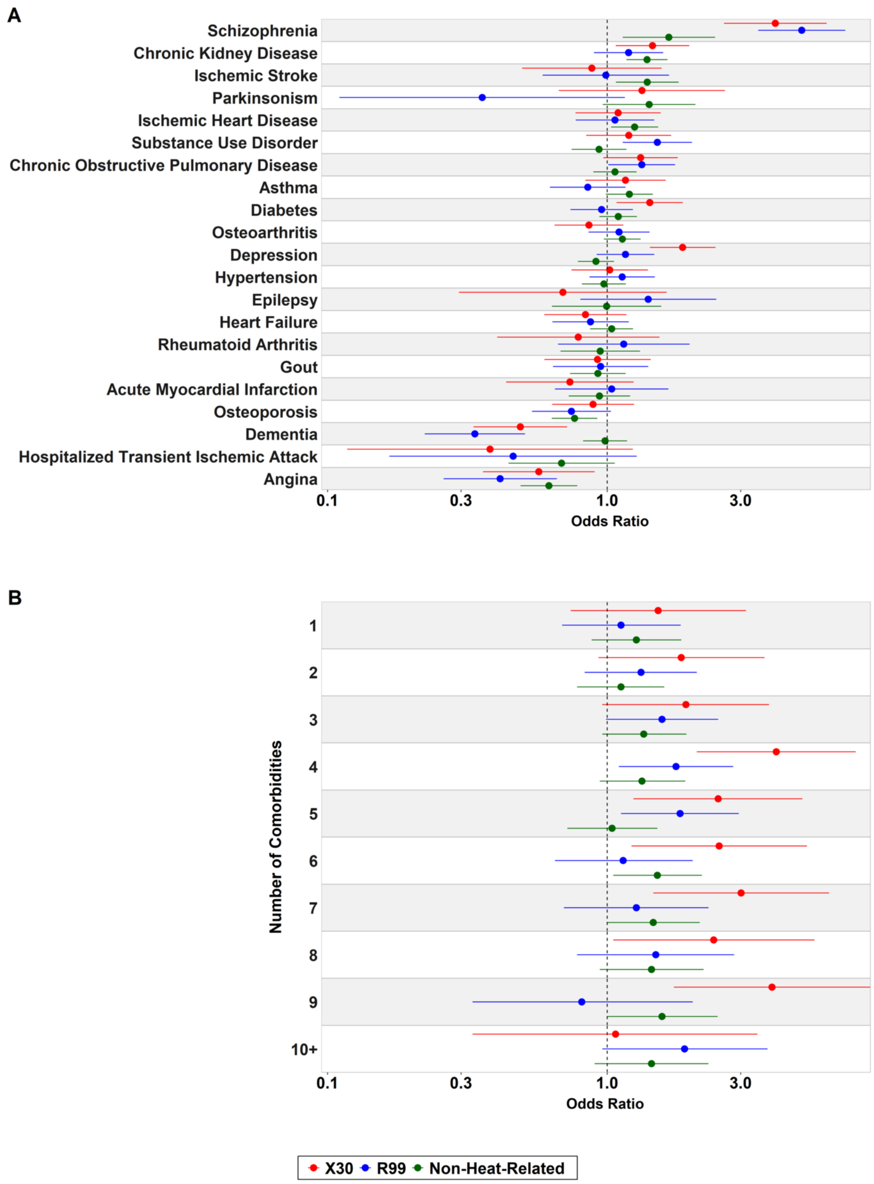


Figure 6. Subgroup analysis of chronic diseases and odds of mortality during the 2021 extreme heat event (EHE) . Odds ratios (ORs) and 95% confidence intervals, derived from conditional logistic regression, for the heat-related (X30, red), pending (R99, blue), and non-heat-related (not X30 or R99, green) cause of death subgroups. Each subgroup is compared with all typical weather deaths. Panel (A) shows the odds of death during the EHE among those with specific chronic diseases (adjusted for age, sex, and all other chronic diseases). Panel (B) shows the odds of death during the EHE associated with the burden of chronic diseases per person (adjusted for age and sex).



Supporting Information for

Chronic diseases associated with mortality in British Columbia, Canada during the 2021 western North America extreme heat event

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Table S3. Burden of chronic diseases and odds of mortality during the 2021 extreme heat event (EHE)

Table S4. Data source citations

Figure S1. Causes of death among those (red) who died during the 2021 extreme heat event (EHE) and among those (blue) who died during typical weather

Table S1. Summary of the 2021 extreme heat event (EHE) by geographic health unit (health service delivery area) in British Columbia, Canada.

Geographic health unit	**Percentage of the total number of EHE deaths**	**Percentage (range) of mean number of typical weather deaths**	**Population-weighted mean of maximum temperatures (°C)**	**Population-weighted mean of maximum temperatures (°C)**	**Population-weighted mean of relative humidity (%)**	**Population-weighted mean of relative humidity (%)**	**Population-weighted mean O_3 (ppb)**	**Population-weighted mean O_3 (ppb)**	**Ποπυλατι ωειγητεδ μεαν $ΠΜ_{2.5}$ (μγ/$μ^3$)**
	June 25-July 02, 2021	**June 25-July 02, 2012-2020**	**EHE**	**Typical Weather**	**EHE**	**Typical Weather**	**EHE**	**Typical Weather**	**EHE**
British Columbia	**100%**	**100% (85.2% – 113.2%)**	**31.6**	**22.7**	**58.9**	**69.8**	**21.2**	**19.9**	**11.5**
East Kootenay	1.7%	2.0% (1.0% – 3.0%)	33.8	22.4	47.3	62.2	26.6	22.3	7.8
Kootenay Boundary	1.4%	2.3% (1.8% – 3.0%)	38.2	26.1	45.9	64.9	19.4	18.1	10.5
Okanagan	8.34%	10.6% (8.8% – 12.2%)	39.4	26.5	36.2	54.2	25.5	24.2	12.0
Thompson Cariboo Shuswap	5.5%	6.0% (4.5% – 7.5%)	38.9	26.2	40.9	56.2	25.5	24.1	24.7
Fraser East	8.4%	6.9% (5.7% – 8.2%)	33.0	23.0	59.4	73.3	27.1	20.8	10.6
Fraser North	15.1%	10.7% (9.3% – 11.8%)	32.1	23.2	57.4	70.3	20.4	18.5	10.6

Geographic health unit	**Percentage of the total number of EHE deaths**	**Percentage (range) of mean number of typical weather deaths**	**Population-weighted mean of maximum temperatures (°C)**	**Population-weighted mean of maximum temperatures (°C)**	**Population-weighted mean of relative humidity (%)**	**Population-weighted mean of relative humidity (%)**	**Population-weighted mean O_3 (ppb)**	**Population-weighted mean O_3 (ppb)**	**Ποπυλατιο ωειγητεδ μεαν $ΠΜ_{2.5}$ (μγ/$μ^3$)**
Fraser South	16.2%	14.1% (10.2% – 17.6%)	30.3	22.7	67.4	76.5	25.9	21.6	9.4
Richmond	2.1%	2.2% (1.0% – 3.5%)	26.2	20.3	71.7	75.7	17.2	19.4	8.5
Vancouver	15.1%	11.3% (9.3% – 12.7%)	28.3	21.7	65.5	72.6	14.0	15.8	10.7
North Shore/Coast Garibaldi	4.6%	6.1% (4.2% – 7.3%)	31.0	21.6	59.7	71.6	13.8	16.7	12.9
South Vancouver Island	7.6%	9.4% (8.0% – 10.2%)	27.9	20.3	64.1	71.9	23.3	19.4	12.3
Central Vancouver Island	6.9%	8.6% (5.9% – 10.6%)	31.9	22.5	59.6	69.0	20.8	21.3	10.8
North Vancouver Island	2.4%	3.7% (2.4% – 4.5%)	30.7	21.5	55.6	68.4	17.3	20.2	9.7
Northwest	1.3%	1.6% (0.5% – 2.7%)	28.1	19.5	65.2	71.8	11.4	18.8	7.5
Northern Interior	2.6%	3.1% (1.9% – 4.2%)	33.1	22.1	54.1	64.7	22.4	21.5	14.9
Northeast	0.8%	1.1% (0.7% – 1.4%)	31.8	22.1	55.7	65.1	22.2	23.4	15.1

Table S2. Chronic diseases and odds of mortality during the 2021 extreme heat event (EHE). Odds ratios (ORs) and 95% confidence intervals, derived from conditional logistic regression, for each chronic disease among all EHE deaths, heat-related deaths (ICD-10 code X30), deaths with pending cause (ICD-10 code R99), and non-heat-related deaths (ICD-10 code not X30 or R99) compared with typical weather deaths. Partially adjusted ORs are adjusted for age and sex; fully adjusted ORs are adjusted for age, sex, and all other chronic diseases.

	Extreme Heat Event (EHE)
	All causes
Demographics	*Partially Adjusted*
Age	– [a]
Male	– [a]
Chronic disease	
Acute Myocardial Infarction	0.89 [0.74,1.08]
Angina	0.69 [0.58,0.81]
Asthma	1.18 [1.03,1.37]
Chronic Kidney Disease	1.35 [1.18,1.53]
Chronic Obstructive Pulmonary Disease	1.22 [1.07,1.39]
Dementia	0.82 [0.70,0.95]
Depression	1.18 [1.06,1.32]
Diabetes	1.17 [1.04,1.32]
Epilepsy	1.13 [0.81,1.59]
Gout	0.99 [0.82,1.19]
Heart Failure	1.03 [0.91,1.18]
Hospitalized: Transient Ischemic Attack	0.64 [0.43,0.93]
Hypertension	1.09 [0.95,1.25]
Ischemic Heart Disease	1.00 [0.88,1.13]
Ischemic Stroke	1.26 [1.01,1.57]
Osteoarthritis	1.07 [0.95,1.21]
Osteoporosis	0.80 [0.69,0.93]
Parkinsonism	1.10 [0.79,1.53]
Rheumatoid Arthritis	0.97 [0.75,1.27]
Schizophrenia	3.24 [2.55,4.11]
Substance Use Disorder	1.31 [1.13,1.53]
[a]Partially adjusted odds ratios for age and sex vary with each chronic disease	[a]Partially adjusted odds ratios for age and

Table S3. Burden of chronic diseases and odds of mortality during the 2021 extreme heat event (EHE). Odds ratios (ORs) and 95% confidence intervals, derived from conditional logistic regression, for the total number of chronic diseases per person among all EHE deaths, heat-related deaths (ICD-10 code X30), deaths with pending cause (ICD-10 code R99), and non-heat-related deaths (ICD-10 code not X30 or R99) compared with typical weather deaths.

	Extreme Heat Event (EHE)	Extreme Heat Event (EHE)	Extreme Heat Even
	All causes	**Heat-related**	**Pending**
Demographics			
Age	1.00 [0.99,1.00]	0.99 [0.98,1.00]	0.98 [0.97,0.98]
Male	1.00 [0.90,1.10]	0.87 [0.68,1.11]	0.99 [0.80,1.23]
Number of Chronic Diseases			
0	Reference	Reference	Reference
1	1.20 [0.92,1.55]	1.52 [0.74,3.13]	1.12 [0.69,1.82]
2	1.21 [0.94,1.55]	1.84 [0.93,3.65]	1.32 [0.83,2.09]
3	1.37 [1.08,1.76]	1.91 [0.96,3.79]	1.57 [0.99,2.49]
4	1.55 [1.21,1.97]	4.02 [2.09,7.73]	1.76 [1.10,2.82]
5	1.28 [0.99,1.66]	2.49 [1.24,4.98]	1.82 [1.12,2.95]
6	1.43 [1.10,1.86]	2.51 [1.22,5.18]	1.14 [0.65,2.02]
7	1.46 [1.11,1.92]	3.01 [1.46,6.21]	1.27 [0.70,2.30]
8	1.44 [1.06,1.96]	2.40 [1.05,5.51]	1.49 [0.78,2.84]

	Extreme Heat Event (EHE)	Extreme Heat Event (EHE)	Extreme Heat Even
9	1.51 [1.08,2.10]	3.88 [1.73,8.72]	0.81 [0.33,2.02]
10+	1.39 [0.99,1.97]	1.07 [0.33,3.44]	1.89 [0.96,3.74]

Table S4. Data source citations.

Data Source	Citation
Vital Statistics	British Columbia Vital Statistics Agency [creator] (2022): BC vital statistics (VS). British Colu
Chronic Disease Registry	British Columbia Ministry of Health [creator] (2022): Chronic disease registry. British Columbia

Figure S1. Causes of death among those (red) who died during the 2021 extreme heat event (EHE) and among those (blue) who died during typical weather. Percentages represent the percent of deaths from each cause of death relative to the total number of deaths during either the EHE or typical weather period.