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The effects of diurnal temperature range on mortality and emergency department presentations in Victoria State of Australia: A time-series analysis

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Abstract

State of Victoria, Australia (SVA) has a wide variation of diurnal temperatures (DTR). DTR has been reported to be associated with risk of mortality and morbidity. We examined the association between exposure to DTR and risk of all-cause mortality and emergency department (ED) presentations in the SVA. We obtained data on daily counts of deaths and ED presentations, and weather data from 1st January 2000–2019. We applied a quasi-Poisson time-series regression analysis to examine the association between daily DTR exposures and risk of mortality and ED presentations. The analyses were queried by age, sex, seasons, ED presentations triages, and departure status. Risk of mortality and ED presentation increased by 0.33% (95% CI: 0.24% – 0.43%), and 0.094% (95% CI: 0.077% – 0.11%) in relation to one degree increase in the daily DTR. The association between DTR and ED presentations was stronger in children (0-15 years) (0.38% [95% CI: 0.34% – 0.42%]) and the elderly (75+ years) (0.34% [95% CI: 0.29% – 0.39%]). Resuscitation, which was consistently accounted for the highest vulnerability to DTR variation, increased by 0.79% (95% CI:0.60%-0.99%). This study suggests that the risk of mortality and ED presentations associates with the increase of DTR. Children, the elderly, and their caregivers need to be made aware of the health risk posed by DTR.

Keywords: Diurnal temperature ranges, mortality, ED presentation, triage, resuscitation, Victoria, Australia

1.0 Introduction

The Intergovernmental Panel on Climate Change (IPCC) has projected an increase in extreme climate hazards (frequency of hot days, cold days)(IPCC, 2022). Studies have shown that climate change effects such as rise in surface air temperature is an important driver of variations in diurnal temperature ranges (DTR)(Easterling et al., 1997). DTR is defined as daily variations in maximum and minimum ambient temperatures. While DTR has reduced globally, changes in land use change (i.e. deforestation, urbanization, urban heat island) , are important factors that could modulate local DTR levels (Doan et al., 2022) .

Generally, differences in spatial patterns of DTR could also be attributed human-based radiative forcing due to a range of atmospheric mechanisms such as aerosol-cloud interactions (Forster and Solomon, 2003). Other natural factors including precipitation, cloud cover, and duration of solar radiation could explain DTR variabilities (Doan et al., 2022) . Though studies may have heightened the knowledge of human health effects associated with heatwaves, DTR is also an important health threat because it is unlikely for populations to undergo acclimatization compared to heatwaves (Benjamin et al., 2019; Guo et al., 2016).

In addition to aerosol-radiation interaction, prior research suggests that interaction between DTR and anthropogenic air pollution (e.g., ozone, particulate matter etc.) are linked to health outcomes such as chronic obstructive pulmonary diseases (COPD) due to their similar pathways to human body (Diao et al., 2021). There have been an increased in association between DTR and cardiovascular disease caused mortality when adjusted with air pollutants such as particulate matter with aerodynamic diameter ≤ 2μm (PM_{10}), sulphur dioxide (SO_2) , and nitrogen dioxide(NO_2)(Zhou et al., 2014).

The continent of Australia is geographically and climatically diverse leading to differences in ambient extreme temperature intensities (defined as maximum daily temperatures) across some of its cities in reference to the equator(Stern et al., 2000). During 1950-2018, there was an increased in DTR in the State of Victoria caused by local climate systems (Clarke et al., 2019). This might be attributed to increase in yearly mean temperature which is slightly >1℃ when compared to both Australia and the global levels (Clarke et al., 2019). This unique local climatic condition of Victoria has made it necessary to fully understand the human health implications of such changing climates (i.e., DTR) across its population.

The health effect of increased DTR has been well documented and found to be associated with an increase in cardiovascular and respiratory disease related hospital admissions especially among the elderly (65 years and above) (Phosri et al., 2020; Zha et al., 2021). Other researchers have investigated DTR and the risk of increased daily mortalities in different cities in hot and cold climates. This is important for instigation of preventive alert systems and response during such extreme conditions (Lee et al., 2019; Yang et al., 2021; Zhao et al., 2017; Zhou et al., 2014). However, very limited numbers of studies have studied DTR exposure and the risk of mortalities and emergency presentations under such different climates (hot and cold seasons) in Australia (Li et al., 2014) . This study presents a special case for further research in Australia because there is an evidence of increasing temperature variations in State of Victoria, and such changes would cause health effects to the population especially the most vulnerable ones (Pearce et al., 2016).

The evidence from previous studies were limited to only Australian city settings , suggesting the link between DTR, childhood asthma and diarrhea (Xu et al., 2013a; Xu et al., 2013b). Similar city scale study has also revealed an association between DTR and mortality during colder seasons only (Lee et al., 2020). Therefore, the extent of burden of mortality and emergency department presentation associated with DTR at State level based on different age, sex, and seasons is unclear.

Future studies are critical because acute health care services (i.e. emergency department presentations) can potentially increase due to upper respiratory tract infections (e.g. influenza) following DTR exposure in cold climates , especially among the elderly and children (Jang and Chun, 2021; Park et al., 2020). It is still imperative to understand the effect of current DTR levels and health outcomes a bigger and geographically diverse areas geographical unit of Australia such as the State of Victoria.

This current study aims to (1) investigate the association between DTR and the risk of mortality and emergency presentations using data from State of Victoria, Australia (SVA) between January 2000 to January 2019 and (2) assess how the relationship varies by triage, departure status, age, sex, and season of years.

2.0 Materials and Methods

2.1 Mortality and emergency departments presentations data

Daily counts of all-cause mortality and ED presentation data in the State of Victoria, Australia (SVA) were obtained from the Australian Bureau of Statistics (ABS).

The health data for Victoria were aggregated from all cities and towns. The daily mortality and ED presentation data were extracted from 1st January 2000 to 1st January 2019. The mortality data were further classified based on sex (male and female), age groups (0-65 years, 65-85 years, and 85+ years). The ED presentation data was stratified according to age (0-15 years, 16-74 years, 75+ years), triage (emergency, resuscitation, urgent, and semi-urgent), and departure status from ED (home, ward, and other).

Triage refers to hospital emergency management procedures that classifies patients according to the severity of their health conditions. Thus, patients whose health conditions falls under triages: resuscitation, emergency, urgent , acute, non-urgent receives a medical care immediately, within minutes, within 1 hour, within hours, and within days, respectively (Gerard et al., 2010). Departure status means where the patient departed to after receiving hospital emergency care services, this could be home , ward, or any other places other those previously mentioned.

The State of Victoria is classified as inner and outer regional remoteness of areas lying in south eastern part of Australia with an approximate land area of 227, 444 km^2(Australian Bureau of Statistics, 2016). The total population of the State as of 2016 was estimated to be 5,926,624 of which females constitutes about 50.9%, the estimated median age for both males and female is 37 years (Australian Bureau of Statistics, 2016).

The Köppen climate classification shows that the climate systems of the State are mostly Oceanic (Cfb) , and humid sub-tropical (Cfa) characterized by lowest (-10.5℃ to 11.7℃) and highest (47.9℃ to 48.1℃) ambient temperature conditions, the annual maximum mean temperature is 19.9℃ (BOM, 2023).

2.2 Temperature data

We obtained daily maximum and minimum air temperature over the State of Victoria from multiple weather stations in the central district of Victoria provided by the Australian Bureau of Meteorology (BOM) (Figure 1). Daily DTR was calculated by subtracting the daily minimum air temperature from the daily maximum air temperature (midnight to midnight). Daily data on ozone (O_3), and particulate matter with an aerodynamic diameter 10µm (PM_{10}) regenerated from air quality monitoring stations located in Central District Victoria were obtained from the Environment Protection Authority (EPA) Victoria. Figure 1 shows the spatial distribution of weather and air pollution monitoring stations in located in Central District Victoria.

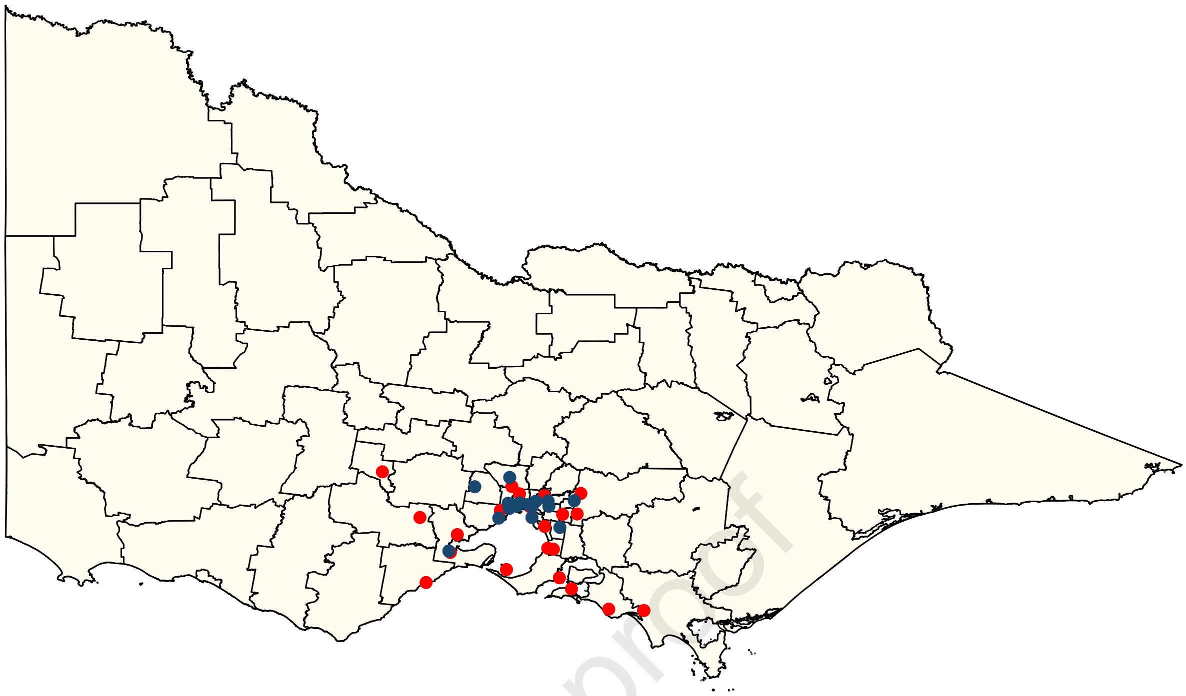

Fig 1. Weather (red) and air (blue) quality monitoring stations providing maximum, minimum temperatures, and air pollutants (Ozone, PM_{10}) data in Central District Victoria

2.3 Statistical analysis

A time series analysis was conducted to examine the association between DTR, mortality, and ED presentations. Daily counts of these outcome data follow the Quasi - Poisson distribution family. We assumed a linear relationship of the association by applying the log-link functions for mortality, and ED presentations count data in order to allow for overdispersion (Zhang et al., 2017) . A natural cubic spline function of time using seven knots per year was used to control for the potential effect of long-term trend and seasonality. The model specification is described below.

$$Y_t \sim Poisson\ (\mu_t)$$

$$\begin{aligned} Log(\mu_t) = \ & log(\mu_t) \\ & = \alpha + \beta(DTR_l) + ns(temp, 7\ knots\ per\ year) \\ & + ns(time, 7\ knots\ per\ year) + \gamma(O_3) + \delta(PM_{10}) + DOW \\ & + offset\ (Log\ [population]) \end{aligned}$$

The (μ_t) represents the expected number of deaths/ED presentations occurring on day t., *l* referring to lag days for DTR. The symbol α is an intercept, β is a coefficient showing mortality/ED presentations association per unit increase in DTR, "ns" is the natural spline function of the time and temperatures. DOW represents the days of the week, and air pollution (O_3 and PM_{10}) as environmental confounders as commonly applied from the previous studies (Phosri et al., 2020; Wang et al., 2022). Due to the varying population size, a log product of natural log (In) was included in the Poisson regression model as an offset (Cheng et al., 2018; Yang et al., 2023). These air quality data are intended to serve as potential confounders to ensure the robustness of the DTR-mortality/ED presentation dose-response relationship (Cheng et al., 2021). Also, we examined the delayed effects for single lags (0,1, 2, 3 days) and cumulative lags (0-1, 0-2 and 0-3 days) of DTR on mortality/ED presentations. For instance, we defined lag0 day, as the same day and lag1 day as the last day of DRT exposure, respectively. Similarly, cumulative lag0-1 day represents the average value of the current and the lag one day of DTR exposure. A stratified analysis was performed to evaluate potential effect modification by age (< 15 - 85+ years), sex (male and female) and season (warm and cold). In this analysis, we defined warm season (including Spring and Summer) as warmer months starting from September to February, and cold season (including Winter and Autumn) as colder months starting from March to August. All the data were presented at 95% confidence intervals where p-value <0.5 was considered statistically significant. All the data analyses were conducted in STATA (version 17) Software (College Station, TX, USA) (StataCorp, 2021).

3 Results

3.1 Descriptive Analysis of ED presentations and Mortalities

A total of 703, 377 deaths and 22.7 million ED presentations were reported in the State of Victoria from 1st January 2000 to 1st January 2019 as shown in Table 1. Death cases were slightly higher in males (50.64%) than females (49.36%), with the highest and lowest deaths occurring among 84+ years and 0-15 years. Regardless of sex, higher ED presentations were reported among 16-74 years (64.32%) followed by 0-5 years (22.17%) people. Based on triage, ED presentations cases were considered semi-urgent (50.32%), urgent (37.84%), emergency (11.14%), and resuscitation (0.7%). The number of patients were departed from home (62.65%) more than from hospital wards (34.15%). A steady and sharp increase in overall ED presentations (including all ages and sexes) whereas the total reported deaths seem relatively constant during the study period (Figure 2).

Table 1 Daily number of deaths (n =7,103) and ED Presentations (n=7,107) by sex and age, ED triage classification, ED departure status, and environmental factors (air quality and temperature levels) in the State of Victoria, Australia, 1st January 2000 to 1st January 2019.

Variable	Mean	Std. dev.	Min	Max	Total	%
Population	5,543, 670	568,613	4,730,855	6,596,880	6,596,880	—
Total Deaths	99.0	14.8	46	182	703,377	100.0
Deaths by Sex						
Death Females	48.9	9.1	18	110	347,219	49.4
Deaths Males	50.1	9.0	19	93	356,158	50.6
Deaths by Age						
Deaths (0-15 years)	2.0	2.0	0	9	14,037	2.0
Deaths (16-64 years)	16.3	4.4	2	34	115,879	16.4
Deaths (65-84 years)	14.7	4.4	2	35	104,485	14.8
Deaths (75-85 years)	28.6	5.9	6	54	203,240	28.8
Deaths (84+ years)	37.4	10.2	7	85	265,704	37.7
Death rate (per 100,000)	1.8	2.6	1.0	2.8	10,662	—
Total ED Presentations	3191.7	782.9	1574	5,586	22,700,000	100.0
Total ED Presentations by Age						
ED Presentations (0-5 years)	708.0	161.4	302	1,379	5,031,810	22.2
ED Presentations (16-74 years)	2058.1	530.7	914	3,667	14,600,000	64.3
ED Presentations (75+ years)	425.6	122.0	173	753	3,024,517	13.3
Triage					22,654,940	100.0

Emergency	355.2	144.9	104	823	2,524,838	11.1
Resuscitation	22.2	6.1	5	66	158,133	0.7
Semi-urgent	1608.1	285.5	812	2,532	11,400,000	50.3
Urgent	1,206.1	385.8	525	2,520	8,571,969	37.8
Departure Status					22,666,504	100.0
Departure-Home	2,000.4	361.8	1,029	3,341	14,200,000	62.6
Departure-Ward	1,089.0	430.0	423	2,154	7,740,157	34.1
Departure-Other	102.2	51.0	8	270	726,347	3.2
Environmental Conditions						
Diurnal temperature (℃)	9.8	4.3	0.7	27.8		
Daily maximum temperature (℃)	19.7	6.0	8.0	45.2		
Daily minimum temperature (℃)	9.8	4.0	-0.9	25.6		
Daily mean temperature (℃)	14.7	4.7	5.4	33.8		
Daily mean O_3 (μg/m^3)	15.9	5.9	0.01	46.0		
Winter O_3 (μg/m^3)	13.5	5.9	0.01	28.9		
Summer O_3 (μg/m^3)	17.4	5.9	1.9	46.0		
Daily mean PM_{10}(μg/m^3)	18.0	9.4	2.3	249.6		
Winter PM_{10}(μg/m^3)	14.2	6.3	4.5	157.3		
Summer PM_{10}(μg/m^3)	20.9	10.8	2.3	133.5		

3.2 Environmental Exposures

The mean DTR over 6940 counts of days of the study period (1st January 2000 to 1st January 2019) were 9.9℃ where the mean daily maximum and minimum temperatures were 19.7℃ and 9.8 ℃, respectively (Table 1). The ambient daily concentration levels of PM_{10} (range 2.3-249.6 μg/m^3) were higher than O_3 (0.01-46.0 μg/m^3). The average concentration (average ± standard deviation) levels of O_3 were higher during the summer (17.4 ±5.9 μg/m^3) season than the winter (13.5 ± 5.9 μg/m^3) , this was also similar for PM_{10} of 20.9 ± 10.8 μg/m^3 and 14.2 ± 6.3 μg/m^3, respectively. The time series analysis in Figure 2 clearly shows a rise in DTR was linked to an increase in ground level ozone caused by ultraviolet radiations, and a decrease in PM_{10}.

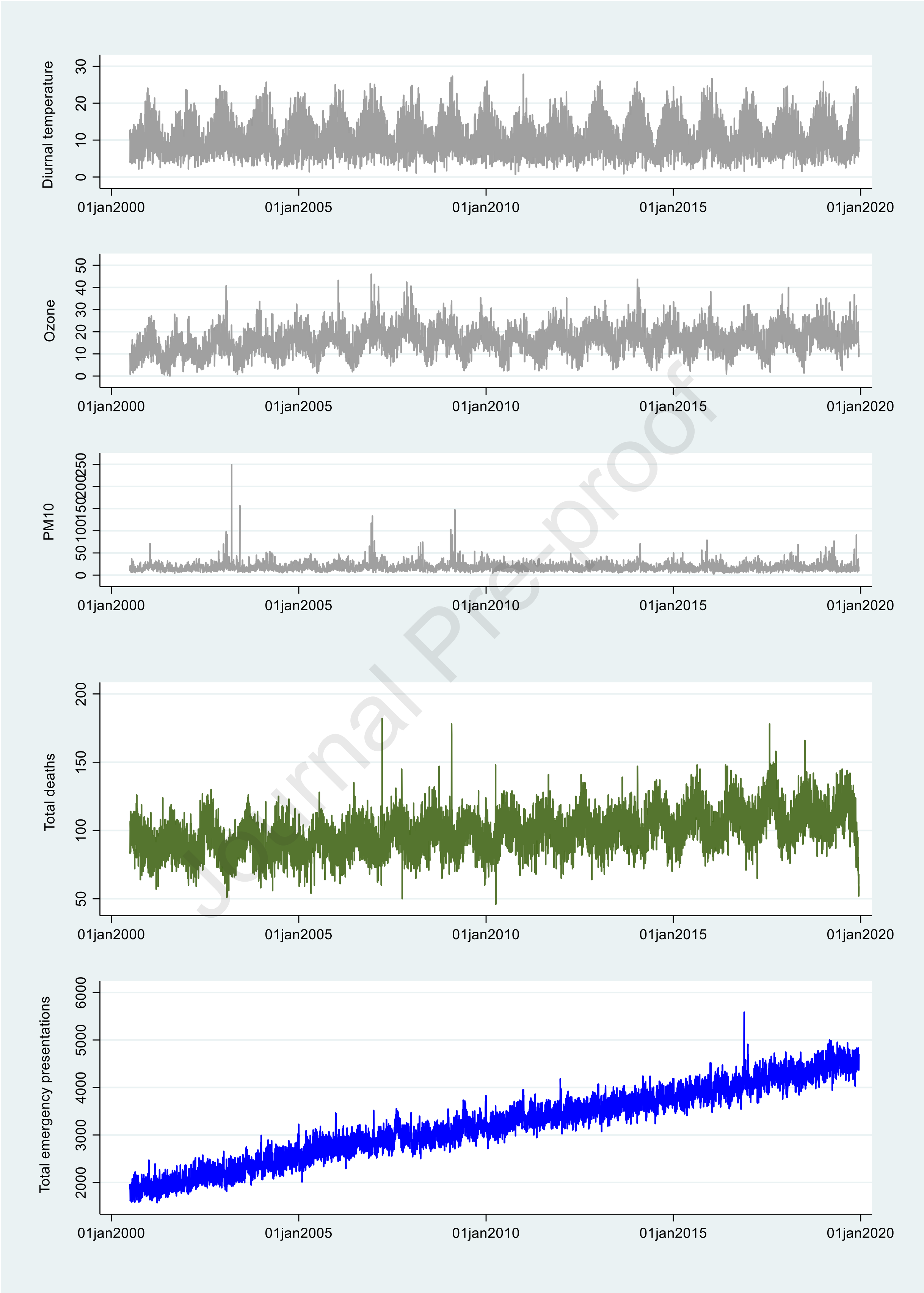

Figure 2. Changes in diurnal temperature, ozone, PM_{10}, mortality, and ED presentations for 6940 counts of days of the study period in the State of Victoria, Australia (1st January 2000 to 1st January 2019

3.3 DTR-Mortality Relationship

The effect of DTR exposure was determined as a percentage (%) increase in risk of all-cause mortalities in relation to the increase in DTR as shown in Figure 3. Overall, a linear association was observed between DTR and mortality with a relative risk of 0.33% (95% CI: 0.24% – 0.43%) on lag0 day and peaked at cumulative lag0-1 day by 0.55% (95% CI: 0.44 – 0.66%). In male population, the risk began at lag0 day by 0.33% (95% CI: 0.19– 0.45%), achieved a highest mortality risk of 0.55% (95 CI: 0.39 –0.70%) at cumulative lag0-1 day whereas the lowest risk of 0.08% (95% CI: - 0.09% – 0.26%) was found at cumulative lag0-3 day. Similar in females, DTR was associated with mortality during lag0 day (0.34% [95% CI: 0.21% – 0.47]), lag0-1 day (0.56% [95% CI: 0.4% – 0.71%]) and lag0-3 day (0.11% [95 CI: 0.06% – 0.28%]) as shown in Figure 3.

With regards to the age groups, we found that the association between DTR and risk of mortality increases with age among the study population. At lag0, the mortality risk was highest among the 85+ years population by 0.39% (95% CI: 0.25% – 0.55%), followed by those with 65-84 years by 0.31% (95%CI: 0.17% – 0.45%), and the 0-64 years group with 0.23% (95% CI: 0.02% – 0.45%). When we estimated the effect of DTR on mortality on lag0-1 lag structure by age, we found that 85+ year sub-group showed the highest cumulative risk of 0.73% (95% CI:0.55 % – 0.91%) than the other age groups (Figure 3).

For season-specific analysis (Figure 3), warmer months DTR levels was associated with mortality on lag0 day, lag1day, lag2 day and lag3day with relative risk of 0.55% (95% CI: 0.43% – 0.67%) ,0.27% (95%Cl: 0.18%-0.35%), -0.086% (95% CI: -0.16%- -0.011%) and -0.17% (95% CI: -0.25% -0.11%), respectively. However, the highest cumulative risk of mortality occurred on lag0-1days (0.83% [95% CI: 0.68% – 0.98%]), and later reduced on lag0-3 days

(0.18% [95% CI: 0.012 % -0.36%]). During the colder months, DTR was associated with mortality on lag0 day (0.038% [95% CI: -0.11% – 0.19%]), lag1day (0.22% [95% CI: 0.11% – 0.33%]), lag2day (0.046% [95% CI: -0.055% –0.14%]) and lag3 day (0.0021% [95% CI: -0.096% – 0.1%]). The cumulative risk slightly for mortality was highest on lag0-1 days with relative risk of 0.28% (95%CI: 0.11% – 0.45%) compared to lag0-3 days (0.21% [95% CI: 0.028% – 0.4%]). Therefore, individuals exposed to DTR have higher risk of mortality during warmer months than colder months (Figure 3).

3.4 DTR-ED Presentations Relationship

The effect of DTR on the ED presentation across the State of Victoria is shown in Figure 4. We found an association between DTR and total ED presentation, the relative risk increased during lag0 day, and cumulative lag 0-1day by 0.094% (95% CI: 0.077%-0.11%) and 0.15% (95 % CI: 0.13 – 0.16%), respectively. These risks increased but did not change much from cumulative lag0-2 days (0.15%; 95% CI: 0.13% – 0.17%), and cumulative lag0-3days (0.15%, 95% 0.13% – 0.17%). At cumulative lag0-1 day, children (0-15 years) were found to have experienced the highest risk of ED presentation by 0.38% (95% CI: 0.34% – 0.42%) followed by the elderly (75+ years) population of 0.34% (95% CI: 0.29% – 0.39%) in relation to increase in DTR.

The highest risk of ED presentation associated with increase in DTR for all age groups were observed during the cold season with 0.21% (95% CI:0.18% – 0.24%) at lag0 day and persisted during cumulative lag0-1 day by 0.2% (95%CI:0.17% – 0.23). However, the ED presentation risk was observed to have decreased by nearly 100% within the previous two days (lag2 days) by 0.02% (95% CI: 0.0026% – 0.04%).

Considering the effect of seasons in DTR-ED presentation relationship, we found that the season did not significantly modify the risk of ED presentation across all the lag structures (lag0day to lag0-3 day). The relative risk of ED presentation during the warmer months were 0.083% (95%CI:0.02%-0.1%), 0.042% (95%CI:0.027%-0.057%), 0.042% (95%CI:0.029%-0.055%), and 0.059% (95%CI:0.047%-0.072%) for lag0 day, lag1 day, lag2day and lag3 day, respectively. The highest risk of ED presentation (0.23% [95% CI: 0.20– 0.26]) occurred on cumulative lag0-3 days. Similar trend of DTR-ED presentation association was also observed during the colder months (Figure 4).

3.5 The DRT-ED Relationship queried by Triages and Patient's Departure Status

The association between DTR and the risk of ED presentations queried by triages and departure status was shown in Figure 4. An increase in DTR on lag0 day was associated with higher resuscitation (0.79% [95% CI:0.60%-0.99%]), this risk did not change much on cumulative lag0-2 days (0.52%, 95% CI:0.28%-0.77%) and cumulative lag0-3 days (0.53%, 95% CI:0.27%-0.79%). Despite the emergency being the highest ED triage presentations (Table 1), it only increased especially at lag0 days by 0.27% (95% CI: 0.22%-0.33) but did not increase on the next day (lag1 day) (-0.04%, (95 % CI: -0.075%-0.0052%)). Semi-urgent triage slightly varied the association between DTR and ED presentation on lag0 day (0.018% [95% CI: -0.0043%- 0.041%]).

The association between an increase in DTR and risk of ED presentation by departure status was also evaluated (Figure 4). A strong association was observed between DTR and patients with other departure status, the risk increased by 0.47% (95% CI:0.36-0.58%) at cumulative lag0-1 day, which was higher than log0 day (0.35% [95% CI: 0.26%-0.44]). The strongest and the weakest DTR-ED presentation association was observed among patients who departed home on lag3 day (0.3% [95% CI:0.27%-0.32%]) and on cumulative lag 0-3 days (0.06% [95% CI: 0.049%-0.075%]), respectively. Additionally, DTR-ED presentation association was weak among patients who were admitted to the hospital wards for all the lag structures except lag0 day with an estimated RR of 0.15% (95%CI: 0.11%- 0.18% (Figure 4).

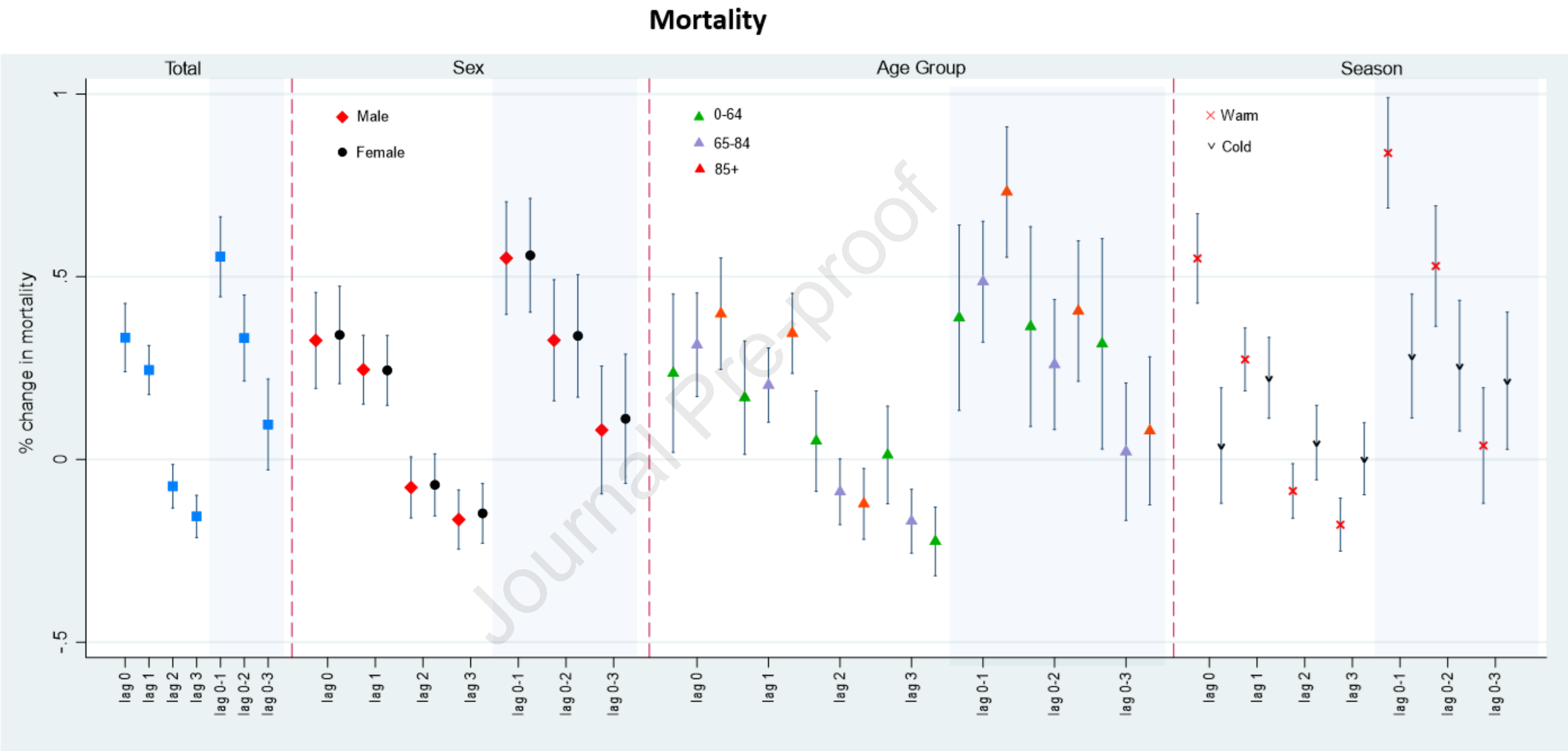

Fig 3. Diurnal temperature range (DTR) and % change in risk of mortality (95% CI) based on different age groups, sex, warm season including Spring and Summer (September-February) and colder season including Autumn and Winter (March -August) in the State of Victoria, Australia from 1st January 2000 to 1st January 2019

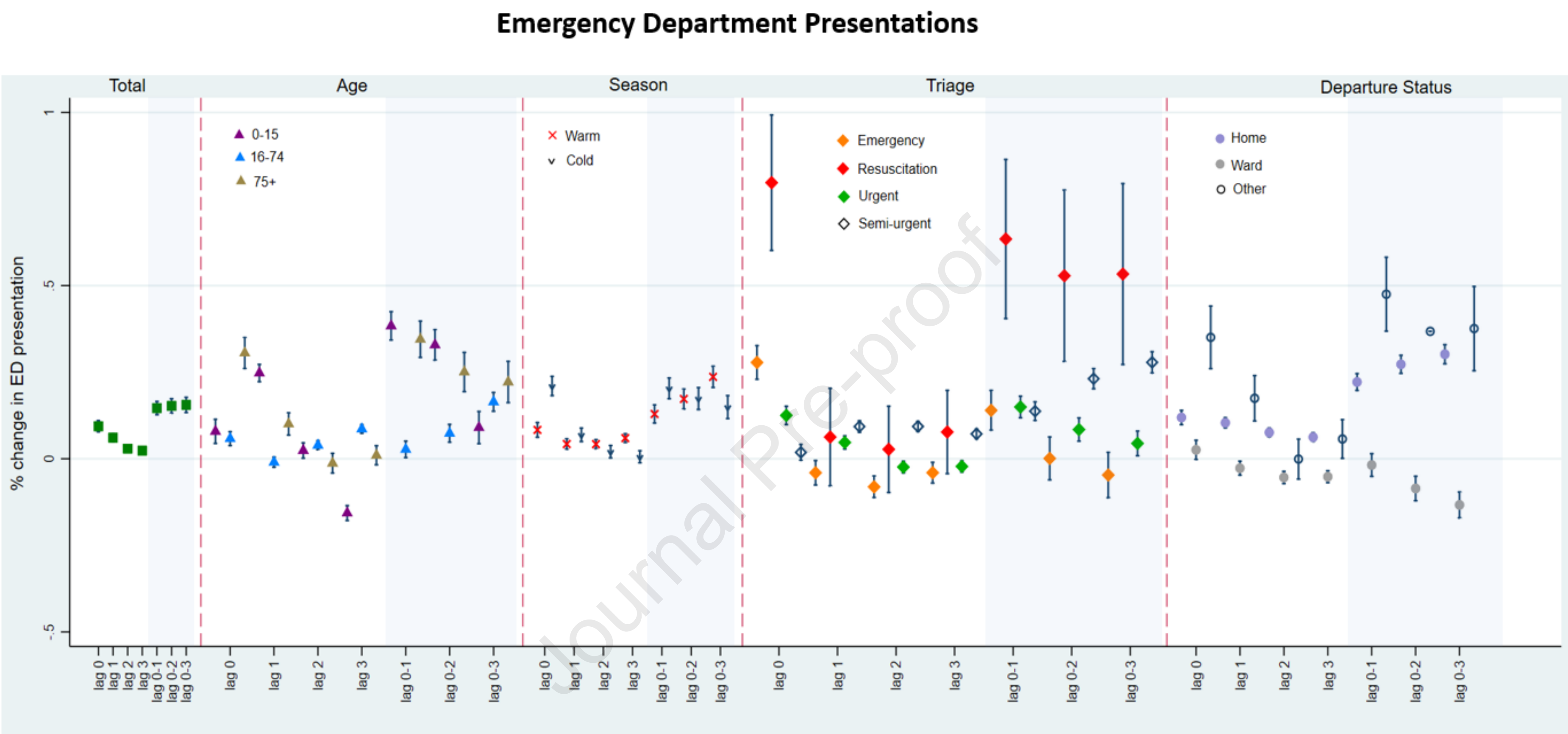

Fig 4. Diurnal temperature range (DTR) and % change in risk ED presentations (95% CI) based on different age groups, warm season including Spring and Summer (September-February) and colder season including Autumn and Winter (March -August) season , ED triage, and departure status in the State of Victoria , Australia from 1st January 2000 to 1st January 2019.

4 Discussions

This is the first study in Australia examining the association between DTR and risk of mortality and ED presentation (January 2000–January 2019) in State of Victoria, Australia (SVA) using time-series design. We observed three notable findings in this study: (1) the risk of mortality and ED presentations increased with the increase of DTR in Victoria, Australia; (2) the association between DTR and the risk of ED presentations was stronger in children (0-15 years) and the elderly (75+ years) than it was in the other age groups; and (3) the association between DTR and the risk of ED presentations of resuscitation triage was greater than that those in emergency, urgent and semi-urgent triages .

We found that short term increased DTR exposure is a risk factor for all-cause mortalities especially among the elderly and children in the State of Victoria, Australia. Our results were found to be consistent with previous reported study in Australia where DTR was linked to poor lung function among asthmatic children (Li et al., 2014).

It should be noted that this is first assessing the association between DTR , mortality and ED presentation in State of Victoria. However, some few studies conducted in Brisbane, Australia have also shown an association between DTR, and childhood asthma including diarrhea (Xu et al., 2013a; Xu et al., 2013b). This clearly shows that DTR is an important climate hazard in Australia.

This health outcome has previously been confirmed by Kan et al. (2007) that increased DTR in cold days are normally associated with respiratory diseases mortality. We also found similar evidence across more than 400 communities in 20 countries indicating that increased DTR could increase global excess mortalities from 1.4% to 10.3% nine decades (Lee et al., 2020).

The association between DTR and mortality are caused by changes in the normal functioning of human physiological systems especially circulatory and renal organs following exposure to increased DTR (Lee et al., 2020; Liu et al., 2015). DTR was associated with decreased in heart rate variability, thus causing decrease in very low frequency power (VLF), low frequency power (LF) , and high frequency power (HF) by 3.9%, 6.9%, and 5.8%, respectively, above than normal(Tang et al., 2021). An increase in temperature variability is linked to nearly 3.95-6.99% reductions in human heart rate variability among the adult population (Tang et al., 2021) . This cardiac response occurred on the same day of exposure (Tang et al., 2021). A systematic review study findings made up of 9 inclusive studies have concluded that the major risk factor for temperature variability is poor functioning of human blood vessels and homeostatic systems (Casas et al., 2016)

It was further highlighted that these abnormal biological mechanisms seem common among the elderly population and those with underlying comorbidities (Casas et al., 2016). This result seems consistent with our current findings where the elderly sub-population (85+ years) group experienced the highest increase in mortalities following daily increased DTR exposure especially during the warmer months. In addition, these abnormal biological responses caused by temperature variability might be an important reason for an increase in the risk of ED presentations among people who have experienced resuscitations. Patients under this particular type of ED triage (i.e., resuscitation) are widely known of having cardiopulmonary health conditions (Ghasemzadeh et al., 2018; Stevenson, 1998), and this could be a major factor for increased ED presentations under this study.

The previous studies relied only on ED presentation data for all the patients without analysing the effect of their related sub-group data such as triage and departure status on

ED presentation risk (Byun et al., 2020; Jang and Chun, 2021; Ponjoan et al., 2021) . Having noted this setback, we included the analysis on the relationship by different triage presentations (resuscitation, emergency, urgent, and semi-urgent) and departure status (home or ward, other) on the risk of ED presentations. Exposure assessment studies have shown that south-eastern part of Australia (where State of Victoria is located), has high levels of DTR than the other parts of the country , especially during the winter season (Plummer et al., 1995). In addition to our findings, it implies that the vulnerable population living in State of Victoria are likely to suffer from the health effect of extreme DRT exposure in future if immediate mitigation actions are not put in place. This calls for the development of future finer spatial scale (suburbs level) DTR -vulnerability assessment to help identify the potential populations who may be risk of DTR exposure in the State of Victoria (Zhang et al., 2018).

While future studies might advance this current knowledge for a better understanding of DTR -mortality/ED presentation relationships, there is a handful of strengths that can be found in this study. This is the first regional study that investigated the association between DTR and risk of mortality/ED presentation outcomes in the State of Victoria, Australia where the analyses of DTR-health outcomes were evaluated for different triage presentations and departure status of the patients. The additional fine resolution sub-group analysis based on age, sex, and season represents socio-demographic and environmental factors that can be also used to identify vulnerable populations.

This study is faced with several limitations. First, since this is a regional study, all the health data (mortality and ED presentation) were aggregated from the fine spatial locations (suburb/cities) to the state level, making it difficult to consider the spatial variations of these health effects. We assumed a linear exposure-response relationship without concurrently accounting for non-linear of the DTR-mortality/ED presentation relationship (Gasparrini et al., 2015). Sub-daily (e.g., hourly) DTR exposure data are required to better understand the short-term risk of ED presentation in Australia especially among the vulnerable population (Cheng et al., 2017).

Since this is a State-level ecological study and observational in nature, it is difficult to presuppose causality in the DTR-mortality/ED presentation association as individual level inferences are difficult to draw. A comprehensive systematic review evaluating the effects of DTR on health using the Hill's criteria should be conducted to explore the causality of the effects. Another limitation of the study is that RR of <1 shows negative TDR-mortality/ED presentation association, which the DTR provides a protective effect. Though, we did adjust our model to account for the effect of air pollution levels relation to mortality and ED presentation. Since, these may not be exhaustive, is important for future studies to explore the contribution these important confounders together with other sociodemographic covariates.

Another important consideration such as type of occupancy, the altitude, population levels in Melbourne including the whole State, proximity of population to monitoring stations, and the locations of the hospitals could provide more insight about spatial variability of DTR and health outcomes (e.g., mortality, ED presentations) . In addition, due to the availability of the original data, we used the different classifications for the oldest age groups (85+ for mortality vs. 75+ for ED presentations), so the comparison of the effects of temperatures on mortality and morbidity would be difficult.

Finally, temperature data used was acquired across different weather stations which may vary in terms of spatial resolution and could not represent the actual DTR exposure level in the State of Victoria. However, since majority of the population in central region of the State of Victoria lives in Melbourne, it is expected DTR won't vary much across different locations. Future studies focusing on finer spatial scales (e.g., consisting of populations size lesser than 200-800 people opposed to state level or statistical area level 2) analysis with thousands and millions of populations. Applying meta-regression analysis to determine DTR -health outcome relationship modified by the modification factors could advance this current knowledge for future DTR-public health policies.

5 Conclusions

This study suggests that the risk of mortality and ED presentations increases with the increase of DTR in the State of Victoria, Australia (SVA). Children (0-15 years), elderly (75+), and their caregivers need to be made aware of this DTR-related health risk. Interventions such as public health alerts systems, and warnings which may potentially reduce health outcomes especially during high DTR levels needs to be investigated. This study could provide a reference point for developing future DTR vulnerability assessment tool to protect the most vulnerable population in SVA. Long-term intervention policies such as including DTR into future State level heat-health action plans especially among the highly vulnerability communities could potentially reduce the adverse health effect of DTR.

Author's Contributions

Patrick Amoatey: Writing Manuscript-draft, Review, Editing, Analysis; **Nicholas J. Osborne:** Review, Editing, Resources, Supervision; **Darsy Darssan:** Statistical analysis, Review, Editing. **; Zhiwei Xu:** Statistical analysis, Review, Editing; **Quang-Van Doan:** Data process, Review, Editing; **Dung Phung:** Conceptualization, Methodology, Formal Analysis, Review, Editing, Resources, Supervision.

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Consent for publication

Not applicable

Declaration of conflict of interest

The authors declare no potential competing conflict of interest that might influence the outcome of this study.

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Highlights:

- The risk of mortality and emergency department (ED) presentations in State of Victoria, Australia (SVA), associated with increase in diurnal temperature (DTR).
- The association between DTR and the risk of ED presentations was stronger in children (0-15 years) and the elderly (75+ years).
- DTR exposure increased the risk of ED resuscitation.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: