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Heatstroke-related ambulance dispatch risk before and during COVID-19 pandemic: Subgroup analysis by age, severity, and incident place

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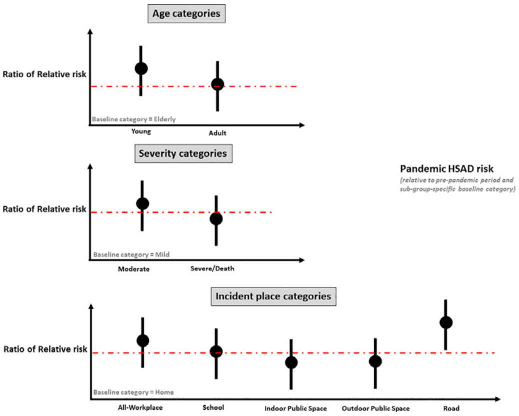
HIGHLIGHTS

- Non-uniform HSAD risk changes in all categories across subgroups.
- Young had higher risk reduction than adult category in age subgroup.
- No difference in risk between moderate and severe/death categories in severity subgroup.
- Compared to home category, all categories had reduced risk, except for road category.

GRAPHICAL ABSTRACT



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ABSTRACT

Background: In summer 2020 under the COVID-19 pandemic, the Ministry of Health, Labour and Welfare has made public warnings that specific preventive measures such as maskwearing and stay-at-home orders, may increase heatstroke risk. In our previous work, we found a lower risk of heatstroke-related ambulance dispatches (HSAD) during the COVID-19 period, however, it is uncertain whether similar risk reductions can be observed in different vulnerable subgroups. This study aimed to determine the HSAD risk during the COVID-19 pandemic by age, severity, and incident place subgroups.

Method: A summer-specific (June–September), time-series analysis was performed, using daily HSAD and meteorological data from 47 Japanese prefectures from 2017 to 2020. A two-stage analysis was applied to determine the association between HSAD and COVID-19 pandemic, adjusting for maximum temperature, humidity, seasonality, and relevant temporal adjustments. A generalized linear model was utilized in the first stage to estimate the prefecture-specific effect estimates. Thereafter, a fixed effect meta-analysis in the second stage was implemented to pool the first stage estimates. Subsequently, subgroup analysis via an interaction by age, severity, and incident place was used to analyze the HSAD risk among subgroups.

Results: A total of 274,031 HSAD cases was recorded across 47 Japanese prefectures. The average total number of HSAD in the pre-COVID-19 period was 69,721, meanwhile, the COVID-19 period was 64,869. Highest reductions in the risks was particularly observed in the young category (ratio of relative risk (RRR) = 0.54, 95% Confidential Interval (CI): 0.51, 0.57) compared to the elderly category. Whereas highest increment in the risks were observed in severe/death (RRR = 1.25, 95% CI: 1.13, 1.37) compared to the mild category.

Conclusion: COVID-19 situation exhibited a non-uniform change in the HSAD risk for all subgroups, with the magnitude of the risks varying by age, severity, and incident place.

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1. Introduction

Global warming caused by industrialization is a large-scale environmental hazard to all the living things on earth (IPCC, 2018). More recently, the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) in 2019 included the high and low non-optimal temperatures as health risk factors (Abbafati et al., 2020), which signaled the need to address the impact of temperature change on human health; a field which is now widely gaining global attention. In Japan, climate-sensitive health outcomes, such as heatstroke and heatstroke ambulance dispatch (HSAD), are associated with increasing temperatures (Fujibe et al., 2018; Ng et al., 2014; Toosty et al., 2021). The disproportionate effect of temperature on the risk of heatstroke in the Japanese population (Kotani et al., 2018) has been documented mainly among the elderly population (Ono and Ueda, 2011). Several studies also noted a geographical variability of these temperature-related heatstroke/HSAD risks across the country (Fujibe et al., 2018; Iwamoto and Ohashi, 2021).

Current literature, however, noted that the emergence of the Coronavirus disease 2019 (COVID-19), which is caused by an enveloped virus with crown-shaped spike and single-stranded RNA, may potentially exacerbate the temperature effects on human health (Bhatt et al., 2020; Lai et al., 2020). Particularly, mask-wearing, staying at home, and social distancing, which have been applied widely to prevent COVID-19 transmission, were regarded as potential driving factors to increase heat stress or risk of exposure to heat (MHLW, 2020b). In Japan, during summer 2020, under the new normal life, the Ministry of Health, Labour and Welfare (MHLW) has made public warnings regarding specific preventive measures, which may affect the risk of heatstroke (MHLW, 2020a). A working group on heatstroke medical care during the COVID-19 issued a recommendation to prepare for heat-illness on 1st June 2020 (Working group on heatstroke medical care during the 2020). However, it was also recognized that there is a lack of scientific evidence towards the limitation of this warning. We then conducted a study investigating the overall impact of the COVID-19 situation on heatstroke by using heatstroke-related ambulance dispatch (HSAD) data in Japan to provide evidence in aid of these precautions/warnings. Contrary to raising concerns issued by the government, we found a reduction in the heatstroke risk during the COVID-19 period (Hatakeyama et al., 2021). This, however, reflects a general HSAD risk and may not necessarily mirror the HSAD risks in different vulnerable subgroups (i.e., age, severity, and incident place). This thus warranted an examination at the subgroup levels to better understand the impact of COVID-19 on HSAD. Given the critical need for maintaining medical resources under the increasing resource constraints due to the COVID-19 pandemic, identifying the risk group of HSAD is beneficial in developing an efficient strategy to overcome the pandemic while harmonizing with essential medical provisions. Also, due to the complex interplay of concurrent interventions such as stay-at-home, social distance cancellation or closure of public facility and mask-wearing, this study focused on the aggregate effect of these interventions, represented by the COVID-19 pandemic situation. Taken all together, this study aimed to determine the HSAD risk during the COVID-19 period by age, severity, and incident place.

2. Materials and methods

2.1. Data

2.1.1. Outcome

Daily HSAD data in the summer season (June to September) from 2017 to 2020 were obtained from the Fire and Disaster Management Agency of the Ministry of Internal Affairs (FDMA) database (FDMA, 2021). HSAD data were aggregated into daily counts, including subgroup information regarding prefecture, age, severity, and incident place; defined by the FDMA. Other subgroup information, such as sex was not obtained because they were not publicly available. The prefecture was categorized into 47 groups according to the Japanese prefecture code. Sub-groups were defined as shown in Table 1.

Table 1
Sub-group definitions by Age, Severity, and Incident place.

Age	
Neonatal	0 to 28 days of age
Child	29 days to 6 years of age
School age	7 to 17 years of age
Adults	18 to 64 years of age
Elderly	Older than 65 years of age

Severity	
Mild	Hospitalization is not required
Moderate	Between severe to mild
Severe	Hospitalization is required for 3 weeks
Death	Confirmed death after the first diagnosis
Others	No confirmation by doctor, unknown cases or those who were carried to other places

Incident place	
Home	Whole areas on the house
Workplace1	Road construction sites, factories, workshops, etc.
Workplace2	Fields, forests, sea, rivers, etc.
School	Kindergarten, nursery school, elementary school, junior high school, high school, vocational school, university, etc.
Indoor public space	Theaters, concert venues, restaurants, department stores, hospitals, public baths, underground platforms of stations, etc.
Outdoor public space	Stadium, outdoor parking lot for each object, outdoor concert venue, outdoor platform of station, etc.
Road	General roads, sidewalks, toll roads, highways, etc.
Other	Places other than the above locations
Road	General roads, sidewalks, toll roads, highways, etc.
Others	Places other than the above locations

2.1.2. Temporal factors

Maximum temperature (in degrees Celsius; °C) and relative humidity (in %) in the study period were obtained from the Atmospheric Environment Regional Observation System (AEROS) and were adjusted accordingly as potential confounders. Measurement of these meteorological variables was through the background stations located in the capital cities in each prefecture. Data for relative humidity was also obtained from the same background monitoring stations. Several background monitoring stations, however, don't monitor relative humidity. In such cases, we utilized the nearest location's relative humidity as a substitute. We followed a similar approach from a previous study in Japan, whereby the stations of Kumagaya city and Hikone city were selected as a substitute for measurements in Saitama and Shiga prefectures, respectively because relative humidity was not monitored in the prefectures' capital cities (Ng et al., 2016). Finally, relevant data from stations were aggregated by selected city level and represented as prefecture-specific mereological parameters.

2.2. Statistical analysis

2.2.1. Two-stage analysis

A two-stage analysis which consists of prefecture-specific time-series analysis at the first stage and a fixed effect meta-analysis (at the second stage), was implemented to estimate the COVID-19 effect on overall HSAD, adjusting for temporal factors, including seasonality and long-term trend. The subsequent pooling of the first stage effects estimate, in this two-stage approach, reduces the uncertainty of those observed if prefecture estimates were to be utilized singly in representing the effect of COVID-19 on HSAD. This study focused on the difference in HSAD risk attributed to the COVID-19 situation since there was no difference in the heat effect before and during COVID-19 (as shown in Fig. S1).

In the first stage analysis, a generalized linear model (GLM) was applied to estimate the prefecture-specific effects estimate. The model used in the first stage analysis was constructed based on the data in Tokyo, which had the largest HSAD cases among 47 prefectures. Once the model building was finalized, the final model was subsequently applied to other prefectures to have consistent modeling parameterization across locations. In the model building process, GLM assumed a quasi-Poisson distribution to account for the overdispersion. Despite that non-linear model being flexible in capturing the exposure-response curve, a simple model was utilized to aid in terms of interpretability (Armstrong, 2006; Hashizume et al., 2009). Given the focus on summer-specific outcome, the upper threshold model or hockey-stick model was considered, which assumed a zero risk below the threshold and a linear increase in the risk beyond the threshold (Armstrong et al., 2011; Guo et al., 2012). It is often found that the temperature-mortality relationship exhibits a nonlinear association with a noticeable lag effect (Armstrong, 2006); however, based on our sensitivity analyses, in Fig. S2, we observed that the risk was largely prominent at Lag 0, with risks diminishing thereafter. A similar study conducted in Japan also observed that the same-day risks (at Lag 0) were evident before and during the pandemic, with no substantial difference in the trend of the risks even after extending to longer lags (Seposo et al., 2021). Thus, we only focused on the same-day maximum temperature effect on HSAD in this study. The model was evaluated by Akaike's Information Criterion for quasi-Poisson (qAIC) as well as an additional sensitivity analysis (Guo et al., 2012). The first stage model is parameterized using Eq. (1):

$$Y_{p,t} \sim Quasipoisson_t \tag{1}$$

$$\begin{aligned}\log\left(Y_{p,t}\right) = \alpha + factor(COVID19) * factor(subgroup) + \beta_1\ Maxtemp_{thr} \\ + ns(Humidity, df = 3) + \beta_2\ DOW + \beta_3 Holiday + \beta_4\ Year \\ + ns(DOS, df = 4) + \varepsilon\end{aligned}$$

where log ($Y_{p,t}$) is HSAD in prefecture *p* on time *t* follows a quasi-Poisson distribution; α is an intercept; *COVID-19* is the main exposure variable, which takes the value of 0 if the period is from 2017 to 2019, whereas it is coded as 1 during 2020. Asterisk (*) signifies the interaction term between the COVID-19 period and with the various categories in each subgroup. $Maxtemp_{thr}$ is the maximum temperature with a threshold at 80th maximum temperature percentile. The detection of the threshold point followed the method utilized in previous work (Hatakeyama et al., 2021). After plotting the prefecture-specific relative threshold based on the maximum temperature percentile, the median value at the 80th temperature percentile was decided for a common threshold point across 47 prefectures (Muggeo, 2003). *Humidity* is a daily relative humidity smoothed by natural cubic splines (NS) with 3 degrees of freedom (df) to capture the non-linear association. The selection of df for relative humidity was decided a priori following previous literature (Armstrong et al., 2011). *DOW* is a categorical variable for day of the week. *Holiday* is a binary variable of a national holiday in Japan. We adjusted for seasonality and long-term trends by including the following variables: *Year*, which is a categorical variable representing the years from 2017 to 2020, and *DOS*, which is the temporal variable representing the day of the season smooth by an NS with 4 df (Tobías et al., 2014). ε is the error term.

In the second stage analysis, a fixed-effects meta-analysis was employed to pool the prefecture-specific effects estimates and eventually generate the nationwide effect. Also, heterogeneity was measured with the I^2 statistic, indicating the proportion of total variation due to prefecture differences (Huedo-Medina et al., 2006). In this study, a *p*-value of 0.05 was specified as a criterion for statistical significance. All analyses were performed using R statistical programming (R Core Team, 2019).

2.2.2. Subgroup analysis via interaction

Several subgroups were aggregated to new subgroups so as to increase statistical power, specifically: young (which included the neonatal, child, and school-age subgroups), severe/death (which included severe and death subgroups), and all-workplace (which included workplace1 and workplace2 subgroups). We excluded the "Others" subgroups in severity and incident place due to its unknown classification, which would make it challenging to aggregate with other groups with well-defined classification. An interaction term (as shown in Eq. (1)) was used to determine whether the HSAD risk during COVID-19 differs by subgroup. Here, we utilized the category with the highest number of HSAD as the comparator category to the remaining categories. Specifically, we used "Elderly", "Mild" and "Home" categories for the age, severity, and incident subgroups, respectively. Results are expressed as the ratio of relative risks (RRR) between the comparator category and the remaining categories in the subgroup (e.g., adult and elderly, young and elderly).

2.2.3. Sensitivity analysis

Since there is no absolute consensus or criteria on the decision of the best model, sensitivity analyses play a critical role in assessing the robustness of the selected model by considering different choice of several approaches and components (Bhaskaran et al., 2013). One source of potential uncertainty is due to the role of air pollution. In this study, the influence of air pollution as a confounder in the overall effect estimate of the final model was examined. In brief, the non-adjusted air pollutant model and the adjusted air pollutant model were compared. Hourly PM2.5 and ozone data in the study period were obtained from AEROS and the National Institute of Environmental Studies (NIES) and aggregated into a daily scale. Photochemical oxidants (Ox) were used in exchange of ozone level because they are comprised mainly of ozone (Kurai et al., 2018). Regarding station selection, the same background stations, which corresponded to the meteorological parameters, were selected. When the relevant air pollutant data were not available, background stations adjacent to the capital city with similar geographical conditions were selected as a replacement. In addition, sensitivity analysis of df specification was also conducted for relative humidity, as well as the examination of pre-pandemic and pandemic temperature effects; all shown in the Supplementary Materials.

3. Results

3.1. Explore data analysis (EDA)

In the period from June to September between 2017 and 2020, a total of 274,031 HSAD cases were recorded in the dataset. Table 2 shows the summary statistics for HSAD and meteorological data of the 47 prefectures by year. 2018 has registered the highest number of HSAD (92,710) in the study period, with correspondingly the highest median maximum temperature (30.2 °C) in the same year. The average total number of HSAD in the pre-COVID-19 period was 69,721; meanwhile COVID-19 period was 64,869. Humidity was around 74% to 77% across the study period, with the highest relative humidity in 2020 (77%).

3.2. Two-stage analysis

In Fig. 1, the nationwide relative risk (RR) of HSAD in 2020 was 0.80 with a 95% confidence interval (95%CI): 0.77, 0.83, indicating lower HSAD risk than pre-COVID-19 period. At the prefecture-level, the majority of prefectures showed statistically significant lower HSAD risk in 2020. In particular, Chiba prefecture showed the lowest RR among 47 prefectures (RR = 0.58, 95%CI: 0.43, 076). Few prefectures showed RRs beyond 1 such as in Iwate, Niigata, Ishikawa, Saga, Nagasaki, and Kumamoto. However, the 95% CI includes 1, indicating statistically non-significant effects

Table 2
Summary statistics of summer-specific HSAD and meteorological data from 2017 to 2020.

				Pre-COVID	COVID
Year	2017	2018	2019	2017–2019	2020
	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)
HSAD (cases/days)	3	4	3	3	4
	(9)	(15)	(10)	(11)	(11)
(Total cases/year)	49,583	92,710	66,869	69,721	64,869
Maximum temperature (°C)	29.4	30.2	29.3	29.6	29.5
	(5.9)	(7.1)	(5.6)	(6.2)	(5.9)
Humidity (%)	74	75	76	75	77
	(14)	(14)	(14)	(14)	(14)

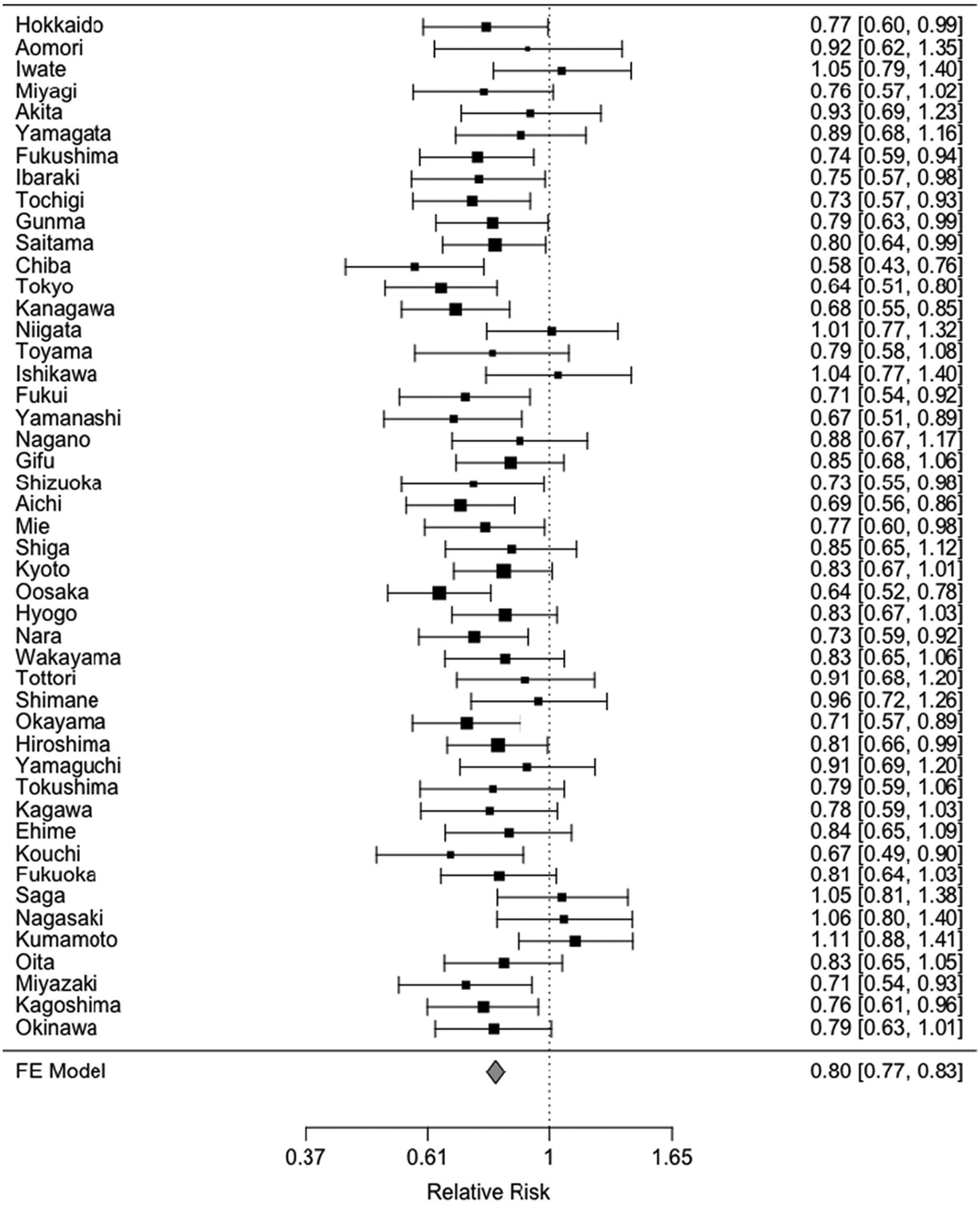

Fig. 1. Forest plot of prefecture-specific relative risk of HSAD during COVID-19 period[1]. [1]Baseline period is the pre-COVID-19 period.

estimates. I^2, which describes the percentage of heterogeneity across each effect estimates, showed a mild heterogeneity of 19.76% ($p = 0.12$).

3.3. Stratified analysis for age, severity, and incident place

Table 3 shows yearly number of HSAD stratified by subgroup. The elderly constitutes a majority of the age group, followed by adult, and young. The elderly accounted for 49.6% of HSAD during the pre-COVID-19 period and increased to 57.9% during the COVID-19 period. Adult accounted for 36.3% of HSAD during the pre-COVID-19 period and decreased to 33.5% during the COVID-19 period. Young accounted for 14.1% of HSAD during the pre-COVID-19 period and decreased to 8.6% during the COVID-19 period.

In severity group, the majority was mild, followed by moderate and severe/death. Mild accounted for 64.4% of HSAD during pre-COVID-19 period, which decreased to 60.2% during COVID-19 period. Moderate accounted for 32.7% of HSAD during pre-COVID-19 periods, which increased to 36.5% during COVID-19 period. Severe/death accounted for 2.5% of HSAD during pre-COVID-19 period, which slightly increased to 2.9% during the COVID-19 period.

In the incident place group, most HSAD occurred at home, followed by road, all-workplace, and outdoor public space. Home accounted for 39.4% of HSAD in the pre-COVID-19 period, which increased to 43.4% during the COVID-19 period. Road accounted for 14.1% of HSAD in the pre-COVID-19 period, which slightly increased to 17.4% during the COVID-19 period. On the other hand, the proportion of school, indoor public space, and outdoor public space were lower during the COVID-19 period than the pre-COVID-19 period.

Fig. 2 indicated the nationwide effect estimates by subgroup of age, severity, and incident place. Compared to each subgroup's comparator category, we observe a non-uniform change in the HSAD risk during COVID-19. The magnitude of HSAD risk reduction was different among subgroups.

Table 3
Summary statistics of HSAD stratified by subgroup (Age, Severity, Incident place).

							Pre-COVID		COVID	
Subgroup	2017		2018		2019		2017–2019		2020	
Age										
Young	7444	(15.0%)	13,716	(14.8%)	8294	(12.4%)	9818	(14.1%)	5585	(8.6%)
Adult	17,873	(36.0%)	34,454	(37.2%)	23,572	(35.3%)	25,300	(36.3%)	21,756	(33.5%)
Elderly	24,266	(48.9%)	44,540	(48.0%)	35,003	(52.3%)	34,603	(49.6%)	37,528	(57.9%)
Severity										
Mild	32,052	(64.6%)	60,513	(65.3%)	42,166	(63.1%)	44,910	(64.4%)	39,037	(60.2%)
Moderate	16,221	(32.7%)	29,716	(32.1%)	22,494	(33.6%)	22,810	(32.7%)	23,662	(36.5%)
Severe/death	1071	(2.2%)	2174	(2.3%)	1920	(2.9%)	1722	(2.5%)	1895	(2.9%)
Others	239	(0.5%)	307	(0.3%)	289	(0.4%)	278	(0.4%)	275	(0.4%)
Incident place										
Home	18,620	(37.6%)	37,650	(40.6%)	26,204	(39.2%)	27,491	(39.4%)	28,121	(43.4%)
All-workplace	6770	(13.7%)	11,958	(12.9%)	8814	(13.2%)	9181	(13.2%)	8664	(13.4%)
School	3634	(7.3%)	6067	(6.5%)	3726	(5.6%)	4476	(6.4%)	2901	(4.5%)
Indoor public space	4122	(8.3%)	8512	(9.2%)	5845	(8.7%)	6160	(8.8%)	4340	(6.7%)
Outdoor public space	6775	(13.7%)	11,824	(12.8%)	8236	(12.3%)	8945	(12.8%)	6130	(9.4%)
Road	6598	(13.3%)	12,389	(13.4%)	10,410	(15.6%)	9799	(14.1%)	11,276	(17.4%)
Others	3064	(6.2%)	4310	(4.6%)	3634	(5.4%)	3669	(5.3%)	3437	(5.3%)
Total	49,583		92,710		66,869		69,721		64,869	

Note: Table 3 describes the yearly number of HSAD divided by subgroup of age, severity, and incident places. The percentage of HSAD was calculated for each subgroup, which is enclosed in parentheses.

In age group, we noted that the adult category (compared to the elderly category) had reduced HSAD risks (RRR = 0.80, 95% CI: 0.76, 0.83; *p-value* < 0.001) during the COVID-19 pandemic, which was also apparent for the young category (RRR = 0.54, 95%CI: 0.50, 0.57; *p-value* < 0.001).

In severity subgroup, moderate category (RRR = 1.20, 95%CI: 1.16, 1.24; *p-value* < 0.001) showed higher HSAD risk than mild category. We also found higher HSAD risks during COVID-19 for severe/death category (RRR = 1.25, 95%CI: 1.13, 1.37; *p-value* < 0.001) compared to the mild category.

In incident place subgroup, results indicated that school (RRR = 0.68, 95%CI: 0.64, 0.73; *p-value* < 0.001), indoor public space (RRR = 0.66, 95%CI: 0.62, 0.71, *p-value* < 0.001), outdoor public space (RRR = 0.66, 95%CI: 0.63, 0.70) and all-workplace (RRR = 0.94, 95% CI: 0.90, 0.98; *p-value* = 0.007) had lower HSAD risk than home category. On the other hand, road-related HSAD risks (RRR = 1.11, 95% CI: 1.06, 1.16; *p*-value < 0.001) were statistically higher than home-occurring HSAD during the COVID-19 period.

4. Discussion

4.1. Prefecture specific and nationwide effect of COVID-19 on HSAD

Nationwide RR of HSAD reduced by 20% during the COVID-19 pandemic (Fig. 1). There are several possible reasons for the overall HSAD reduction during the COVID-19 pandemic (Hatakeyama et al., 2021). First, the reduction of the total number of ambulance dispatches was observed during COVID-19 (approximately 11.4%), which may have led to the concurrent reduction of HSAD (MIC, 2021). Second, the availability of alternative consultation services for COVID-19 may have minimized the ambulance service utilization for heat-related illness due to similar

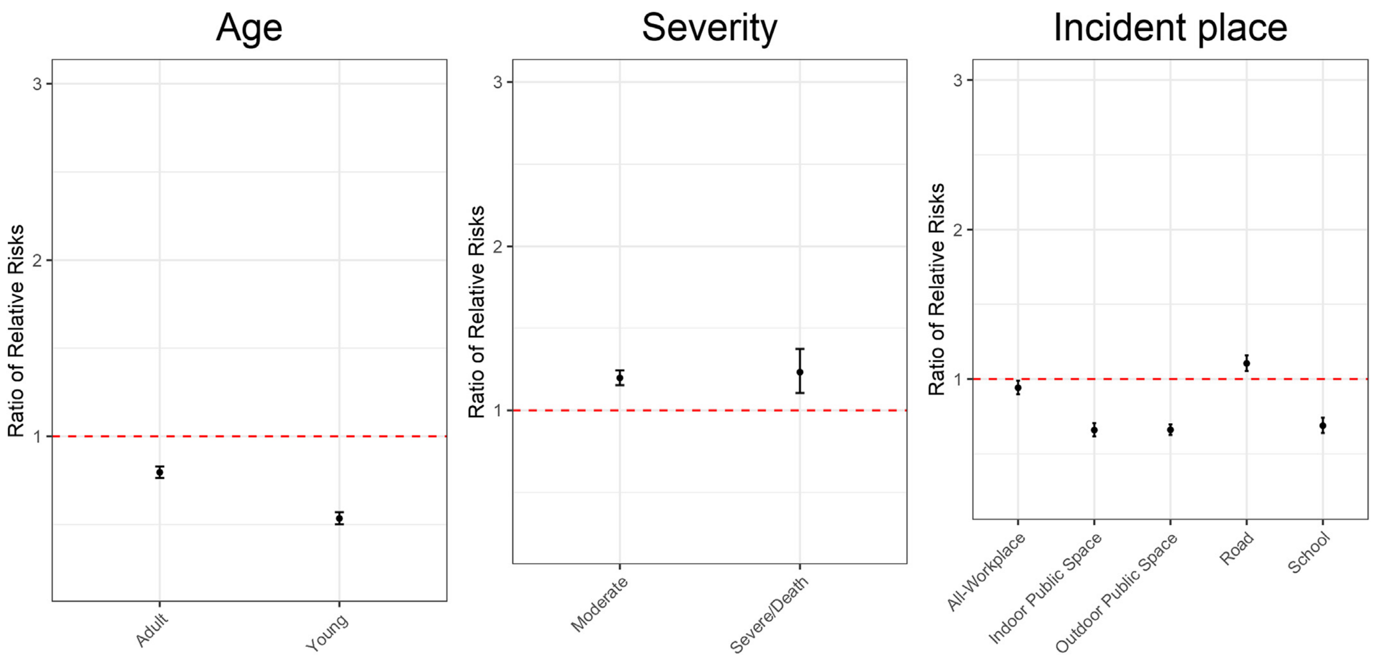

Fig. 2. HSAD risk stratified by subgroup during COVID-19 period^{1,*} ^{1}Baseline period is the pre-COVID-19 period. *The reflected categories are compared to the category with the highest HSAD case in the subgroup.

symptoms between COVID-19 and heatstroke, such as fever and exhaustion (MHLW, 2020b; Nakahara et al., 2021). Third, stay-at-home orders and movement restrictions may have protected the population from exposure to heat outside (Hanibuchi et al., 2021). Fourth, people may have special attention to heat-related illness prevention in 2020 due to the strengthening of heat-stroke awareness (Meiji Yasuda Life Insurance, 2020).

4.2. Subgroup analysis via interaction for age, severity, and incident place

Stratifying by subgroups revealed a generally similar reduction in HSAD cases during the pandemic, except for the elderly subgroup alongside the home and road (incident place) subgroups, which exhibited slightly higher mean HSAD cases, as shown in Table 3. Otani et al. (2021) similarly noted the amplification of HSAD cases of the elderly in Tottori, Japan. Typically, these heatstroke incident cases among Japanese elderly occur at home, which coincides with the increase in the mean HSAD cases of the home incident place subgroup. The increased stay of the elderly in their domicile may be related to the disruption of their access to several short-term and long-term health care services (Uryu et al., 2021).

Subgroup analysis, employing an interaction term, revealed statistically significant differences of HSAD risk among age, severity, and incident place subgroup during the COVID-19 period compared to the pre-COVID-19 period (as shown in Fig. 2). We observed a non-uniform change in the risks between and among categories within subgroups. In the succeeding sections, we attempt to elucidate the possible factors that have contributed to the variation in the changes in HSAD risk beween and among categories across subgroups.

4.2.1. Age

In the age subgroup, both the young and adult categories exhibited statistically significant reduction in the HSAD risk compared to the elderly category. The observed non-uniform risk reduction in the different age categories may possibly be related to the physical and physiological differences potentially inherent to age-related characteristics. In Northern Italy, Santi et al. (2021) similarly observed an overall reduction in emergency department visits across all age groups. Another study reported that the majority of HSAD in the young subgroup occurred outside (more than 60%), especially during outdoor play and sports activities in school, which increases their exposure to heat and sunlight (Ono, 2009). Considering that these activities were mostly restricted during the COVID-19 situation, it is reasonable that the significant reduction of heat exposure on the outside have led to greater HSAD reduction in the young subgroup. Our finding in the young subgroup was similar to the study which investigated the emergency departments attendances under COVID-19 in the UK, reporting that the reduction might be due to the activity reductions during lockdown were substantial in young people than in the elderly (Wyatt et al., 2021). This was also observed in Bologna Metropolitan Area, in Italy, whereby pediatric emergency department visits were reduced by 83.2%, which was substantially higher than those for adult (62.9% reduction) and elderly emergency department visits (64.0% reduction) (Santi et al., 2021). Similar to perhaps the universal reason of risk avoidance in health facilities, Kostopoulou et al. (2021) highlights that the reluctance of parents to risk their children's exposure to COVID-19 in a health-care setting drives the reduction of health facility visits.

HSAD in the adult subgroup is more likely to be related to summer-specific event, and workplace-related, especially for physical labor such as agroforestry, civil engineering, and manufacturing (JAAM, 2015). Although the physical work cannot be substituted by remote work, the cancellation of summer-related events, such as live concerts and marathon competitions may have moderately reduced the HSAD risk in the adult subgroup.

4.2.2. Severity

In the severity subgroup, compared to the mild subgroup, both the moderate and severe/death subgroups exhibited statistically significant increments in the HSAD risk during the COVID-19 pandemic. The comparably reduced HSAD risk in the mild category compared to the other categories might be explained by the hesitation of hospital visits, similar to recent studies conducted in several European countries (Kastritis et al., 2020; Santi et al., 2021). In Greece, Kastritis et al. (2020) noted that emergency department visits for low risk, non-specific symptoms, and causes (e.g., fatigues, back or other non-specific pain, etc.) reduced substantially during the pandemic. We presuppose that those with mild symptoms may have chosen homecare rather than hospital care due to fear of COVID-19 infection (Takakubo et al., 2021). The increment in the risks in the moderate and severe/death subgroups might be explained by the less hesitation for ambulance utilization due to the urgent nature of the condition rather than those of the mild cases (Chen et al., 2021; Katayama, 2021).

4.2.3. Incident place

Compared to the highly incident HSAD subgroup of home, school, all-indoor public space, outdoor public space and all-workplace showed a non-uniform reduction of the risks, whereas road related HSAD risks were found to be comparably higher during the COVID-19 period. The restriction of outdoor activities and closure or cancellation of the public facility may be related to the changes in the risk (Uryu et al., 2021). Prior to summer in 2020, stay-at-home orders have been a serious concern for increased HSAD risk, however, the result showed the risk at home was reduced. Although stay-at-home orders or remote work increased the percentage of people who spend time at home, the increased portion were mainly young and adult (Hanibuchi et al., 2021), who are more responsive to changes in environmental conditions rather than the elderly. Owing to this, they could manage appropriate temperature control using an air-condition (AC) or fan, and it may not have led to a significant increase in HSAD risk at home (Yasuhi et al., 2010). However, the lack of AC data limits the exploration of this assumption. Thus, further study is needed taking into account this potential variable. It interesting to note that while stay-at-home restrictions were in place, road related HSAD risks were higher during the COVID-19 pandemic. Though counterintuitive, this may potentially be related to occupations requiring manual labor such as construction workers, which were less impacted due to the nature of their work. In a recent report, which surveyed the impact of COVID-19 infection on work and daily life during the state of emergency in Japan, it was noted that occupations such as construction experienced less reduction in their working hours compared to other sectors (e.g. sales workers, service workers, transport workers) (JILPT, 2021; Tomohiro, 2021). In the period from second week of April 2020 to fourth week of July 2020, which coincides with the State of Emergency declaration, the construction workers experienced a range of 0- to 3-hour reduction in working hours compared to pre-pandemic working period, whereas the service workers experienced a range of 11.2- to 4.4-hour reduction in working hours (compared to pre-pandemic period) (Tomohiro, 2021).

5. Strengths and limitations

This study has several limitations. First, before-and-after design, such as this study, suffers from a poor interval validity since it is not possible to exclude the underlying trends as a cause for any change. A workaround for this limitation is the utilization of a control group, which could aid in adjusting for the history bias due to time-varying confounders, in particular co-interventions and other events concurrent with the intervention (Lopez Bernal et al., 2018). Second, weather parameters and air pollutant data were obtained from a monitoring station located in the central city, which may not precisely capture the spatial and geographical heterogeneity within the prefecture. Several studies have noted the spatial heterogeneity of exposures on various health outcomes (Chen et al., 2015; Zhou et al., 2014), and suggest that these spatial variabilities be taken into consideration to reduce exposure misclassification and subsequent uncertainty in the exposure-response risk estimation. Third, 2020 was used as a proxy of the COVID-19 situation effect. Potential continuous variables such as daily instantaneous reproduction number (Yu, 2020) or case fatality rate (Hassan et al., 2020) may provide a different vantage point in estimating the HSAD risk. However, this might not truly represent the possible causal mechanism related to the reduction of HSAD. Further study is required with appropriate indicator variables to understand individual effects under COVID-19 situations such as mask-wearing, stay-at-home orders, and other related interventions. Fourth, changes in regional variables such as air-condition usage, potentially be related to the HSAD risk, were not considered in this study due to the lack of granular data that could match the prefecture-specific risk estimates. Fifth, HSAD data used in the study was the morbidity data of heat-related illness, which was not able to cover death at home due to delay of detection and treatment. It has been noted that effect of temperature on mortality and morbidity outcomes vary in magnitude (McGeehin and Mirabelli, 2001; Song et al., 2017), and thus its subsequent examination may provide insightful results. Sixth, our result cannot be simply generalized to other countries due to the variation of medical service, recognition of heatstroke, climate, and COVID-19 situation, which are unique to each country. Nevertheless, this is the first study to investigate the impact of the COVID-19 situation on HSAD by subgroup. Also, utilization of multiple locations and subsequent pooling via meta-analysis increases confidence over the pooled effects estimates versus using a single site.

6. Conclusions

The COVID-19 situation has led to a substantial reduction in HSAD cases. Furthermore, the effect of the COVID-19 situation exhibited a non-uniform change in the HSAD risk for all subgroups, with the magnitude of the risks varying by age, severity, and incident place.

CRediT authorship contribution statement

Koya Hatakeyama: Study conceptualization, data curation, statistical analysis, writing-original draft; Xerxes Seposo: Study conceptualization, data curation, statistical analysis, writing-original draft, reviewing and editing.

Declaration of competing interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2022.153310.

References

Abbafati, C., Machado, D.B., Cislaghi, B., Salman, O.M., Karanikolos, M., McKee, M., et al., 2020. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the global burden of disease study 2019. Lancet 396, 1223–1249.

Armstrong, B., 2006. Models for the relationship between ambient temperature and daily mortality. Epidemiology 17, 624–631.

Armstrong, B.G., Chalabi, Z., Fenn, B., Hajat, S., Kovats, S., Milojevic, A., et al., 2011. The association of mortality with high temperatures in a temperate climate: England and Wales. J. Epidemiol. Community Health 65, 340–345.

Bhaskaran, K., Gasparrini, A., Hajat, S., Smeeth, L., Armstrong, B., 2013. Time series regression studies in environmental epidemiology. Int. J. Epidemiol. 42, 1187–1195.

Bhatt, T., Kumar, V., Pande, S., Malik, R., Khamparia, A., Gupta, D., 2020. A review on COVID-19. Indian J.Pediatr. 87, 281–286.

Chen, K., Huang, L., Zhou, L., Ma, Z., Bi, J., Li, T., 2015. Spatial analysis of the effect of the 2010 heat wave on stroke mortality in Nanjing, China. Sci. Rep. 5, 10816.

Chen, J., Cheng Yr, Fu., Xy, Wang Cy, Wen, W., Ni, J., et al., 2021. Exploring the impact of the COVID-19 epidemic on the medical emergency calls and calls for cardiovascular diseases in Hangzhou, China. Ir. J. Med. Sci. 21, 1–5.

FDMA, 2021. Heatstroke Information. FDMA.

Fujibe, F., Matsumoto, J., Suzuki, H., 2018. Regional features of the relationship between daily heat-stroke mortality and temperature in different climate zones in Japan. SOLA 14, 144–147.

Guo, Y., Punnasiri, K., Tong, S., 2012. Effects of temperature on mortality in Chiang Mai City, Thailand: a time series study. Environ. Health 2012, 11.

Hanibuchi, T., Yabe, N., Nakaya, T., 2021. Who is staying home and who is not? Demographic, socioeconomic, and geographic differences in time spent outside the home during the COVID-19 outbreak in Japan. Prev. Med. Rep. 21.

Hashizume, M., Wagatsuma, Y., Hayashi, T., Saha, S.K., Streatfield, K., Yunus, M., 2009. The effect of temperature on mortality in rural Bangladesh-a population-based time-series study. Int. J. Epidemiol. 38, 1689–1697.

Hassan, M.M., El Zowalaty, M.E., Khan, S.A., Islam, A., Nayem, M.R.K., Järhult, J.D., 2020. Role of environmental temperature on the attack rate and case fatality rate of coronavirus disease 2019 (covid-19) pandemic. Infect.Ecol.Epidemiol. 10, 1792620.

Hatakeyama, K., Ota, J., Takahashi, Y., Kawamitsu, S., Seposo, X., 2021. Effect of the COVID-19 pandemic on heatstroke-related ambulance dispatch in the 47 prefectures of Japan. Sci. Total Environ. 768, 145176.

Huedo-Medina, T.B., Sanchez-Meca, J., Marin-Martinez, F., Botella, J., 2006. Assessing heterogeneity in meta-analysis: I2 or q statistic? Psychol. Methods 11, 193–206.

IPCC, 2018. Summary for Policymakers. IPCC.

Iwamoto, Y., Ohashi, Y., 2021. Assessing the climatological relationship between heatstroke risk and heat stress indices in 47 prefectures in Japan. GeoHazards 2, 321–331.

JAAM, 2015. Heatstroke Medical Guideline 2015.

JILPT, 2021. What impacts is the COVID-19 crisis having on work and daily life? —from the results of "survey on the impact that spreading novel coronavirus infection has on work and daily life" (May 2020 survey). Japan Labour Issues. Japan Institute for Labour Policy and Training.

Kastritis, E., Tsitsimpis, K., Anninos, E., Stamatelopoulos, K., Kanakakis, I., Lampropoulos, C., et al., 2020. Significant reduction in the visits to the emergency room department during the COVID-19 pandemic in a tertiary hospital in Greece: indirect victims of the pandemic? Medicine 99, e23845.

Katayama, Y., 2021. Incidence and mortality of patients transported by ambulance during the RST surge of the COVID-19 pandemic in Osaka Prefecture, Japan. Res. Square 1–21.

Kostopoulou, E., Gkentzi, D., Papasotiriou, M., Fouzas, S., Tagalaki, A., Varvarigou, A., et al., 2021. The impact of COVID-19 on paediatric emergency department visits. A one-year retrospective study. Pediatr. Res, 1–6 https://doi.org/10.1038/s41390-021-01815-w.

Kotani, K., Ueda, K., Seposo, X., Yasukochi, S., Matsumoto, H., Ono, M., et al., 2018. Effects of high ambient temperature on ambulance dispatches in different age groups in Fukuoka, Japan. Glob. Health Action 11, 1437882.

Kurai, J., Noma, H., Sano, H., Iwata, K., Tohda, Y., Watanabe, M., 2018. Association of short-term ozone exposure with pulmonary function and respiratory symptoms in schoolchildren: a panel study in a western Japanese city. J.Med.Investig. 65, 236–241.

Lai, C.C., Wang, C.Y., Wang, Y.H., Hsueh, S.C., Ko, W.C., Hsueh, P.R., 2020. Global epidemiology of coronavirus disease 2019 (COVID-19): disease incidence, daily cumulative index, mortality, and their association with country healthcare resources and economic status. Int. J. Antimicrob. Agents 55, 105946.

Lopez Bernal, J., Cummins, S., Gasparrini, A., 2018. The use of controls in interrupted time series studies of public health interventions. Int. J. Epidemiol. 47, 2082–2093.

McGeehin, M.A., Mirabelli, M., 2001. The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. Environ. Health Perspect. 109, 185–189.

Meiji Yasuda Life Insurance C, 2020. The Questionnaire Survey Regarding Health (in Japanese).

MHLW, 2020. Stop the Spread of COVID-19; How to Avoid the 3.

MHLW, 2020. Preventive Actions Against Heatstroke for 2020 (in Japanese).

MIC, 2021. Preliminary Report of the Number of Total Ambulance Dispatches in 2020.

Muggeo, V.M.R., 2003. Estimating regression models with unknown break-points. Stat. Med. 22, 3055–3071.

Nakahara, S., Kanda, J., Miyake, Y., Sakamoto, T., 2021. High incidence of heat illness and the potential burden on the health care system during the COVID-19 pandemic. Lancet Reg. HealthWest.Pac. 6, 100070.

Ng, C.F.S., Ueda, K., Ono, M., Nitta, H., Takami, A., 2014. Characterizing the effect of summer temperature on heatstroke-related emergency ambulance dispatches in the kanto area of Japan. Int. J. Biometeorol. 58, 941–948.

Ng, C.F.S., Boeckmann, M., Ueda, K., Zeeb, H., Nitta, H., Watanabe, C., et al., 2016. Heat-related mortality: effect modification and adaptation in Japan from 1972 to 2010. Glob. Environ. Chang. 39, 234–243.

Ono, M., 2009. Global warming and heat disorders. Jpn.J.Biometeorol. 14, 263–270.

Ono, M., Ueda, K., 2011. Heatstroke in elderly population in Japan. Epidemiology 22, S172.

Otani, S., Ishizu, S.F., Masumoto, T., Amano, H., Kurozawa, Y., 2021. Elevated heat stroke risk in older adults indirectly caused by COVID-19 restrictions in a provincial prefecture of Japan. Med.Sci.Forum 4, 22.

R Core Team, 2019. R: A Language And Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. R Core Team.

Santi, L., Golinelli, D., Tampieri, A., Farina, G., Greco, M., Rosa, S., et al., 2021. Non-covid-19 patients in times of pandemic: emergency department visits, hospitalizations and cause-specific mortality in northern Italy. PLOS ONE 16, e0248995.

Seposo, X., Madaniyazi, L., Ng, C.F.S., Hashizume, M., Honda, Y., 2021. COVID-19 pandemic modifies temperature and heat-related illness ambulance transport association in Japan: a nationwide observational study. Environ. Health 20, 122.

Song, X., Wang, S., Hu, Y., Yue, M., Zhang, T., Liu, Y., et al., 2017. Impact of ambient temperature on morbidity and mortality: an overview of reviews. Sci. Total Environ. 586, 241–254.

Takakubo, T., Odagiri, Y., Machida, M., Takamiya, T., Fukushima, N., Kikuchi, H., et al., 2021. Changes in the medical treatment status of Japanese outpatients during the coronavirus disease 2019 pandemic. J.Gen.Fam.Med. 22, 246–261.

Tobías, A., Armstrong, B., Gasparrini, A., Diaz, J., 2014. Effects of high summer temperatures on mortality in 50 Spanish cities. Environ.Health 13 48-48.

Tomohiro, T., 2021. Working hours under the covid-19 pandemic in japan: Reviewing changes by situation phase during and after the 2020 state of emergency declaration. Japan Labor Issues. Japan Institute for Labour Policy and Training, Tokyo, Japan.

Toosty, N.T., Hagishima, A., Tanaka, K.-I., 2021. Heat health risk assessment analysing heatstroke patients in Fukuoka city, Japan. PLOS ONE 16, e0253011.

Uryu, S., Tanoue, Y., Nomura, S., Matsuura, K., Makiyama, K., Kawashima, T., et al., 2021. Trends in emergency transportation due to heat illness under the new normal lifestyle in the COVID-19 era, in Japan and 47 prefectures. Sci. Total Environ. 768, 144723.

Working group on heatstroke medical care during the C, 2020. Heatstroke management during the covid-19 epidemic: recommendations from the experts in Japan. Acute Med. Surg. 7, 1–10.

Wyatt, S., Mohammed, M.A., Fisher, E., McConkey, R., Spilsbury, P., 2021. Impact of the sars-cov-2 pandemic and associated lockdown measures on attendances at emergency departments in English hospitals: a retrospective database study. Lancet Reg. Health Eur. 2.

Yasuhi, M., Tohru, A., Kenichiro, I., Hiroshi, O., Takayasu, K., Syuuji, S., 2010. Characteristics of heatstroke patients in Japan; heatstroke study2008. JAAM 21, 230–244.

Yu, X., 2020. Impact of mitigating interventions and temperature on the instantaneous reproduction number in the COVID-19 pandemic among 30 us metropolitan areas. One Health 10, 100160.

Zhou, M.G., Wang, L.J., Liu, T., Zhang, Y.H., Lin, H.L., Luo, Y., et al., 2014. Health impact of the 2008 cold spell on mortality in subtropical China: the climate and health impact national assessment study (Chinas). Environ. Health 13, 60.