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## Title

Regional incidence risk of heat stroke in elderly individuals considering population, household structure, and local industrial sector

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## Abstract

This study aims to clarify the regional characteristics of heat stroke incidence patterns inside and outside residences among the elderly from the perspective of working and living conditions. The study area comprised 41 municipalities belonging to Hyogo Prefecture in Japan. Based on information on heat stroke emergency medical evacuees in each municipality from 2011 to 2020, the regional differences in the incidence risk of heat stroke were analyzed. The results revealed that the number of cases and the proportion of males and females among them were related to the demographic structure of each municipality. A grouping analysis was conducted to classify the characteristics of each municipality based on the relationship between the incidence risk of heat stroke and the industrial structure. A factor analysis and binomial logistic regression analysis were also conducted to investigate the effect of demographic structure on the incidence risk of heat stroke. The results indicate that the incidence risk of heat stroke is correlated with industrial and demographic structures, and the risk is likely to vary regionally.

**Keywords.**

Heat stroke; elderly people; regional characteristics; industrial structure; population and household structure; spatial analysis

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## 1. Introduction

The United Nations Office for Disaster Risk Reduction (UNDRR, 2018) reported that more than 166,000 people globally have died from 1998 to 2017 due to weather-related disasters caused by extremely high temperatures. According to the Intergovernmental Panel on Climate Change (IPCC, 2021), the global average surface temperature (global-mean surface air temperature (GSAT)) increased by 0.99 °C from 1850 to 1990. Simulations of the GSAT up to 2100 indicate that the frequency of extreme high temperatures that usually occur once every 10 y is expected to increase by 4.1 times compared to 1850–1900 (IPCC, 2021). The World Health Organization (WHO, 2021) reported that climate-sensitive health risks, such as heat-related illnesses, are disproportionately experienced by the most vulnerable and disadvantaged, including women, children, ethnic minorities, poor communities, migrants or displaced persons, older populations, and those with underlying health conditions.

The aging of the population also increases the incidence risk of heat stroke (World Meteorological Organization (WMO) & WHO, 2015). According to the Japan Cabinet Office (2021), the national aging rate (percentage of population aged 65 and over) in 2020 reached 28.8%, which is the highest worldwide. The Japan Fire and Disaster Management Agency (JFDMA, 2021) reported an overall upward trend in the number of emergency medical evacuations from 2016 to 2020. In 2018, Japan experienced record high temperatures, and 95,137 emergency medical evacuations caused by heat stroke were registered (JFDMA, 2021), which was the highest number since the JFDMA began its survey in 2010. The elderly account for more than 50% of all emergency medical evacuees, and this percentage has increased in recent years (JFDMA, 2021). The National Institute for Environmental Studies (2015) reported the majority of the elderly heat stroke episodes occurs in residences, but the incidence outdoors associated with work and exercise is also high.

Although the onset of heat stroke is strongly related to environmental temperature, the trend is not straightforward, so warmer regions do not necessarily present higher incidence rates. For example, Japan is long from north to south, with different climatic divisions. The southernmost prefecture, Okinawa Prefecture, and the northernmost prefecture, Hokkaido, present humid subtropical (Cfa) and warm humid continental (Dfa and Dfb) climates, respectively, according to the Köppen climate classification. The incidence pattern of heat stroke in Okinawa Prefecture is eight times higher during work and four times higher during exercise compared to cities in the Honshu area, where Tokyo is located. However, the other incidence rates outside of work and exercise are comparable to those in Sapporo, a city located in Hokkaido (Ono, 2009; Environmental Innovation and Communication Organization, 2017). Therefore, factors leading to the onset of heat stroke are not necessarily related only to environmental temperature, but also to regional differences in the manner individuals work and live. However, the factors contributing to the onset risk of heat stroke considering the working and living characteristics of individuals remain largely unclear (Environmental Innovation and Communication Organization, 2017).

This study investigates the risk of heat stroke among the elderly by characterizing the pattern of heat stroke incidence inside and outside residences from the perspective of working and living styles. The case study includes 41 municipalities in Hyogo Prefecture, Japan. The characteristics related to the incidence risk of heat stroke were quantitatively identified by municipality. The correlation between the incidence risk of heat stroke and regional characteristics was determined based on demographic information and the industrial structures of each municipality. By clarifying the characteristics and differences in the incidence of heat stroke in each municipality, governments can develop more effective prevention measures.

Many studies have investigated the incidence and prevention of heat stroke in a wide range of research fields, including meteorology, epidemiology, physiology, and hygiene. For example, Gifford et al (2019), Kim et al (2014), and Lin et al (2019) discussed the impact of temperature and differences in personal attributes such as age, gender, work, and medical history on the risk of developing heat stroke. Regarding the incidence risk in residences, Alessandrini et al (2019), Ikaga (2012), and Kayaba et al (2013) discussed the relationship between the heat stroke onset and environmental temperature, ventilation, and use of air conditioning in elderly's residences. Iwata et al (2008) analyzed the living arrangements of elderly individuals who developed heat stroke based on their household composition and nursing care services. Regarding regional characteristics of the onset, Akatsuka et al (2014), Hoshi et al (2010), Ma et al (2015), Oka and Hijioka (2021), Sung et al (2013), Toosy et al (2021), Yang et al (2019), and Yokoyama & Fukuoka (2006) analyzed the relationship between temperature and regional differences considering the number of emergency transports and deaths caused by heat stroke. O'Malley & Kikumoto (2021) used remote sensing to determine the relationship between surface temperature and regional differences in Tokyo. Regarding the impact of heat stroke on medical resources, Hatakeyama et al (2021) and Uryu et al (2021) analyzed the impact of the COVID-19 pandemic on the emergency transport of heat stroke cases.

Many studies indicate that the elderly are at higher incidence risk of heat stroke. In particular, the insulation performance of homes and the use of air conditioning can substantially influence the onset of a heat stroke. However, Ozaki et al (2020) argue that heat strokes can gradually worsen throughout several days, and people might be transported after the onset event or return home from outdoors. Kodera et al (2019) showed that the loss of body water content is related to the onset of heat strokes. Based on an analysis of an urban space in Paris, Benmarhnia et al (2017) also argued that areas with more deaths among the elderly caused by heat waves are related to socioeconomic factors and air pollution. To fundamentally reduce the incidence risk of heat strokes in the elderly, the incidence risk outside residences should also be considered. Accordingly, the novelty of this study is the identification of the regional heat stroke incidence patterns among the elderly both indoors and outdoors.

## 2. Materials and methods

### 2.1 Case study area

Figure 1 shows the location of Hyogo Prefecture. This Prefecture comprises 41 municipalities, with an area of approximately 9,400 $km^2$ and a population of approximately 5.4 million, as of 2022 (Hyogo Prefecture, 2022). The population is concentrated in the southern coastal area, where commerce and industry are dominant, around the capital city of Kobe. The northern part is a relatively agricultural area. The annual aging rate in Hyogo Prefecture was 28.9% in 2021, which was almost the same as the national rate of 28.8% (Japan Cabinet Office, 2021). The aging rates in Kobe, Ashiya, and Toyooka (Figure 1) are 28.4%, 29.8%, and 34.7%, respectively (Hyogo Prefecture, 2021b). The aging rate is relatively low in the southern part of the Prefecture, but tends to increase in the northern part.

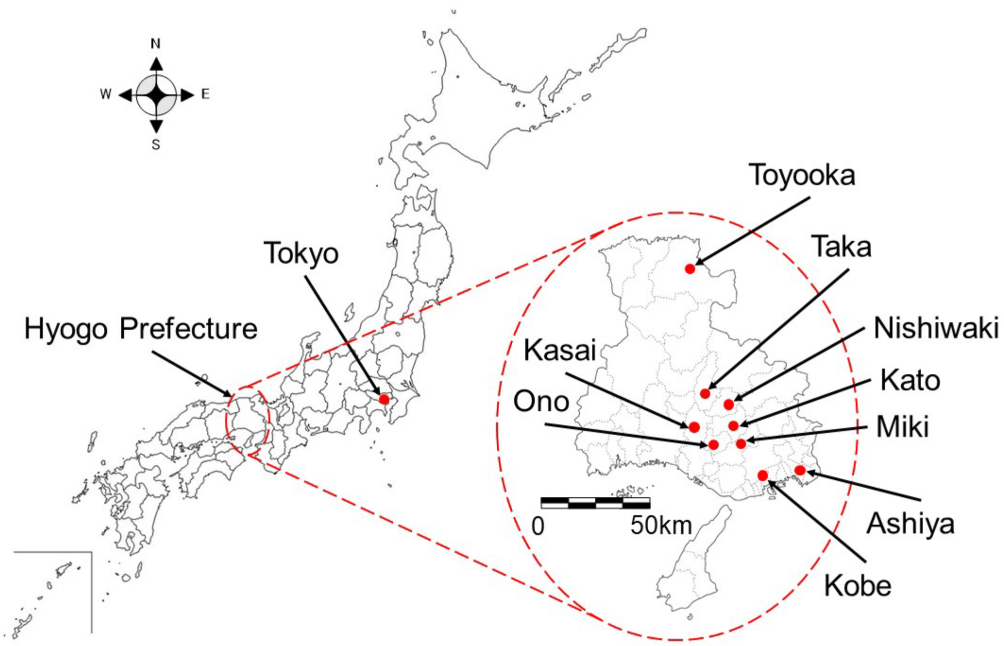



Figure 1 Location of Hyogo Prefecture

Based on the Köppen climate classification, most of the Hyogo Prefecture area presents a humid subtropical climate (Cfa), and only a part of the northern area belongs to the hot humid continental climate (Dfa). In 2021, the daily mean temperatures in Kobe and Toyooka were 17.5 °C and 15.2 °C, and their daily maximum mean temperatures were 21.1 °C and 20.9 °C, respectively. These data indicate that there are no practical differences between the temperatures of the north and south (Japan Meteorological Agency (JMA), 2022). However, in 2021, the annual precipitation was two times larger in the northern area (1,016 and 2,122 mm, respectively) because of the higher snowfall rates (JMA, 2022).

**2.2 Data collection**

This study analyzes data on medical evacuees from heat stroke emergencies in various municipalities, as reported by the fire department of each municipality. There are 24 fire departments in Hyogo Prefecture. One fire department can serve one or multiple municipalities. All fire departments were interviewed and asked to provide data on medical evacuees from heat stroke emergencies from 2011 to 2020. Data from 15 departments were obtained. Among them, detailed information on the sex, age, location, and date of heat stroke onset was obtained from five fire departments (Ashiya, Toyooka, Ono, Miki, and Kita-Harima), consisting of four municipalities, namely Kasai, Katoh, Taka, and Nishiwaki (Figure 1). Data could not be obtained from all fire departments because these reports contain personal information, and each fire department had different rules regarding the provision of personal information.

The characteristics of heat stroke are difficult to analyze on a case-by-case basis due to confidentiality regulations. However, since data is available for a nine-year period, statistical analysis of heat stroke is possible. In order to conduct an analysis based on the hypothesis that cases of heat stroke can be related to local residents' lifestyles, data on household status and the number of household members are used as parameters for categorizing municipality-specific housing characteristics, and data on the industrial structure of the region as a parameter for categorizing work habits. The industrial structure is shown in Table 1, which includes number of workers per industry in each municipality. Similarly, data on household status and the number of household members were assessed for each municipality. These data were retrieved from each municipality's website and the Statistics Bureau of Japan (2019 & 2021). Based on these data, an analysis of the incidence risk of heat stroke was conducted based on the characteristics of each municipality.

### 2.3 Characterization of heat stroke onset

This section analyzes the statistical relationship between the number of cases and the total regional population, incidence rate (the ratio of the number of cases to the total regional population), and aging rate (the ratio of the population aged 65 and over to the total population) using linear regression. We used data on emergency heat stroke cases obtained from the fire department to determine the number of cases and incidence rate. The incidence rate per age group was calculated by multiplying the age-specific incidence rate and the proportion of that age group in the total population, and then dividing this value by the total population.

### 2.4 Correlation between industrial structure and risk of heat stroke

Based on the analysis results described in Section 2.3, the regional characteristics of the incidence risk of heat stroke in each municipality were investigated. A grouping analysis was conducted using ArcGIS Ver. 10.3.1. The grouping analysis combines attribute factors and spatial elements of the study area to perform a comprehensive cluster analysis. The grouped areas are spatially linked and, therefore, present a high degree of similarity between physical characteristics (e.g., regional infrastructure development and regional functions) and demographic characteristics (e.g., ethnicity, education level, and lifestyle). The results facilitate the development and implementation of policies (Esri, 2018; Zhan et al, 2017).

The grouping analysis can be used to evaluate and identify the optimal number of groups. This optimal number was obtained using the Calinski–Harabasz pseudo F-statistic, which outputs the F statistic as the value obtained by dividing the similarity within groups by the heterogeneity between groups. The F statistic was calculated using following equations (Esri, 2018; Zhan et al, 2017).

$$F\ statistic = \frac{\left(\frac{R^2}{n_c - 1}\right)}{\left(\frac{1 - R^2}{n - n_c}\right)}, \tag{1}$$

$$R^2 = \frac{SST - SSE}{SST}, \tag{2}$$

$$SST = \sum_{i=1}^{n_c} \sum_{j=1}^{n_i} \sum_{k=1}^{n_v} \left(V_{ij}^k - \overline{V^k}\right)^2, \tag{3}$$

$$SSE = \sum_{i=1}^{n_c} \sum_{j=1}^{n_i} \sum_{k=1}^{n_v} \left(V_{ij}^k - \overline{V_i^k}\right)^2, \tag{4}$$

where *SST*: heterogeneity between groups; *SSE*: similarity within groups; *n: number* of features; $n_i$: number of features in group *I*; $n_c$: number of groups; $n_v$: number of variables; $V_{ij}^k$: value of *k* variables for features *j* in group *i*; $\overline{V_i^k}$ : average value of *k* variables for all features; and $\overline{V_{ij}^k}$ : average value of *k* variables of features *j* in group *i*.

The variables used as input for the group analysis are listed in Table 1. This study assumes that municipalities are constructed primarily from industrial and demographic structures. The industrial structure was considered in this study because it is linked to the economy of the region and influences people's lifestyles. For example, primary industries are often sole proprietorships or family businesses in Japan and, in many cases, working alone is not a hindrance (Japan Ministry of Agriculture, Forestry and Fisheries (JMAFF), 2021). In contrast, secondary and tertiary industries are often managed by multiple people. A relative increase in the per capita income in below-average regions has been typically associated with structural change, followed by long-run shifts from agriculture to industry and, subsequently, to tertiary or trade and services (Miernyk, 1982). This association assumes that the degree of human interaction increases with the change from primary to tertiary industry. Similarly, this study assumes that municipalities with active tertiary industries likely have more convenient transportation and community accessibility. Another reason for selecting the industrial structure is that local residents, as the labor resources of the area, are essential to developing the industrial sector. This study assumes that municipalities with a larger working-age population have higher productivity and, conversely, municipalities with a larger elderly population have lower productivity.

Table 1 Variables used as input for the group analysis

| Properties | | | Variables |
|---|---|---|---|
| Industrial structure | Primary industry | Agriculture, forestry and fishing | Number of employees in each industry as a percentage of total number of employees in each municipality |
| | Secondary industry | Mining, quarrying, gravel extraction, construction and manufacturing | |
| | Tertiary industry | Electricity, gas, heat supply and water supply; information and communications, transportation and postal services, wholesale and retail, financial services, insurance, real estate and goods rental, academic research, professional and technical services, lodging and food services, lifestyle-related services and entertainment, education and learning support, medical services and welfare, multiservice business and miscellaneous | |
| Demographic structure | Population under the age of 15 | | Percentage of population under the age of 15 as a percentage of total population in each municipality |
| | Population of 15-64 years old | | Percentage of 15-64 years old population to total population in each municipality |
| | Population over the age of 65 | | Percentage of population over the age of 65 in each municipality's total population |
| | Household Population | | Percentage of total population to total households in each municipality's total population |
| | Number of nuclear family households | | Percentage of total population to total nuclear family households in each municipality's total population |

Based on the variables related to industrial structure (Table 1), the coefficient of specialization was used to identify the characteristic industries of the region. The coefficient of specialization is a general indicator of the degree of industry segregation in a particular region (North, 1955). This coefficient was calculated using the following equation, and a result greater than 1 was considered relatively distinctive.

$$LQ = \frac{Q_{ij}}{Q_j}, \quad (5)$$

where $LQ$: coefficient of specialization; $Q_{ij}$: ratio of employees in industry $j$ and municipality $i$; $Q_j$: ratio of employees in industry $j$ in Hyogo Prefecture.

### 2.5 Correlation between population, household composition, and risk of heat stroke

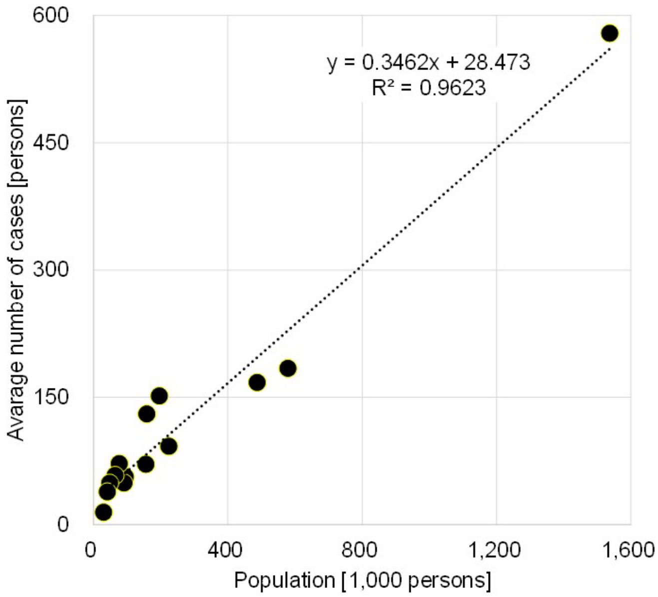
After the elderly leave the workforce, their daily lives are expected to shift from the workplace to the community and family, and they are expected to become more connected with the local community. Therefore, a factor analysis was applied to determine the correlation between the incidence risk in the daily life of the elderly in each group classified in Section 2.4 and each demographic structure. The variables shown in Table 1 were used to estimate the demographic structure. Based on the factor scores obtained for each group, a binomial logistic regression analysis was applied to analyze the factors contributing to the onset of heat stroke in the residences of the elderly. The onset of heat strokes within residences was set as the explained variable. The explanatory variables are the factor scores of the groups belonging to those areas, and they were derived from the factor analysis.

## 3. Results and discussion

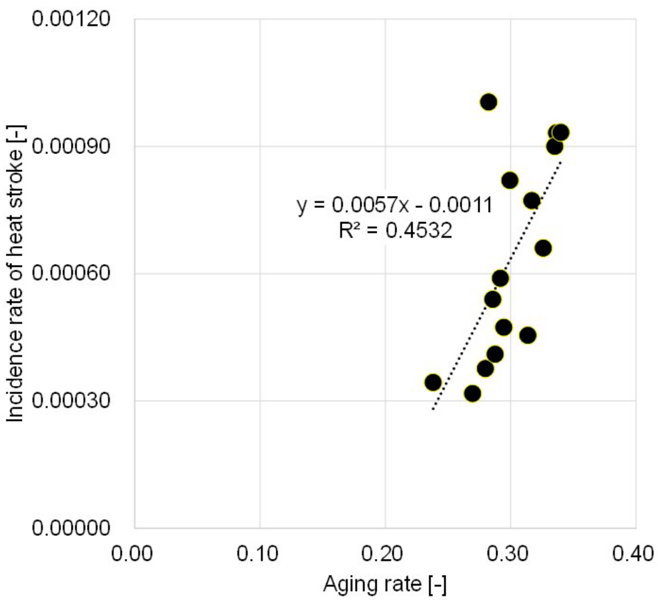
### 3.1 Regional differences in the number of cases and incidence

Figure 2 shows the relationship between population and incidence of heat stroke. The average number of cases in each municipality from 2011 to 2020 and the population of each municipality were highly correlated, with a correlation coefficient of 0.96, significant at the 1% level (Figure 2 (a)). The correlation between the incidence rate of heat stroke in the population of each municipality and the aging rate was low (0.45), but significant at the

1% level (Figure 2 (b)). The number of heat stroke cases was strongly influenced by the total population of the municipalities. The incidence of heat stroke was higher in municipalities where the elderly, who are considered vulnerable to heat stroke, represent a larger proportion of the total population.




(a) Population and average number of cases in each municipality



(b) Aging rate and incidence rate of heat stroke

Figure 2 Correlation between population and incidence of heat stroke

The following analysis focused on two municipalities, Ashiya and Toyooka, which are geographically distant from each other, and for which detailed data on heat stroke were obtained from the fire departments. Table 2 shows the regional differences in incidence rates by age group. Hyogo Prefecture (2012) examined the outing rate[1] of the local population by age group and obtained 80% for people of 60 y old, and 40–50% for those over 75 y. Fujita et al (2004) also reported that the frequency of outing clearly decreased after the age of 80 for both men and women. Therefore, the rate of outing decreased with age, whereas the time spent at home increased, and the incidence of heat stroke in residences increased. This decreased the differences between regional onsets. Moreover, the incidence rate tends to increase up to age 84 and decrease after age 85. The reason for this might be the decrease in outdoor activities associated with the decline in physical and mental functions. A decrease in the frequency of outdoor activities leads to avoidance of places with strong sunlight. Consequently, the incidence rate outdoors might decrease.

Table 2 Differences in regional incidence by age group

(a) Ashiya

[1] Outing rate means percentage of those who went out on the surveyed days.

| | | Percentage of cases in each age group population | | | Percentage of cases and location of onset | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total | Male | Female | Road | Residence | Working area | Public ingress and egress | Other |
| 5 age Group (60+) | 60-64 | 9.0% | 4.5% | 4.5% | 21.4% | 42.9% | 0.0% | 35.7% | 0.0% |
| | 65-69 | 10.8% | 9.1% | 1.7% | 28.0% | 40.0% | 4.0% | 24.0% | 4.0% |
| | 70-74 | 14.9% | 9.0% | 5.8% | 17.4% | 56.5% | 0.0% | 21.7% | 4.3% |
| | 75-79 | 14.0% | 8.2% | 5.7% | 23.2% | 58.9% | 0.0% | 12.5% | 5.4% |
| | 80-84 | 23.0% | 12.5% | 10.5% | 25.0% | 63.2% | 1.5% | 10.3% | 0.0% |
| | 85-89 | 19.4% | 8.6% | 10.8% | 27.8% | 68.5% | 0.0% | 3.7% | 0.0% |
| | 90-94 | 7.2% | 2.7% | 4.5% | 16.7% | 83.3% | 0.0% | 0.0% | 0.0% |
| | 95-99 | 1.8% | 0.9% | 0.9% | 0.0% | 100.0% | 0.0% | 0.0% | 0.0% |

(b) Toyooka

| | | Percentage of cases in each age group population | | | Percentage of cases and location of onset | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total | Male | Female | Road | Residence | Working area | Public ingress and egress | Other |
| 5 age Group (60+) | 60-64 | 5.2% | 4.2% | 1.0% | 0.0% | 65.0% | 20.0% | 5.0% | 10.0% |
| | 65-69 | 9.3% | 7.3% | 1.9% | 16.7% | 45.8% | 16.7% | 4.2% | 16.7% |
| | 70-74 | 8.5% | 5.7% | 2.8% | 18.2% | 51.5% | 12.1% | 6.1% | 12.1% |
| | 75-79 | 20.7% | 15.4% | 5.4% | 12.9% | 41.9% | 6.5% | 12.9% | 25.8% |
| | 80-84 | 25.2% | 16.3% | 8.9% | 7.8% | 54.9% | 11.8% | 2.0% | 23.5% |
| | 85-89 | 20.0% | 12.6% | 7.4% | 18.6% | 60.5% | 4.7% | 7.0% | 9.3% |
| | 90-94 | 8.9% | 2.8% | 6.1% | 6.3% | 68.8% | 6.3% | 0.0% | 18.8% |
| | 95-99 | 2.2% | 1.1% | 1.1% | 0.0% | 75.0% | 0.0% | 0.0% | 25.0% |

Regarding gender differences, males presented higher incidence rates, but the incidence rate among females tended to increase significantly with age. By municipality, Toyooka presented a higher incidence rate among younger groups than Ashiya. Conversely, in Ashiya, the incidence rate rapidly increased from the age of 75. Gender differences in incidence rates may be related to the health status of men and women. According to the Japan Ministry of Health, Labour and Welfare (JMHLW, 2020), the average life expectancy of Japanese in 2016 was 80.98 y for men and 87.14 y for women. Females have a longer life expectancy than males, and the proportion of females in the relevant age population might be expanded as a result of aging. Therefore, the proportion of women in the total number of cases might also be expanded.

Regarding the onset location, nearly half of the cases in Ashiya for people aged 85 to 89 y were in residences. Among those aged 90 y and older, more than half of the cases occurred in residences. Conversely, in Toyooka, most cases among those aged 90–95 occurred in the workplace. Ashiya presented a relatively higher incidence rate than Toyooka on roads and at public ingress and egress[2]. This was attributed to the better public transportation system and higher distribution density of retail business establishments in Ashiya than in Toyooka. The transportation share of walking and cycling in the Ashiya region is 24.3% higher than that in the Toyooka region (Hyogo Prefecture, 2012), which suggests that the elderly in Ashiya are more likely to walk or cycle.

In contrast, Toyooka, with an aging rate of 31.7%, has a smaller working-age population than Ashiya, and more people are engaged in agriculture and forestry. That is, residents of Toyooka continue to work even in their old age, which is likely the reason for the higher incidence rate of heat stroke at work.

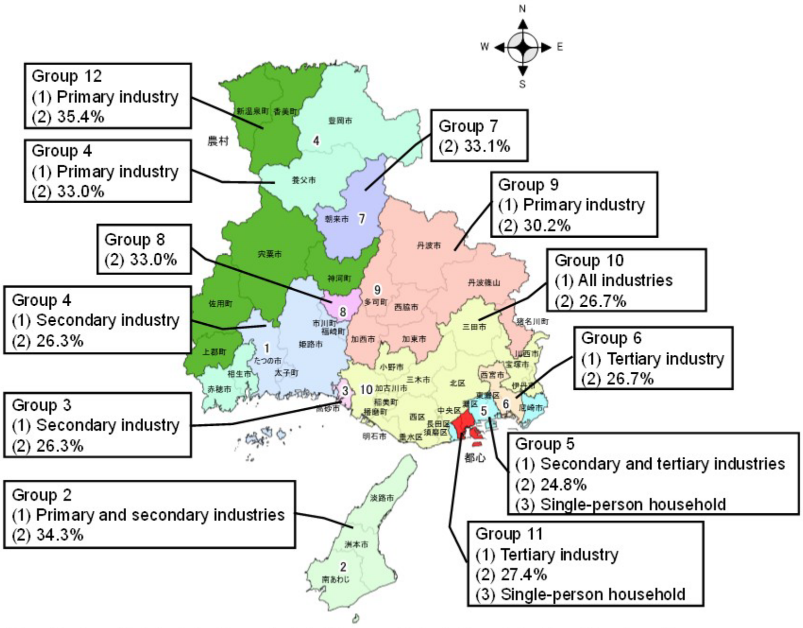
### 3.2 Regional risk of developing heat stroke

#### 3.2.1 Grouping analysis

The results of the group analysis are shown in Figure 3. Hyogo Prefecture was divided into 12 groups, and the components of each group are shown in Table 3. Industries with coefficients of specialization greater than 1 are shown in bold and italics. Groups 1–10 belong to the middle region, which includes mainly residential areas, and the percentage of nuclear family households exceeds 50% in all of them. Group 11 consists of the urban center of Kobe, where the tertiary industry is active. Although the number of households is small, there are many single-person households. Group 12 is characterized by agriculture, forestry, fisheries, and mining industries. Its tertiary industry is not active, and the aging rate is high, at 35.4%. Groups 5 and 10 are industrial areas near the city

[2] Public ingress and egress mean places where a large number of people gather.

center. Groups 7 and 8 have small populations and, thus, it is difficult to determine their characteristic industries based on the coefficient of specialization. As an overall trend, the results indicate that as the distance from the city center increases, the characteristic industries shift from tertiary to primary, and the aging rate gradually increases.




Note: (1) characteristic industries calculated from coefficient of specialization, (2) aging rate, and (3) characteristic population and household structures calculated from factor analysis.

Figure 3 Results of group analysis

Table 3 Components of each group

| Group number | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industrial structure (Coefficients of specialization) | Agriculture and forestry | ***1.02*** | 0.50 | 0.00 | 0.60 | 0.04 | 0.08 | 0.04 | 0.00 | ***1.82*** | ***2.69*** | 0.11 | ***1.79*** |
| | fishing (industry) | 0.00 | ***1.19*** | 0.00 | ***3.29*** | 0.21 | 0.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | ***3.71*** |
| | Mining, quarrying, gravel extraction | 0.00 | 0.00 | ***2.72*** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | ***5.97*** |
| | construction industry | ***1.39*** | 0.16 | 0.12 | 0.21 | ***1.80*** | 0.70 | 0.02 | 0.01 | 0.32 | ***3.09*** | 0.73 | 0.12 |
| | manufacturing industry | ***1.83*** | 0.19 | 0.10 | 0.25 | ***1.49*** | 0.27 | 0.07 | 0.01 | 0.64 | ***2.69*** | 0.99 | 0.17 |
| | Electricity, gas, heat supply and water supply | 0.64 | ***1.46*** | 0.00 | 0.07 | 0.20 | 0.22 | 0.00 | 0.00 | 0.42 | ***1.76*** | ***3.74*** | 0.17 |
| | telecommunications industry | 0.77 | 0.03 | 0.15 | 0.03 | 0.96 | 0.65 | 0.00 | 0.00 | 0.11 | ***3.03*** | ***2.93*** | 0.02 |
| | Transportation and postal service | 0.69 | 0.15 | 0.06 | 0.08 | ***3.16*** | 0.45 | 0.02 | 0.00 | 0.43 | ***2.43*** | ***1.19*** | 0.03 |
| | Wholesale and retail | ***1.01*** | 0.12 | 0.05 | 0.10 | ***1.19*** | 0.91 | 0.04 | 0.00 | 0.20 | ***2.98*** | ***2.03*** | 0.05 |
| | Finance and insurance | ***2.26*** | 0.08 | 0.07 | 0.01 | ***1.36*** | 0.87 | 0.05 | 0.00 | 0.07 | ***1.94*** | ***1.90*** | 0.08 |
| | Real estate and goods rental | 0.88 | 0.16 | 0.08 | 0.11 | ***1.68*** | ***1.39*** | 0.01 | 0.00 | 0.16 | ***2.79*** | ***1.41*** | 0.03 |

### 3.2.2 Influence of industrial structure on the risk of heat stroke

Table 4 shows the aggregate data of transports attributed to heat stroke events for the five fire departments (Ashiya, Toyooka, Ono, Miki, and Kita-Harima), for which detailed data on the number of cases were available. Standardized incidence rates were used to eliminate the influence of population differences in each age group on incidence rates. The incidence rate of each age group was multiplied by the population in the relevant age group and divided by the total population.

Table 4 Data from fire departments

| | | Toyooka | | Kitaharima | | Miki | | Ono | | Ahiya | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Group | | 4 | | 9 | | 10 | | 10 | | 6 | |
| Distinctive Industries | | Primary industry | | Primary industry | | Secondary industry | | Secondary industry | | Tertiary industry | |
| Number of cases by gender | | Male 385 | Female 206 | Male 605 | Female 368 | Male 450 | Female 260 | Male 300 | Female 198 | Male 329 | Female 233 |
| Standardized Incidence rates by 5 age group | 0-4 | 4% | 0% | - | - | 0% | 1% | - | - | 2% | 1% |
| | 5-9 | 5% | 1% | - | - | 5% | 3% | - | - | 6% | 3% |
| | 10-14 | 31% | 22% | - | - | 22% | 17% | - | - | 17% | 4% |
| | 15-19 | 30% | 29% | - | - | 24% | 15% | - | - | 32% | 18% |
| | 20-24 | 7% | 3% | - | - | 13% | 6% | - | - | 12% | 4% |
| | 25-29 | 8% | 2% | - | - | 10% | 3% | - | - | 6% | 4% |
| | 30-34 | 13% | 4% | - | - | 13% | 2% | - | - | 1% | 3% |
| | 35-39 | 11% | 0% | - | - | 15% | 5% | - | - | 5% | 7% |
| | 40-44 | 16% | 7% | - | - | 26% | 5% | - | - | 6% | 6% |
| | 45-49 | 10% | 4% | - | - | 28% | 8% | - | - | 18% | 9% |
| | 50-54 | 17% | 4% | - | - | 25% | 9% | - | - | 22% | 13% |
| | 55-59 | 15% | 7% | - | - | 21% | 10% | - | - | 12% | 9% |
| | 60-64 | 30% | 6% | - | - | 15% | 9% | - | - | 13% | 10% |
| | 65-69 | 32% | 9% | - | - | 38% | 19% | - | - | 27% | 8% |
| | 70-74 | 35% | 15% | - | - | 45% | 17% | - | - | 31% | 16% |
| | 75-79 | 29% | 12% | - | - | 39% | 22% | - | - | 41% | 29% |
| | 80-84 | 35% | 26% | - | - | 19% | 18% | - | - | 34% | 32% |
| | 85-89 | 15% | 16% | - | - | 8% | 16% | - | - | 13% | 23% |
| | 90-94 | 2% | 9% | - | - | 1% | 3% | - | - | 2% | 6% |

Based on the group coefficient of specialization, the characteristic industries of Ashiya, which belongs to Group 6, were considered tertiary industries, whereas those of Toyooka and Kita-Harima, which belong to Groups 4 and 9, were considered primary. However, it was difficult to determine the main industries of Miki and Ono, which belong to Group 10, based on the coefficient of specialization. Therefore, the coefficient of specialization for the gross domestic product (GDP) was calculated by dividing the ratio of the secondary industry contribution to each municipality's GDP by the ratio of the secondary industry contribution to Hyogo Prefecture's GDP (Hyogo Prefecture, 2021a). The obtained coefficient of specialization exceeded 1 for Miki and Ono. Therefore, although all industries in these municipalities are actively developing, the secondary industry was considered the most distinctive industry compared to Ashiya, Kita-Harima, and Toyooka.

A limitation of this study was the lack of detailed data on heat stroke emergency medical evacuees for all municipalities, so further investigation with supplemental data is needed. However, the grouping analysis and analysis of industrial structure suggest a correlation between the incidence risk of heat stroke and industrial structure. For example, municipalities characterized by primary and secondary industries are at higher risk of exertional heat stroke, and the overall incidence rates for these regions tend to be higher. Municipalities characterized by tertiary industry have a lower risk of exertional heat stroke, and a higher incidence among the elderly is expected. Moreover, the incidence rate for women over 85 y of age in all regions was higher than that for men.

#### 3.2.3 Effects of population and household composition on the risk of heat stroke

The factor loadings for each factor (Table 5) were obtained by the factor analysis based on the demographic structure data in Table 3. Cumulative contribution ratios of 0.7 or greater in absolute value were used. Therefore, two common factors were aggregated from the nine variables of demographic structure. The variables with positive high loadings for factor (1) were “population under age of 15” and “number of nuclear family households.” Conversely, the variables “number of single-person households” and “number of elderly single-person households” presented high negative loadings. Based on that, factors (1) and (2) were interpreted as "families with children" and "families with elderly couples only,” respectively. The factor scores of each group are shown in the lower part of Table 3. The higher the score of the corresponding factor in each group, the more pronounced the characteristics of that factor relative to the group. Conversely, if the scores for both factors are low, the group is interpreted as having a large number of single households. Groups 3 and 10 presented factor (1) scores above 1. Therefore, their family type is likely relatively dominated by nuclear families with children. Conversely, Groups 8 and 12, whose scores for factor (2) exceeded 1, are likely dominated by families with elderly couples only. Groups 5 and 11 presented negative scores for both factors, which suggests that they are relatively characterized by single-person households.

Table 5 Result of factor analysis

| | | Factor (1) | Factor (2) |
|---|---|---|---|
| Variables | Population under the age of 15 | 0.82 | -0.13 |
| | Population of 15-64 years old | -0.02 | -0.9 |
| | Population over the age of 65 | -0.19 | 0.91 |
| | Household Population | 0.59 | 0.78 |
| | Number of nuclear family households | 1 | 0.06 |
| | Number of single-person households | -0.74 | -0.67 |
| | Number of nuclear family households with a household member aged 65 or older | 0.61 | 0.75 |
| | Number of elderly couple only households | 0.67 | 0.71 |
| | Number of elderly single-person households | -0.85 | -0.26 |
| Eigenvalue | | 4.149 | 3.859 |
| Contribution ratio | | 46.10% | 42.88% |
| Cumulative Contribution Ratio | | 46.10% | 88.97% |

The effect of household composition on the incidence risk of heat stroke in residences was determined using a binomial logistic regression analysis, and the results are shown in Table 6. The results indicate that both factors were significantly correlated at the 1% level. The coefficients of factors (1) and (2) were both negative, which suggests that the incidence risk of heat stroke in residences might be lower for elderly individuals with a roommate, and higher for those living alone. Therefore, the results suggest that family type might affect the risk of in-home incidence among the elderly.

Table 6 Results of binomial logistic regression analysis

| Variables | partial regression coefficient | odds ratio | 95% confidence interval for odds ratio | *p*-value | |
|---|---|---|---|---|---|
| Factor (1) | -2.71 | 0.07 | 0.051-0.087 | $p<0.01$ | ** |
| Factor (2) | -0.43 | 0.65 | 0.54-0.79 | $p<0.01$ | ** |

**: $p<0.01$

The results of the binomial logistic regression analysis suggest that elderly single-person households are at a higher incidence risk of heat stroke in their residences. This might be associated with the aging of new towns in Japan. In Japan, mainly around the 1960s, during the period of rapid economic growth, large residential areas were developed for "family households," which included a married couple and children, as the standard household to accommodate the influx of population into urban areas and their housing needs. Initially, a group of salaried workers of child-rearing age moved in all at once, and a local community was formed by the same generation (Akatsuka, 2014). Recently, problems such as aging residents, aging housing, and smaller families have become apparent. According to the Hyogo Prefecture (2016), half of all large new towns in Hyogo Prefecture have a higher aging population than the surrounding areas. Whereas family households accounted for the largest percentage of family types in 1985, single-person households have been the most common household type since 2015. Older homes have inadequate roof insulation, and their indoor temperatures are more likely to rise, which increases the incidence risk of heat stroke (Sawada, 2015). In addition, the lack of adequate transportation in many new towns increases the likelihood of the elderly staying confined, which can negatively impact their physical and mental health. The results suggest that the housing environment significantly contributes to the higher incidence risk of heat stroke in the residences of elderly single-person households.

## 4. Conclusions

This study analyzed the regional incidence risk of heat stroke among the elderly based on demographic and industrial structures. The main findings are described as follows.

(1) The analysis of regional differences in the risk of heat stroke incidence revealed that the number of heat stroke cases and the respective proportion of men and women affected are correlated with the regional demographic structure. Gender differences in

incidence were smaller in municipalities with active tertiary industries, and males tended to be at greater incidence risk of heat stroke in areas with active primary and secondary industries, where the incidence risk of exertional heat stroke is greater.

(2) Grouping analysis was applied and each municipality was classified into 12 groups based on industrial structure. Although further study is needed, the results of the grouping analysis and industrial structure analysis suggest a correlation between the incidence risk of heat stroke and the regional industrial structure. For example, the results suggest that municipalities characterized by primary and secondary industries are at higher risk of exertional heat stroke and, therefore, tend to be associated with a higher overall regional incidence of heat stroke. Municipalities characterized by tertiary industry are at lower risk of exertional heat stroke, which is demonstrated by the higher incidence among the elderly.

(3) To analyze the effect of demographic structure on the incidence risk of heat strokes, a factor analysis was applied using population and household composition as variables. Households were categorized into "families with children" and "families with elderly couples only." Applying the factor analysis results to each group, two factors were extracted: a group with many families consisting of elderly couples only and a group with single-person households were extracted.

(4) A binomial logistic regression analysis was applied to analyze the effect of household composition on the incidence risk in residences. The results revealed that the risk of residential onset was lower for elderly individuals with a roommate and higher for elderly-alone households.

The study limitations include the lack of data on heat stroke cases for all municipalities and the need to analyze geographic data of each municipality, including topography and weather conditions. Nevertheless, the results indicate that industrial and demographic structures are related to the risk of heat stroke incidence, which is likely to vary regionally. Each municipality should consider preventive measures according to its locality, considering that the incidence risk of heat stroke is a regional phenomenon. For example, in areas where primary industries are active, employees should be encouraged to work away from strong sunlight throughout the day. Promoting mechanization policies in agriculture can also be effective in reducing the incidence risk for those employees. In areas where secondary industries are active, preventive measures include ensuring that workers have correct knowledge of occupational safety and preventing the onset of heat stroke by monitoring workers. In areas with active tertiary industries, the incidence risk of exertional heat stroke is low, but the incidence is high among the elderly in their residences and daily activities. Therefore, preventive measures include support for home remodeling and the daily activities of the elderly.

The increasingly aged society and the accompanying increase in the number of single-person households is a social problem in not only Japan but also many other countries. Governments must take countermeasures against the increasing frequency of heat stress caused by high temperatures due to climate change (IPCC, 2021). This study reveals that elderly households and single-person households are more prone to the risk of heat stroke. Governments and municipalities should act to reduce the incidence risk of heat stroke among the elderly, who are vulnerable groups.

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