Impact Assessment of Heat Stress on Population Health in Japan and China

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Abstract

In accordance with the rapid increase in greenhouse gas emissions, climate models predict an increase in the global surface temperature in the future. With regard to human health, it is thought that global warming may have a critical impact due to increased heat stress in summer. Furthermore, enormous population growth is accelerating the heat island phenomenon in urban areas. Since global warming and the heat island phenomenon will increase heat stress in summer in communities, this paper examines population health risks caused by heat stress.

An epidemiological survey showed the incidence of heat-related illness to be significantly correlated to high temperatures in Japan and China. The incidence of heat-related illness in populations especially among the elderly increased exponentially with rising maximum daily temperatures in summer. The incidence of heat-related illness increased in the daytime when the maximum daily temperature and the heat index temperature in summer rose above the threshold temperature. The incidence of pneumonia was correlated with cold temperatures in winter and hot temperatures in summer. Therefore, it is necessary to study age- and gender-dependent health damage of populations in local communities under extreme heat stress in hot environments.

To evaluate the age-related response of populations against health damage from hot temperatures, we studied the biomedical response of animals to heat stress. Conditions of hyperthermia caused by exposure to hot environments resulted in marked damage to some essential organs in animals. Damage from heat-stress-inducible oxygen free radicals becomes more severe in aged animals. Since aging and hyperthermia have a synergistic effect on peroxidative damage, it is essential to have protective enzyme activities against oxygen free radicals.

To prevent health impacts from heat stress in populations due to global warming and the heat island phenomenon, it will be necessary to improve environment design in urban and rural areas and to promote population health in aged persons in the world.

Key words: free radical, heat island, heat stress, heat stroke, pneumonia

1. Introduction

In accordance with the rapid increase in greenhouse gas emissions through anthropogenic fuel burning, climate models predict an increase in the global mean temperature of 0.8°C - 2.6°C and 1.4°C - 5.8°C by the years 2050 and 2100, respectively (IPCC, 2001a). Global warming appears to be strongly linked to increased population globally and economic growth in recent decades (IPCC, 2000).

Reports by the Intergovernmental Panel on Climate Change (IPCC) indicate that one of the most important direct impacts of global warming may be a greater frequency and greater duration of exposure to hot temperatures, especially during the summer months (IPCC, 2001b). Populations at risk including aged persons should be facing health impacts of climate change (McMichael *et al.*, 1996; Ando, 1998).

Typical hyperthermia in humans sometimes occurs in cases of severe heat stress in summer or as a result of hard exercise regardless of location throughout the world. In some large cities in temperate regions, extreme heat stress is associated with an enhanced heat island effect (Hawkins-Bell & Rankin, 1994;

Donoghue *et al.*, 1995; Hales *et al.*, 1996). The heat-related morbidity and mortality from factors such as the incidence of heat stroke in aged persons has been shown to increase as a result of exposure to extremely hot temperatures in summer (Kalkstein, 1994; Ando *et al.*, 1996; Piver *et al.*, 1999; Vandentorren *et al.*, 2004). Heat stroke, heat cramps and heat exhaustion are caused by severe hyperthermia, and body temperatures of typical patients exceed 40°C. Many organs such as the liver, kidney and central nervous system are damaged by severe hyperthermia and thrombus infarcts, and death from heat stroke may be caused by injury to these organs (Hales & Richards, 1987; Ando *et al.*, 1997).

Since heat stress is an important risk factor in global warming and the heat island phenomenon, it is necessary to evaluate the health impacts of heat stress on human and animal populations.

2. Materials and Methods

2.1 Epidemiological research

Epidemiological research was carried out in Tokyo, Japan, and Wuhan, China, to evaluate the health risks of populations to heat stress in hot and humid summers in the Asian monsoon region. The populations of these cities are 12.8 million and 4.8 million residents, respectively. The monthly mean temperature of the hottest month during the past 30 years was 27.1°C in August in Tokyo and 28.6°C in July in Wuhan. The monthly average relative humidity during these months was 73% in Tokyo and 79% in Wuhan, respectively.

The patients in this study were analyzed using emergency transportation records in Tokyo and Wuhan as a database. Furthermore to analyze the relationship between heat-related illness and temperature, heat-related illness data in these cities have been calculated according to gender and age.

A longitudinal epidemiological study concerning the relationship between hot summer weather and heat-related illness was carried out. The present study was summarized for high temperature and heat-related illness in Tokyo, Japan, and Wuhan, China, during 1980 to 1995 and 1996 to 2002, respectively.

2.2 Model experiment

For impact assessment using an experimental model expressing the relationship between heat stress and aging, SPF-grade 5-week-old male Fisher rats were housed in 25±0.5°C under a 12-h light and 12-h dark cycle. Rats at 7 weeks, 12 months, 17 months and 25 months in age, were randomly divided and kept in rooms at 25±0.5°C, 30±0.5°C, 32±0.5°C and 35±0.5°C at a relative humidity of 40±10% for periods of 3 to 42 days. After exposure to various environmental temperatures, animals were sacrificed between 10:00 and 12:00 a.m. by severing the main abdominal artery while under ether anesthesia. Tissue and organ

cell samples were prepared for biochemical analysis for various enzyme activities.

2.3 Statistical evaluation

Statistical analyses were carried out using the F and t-test of Snedecor and Cochran (1967), and P<0.05 was considered significant.

3. Results

The effects of temperature on the incidence of heat-related illness in Tokyo proved that there was a definite threshold temperature depending on age. The incidence of heat-related illness increased in the daytime when the maximum daily temperature and the heat index temperature (a combination of daily mean temperature and relative humidity) in summer rose above the threshold temperature. The incidence of heat-related illness in the elderly was higher than in younger persons as shown in Figs. 1(a) and 1(b).
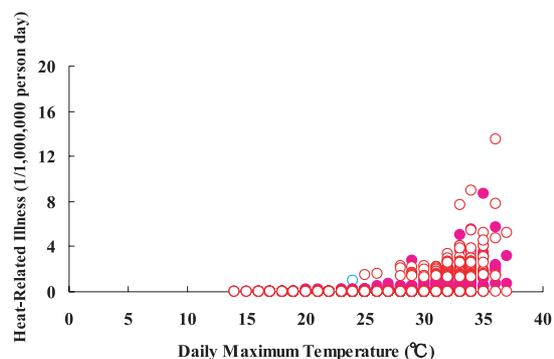

Fig. 1(a) Relationship between the incidence of heat-related illness and the daily maximum temperature in male children (0-14 years old ○), adults (15-64 years old ●) and elderly (more than 65 years old ○) in Tokyo, Japan.
(Y-axis: incidence per million people per day at given daily maximum temperature)
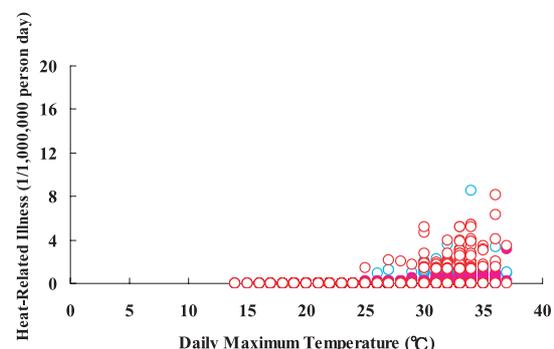

Fig. 1(b) Relationship between the incidence of heat-related illness and the daily maximum temperature in female children (0-14 years old ○), adults (15-64 years old ●) and elderly (more than 65 years old ○) in Tokyo, Japan.
(Y-axis: incidence per million people per day at given daily maximum temperature)

To examine the regression models for heat-related illness as functions of climatic variables, we analyzed the relationship among heat-related illness, the daily maximum temperature and the heat index temperature in Tokyo, Japan. It was proven that the incidence of heat-related illness increased according to rising heat index temperature and daily maximum temperature. The incidence of heat-related illness seemed to increase exponentially with heat index temperature (Fig. 2(a)) and daily maximum temperature (Fig. 2(b)). The incidence of heat-related illness was significantly correlated with the exponential value of daily maximum temperature (r^2=0.986 P<0.001) and heat index temperature in summer (r^2=0.963 P<0.001).

The summer heat in Wuhan also seemed to affect the incidence of heat-related illness exponentially (r^2=0.922 P<0.001). However, the threshold temperature causing heat-related illness was about 5°C higher than in Tokyo, as shown in Figs. 2(b) and 3.

The critical threshold temperature of heat-related illness differed significantly between Tokyo and Wuhan. However, the exponential relationships between the daily maximum temperature and the incidence of heat-related illness in these cities were similar.

The maximum temperature in August was the most important risk factor for heat-related illness in Wuhan, China. During 1996 to 2002, the percent incident cases of heat-related illness in June, July, August and September were 2.2%, 84.8%, 12.6% and 0.4%, respectively. The relationship between the monthly maximum daily temperature and the monthly number of cases of heat-related illness in summer had a significant positive correlation (r^2=0.828, P<0.05).

Just as in Tokyo, it was proven that men were more sensitive to heat-related illness than women in Wuhan. The percent incidence of heat-related illness was 61.3% in men and 38.7% in women. Just as in Tokyo, elderly persons (more than 60 years old) had a higher risk for heat-related illness than younger ones (less than 60 years old). The percent incidence of heat-related illness in elderly persons and younger ones was 77.8% and 22.2%, respectively.

The percentage of location of outbreaks of heat-related illness at home, outdoors and at workplaces were 37%, 36% and 27%, respectively. More than 70% of heat-related illness patients in Wuhan showed hyperthermia (71.3%) and 16.1% of the patients showed an increase in armpit body temperature to over 40°C. Fifty-eight percent of the patients were diagnosed with heat stroke and 42%, with heat exhaustion or heat cramps.

The occupations of heat-related illness patients in Wuhan are summarized in Fig. 4(a). Forty-three percent of heat-related illness patients were workers. Twenty-seven percent of the patients had no occupation outside the home. The percentages of the patients who were farmers, clerks, students and engineers were 4%, 4%, 4% and 2%, respectively.

The prognoses of heat-related illness patients in Wuhan are summarized in Fig. 4(b). Fifty percent of heat-related illness cases were inpatients in hospital.
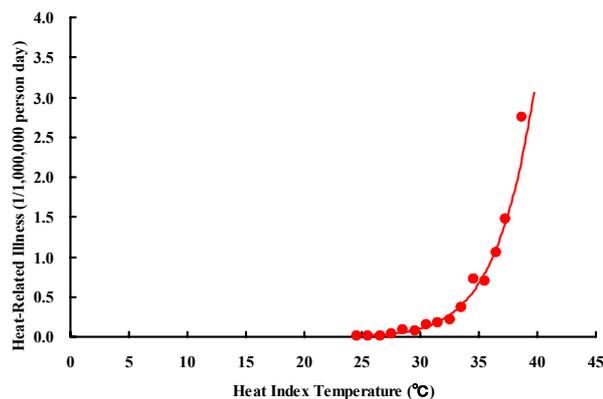

Fig. 2(a) Relationship between the incidence of heat-related illness and the heat index temperature in Tokyo, Japan.
(Y-axis: incidence per million people per day at given heat index temperature ; Line: exponential regression line)
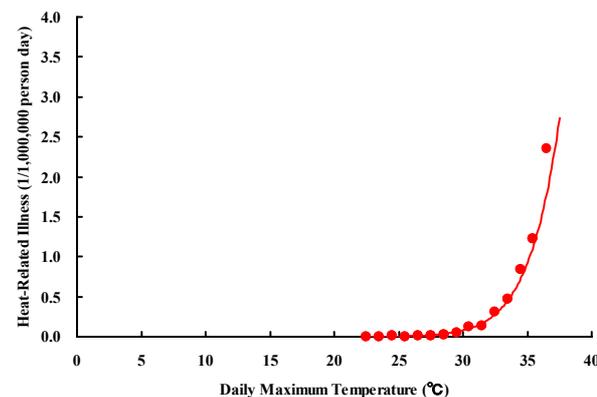

Fig. 2(b) Relationship between the incidence of heat-related illness and the daily maximum temperature in Tokyo, Japan.
(Y-axis: incidence per million people per day at given daily maximum temperature; Line: exponential regression line)
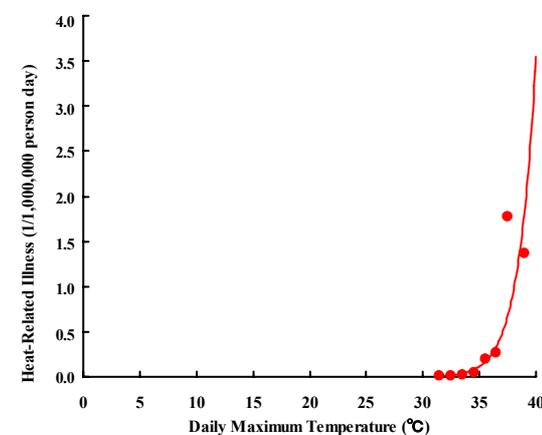

Fig. 3 Relationship between the incidence of heat-related illness and the daily maximum temperature in Wuhan, China.
(Y-axis: incidence per million people per day at given daily maximum temperature; Line: exponential regression line)

Twenty-nine percent of the patients showed serious syndromes and the mortality among cases of heat-related illness was 4.2%.

When establishing preventive procedures for heat stress caused by hot summers, the temperature-dependent incidence of diseases must be analyzed. The incidence of pneumonia differs completely depending on temperature and age as shown in Figs. 5(a), 5(b) and 5(c). The highest risk group is the elderly and one of the most important factors in outbreaks of pneumonia is the environmental temperature.

Environmental temperatures in cold and hot climates bring a serious risk for pneumonia among the elderly. For prevention of pneumonia in the elderly, it is necessary to improve the living environment in cold temperatures in winter as well as in hot temperatures in summer.

To assess the biomedical impacts of heat stress, model experiments were carried out. Hyperthermia was observed in animals and rectal temperature immediately increased and exhibited thermal homeostasis after exposure to hot environments during heat stress. Oxygen free radical damage to various organs and tissues was one of the most serious outcomes of heat stress. In young animals, activities of protective enzymes against oxygen free radicals, such as hepatic

GSH peroxidase, especially selenium GSH peroxidase, were strongly induced in response to increased environmental temperatures. In aged animals, however,
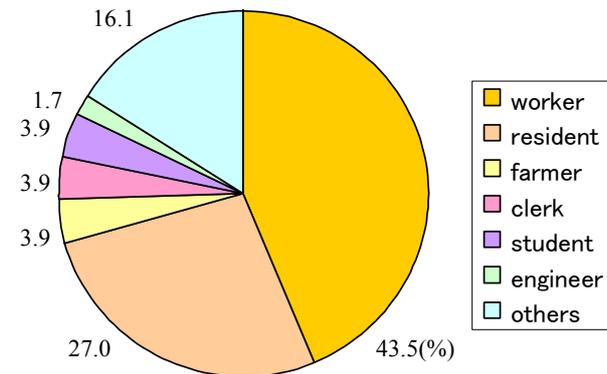

Fig. 5(a) Relationship between the incidence of pneumonia and the daily mean temperature in male (━) and female (━) children (0-14 years old) in Tokyo, Japan.
(Y-axis: incidence per million people per day at given daily mean temperature)

Fig. 5(b) Relationship between the incidence of pneumonia and the daily mean temperature in male (━) and female (━) adults (15-64 years old) in Tokyo, Japan.
(Y-axis: incidence per million people per day at given daily mean temperature)

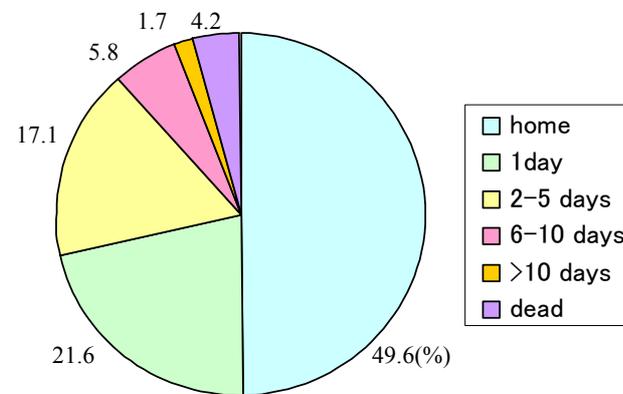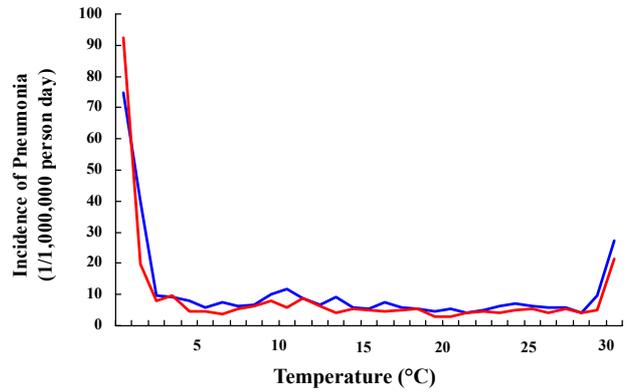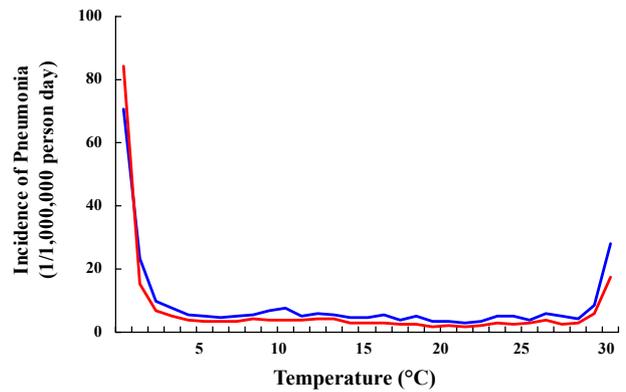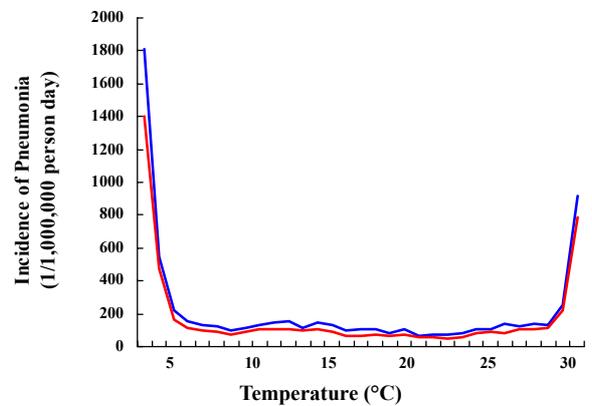**Fig. 4(a)** Occupations of heat-related illness patients in Wuhan, China.

Fig. 4(b) Prognosis for inpatients undergoing treatment for heat-related illness in hospitals in Wuhan, China.

Fig. 5(c) Relationship between the incidence of pneumonia and the daily mean temperature in male (━) and female (━) elderly persons (more than 65 years old) in Tokyo, Japan.
(Y-axis: incidence per million people per day at given daily mean temperature)
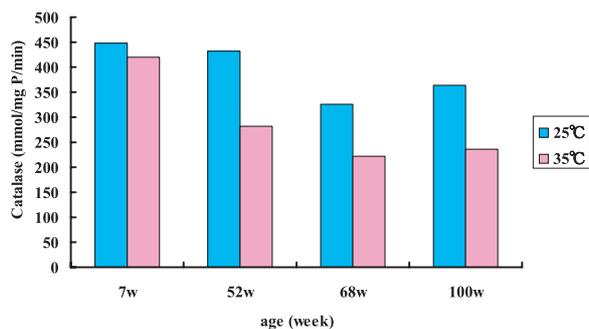
Fig. 6(a) Age dependent hepatic catalase activity of rats: control (■) and undergoing heat stress (■).
(In 52-week-old, 68-week-old and 100-week-old animals, catalase activities were significantly decreased by heat stress, P<0.01)
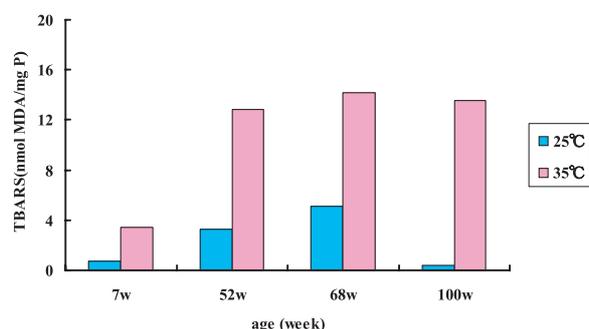

Fig. 6(b) Age dependent hepatic lipid peroxidation of rats: control (■) and undergoing heat stress (■).
(In 7-week-old, 52-week-old, 68-week-old and 100-week-old animals, TBARS, an indicator of lipid peroxidation, was significantly increased by heat stress, P<0.01)

GSH peroxidase and catalase were significantly decreased by heat stress as shown in Fig. 6(a). Since activities of protective enzymes such as peroxidase and catalase were markedly inhibited by heat stress, an indicator of lipid peroxidation (TBARS: thibarbituric acid reacting substances) was strongly induced in aged animals as shown in Fig. 6(b).

4. Discussion

In Tokyo (Japan) and Wuhan (China), it was proven that the incidence of heat-related illness increased exponentially with daily maximum temperature and heat index temperature. From the point of view of adaptation, a significant difference was observed in the critical threshold temperature for heat-related illness in Tokyo and Wuhan. However, the relationship between hot summer temperatures and the incidence of heat-related illness in Japan and China, situated in the temperate latitudes of Monsoon Asia were completely similar. Therefore, prevention of heat-related illness will require an effective risk management strategy for health impacts from heat stress in summer.

The incidence of heat-related illness differs com-

pletely depending on age, and the highest risk is observed among the elderly in Tokyo, Japan, and Wuhan, China. To prevent heat-related illness in the elderly, it is necessary to adopt mitigation options for hot temperatures. Summer heat caused by global warming and the heat island phenomenon will bring a remarkable increase in heat stress, therefore procedures to reduce heat in urban and rural areas may be necessary in the future. Statistical forecast models for heat stress have also been established based on the relationship between heat-related illness and meteorological factors, such as heat wave temperature weather forecast indexes established in China (Yang *et al.*, 2000).

Since the most important site of outbreaks of heat-related illness in Japan is outdoors, it will be necessary to improve the outside environment and to limit outdoor activities in hot weather to reduce risks among the elderly. In China, on the other hand, similar numbers of outbreaks occur outdoors and at home, therefore mitigation options are necessary for improving both indoor and outdoor conditions.

In China, occupational heat-related illness also has a high incidence; therefore preventive measures have been adopted including air conditioning, reduction of labor intensity, implementation of health standards, education and emergency treatment (Liang, 1999; Yi *et al.*, 2001).

It is necessary to evaluate preventive medicine for heat stress on heat-related illness, chronic diseases and indirect human health impacts such as pneumonia, therefore research on population impacts of heat stress will be among the most important subjects in bioclimatology in the future. For human health, it is thought that global warming and the heat island phenomenon may have a critical impact due to increased heat stress in summer (McGeehin & Mirabelli, 2001).

Since aging and hyperthermia have a synergistic effect on thermal damage in animals, the age-related response of animals and humans to damage from hyperthermia may be essential for survival and recovery from thermal injury in aging (Ando *et al.*, 1994, 1997). These results coincide with an epidemiological analysis of heat wave impacts in Nanjing, China, in 1988. In heat waves, when intense heat exceeded a daily maximum temperature of 36°C, a remarkable increase in the incidence of heat-related illness and mortality caused by heat strokes was observed in proportion to the atmospheric temperature above the threshold value (Ando *et al.*, 1998a, 1998b).

Since the epidemiological results and experimental model evidence show the impacts of heat stress greatly increase with aging, it is important to evaluate methods of assessing the impact of increased heat stress on human populations in the future (Ando, 1998; Vandentorren *et al.*, 2004; Conti *et al.*, 2005). For reducing risks of health impacts on populations from heat stress due to global warming and the heat

island phenomenon, it will be necessary to improve the environmental design of urban and rural communities and to promote the health status of residents.

5. Conclusion

The relationships between summer temperatures and the incidence of heat-related illness in Tokyo and Wuhan were strikingly similar. Furthermore, the incidence of heat-related illness increased exponentially with daily maximum temperature and heat index temperature.

Hot summers caused by global warming and the heat island phenomenon will bring a remarkable health risk from pneumonia to the elderly. Therefore, mitigation options will be necessary to improve the outside environment.

Since aging and hyperthermia have a synergistic effect on thermal damage in animals and humans, understanding the age-related response of humans to damage from hyperthermia will be essential for promoting population health.

As an option for mitigating global warming and the heat island phenomenon, it will be necessary to improve the environment design of urban and rural communities situated in the temperate latitudes of Japan, China and the world.

Acknowledgements

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