Front. Environ. Sci. Eng. 2023, 17(9): 105
https://doi.org/10.1007/s11783-023-1705-1

RESEARCH ARTICLE

Evaluating the short-term effect of ambient temperature on non-fatal outdoor falls and road traffic injuries among children and adolescents in China: a time-stratified case-crossover study

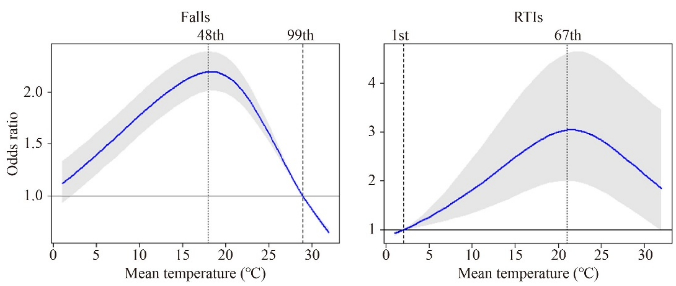
Hao Zheng[1,#], Jian Cheng[2,3,#], Hung Chak Ho[4], Baoli Zhu[1], Zhen Ding[1], Wencong Du[5], Xin Wang[6], Yang Yu[1], Juan Fei[1], Zhiwei Xu[7], Jinyi Zhou (✉)[5], Jie Yang (✉)[6]

1 Department of Environmental Health, Jiangsu Provincial Center for Disease Control and Prevention, Nanjing 210009, China
2 Department of Epidemiology and Biostatistics, School of Public Health, Anhui Medical University, Hefei 230032, China
3 Anhui Province Key Laboratory of Major Autoimmune Disease, Hefei 230032, China
4 Department of Anaesthesiology, School of Clinical Medicine, The University of Hong Kong, Hong Kong 999077, China
5 Department of Noncommunicable Diseases, Jiangsu Provincial Center for Disease Control and Prevention, Nanjing 210009, China
6 Department of Child and Adolescent Health Promotion, Jiangsu Provincial Center for Disease Control and Prevention, Nanjing 210009, China
7 School of Public Health, University of Queensland, Queensland 4006, Australia

HIGHLIGHTS

- A study assessing the temperature-injury relationship was conducted among students.
- The maximum risks of injury appeared at moderate temperatures.
- The temperature effect on outdoor falls was greater in older students.

GRAPHIC ABSTRACT



ARTICLE INFO

Article history:
Received 21 September 2022
Revised 2 March 2023
Accepted 3 March 2023
Available online 1 April 2023

Keywords:
Ambient temperature
Fall
Road traffic injury
Student
China

ABSTRACT

Although studies have suggested that non-optimal temperatures may increase the risk of injury, epidemiological studies focusing on the association between temperature and non-fatal injury among children and adolescents are limited. Therefore, we investigated the short-term effect of ambient temperature on non-fatal falls and road traffic injuries (RTIs) among students across Jiangsu Province, China. Meteorological data and records of non-fatal outdoor injuries due to falls and RTIs among students aged 6–17 were collected during 2018–2020. We performed a time-stratified case-crossover analysis with a distributed lag nonlinear model to examine the effect of ambient temperature on the risk of injury. Individual meteorological exposure was estimated based on the address of the selected school. We also performed stratified analyses by sex, age, and area. A total of 57322 and 5455 cases of falls and RTIs were collected, respectively. We observed inverted U-shaped curves for temperature-injury associations, with maximum risk temperatures at 18 °C (48th of daily mean temperature distribution) for falls and 22 °C (67th of daily mean temperature distribution) for RTIs. The corresponding odds ratios (95% confidence intervals) were 2.193 (2.011, 2.391) and 3.038 (1.988, 4.644) for falls and RTIs, respectively. Notably, there was a significant age-dependent trend in which the temperature effect on falls was greater in older students (P-trend < 0.05). This study suggests a

✉ Corresponding authors
E-mails: zhoujinyi74@sina.com (J. Zhou);
july-summer@jscdc.cn (J. Yang)

# These authors contributed equally to this work.

Special Issue—Climate Change and Public Health: Emerging Impacts and Responses (Responsible Editors: Can Wang, Shihui Zhang, Derrick Ho & Miriam Marlier)

significant association between ambient temperature and students' outdoor falls and RTIs. Our findings may help advance tailored strategies to reduce the incidence of outdoor falls and RTIs in children and adolescents.

1 Introduction

Injury is an important preventable cause of health loss, leading to substantial disability-adjusted life years (DALYs) worldwide (WHO, 2021b). Unintentional injuries are unexpected injuries that do not result from a person's intent to harm, accounting for a significant proportion of DALYs, especially among children and adolescents (Han et al., 2019). In 2019, global transport and unintentional injuries for adolescents (aged 10–24 years) accounted for 25% of mortality and 14% of DALYs (GBD 2019 Adolescent Transport and Unintentional Injuries Collaborators, 2022). The leading causes of unintentional injury-related DALYs for adolescents were road traffic injuries (RTIs) (ranked 1st) and falls (ranked 22nd) in 2019 (GBD 2019 Diseases and Injuries Collaborators, 2020). In China, RTIs and falls were the 5th and 17th leading causes of national DALYs in 2017, respectively (Zhou et al., 2019), and the age-standardized incidence of injuries increased by 50.6% between 1990 and 2017 (Duan et al., 2019). Thus, it is crucial to identify potentially related factors and advance prevention measures to reduce the increasing incidence of non-fatal unintentional injuries.

Studies have revealed that non-optimal ambient temperatures may increase the risk of injury mortality (Basagaña et al., 2011; Joe et al., 2016; Pan et al., 2022) and morbidity (McInnes et al., 2017; Martínez-Solanas et al., 2018; Kim et al., 2019). A recent comprehensive study in Republic of Korea (Lee et al., 2020) found that high and low temperatures significantly increased the risk of non-fatal injury, and this correlation varied by the cause of injury. Children and adolescents are prone to outdoor environmental factors due to their increased independence and elevated activity levels (Patton et al., 2016). Ambient temperature changes may affect human behavioral patterns and traffic intensity (Abe et al., 2008; Gao et al., 2016; Lio et al., 2019). For instance, an optimal ambient temperature may lead to increased outdoor activities among children and adolescents, resulting in a rising incidence of unintentional injuries. Hussain et al. reported that the incidence of head injury among children increased during warmer months in the UK, possibly associated with open windows due to high temperature (Hussain et al., 2007). Understanding the effect of ambient temperature on non-fatal unintentional injury among the young population would help decision-makers formulate tailored intervention strategies to reduce the injury incidence related to temperature. However, to our knowledge, few epidemiological studies have evaluated the impact of temperature on non-fatal injury incidence in children and adolescents.

Therefore, we used a unique school-based injury surveillance database in eastern China to examine the short-term effect of ambient temperature on non-fatal unintentional falls and RTIs among students. We hypothesized that temperature-injury associations might differ for falls and RTIs. We then examined whether the associations varied by sex, age, and area.

2 Materials and methods

2.1 Data collection

Daily records of non-fatal unintentional injuries among students were obtained from Jiangsu Provincial Student Injury Surveillance System (SISS), China. The details of SISS have been described previously (Yang et al., 2016; Du et al., 2017). This is China's first provincial surveillance system to monitor and manage the occurrence of non-fatal injury in students, covering more than 90% of primary, middle, and high schools in Jiangsu Province. The SISS collects injury cases at any outdoor or indoor location, including school, home, or other places. To accurately evaluate the temperature-injury association, we only selected injury cases that occurred outdoors. The information collected include general information (sex, age, region, and school) and details of injury cases (date, location, type, and intention). The SISS records the cases occurring only within the school term. Thus, injuries that occurred in non-school term periods, namely, the summer (July and August) and winter (February) holidays were not included. Injuries diagnosed in the hospital as a specific type of harm or caused at least one day of leave were included in the SISS.

Daily meteorological variables (mean temperature, relative humidity, rainfall, wind speed, and atmospheric pressure) of fixed meteorological monitoring stations were collected from Jiangsu Provincial Meteorological Center. The daily air quality index (AQI) of each city in Jiangsu Province was obtained from the Jiangsu Provincial Environmental Monitoring Center.

2.2 Outcome

We extracted daily records of non-fatal unintentional falls and RTIs among students aged 6–17 from January 1, 2018, to December 31, 2020, in Jiangsu Province. Falls and RTIs were coded according to the International

Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD 10), with W00–W19 (ICD 10 codes) for falls and V01–V99 (ICD 10 codes) for RTIs. Specifically, a fall is defined as an event that results in a person coming to rest inadvertently on the ground, floor, or other lower level (WHO, 2021a). An RTI is defined as resulting in bodily injury to a person caused by a collision or incident with a vehicle. We selected outdoor falls and RTIs because they were the leading causes of non-fatal injury (Du et al., 2017), and outdoor injury may be related to ambient temperature (Lee et al., 2020).

2.3 Exposure assessment

To measure the exposure of injury cases, we used the variables from the nearest meteorological station based on the address of the selected school. The distances from the selected school to its nearest monitoring station ranged from 0.1 to 178.6 km, with a median of 18.3 km. A total of 59 meteorological monitoring stations were assigned to 2702 schools to evaluate the students' meteorological exposure. We did not obtain the residential addresses of cases due to the unavailable data. However, we believe that the routine activities of students were not far from their schools before the end of school term due to the nearby enrollment policy in China. Thus, the school-based estimates could represent the participants' environmental exposure levels (Mazaheri et al., 2014; Zhang et al., 2019; Zheng et al., 2021).

2.4 Study design

The short-term effect of temperature on injuries was evaluated based on a time-stratified case-crossover design, which has been widely used to explore the environmental impact on mortality and morbidity (Lee et al., 2020; Xu et al., 2020; Pan et al., 2022). This study design compared ambient temperature exposure levels of identical students on the case day and the control day (i.e., the same day of the week in the same year and month). For instance, an injury case occurred on Thursday, June 14, 2018, and all other Thursdays in June 2018 were selected as control days (i.e., June 7, June 21, and June 28). Thus, some confounders, such as age, sex, seasonality, and long-term trends, were automatically controlled (Maclure, 1991).

2.5 Statistical analysis

A conditional logistic regression was applied to analyze the short-term effect of temperature exposure on outdoor injuries. The odds ratio (OR) and 95% confidence interval (CI) were estimated after adjusting for holidays and 3-day moving averages (lag 0–2) of relative humidity, atmospheric pressure, and rainfall (Pan et al., 2022). We selected the covariates based on previous studies (Lee et al., 2020; Pan et al., 2022) and the correlations between temperature and other meteorological variables (see Tables S1 and S2). In addition, we adjusted for the possible confounding effect of the COVID-19 pandemic by adding a dichotomous variable in the model, depending on whether a day was a lockdown day during the study period. Since ambient temperature may have a delayed effect on injury, a distributed lag nonlinear model (DLNM) was adopted to examine the nonlinear temperature-injury relationship. DLNM can describe the complex nonlinear and lagged dependencies of the temperature-injury relationship by combining two functions that define the exposure-response relationship and the lag–response relationship, respectively (Gasparrini, 2014). The Akaike information criterion was used to evaluate the model performance. A natural cubic spline function with 3 degrees of freedom (*df*) was used for both the exposure-response and lag-response relationship. A maximum lag of 7 days was selected considering the possible delayed effects (Hu et al., 2020).

The overall lag-cumulative effects curve was presented as the main result of the temperature-injury association. We defined the temperature that may generate the maximum risk as the maximum risk temperature (MaxRT). We calculated the OR associated with MaxRT by setting the reference value at the minimum risk temperature (MinRT) representing the lowest temperature risk. The MaxRT and MinRT were defined between the 1st and 99th percentiles of temperature (Kim et al., 2019; Lee et al., 2020; Pan et al., 2022).

We further conducted stratified analyses to obtain the specific temperature-injury ORs by sex (male and female), age (6–8, 9–11, 12–14, and 15–17), and area (urban and rural). The age groups were categorized into four groups according to the different study stages in schools. Children aged 6–8 years are in grades 1–3 in primary school; students aged 9–11 are in grades 4–6 in primary school; students aged 12–14 are middle-school students; adolescents aged 15–17 are high-school students. We used the 2-sample z-test to examine differences between two comparable groups (Altman and Bland, 2003). Meta-regression was applied to perform linear trend estimation between multi-age groups (Shi and Copas, 2004).

A series of sensitivity analyses were performed to verify the robustness of our results. First, we changed the maximum lag period from 0 to 7 days to 0–3, 0–10, and 0–14 days. Second, the natural cubic spline for the exposure-response curve was changed to the quadratic B-spline. Third, we changed the *df* for the exposure-response relationship from 3 to 2, 4, and 5. Fourth, wind speed and AQI data were fitted into the model to assess the modification effects on temperature-injury association. Last, we changed the percentile range (1st–99th percentiles) of the temperature distribution to 5th–95th percentiles and 10th–90th percentiles.

All statistical analyses were performed using R software (version 4.2.0). The “survival” and “dlnm” packages were used to fit the temperature-injury association. A two-sided P value < 0.05 was considered to be statistically significant.

3 Results

3.1 Data description

A total of 57322 and 5455 cases of non-fatal outdoor falls and RTIs were collected from the SISS during 2018–2020, respectively. More than half of the injuries were males for falls (66.8%) and RTIs (63.5%). Students aged 9–11 years accounted for 27.5% of the total cases of falls, which was slightly higher than any other age group. For RTIs, students aged 12–14 years had the highest proportion (35.0%) among the four age groups. Most fall cases occurred in students living in urban areas (54.9%), whereas students living in rural areas constituted 58.1% of the cases for RTIs. The descriptive statistics for the falls and RTIs among students are presented in Table 1.

Table 2 represents the descriptive statistics of daily weather variables and AQI on case days and control days

Table 1 Descriptive statistics for the cases of falls and RTIs in students in Jiangsu Province, China, 2018–2020

Variables	Categories	Falls	RTIs
Total		57322 (100%)	5455 (100%)
Sex	Male	38303 (66.8%)	3467 (63.5%)
	Female	19019 (33.2%)	1988 (36.5%)
Age group (years)	6–8	14434 (25.2%)	992 (18.2%)
	9–11	15765 (27.5%)	1136 (20.8%)
	12–14	15473 (27.0%)	1910 (35.0%)
	15–17	11650 (20.3%)	1417 (26.0%)
Area	Urban	31481 (54.9%)	2285 (41.9%)
	Rural	25841 (45.1%)	3170 (58.1%)

Table 2 Summary statistics of daily meteorological variables and AQI on case days and control days for falls and RTIs in Jiangsu Province, China, 2018–2020

Injuries	Variables	Min	P25	P50	P75	Max	Mean	SD
Falls (on case days)	Mean temperature (°C)	0.2	12.9	18.4	23.2	32.9	17.6	7.1
	Relative humidity (%)	20.5	61.4	69.3	78.6	100.0	69.4	13.2
	Atmospheric pressure (hPa)	993.3	1010.1	1016.6	1022.3	1041.1	1016.5	8.6
	Rainfall (mm)	0	0	0	0	10.0	0.1	0.3
	Wind speed (m/s)	0.2	1.3	1.7	2.2	8.3	1.8	0.7
	AQI	14.0	47.0	61.0	81.0	292.0	67.3	28.5
Falls (on control days)	Mean temperature (°C)	0.1	12.1	18.3	23.3	32.9	17.4	7.3
	Relative humidity (%)	20.5	62.5	71.4	81.9	100.0	71.6	14.0
	Atmospheric pressure (hPa)	993.3	1009.8	1016.3	1022.3	1040.8	1016.3	8.7
	Rainfall (mm)	0	0	0	0	10.0	0.1	0.4
	Wind speed (m/s)	0.1	1.3	1.7	2.2	10.5	1.8	0.7
	AQI	10.0	45.0	58.0	79.0	321.0	64.8	29.3
RTIs (on case days)	Mean temperature (°C)	0.3	12.0	17.9	23.0	32.2	17.1	7.4
	Relative humidity (%)	20.5	59.6	69.3	79.5	100.0	69.4	14.6
	Atmospheric pressure (hPa)	993.3	1008.4	1015.5	1021.5	1040.3	1015.2	8.8
	Rainfall (mm)	0	0	0	0	5.2	0.1	0.4
	Wind speed (m/s)	0.3	1.3	1.7	2.3	7.7	1.8	0.8
	AQI	14.0	46.0	60.0	80.0	321.0	66.6	30.1
RTIs (on control days)	Mean temperature (°C)	0.3	11.5	17.7	23.2	32.6	16.9	7.6
	Relative humidity (%)	20.5	60.3	70.1	80.2	100.0	69.8	14.2
	Atmospheric pressure (hPa)	993.3	1008.2	1015.3	1021.6	1041.1	1015.2	9.1
	Rainfall (mm)	0	0	0	0	10.0	0.1	0.4
	Wind speed (m/s)	0.3	1.3	1.7	2.3	11.1	1.8	0.8
	AQI	10.0	46.0	60.0	80.0	321.0	67.1	31.8

Notes: Min, minimum; Max, maximum; SD, standard deviation; AQI, air quality index.

for falls and RTIs. The daily mean temperature ranged from 0.2 to 32.9 °C for falls and 0.3 to 32.2 °C for RTIs on case days. Daily mean temperatures for the cases of falls and RTIs were highly negatively correlated with atmospheric pressures (r = −0.821 for falls and r = −0.820 for RTIs) (Tables S1 and S2).

3.2 Temperature-injury association

Fig. 1 shows the lag-cumulative temperature-injury associations for falls and RTIs. Table 3 presents the corresponding numeric estimates for Fig. 1. We observed inverted U-shaped curves for the temperature-injury associations. Given the different exposure-response curves for falls and RTIs, different MinRTs were selected as the references to calculate ORs. The highest risk was reached at 18 °C (48th percentile of the temperature distribution) for falls, with an OR of 2.193 (95% CI: 2.011, 2.391) compared with that at MinRT. For RITs, the OR and 95% CI of the maximum risk was 3.038 (1.988, 4.644) at 22 °C (67th percentile of the temperature distribution) compared with the risk at MinRT. No significant difference was found for the temperature-injury associations between falls and RTIs (P = 0.140).

3.3 Subgroup analysis

Fig. 2 depicts the cumulative ORs and 95% CIs in the stratified analyses by sex, age group, and area. The corresponding numeric data are shown in Table 3. A significant increasing trend of the temperature-fall association was found for students in the four age groups

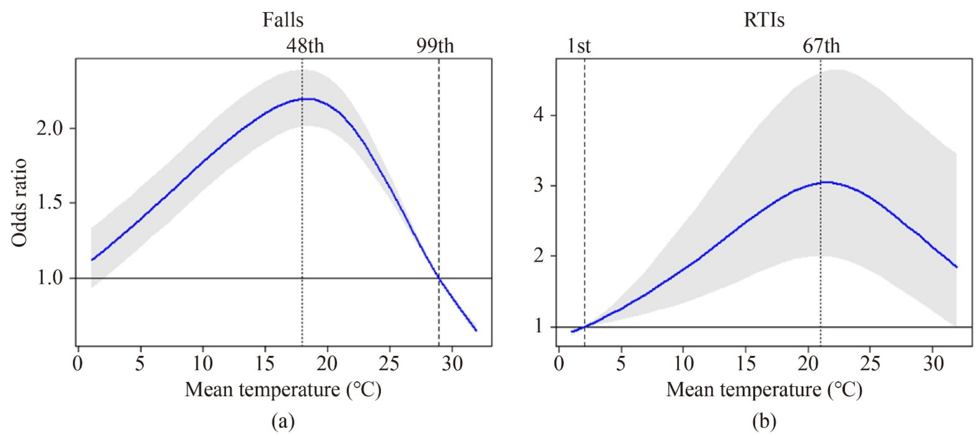


Fig. 1 Overall lag-cumulative (0–7 days) exposure-response associations for falls (a) and RTIs (b). The dashed vertical line represents the minimum risk temperature, and the dotted vertical line represents the maximum risk temperature. Shaded areas represent 95% confidence intervals.

Table 3 ORs and 95% CIs for falls and RITs and the corresponding subgroups in students in Jiangsu Province, China, 2018–2020

Variables	Categories	Falls				RTIs			
		MinRT (%)	MaxRT (%)	OR (95% CI)	P value	MinRT (%)	MaxRT (%)	OR (95% CI)	P value
Overall		29 (99)	18 (48)	2.193 (2.011, 2.391)		2 (1)	22 (67)	3.038 (1.988, 4.644)	
Sex									
	Male	29 (99)	18 (48)	2.211 (1.990, 2.458)	0.815#	2 (1)	22 (67)	2.852 (1.666, 4.885)	0.724#
	Female	29 (99)	19 (54)	2.164 (1.871, 2.504)		2 (1)	22 (68)	3.340 (1.673, 6.670)	
Age groups (years)									
	6–8	29 (99)	20 (53)	1.523 (1.310, 1.772)	<0.0001*	2 (1)	30 (99)	6.996 (1.926, 25.406)	0.818*
	9–11	29 (99)	19 (50)	1.669 (1.426, 1.953)		2 (1)	17 (46)	2.482 (1.043, 5.911)	
	12–14	29 (99)	17 (45)	3.235 (2.707, 3.865)		2 (1)	23 (76)	1.953 (0.954, 3.998)	
	15–17	29 (99)	18 (54)	4.062 (3.303, 4.996)		2 (1)	21 (61)	4.766 (2.026, 11.215)	
Area									
	Urban	29 (99)	19 (53)	2.133 (1.908, 2.385)	0.470#	2 (1)	21 (63)	3.885 (2.048, 7.366)	0.326#
	Rural	29 (99)	18 (48)	2.272 (1.995, 2.588)		2 (1)	22 (67)	2.538 (1.451, 4.439)	

Notes: MinRT, Minimum risk temperature (°C); MaxRT, Maximum risk temperature (°C). #, P for difference; *, P for trend.

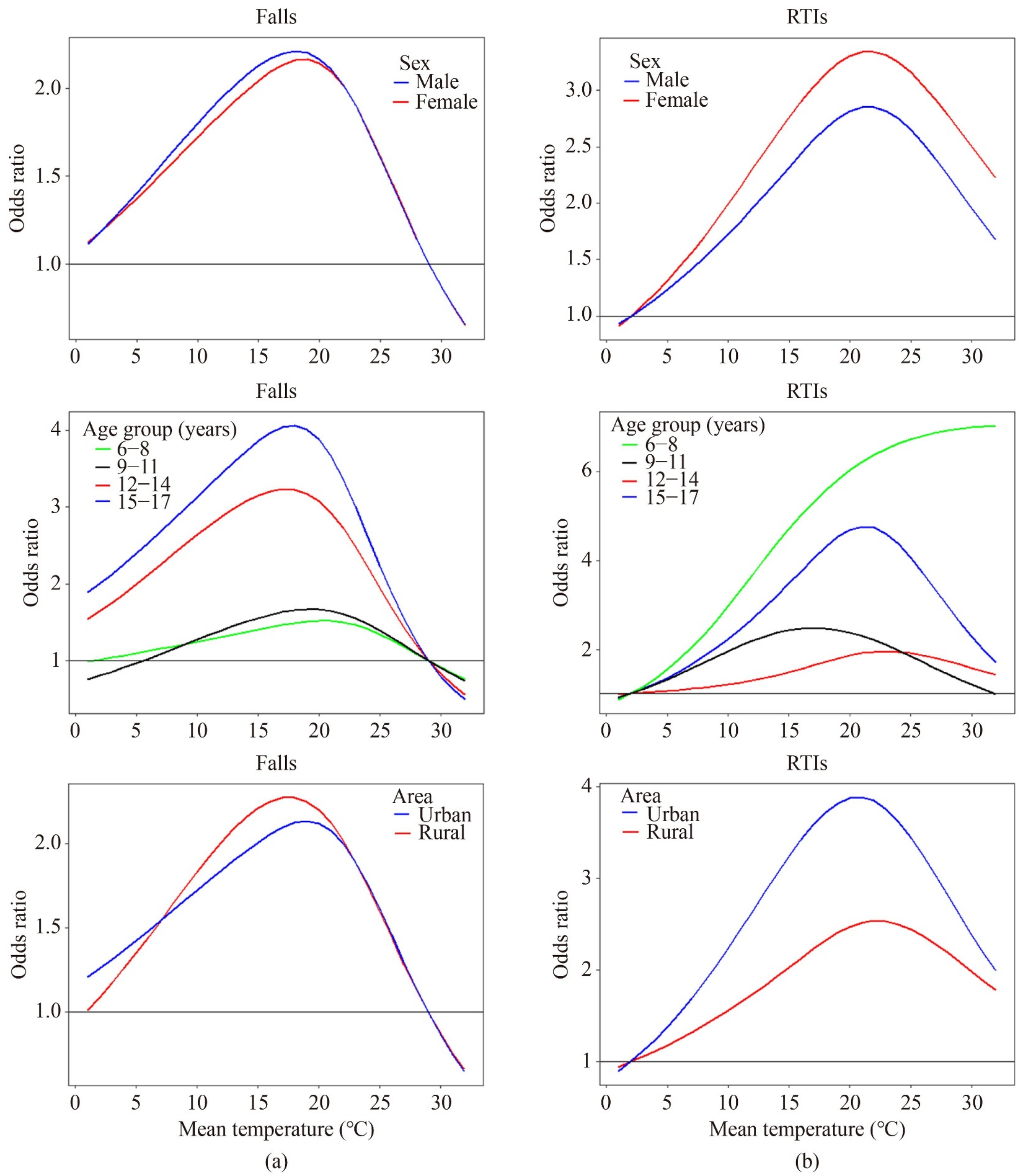


Fig. 2 Overall lag-cumulative ORs with 95% CIs for falls (a) and RTIs (b) in subgroup analyses by sex, age group, and area.

(P-trend < 0.05). We observed that the short-term effect of temperature on falls increased with age increment, and the most vulnerable age group was the students aged 15–17 with an OR of 4.062 (95% CI: 3.303, 4.996). For RTIs, the highest risk was observed in students aged 6–8 with an OR of 6.996 (95% CI: 1.926, 25.406). However, a linear trend was found between the multiple age groups for RITs. Additionally, we did not observe significant differences in sex and area for either falls or RTIs.

3.4 Sensitivity analysis

Sensitivity analysis showed that the association estimates were generally robust after altering parameters in the model (Figs. S1 and S2). The temperature-fall cumulative effects increased when using lag 0–10 or 0–14 days, while the effect of temperature on RTIs decreased slightly when applying lag 0–3 days. The analysis employing df = 2, 4, or 5 for the exposure-response association instead of df = 3 generally represented similar temperature-injury curves except for df = 5. Additionally, the temperature-injury relationships remained stable using the B spine function and different MinRTs in the model. The corresponding numeric estimates for Figs. S1 and S2 are presented in Table S3.

4 Discussion

In this study, using a unique school-based injury surveillance database in China, we investigated the short-term effect of ambient temperature on non-fatal outdoor falls and RITs among students aged 6–17 years in Jiangsu Province during 2018–2020. This study found inverted U-shaped curves between temperature and injuries, whereby the maximum risks appeared at moderate temperatures for both falls and RTIs. The effect of temperature on falls was significantly increased with age. To the best of our knowledge, this is the first study to explore the temperature-outdoor injury relationship in a school-based population. Our results indicate the necessity of formulating tailored prevention strategies to reduce the risk of outdoor injury in moderate temperature conditions for children and adolescents.

The associations between temperature and falls, and RTIs have been reported in previous studies. Generally, most previous studies suggested a significant association between high temperature and falls (Parslow et al., 2005; Adam-Poupart et al., 2015) or RTIs (Nofal and Saeed, 1997; Basagaña et al., 2015). Similar to the findings of our study, a study in Beijing (China) (Ma et al., 2016) found that accidental casualties happen more frequently on warm days, and the greatest possibility of emergency visits for accidental casualties occurred at 26 °C. An Italian study assessing the relationship between work-related accidents and hot weather conditions reported that the peak of accidents occurred on days with high but not extreme temperatures (24.8–27.5 °C) (Morabito et al., 2006). Two previous studies have observed different relationships of temperature with falls and RTIs. Liang and colleagues (Liang et al., 2021) reported that high temperature (27.9 °C, 90 percentile of ambient temperature) significantly increased the risk of falls, and low temperature (5th percentile) significantly increased the risk of falls in elderly individuals. A study in Republic of Korea (Lee et al., 2020) found that the risk of falls occurred at high temperatures, but both high and low temperatures significantly increased the risk of incidence of RTIs. The effect of low temperature was not observed in our study. The discrepancy may be explained by the differences in types of injury, targeted populations, and meteorological conditions between various studies. For instance, the elderly are more likely to fall or have traffic accidents on wet or slippery roads at low temperatures (Xu et al., 2012), which is different from young people. Another plausible explanation was that the school-based active surveillance database used in our study may collect more potential injury cases, which is different from those collected from hospitals.

The mechanism of ambient temperature and injury incidence been widely reported for various types of injuries, thermoregulatory system dysfunction (Cheshire, 2016), cognitive function impairment (Mann, 2013; Nindl et al., 2013), and changed behavioral patterns (Stevens et al., 2007) were considered the potential driving factors. However, most previous studies did not distinguish injury cases indoors or outdoors, which is critical to interpreting the temperature-injury relationship. We speculate that ambient temperature may affect outdoor behavioral patterns in children and adolescents and traffic intensity (Liang et al., 2021). In our study, moderate temperatures may promote the outdoor physical activity among children and adolescents and increase traffic intensity (Cools et al., 2010), which eventually increases the risk of outdoor falls and RTIs (Morabito et al., 2006; Morency et al., 2012; Ma et al., 2016). Our findings suggest that safety education and injury protection measures for outdoor activities must be further strengthened in children and adolescents when ambient temperature is supportive of outdoor activities.

A novel finding of our studies is that the effect of temperature on falls increased with age, suggesting that the students in high school are most affected by temperature. A possible explanation is that the frequency and scope of school activities in warm temperatures increase with age, leading to an increased risk of falls. In contrast, we also found the greatest risk in students aged 6–8 in the temperature-RTIs association, indicating that effective intervention measures urgently need to be implemented to reduce the risk of temperature-RITs in this age group. Similar effects of temperature on falls and RTIs were observed for both males and females. Additionally, we observed that the risk of ambient temperature on RTI in the urban regions was slightly higher than that in the rural regions. High population density and traffic intensity in urban regions may be contributing factors (Cools et al., 2010; Gao et al., 2016). Generally, our findings suggest the importance of considering age differences when formulating outdoor injury prevention strategies related to temperature in children and adolescents.

This study has several limitations. First, we did not obtain records of injuries that may occur during the winter or summer holidays. The relationship between injuries and extreme temperatures needs to be further studied. Second, the incidence of injury may be underestimated due to the possibility of underreporting. However, as the first provincial school-based active surveillance system for injury in China (Yang et al., 2016), the SISS has the advantage of collecting students' injury records over those collected by hospitals. Third, the findings may not be applicable to other regions due to the restricted scale. More large-scale studies are required to determine the temperature-injury correlation in the future.

5 Conclusions

This is the first study to determine the short-term effect of ambient temperature on falls and RTIs based on a unique school-based injury monitoring system in China. We found inverted U-shaped curves of the temperature-injury associations whereby the maximum risks occurred at moderate temperatures, and the identified MaxRT for

RTIs was higher than for falls. Our findings may be useful in establishing targeted interventions to reduce the risk of outdoor falls and RTIs associated with temperature among children and adolescents.

Authorship Contribution Statement **Hao Zheng**: Conceptualization, Methodology, Software, Formal analysis, Data curation, Writing - original draft, Writing-review and editing. **Jian Cheng:** Methodology, Formal analysis, Writing-review and editing. **Hung Chak Ho:** Writing-review and editing. **Baoli Zhu:** Writing-review and editing. **Zhen Ding:** Date curation, Writing-review and editing. **Wencong Du**: Data curation, Writing-review and editing. **Xin Wang:** Data curation, Writing-review and editing. **Yang Yu:** Writing-review and editing. **Juan Fei:** Writing-review and editing. **Zhiwei Xu:** Writing-review and editing. **Jinyi Zhou:** Conceptualization, Project administration, Writing-review and editing. **Jie Yang:** Conceptualization, Project administration, Validation, Writing-review and editing.

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

Electronic Supplementary Material Supplementary material is available in the online version of this article at https://doi.org/10.1007/s11783-023-1705-1 and is accessible for authorized users.

References

Abe T, Tokuda Y, Ohde S, Ishimatsu S, Nakamura T, Birrer R B (2008). The influence of meteorological factors on the occurrence of trauma and motor vehicle collisions in Tokyo. Emergency Medicine Journal, 25(11): 769–772

Adam-Poupart A, Smargiassi A, Busque M A, Duguay P, Fournier M, Zayed J, Labrèche F (2015). Effect of summer outdoor temperatures on work-related injuries in Quebec (Canada). Occupational and Environmental Medicine, 72(5): 338–345

Altman D G, Bland J M (2003). Interaction revisited: the difference between two estimates. BMJ (Clinical Research Ed.), 326(7382): 219

Basagaña X, Escalera-Antezana J P, Dadvand P, Llatje Ò, Barrera-Gómez J, Cunillera J, Medina-Ramón M, Pérez K (2015). High ambient temperatures and risk of motor vehicle crashes in Catalonia, Spain (2000–2011): a time-series analysis. Environmental Health Perspectives, 123(12): 1309–1316

Basagaña X, Sartini C, Barrera-Gómez J, Dadvand P, Cunillera J, Ostro B, Sunyer J, Medina-Ramón M (2011). Heat waves and cause-specific mortality at all ages. Epidemiology (Cambridge, Mass.), 22(6): 765–772

Cheshire W P Jr (2016). Thermoregulatory disorders and illness related to heat and cold stress. Autonomic Neuroscience, 196: 91–104

Cools M, Moons E, Wets G (2010). Assessing the impact of weather on traffic intensity. Weather, Climate, and Society, 2(1): 60–68

Du W, Yang J, Zhou J, Wu M (2017). Study of injury surveillance among students in Jiangsu Province from 2013 to 2015. Jiangsu Journal of Preventive Medicine, 28(02): 153–155 (in Chinese)

Duan L, Ye P, Juanita A H, Jin Y, Wang Y, Er Y, Deng X, Gao X, Ji C, Wang L, Marlena S B, W Cliff M, Caitlin N H, Liu Z, Mari S, Spencer J L, Theo V, Christopher J L M (2019). The burden of injury in China, 1990–2017: findings from the Global Burden of Disease Study 2017. Lancet. Public Health, 4(9): e449–e461

Gao J, Chen X, Woodward A, Liu X, Wu H, Lu Y, Li L, Liu Q (2016). The association between meteorological factors and road traffic injuries: a case analysis from Shantou city, China. Scientific Reports, 6(1): 37300

Gasparrini A (2014). Modeling exposure-lag-response associations with distributed lag non-linear models. Statistics in Medicine, 33(5): 881–899

GBD 2019 Adolescent Transport and Unintentional Injuries Collaborators (2022). Adolescent transport and unintentional injuries: a systematic analysis using the Global Burden of Disease Study 2019. Lancet Public Health, 7(8): e657–e669

GBD 2019 Diseases and Injuries Collaborators (2020). Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet, 396(10258): 1204–1222

Han L, You D, Gao X, Duan S, Hu G, Wang H, Liu S, Zeng F (2019). Unintentional injuries and violence among adolescents aged 12–15 years in 68 low-income and middle-income countries: a secondary analysis of data from the Global School-Based Student Health Survey. Lancet Child Adolesc Health, 3(9): 616–626

Hu J, Wen Y, Duan Y, Yan S, Liao Y, Pan H, Zhu J, Yin P, Cheng J, Jiang H (2020). The impact of extreme heat and heat waves on emergency ambulance dispatches due to external cause in Shenzhen, China. Environmental Pollution, 261: 114156

Hussain N, Mewasingh L, Gosalakkal J (2007). Is the heat wave increasing the number of falls from open windows among children? Archives of Disease in Childhood, 92(1): 90

Joe L, Hoshiko S, Dobraca D, Jackson R, Smorodinsky S, Smith D, Harnly M (2016). Mortality during a large-scale heat wave by place, demographic group, internal and external causes of death, and building climate zone. International Journal of Environmental Research and Public Health, 13(3): 299

Kim Y, Kim H, Gasparrini A, Armstrong B, Honda Y, Chung Y, Ng C F S, Tobias A, Iniguez C, Lavigne E, et al. (2019). Suicide and ambient temperature: a multi-country multi-city study. Environmental Health Perspectives, 127(11): 117007

Lee H, Myung W, Kim H, Lee E M, Kim H (2020). Association between ambient temperature and injury by intentions and mechanisms: a case-crossover design with a distributed lag nonlinear model. Science of the Total Environment, 746: 141261

Liang M, Ding X, Yao Z, Duan L, Xing X, Sun Y (2021). Effects of ambient temperature and fall-related injuries in Ma'anshan, Anhui Province, China: a distributed lag nonlinear analysis. Environmental Science and Pollution Research International, 28(41): 58092–58103

Lio C F, Cheong H H, Un C H, Lo I L, Tsai S Y (2019). The association between meteorological variables and road traffic injuries: a study from Macao. PeerJ, 7: e6438

Ma P, Wang S, Fan X, Li T (2016). The impacts of air temperature on accidental casualties in Beijing, China. International Journal of Environmental Research and Public Health, 13(11): 1073

Maclure M (1991). The case-crossover design: a method for studying transient effects on the risk of acute events. American Journal of Epidemiology, 133(2): 144–153

Mann J J (2013). The serotonergic system in mood disorders and suicidal behaviour. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 368(1615): 20120537

Martínez-Solanas E, Lopez-Ruiz M, Wellenius G A, Gasparrini A, Sunyer J, Benavides F G, Basagana X (2018). Evaluation of the impact of ambient temperatures on occupational injuries in Spain. Environmental Health Perspectives, 126(6): 067002

Mazaheri M, Clifford S, Jayaratne R, Megat Mokhtar M A, Fuoco F, Buonanno G, Morawska L (2014). School children's personal exposure to ultrafine particles in the urban environment. Environmental Science & Technology, 48(1): 113–120

McInnes J A, Akram M, Macfarlane E M, Keegel T, Sim M R, Smith P (2017). Association between high ambient temperature and acute work-related injury: a case-crossover analysis using workers' compensation claims data. Scandinavian Journal of Work, Environment & Health, 43(1): 86–94

Morabito M, Cecchi L, Crisci A, Modesti P A, Orlandini S (2006). Relationship between work-related accidents and hot weather conditions in Tuscany (central Italy). Industrial Health, 44(3): 458–464

Morency P, Voyer C, Burrows S, Goudreau S (2012). Outdoor falls in an urban context: winter weather impacts and geographical variations. Canadian Journal of Public Health, 103(3): 218–222

Nindl B C, Castellani J W, Warr B J, Sharp M A, Henning P C, Spiering B A, Scofield D E (2013). Physiological employment standards III: physiological challenges and consequences encountered during international military deployments. European Journal of Applied Physiology, 113(11): 2655–2672

Nofal F H, Saeed A A (1997). Seasonal variation and weather effects on road traffic accidents in Riyadh city. Public Health, 111(1): 51–55

Pan R, Honda Y, Minakuchi E, Kim S E, Hashizume M, Kim Y (2022). Ambient temperature and external causes of death in Japan from 1979 to 2015: a time-stratified case-crossover analysis. Environmental Health Perspectives, 130(4): 047004

Parslow R C, Morris K P, Tasker R C, Forsyth R J, Hawley C A (2005). Epidemiology of traumatic brain injury in children receiving intensive care in the UK. Archives of Disease in Childhood, 90(11): 1182–1187

Patton G C, Sawyer S M, Santelli J S, Ross D A, Afifi R, Allen N B, Arora M, Azzopardi P, Baldwin W, Bonell C, et al. (2016). Our future: a Lancet commission on adolescent health and wellbeing. Lancet, 387(10036): 2423–2478

Shi J Q, Copas J B (2004). Meta-analysis for trend estimation. Statistics in Medicine, 23(1): 3–19, 159–162

Stevens J A, Thomas K E, Sogolow E D (2007). Seasonal patterns of fatal and nonfatal falls among older adults in the U.S. Accident; Analysis and Prevention, 39(6): 1239–1244

WHO (2021a). Falls. Geneva: World Health Organization

WHO (2021b). Injuries and Violence. Geneva: World Health Organization

Xu G, Ying Y, Liu Y, Chang W, Ni H, Zhu Y, Xu R, Dong H, Shi N, Ma X, et al. (2012). Incidences, types, and influencing factors of snow disaster-associated injuries in Ningbo, China, 2008. Disaster Medicine and Public Health Preparedness, 6(4): 363–369

Xu R, Xiong X, Abramson M J, Li S, Guo Y (2020). Ambient temperature and intentional homicide: a multi-city case-crossover study in the US. Environment International, 143: 105992

Yang J, Du W, Zhou J, Zhang Y, Zhang X, Yang Y, Wu M (2016). Exploration and analysis on network based student injury surveillance system establishment in Jiangsu Province, China. Injury Medicine (Electronic-Edition), 5(02): 10−15 (in Chinese)

Zhang Z, Dong B, Li S, Chen G, Yang Z, Dong Y, Wang Z, Ma J, Guo Y (2019). Exposure to ambient particulate matter air pollution, blood pressure and hypertension in children and adolescents: a national cross-sectional study in China. Environment International, 128: 103–108

Zheng H, Xu Z, Wang Q, Ding Z, Zhou L, Xu Y, Su H, Li X, Zhang F, Cheng J (2021). Long-term exposure to ambient air pollution and obesity in school-aged children and adolescents in Jiangsu Province of China. Environmental Research, 195: 110804

Zhou M, Wang H, Zeng X, Yin P, Zhu J, Chen W, Li X, Wang L, Wang L, Liu Y, et al. (2019). Mortality, morbidity, and risk factors in China and its provinces, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet, 394(10204): 1145–1158