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Relationships between cold-temperature indices and all causes and cardiopulmonary morbidity and mortality in a subtropical island☆,☆☆

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HIGHLIGHTS

- Cold temperature elevated mortality from all causes and circulatory diseases.
- Cold temperatures caused greater impact on outpatient visits of respiratory diseases.
- Average temperature was the optimal cold index in association with mortality.
- Minimum temperature was most associated with outpatient visits of respiratory disease.

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ABSTRACT

This study aimed to identify optimal cold-temperature indices that are associated with the elevated risks of mortality from, and outpatient visits for all causes and cardiopulmonary diseases during the cold seasons (November to April) from 2000 to 2008 in Northern, Central and Southern Taiwan. Eight cold-temperature indices, average, maximum, and minimum temperatures, and the temperature humidity index, wind chill index, apparent temperature, effective temperature (ET), and net effective temperature and their standardized Z scores were applied to distributed lag non-linear models. Index-specific cumulative 26-day (lag 0–25) mortality risk, cumulative 8-day (lag 0–7) outpatient visit risk, and their 95% confidence intervals were estimated at 1 and 2 standardized deviations below the median temperature, comparing with the Z score of the lowest risks for mortality and outpatient visits. The average temperature was adequate to evaluate the mortality risk from all causes and circulatory diseases. Excess all-cause mortality increased for 17–24% when average temperature was at $Z = -1$, and for 27–41% at $Z = -2$ among study areas. The cold-temperature indices were inconsistent in estimating risk of outpatient visits. Average temperature and THI were appropriate indices for measuring risk for all-cause outpatient visits. Relative risk of all-cause outpatient visits increased slightly by 2–7% when average temperature was at $Z = -1$, but no significant risk at $Z = -2$. Minimum temperature estimated the strongest risk associated with outpatient visits of respiratory diseases. In conclusion, the relationships between cold temperatures and health varied among study areas, types of health event, and the cold-temperature indices applied. Mortality from all causes and circulatory diseases and outpatient visits of respiratory diseases has a strong association with cold temperatures in the subtropical island, Taiwan.

Abbreviations: AIC, Akaike's information criterion; AT, apparent temperature; CI, confidence interval; CWB, Central Weather Bureau; DLNM, distributed lag non-linear model; ET, effective temperature; Flu, influenza; NET, net effective temperature; NHRI, National Health Research Institute; PM10, particulate matter less than 10 μm in aerodynamic diameter; RR, relative risk; RH, relative humidity; THI, temperature humidity index; TEPA, Taiwan Environmental Protection Administration; WCI, wind chill index; WS, wind speed; WVP, water vapor pressure.

☆ Authors' contribution: All the authors who participated in this study contributed a remarkable part of it. YK Lin, YC Wang, PL Lin, MH Li and TJ Ho designed the study methods and obtained the research data. YC Wang performed the statistical analyses. YK Lin and YC Wang drafted and finalized the manuscript. All authors have read and approved the final version of the manuscript.

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1. Introduction

High temperatures have garnered considerable attention in Europe and the US because of their short-term adverse health impacts. Increased mortality, emergency room visits, and hospital admissions worldwide have been associated with vulnerable populations exposed to heat waves (Anderson and Bell, 2011; Knowlton et al., 2009; Semenza et al., 1999). However, several studies reported that the adverse health effects of cold temperatures may be more significant than those of high temperatures in Spain, Canada, Shanghai, and Taiwan (Gomez-Acebo et al., 2010; Lin et al., 2011; Ma et al., 2011; Martin et al., 2012; Wang et al., 2012). Mortality risk associated with low temperatures is likely underestimated when studies fail to address the prolonged effect of low temperature (Martin et al., 2012; Mercer, 2003).

Ambient temperatures, including mean, maximum, and minimum temperatures, are usually used to assess temperature-related adverse health effects (Hajat et al., 2007; McMichael et al., 2008; Medina-Ramon and Schwartz, 2007). However, other weather variables, such as relative humidity (RH), wind speed (WS), and water vapor pressure may also affect human perceptions of ambient temperature. The cold effect is most severe when accompanied by strong winds (Kunst et al., 1993). Therefore, composite indices, including the temperature humidity index (THI), wind chill index (WCI) (Kunst et al., 1994; Woodall, 2004), apparent temperature (AT) (Anderson and Bell, 2009; Chung et al., 2009), effective temperature (ET) (Gomez-Acebo et al., 2010; Gonzalez et al., 1974) and net effective temperature (NET) (Gomez-Acebo et al., 2010; Li and Chan, 2000), have been applied to evaluate health risks associated with cold spells or low temperatures. However, few studies have focused on the cold effect in subtropical areas and its relationship to cold-temperature indices (Gomez-Acebo et al., 2010).

Previous studies have indicated that the effect of cold temperatures on morbidity and mortality varies by the physical environment. Wichmann et al. (2011) reported that no significant association exists between maximum apparent temperature and hospital admissions for respiratory, cardiovascular, and cerebrovascular diseases in Denmark (Wichmann et al., 2011). Multicity studies reported the cold effects were most significant in warm regions (1997; Langford and Bentham, 1995; Wang et al., 2012) or areas with moderate winter climates (Conlon et al., 2011). Residents in warm regions have less physical, social, and behavioral adaptations to low temperatures. Residing in a subtropical area with high temperatures and high humidity, the population in Taiwan is more susceptible to low temperatures than to high temperatures (Chen et al., 1995; Lin et al., 2011; Wang et al., 2012; Wu et al., 2011; Yang et al., 2009). Therefore, this study aimed to identify cold-temperature indices appropriate to evaluate the association between temperature and health events in Taiwan. This study reported the cumulative relative risks for mortality and outpatient visits of all causes and cardiopulmonary diseases associated with eight standardized cold-temperature indices—average, maximum, and minimum temperatures, and THI, WCI, AT, ET, and NET.

2. Materials and methods

2.1. Study setting

We obtained vital statistics from the Department of Health, Taiwan, universal health insurance claims from the National Health Research Institutes, daily meteorological data from the Central Weather Bureau, Taiwan, and daily air pollution data from Taiwan Environmental Protection Administration, for the period between 2000 and 2008. Representative data of the study population, climate and air pollution in Taiwan were extracted for three major metropolitan areas: Taipei (Taipei City and New Taipei City); Central Taiwan (Taichung, Zhanghua and Nantou); and Southern Taiwan (Kaohsiung and Pingtung), which accounted for 63.7% of Taiwan's total population.

Daily area-specific deaths from all causes (ICD9 000-999), Circulatory diseases (ICD9 390-459), and respiratory diseases (ICD9 460-519), as defined by the *9th Revision* of the *International Classification of Diseases* (ICD9), were compiled for analysis.

The National Health Research Institutes has established a database with insurance claims data for a representative cohort of one million residents, representing all insured residents in Taiwan (Taiwan National Health Insurance Research Database, 2012). Diseases were also coded according to the 9th revision of the International Classification of Diseases with Clinical Modification (ICD9 CM). Daily area-specific outpatient visits for all causes (ICD9 CM 000-999), circulatory (ICD9 CM 390-459), and respiratory (ICD9 CM 460-519) diseases were retrieved from these electronic records.

The Central Weather Bureau provided us the hourly surface weather records (*i.e.*, average, maximum, and minimum temperatures, RH, dew-point temperature, water vapor pressure, and WS), available at 3, 4 and 4 stations in Taipei, Central Taiwan, and Southern Taiwan, respectively (Taiwan Central Weather Bureau, 2012). The Taiwan Air Quality Monitoring Network established by the Taiwan Environmental Protection Administration has accumulated also hourly data of 74 stationary monitoring stations distributed throughout the island since 1993 (Taiwan

Table 1
Summary of the single and composite cold-temperature indices used in this study.

Index name	Abbreviation	Variables used	Equation/definition
Daily average temperature	Tavg.	Air temperature (°C)	Daily 24 hour average
Daily maximum temperature	Tmax.	Air temperature (°C)	The maximum hourly temperature in a day
Daily minimum temperature	Tmin.	Air temperature (°C)	The minimum hourly temperature in a day
Temperature humidity index (Rosenberg et al., 1983)	THI	1. T: air temperature (°C) 2. t_b: dew point temperature (°C)	$\mathrm{THI} = \mathrm{T} - 0.55 \times \left[1 - \frac{\mathrm{EXP}\left(\frac{17.269 \times t_b}{t_b + 273}\right)}{\mathrm{EXP}\left(\frac{17.269 \times T}{T + 273}\right)}\right] \times (\mathrm{T} - 14)$
Wind chill index(Osczevski and Bluestein, 2005)	WCI	1.T: air temperature (°C) 2.vh: wind speed (km/h)	$\mathrm{WCI} = 13.12 + 0.6215\mathrm{T} - 11.37\mathrm{vh}^{0.16} + 0.3965\mathrm{T} \cdot \mathrm{vh}^{0.16}$
Apparent temperature (Steadman, 1984)	AT	1. T: air temperature (°C) 2. e: water vapor pressure (KPa) 3. v: wind speed (m/s)	$\mathrm{AT} = -2.7 + 1.04 \times \mathrm{T} + 2\mathrm{e} - (0.65\mathrm{v})$
Effective temperature (Gonzalez et al., 1974)	ET	1.T: ambient temperature (°C) 2. H: relative humidity (%)	$\mathrm{ET} = \mathrm{T} - 0.4(\mathrm{T} - 10)(1 - 0.01\mathrm{H})$
Net effective temperature (Li and Chan, 2000)	NET	1.T: ambient temperature (°C) 2. H: relative humidity (%) 3. v: wind speed (m/s)	$\mathrm{NET} = 37 - \frac{37 - \mathrm{T}}{0.68 - 0.0014\mathrm{H} + (1.76 + 1.4\mathrm{v}^{0.75})^{-1}} - 0.29\mathrm{T}(1 - 0.01\mathrm{H})$