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SHORT NOTE

Links between Night-Time Thermoneutral Zone and Mortality from Circulatory Causes in the Elderly Population of Cyprus

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Abstract

Background: The relationship between non-thermoneutral zone temperatures with increased mortality in elderly individuals is well established. However, less is known regarding the effect of night-time temperature on mortality in elderly individuals. The aim of this study was to investigate the association between night-time temperature and mortality in elderly people (≥ 70 years) in Cyprus.

Methods: All-cause mortality data covering the period 2004-2014 were retrieved from the Health Monitoring Unit of the Cypriot Ministry of Health. Midnight (00:00) temperature data from weather stations across the island of Cyprus covering the same time period were collected from www.wunderground.com. Night-time temperatures were categorized into six 5-degree Celsius categories (≤ 8 °C, 9-13 °C, 14-18 °C, 19-23 °C, 24-28 °C, and ≥ 29 °C). The 19-23 °C category was defined as thermoneutral zone.

Results: A total of 43,107 elderly individuals died during the monitored period and the most prevalent cause of death was "diseases of the circulatory system" (41.5%; $p < 0.001$). Mortality due to diseases of the circulatory system was significantly reduced when night-time temperature was at the thermoneutral zone during the previous night ($p < 0.05$). The prevalence of deaths due to circulatory causes was higher for females compared to males ($p < 0.001$) (Cohen's $d = 0.34$). Furthermore, there was higher prevalence of deaths during extreme night time temperatures compared with thermoneutral zone ($0.24 \geq$ Cohen's $d \leq 1.01$).

Conclusion: Mortality due to circulatory causes, the most prevalent cause of death in Cyprus, is increased when night-time temperature is above or below the thermoneutral zone.

Keywords

Temperature, Aging, Death, Thermoregulation, Circulation, Cardiovascular

Introduction

Humans are tropical animals capable to survive and acclimatize to hot climates [1]. However, extreme ambient temperatures can variously affect the human cognitive [2], athletic [3], and work performances [4]. Furthermore, several studies showed that there is an association between environmental conditions and mortality. More precisely, this association has been reported since the 1940s [5]. For instance, the increase in mortality rate during the summer can be as high as 400% [5]. The association between mortality and ambient temperature is cause-specific, as some studies have reported that both cold and hot ambient temperatures increases mortality rates due to cardiovascular causes [1,5-10]. Furthermore, the relationship between ambient temperature and all-cause mortality rate is not the same in all age groups; the daily number of heat-related deaths is more prevalent among elderly individuals [6,11]. Indeed, it is well known that aging is associated with a reduced thermoregulatory capacity, especially when work or exercise in hot environments [3,12-16]. Moreover, heat exposure negatively affects a number of body tissues and systems and there are distinct sex differences in thermoregulatory capacity for individuals resting or exercising in the heat [12,13,17,18]. However, our knowledge on these issues is derived primarily from studies assessing the effects of daytime temperature on human physiology and health, while, further research is required to elucidate if night-time temperature affects mortality rates in elderly individuals. Therefore, the purpose of this study was to investigate the association be-

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tween night-time temperature and mortality in elderly people (≥ 70 years) in Cyprus.

Methods

All-cause mortality data covering the period 2004 to 2014 were retrieved from the Health Monitoring Unit of the Cypriot Ministry of Health. Analyses were focused on elderly individuals (> 70 yrs) due to the well-known fact that this age-group is more sensitive to fluctuations in temperature [6,11]. Midnight (00:00) temperature data from weather stations across the island of Cyprus (one for each district: Nicosia, Limassol, Larnaca, Paphos, and Ammochostos) covering the same time period were collected from [19].

The two databases were merged so that each death was associated with meteorological data from the closest possible weather station. Moreover, night temperatures [midnight temperature of the previous night (00:00)] were matched with each death from circulatory causes that occurs on the following day. Night-time temperatures were categorized into six 5-degree Celsius categories (≤ 8 °C, 9 to 13 °C, 14 to 18 °C, 19 to 23 °C, 24 to 28 °C, and ≥ 29 °C). The 19 to 23 °C category was defined as thermoneutral zone. The classical thermoneutral zone, i.e. not the functional thermoneutral zone, is defined as the range of ambient temperature at which the thermoregulation of human body is achieved solely through regulating dry heat loss, without regulatory changes in metabolic heat production or evaporative heat loss [20]. Furthermore, analyses were conducted to identify possible differences between extreme night-time temperatures and thermoneutral zone during cold (i.e., October to March) and warm months (i.e., April to September). Extreme night-time temperatures were considered the lowest and highest temperatures recorded during warm and cold months.

Chi-square analysis was used for pairwise comparisons (i) Between different mortality causes, as well as (ii) Daily mortality due to circulatory causes between the two sexes. One-way ANOVA with *post hoc* t tests and effect sizes were used to detect differences in mortality rates among the six ambient temperature categories previously defined. Independent-Samples t-tests and effect sizes were used to compare the daily number of deaths due to circulatory causes for females and males. The same analyses were used to compare the daily number of deaths due to circulatory causes between extreme night-time temperatures and thermo-

Table 1: Number and prevalence for the different causes of death in the elderly Cypriot population during the study period.

Cause of death	Deaths (n)	Prevalence (%)
Diseases of the circulatory system	17,899	41.52
Neoplasms	7,521	17.45†
Endocrine, nutritional and metabolic diseases	3,753	8.71†
Diseases of the respiratory system	3,708	8.60
Symptoms, signs, abnormal findings, ill-defined causes	2,532	5.87†
Diseases of the genitourinary system	1,586	3.68†
Diseases of the digestive system	1,475	3.42
External causes of morbidity and mortality	1,347	3.12*
Diseases of the nervous system and the sense organs	1,203	2.79*
Mental and behavioural disorders	676	1.57†
Infectious and parasitic diseases	577	1.34*
Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism	291	0.68†
Diseases of the skin and subcutaneous tissue	278	0.64
Diseases of the musculoskeletal system/connective tissue	237	0.55
Congenital malformations and chromosomal abnormalities	24	0.06†
Total	43,107	

Note: *Indicates statistically significant difference from the above death cause at p ≤ 0.05; †Indicates statistically significant difference from the above death cause at p ≤ 0.001.

Table 2: Average daily number of deaths due to circulatory causes and differences in the number of deaths between ambient temperature categories and sexes. "Temperature" represents the six ambient temperature categories. "Males" and "Females" represent the average daily number of deaths (mean ± SD) of males and females, respectively. "Effect size" represents the differences (Cohen's d) between the average daily number of deaths of females and males.

Temperature	Males	Females	Effect size
≤ 8 °C	1.11 ± 0.75*	1.21 ± 0.64*	0.14
9 to 13 °C	1.02 ± 0.70*	1.23 ± 0.68*†	0.30
14 to 18 °C	0.96 ± 0.68	1.18 ± 0.63*†	0.33
19 to 23 °C	0.89 ± 0.64	1.14 ± 0.59†	0.40
24 to 28 °C	0.92 ± 0.65	1.16 ± 0.63†	0.38
≥ 29 °C	0.9 ± 0.85	1.28 ± 0.75†	0.46

Note: *Indicates statistically significant difference from the thermoneutral zone (19 to 23 °C) at p < 0.001; †Indicates statistically significant difference between sexes at p < 0.001.

neutral zone during cold and warm months. Also, Spearman's rho correlation coefficient was conducted to examine the association between night-time temperature and daily mortality due to circulatory causes. Statistical analyses were conducted using the SPSS v22.0 software package (IBM, Armonk, NY, USA). The level of significance was set at $p < 0.05$.

Results

During the study period the night-time temperature (16.4 ± 5.9 °C) ranged from 1 °C to 34 °C, and was 30.8% lower compared to the midday temperature (23.7 ± 7.1 °C; ranging from 5 °C to 45 °C) of the same time period. Furthermore, a total of 43,107 elderly individuals died during the monitored period (73.8% of the total deaths across all ages) and the most prevalent cause of death for elderly individuals was "diseases of the circulatory system" (41.5%, $p < 0.001$) (Table 1). Based on this finding, further analyses were focused on this mortality cause. Sex-dependent analysis revealed that deaths due to circulatory cause are more prevalent in female compared to male elderly individuals [females: 9,745 out of 22,391 deaths from all causes (43.5%); males: 8,154 out of 20,716 deaths from all causes (39.4%)] ($p < 0.001$). More precisely, the average daily number of deaths due to circulatory causes was significantly higher for females (1.25 ± 0.72 deaths per day) compared to males (0.98 ± 0.74 deaths per day; $p < 0.001$) (Table 2).

There was a significant difference in mortality rate among the different ambient temperature categories [$F_{(5,9972)} = 10.189$, $p < 0.001$]. Specifically, mortality due to circulatory causes was significantly increased when night-time temperature was ≤ 8 °C and ≥ 29 °C ($p < 0.05$; Figure 1). Moreover, mortality due to diseases of the circulatory system was significantly reduced when night-time temperature was at the thermoneutral zone during the previous night ($p < 0.05$; Figure 1). Also, during the colder months of the year (i.e., October to March), daily mortality during thermoneutral nights (1.01 ± 0.65 deaths/day) was significantly lower by 48.5% (1.5 ± 0.71 deaths/day; d = 0.75) and 65.4% (1.67 ± 0.58 deaths/day; d = 1.01) compared to mortality during the coldest (1 °C) and the warmest (25 °C) nights, respectively. Also, during the warmer months of the year (i.e., April to September), daily mortality during thermoneutral nights (0.99 ± 0.58 deaths/day) was significantly lower by 14.1% (1.13 ± 0.99 deaths/day; d = 0.24) and 30.3% (1.29 ± 1.38 deaths/day; d = 0.50) compared to mortality during the coldest (8 °C) and the warmest (34 °C) nights, respectively. Finally, although Spearman's correlation coefficients did not demonstrate a relationship between the night-time temperature and mortality due to circulatory causes ($r < 0.071$), there was a tendency toward increased mortality rate above and below the thermoneutral zone (Figure 1).

Discussion

The first quarter of human lifespan is characterized by growing and improvement of physiological functions, whereas the last quarter is related with tissue damage and decreased physiological function [21]. This age-related reduction in human function seems to be more

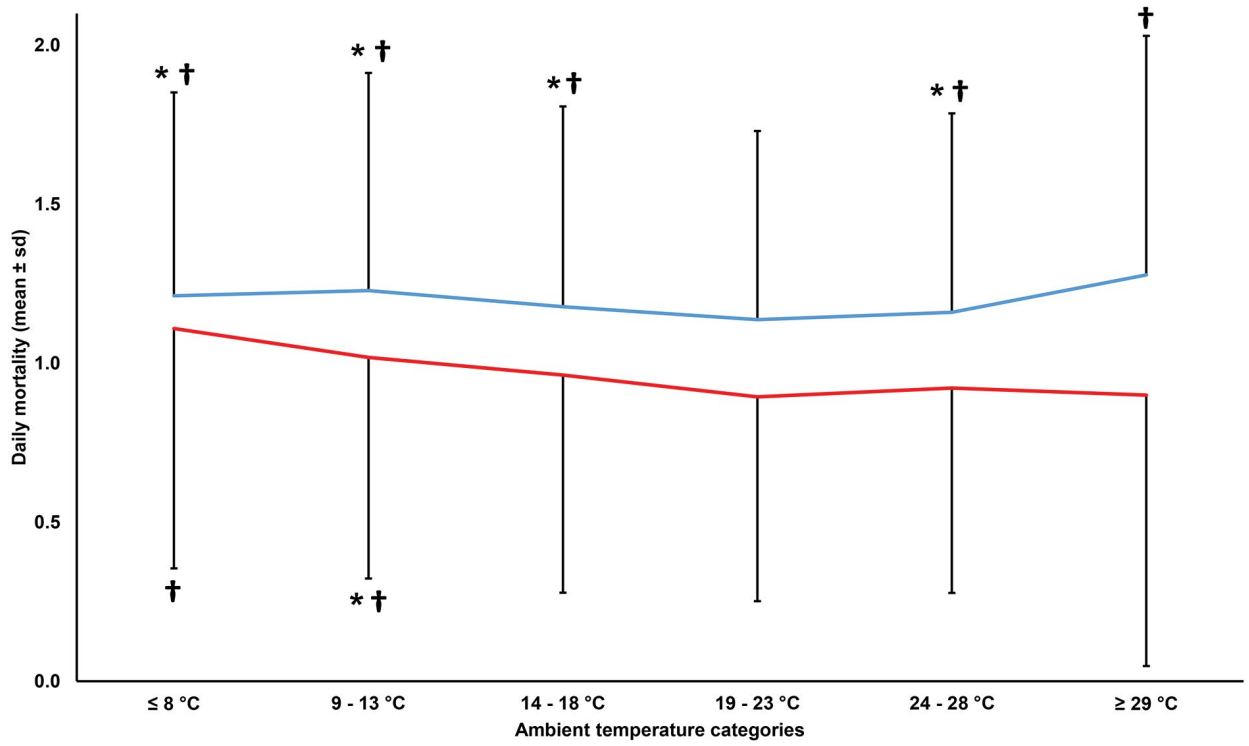

Figure 1: Differences in number of deaths between the different ambient temperature categories.

Note: * = Significantly different ($p < 0.05$) compared to the following temperature category; † = Significantly different ($p < 0.05$) compared to the thermoneutral zone (19-23 °C) temperature.

pronounced in high and low weather temperatures. In this respect, the main finding of this study was the significantly increased mortality rate due to circulatory causes when night-time temperature falls above or below the thermoneutral zone.

To the best of our knowledge, this is the first study to investigate the association between night-time temperature and mortality due to circulatory causes. Our findings are consistent with published studies on the health effects of daytime temperature, showing that both heat and cold ambient temperatures can affect mortality rate due to circulatory causes [1,5-9,22,23]. The sex differences found in the present study in terms of mortality rates due to circulatory diseases can be explained by the well-known physiological differences between men and women, which includes differences in body surface area, body composition, and aerobic capacity. Furthermore, the Eurowinter group suggests that clothing is also an important modifier, as females living in warm climates are more likely to wear skirts at low temperatures and more likely also to stand still and to shiver [23].

Heat-related mortality occurs due to increased levels of stress on the cardiovascular system during warm weather conditions [1]. These effects are more pronounced in elderly individuals due to their reduced ability to adapt to temperature changes [11]. Elderly individuals usually suffer more from pre-existing cardiovascular diseases compared with younger individuals and are, thus, more susceptible to heat pathologies that may lead to death [11]. However, even a healthy older individual, with no history of cardiovascular diseases, has increased odds for dying due to cardiovascular diseases during prolonged environmental heat exposure compared with a young individual [1]. In fact, when environmental temperature surpasses the limit of thermal tolerance, young individuals can increase their cutaneous blood flow by twice as much as elderly individuals (5800 $mL \cdot min^{-1}$ vs. 2700 $mL \cdot min^{-1}$, respectively) [1,24]. Furthermore, during passive heating to the limits of thermal tolerance, younger individuals also have greater cardiac output and lower heart rate (i.e. expressed as percentage of maximal heart rate) compared to elderly individuals [24]. Moreover, older individuals store more heat during rest or exercise in hot environments, as compared to young adults [12,13,15,17].

Considering cold night temperatures, it should be expected that the improvements in standard of living (housing quality, clothing, and heating) in Cyprus will decrease the number of cold-related fatalities due to circulatory causes [6]. In this regard, we found that, during nights with temperature < 22 °C, mortality due to circulatory causes was inversely correlated with ambient temperature (i.e., lower temperatures were associated with increased mortality). These results are consistent with previous studies demonstrating that low ambient temperature is associated with increased mortality due to circulatory causes [6-9,22,23]. The pathophysiology underlying the effects of low temperature on circulatory mortality is related to an increase in blood pressure [25].

According to our findings, nights with ambient temperature at the thermoneutral zone demonstrate reduced mortality rates from circulatory causes during the following day. Furthermore, the results of this study could help elderly people who live in such environments (i.e., subtropical climate - Mediterranean) to effectively prevent death from circulatory causes. Nevertheless, we acknowledge that the present study has several limitations that future studies should be consider. First, our mortality data did not include the exact time of death of each individual. Therefore, we were not able to further investigate how time of death is affected by the night-time temperature. Secondly, this study included data exclusively from elderly individuals from Cyprus, which means that these individuals were acclimatized to Cyprus' climate temperatures. Moreover, it is logical to assume that the majority of deaths occurred indoors, and that indoor (i.e., sleep environment) and outdoor temperatures were not the same during the study period. While this issue may have affected our findings, a previous well-cited study showed that there is a strong linear relationship between the outdoor temperature and the indoor comfort temperature in buildings which are neither cooled nor heated [26]. Furthermore, a recent study proposed that night ventilation (e.g., open windows) is an effective strategy for passive cooling in Cyprus [27]. These, combined with the low level of criminality in Cyprus [28], encourage Cypriot citizens to sleep with open windows increasing, therefore, their exposure to the outdoor environment during the night. Future studies should include a larger sample size in order to investigate further aspects of mortality from circulatory cause in elderly.

Conclusion

Mortality due to circulatory causes, the most prevalent cause of death in Cyprus, is increased when night-time temperature is above or below the thermoneutral zone. Future studies should investigate how time of death can also be affected by night time temperatures.

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