Maturitas 69 (2011) 197–202

Contents lists available at ScienceDirect

Maturitas

journal homepage: www.elsevier.com/locate/maturitas

Review

Preventing cold-related morbidity and mortality in a changing climate

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ARTICLE INFO

Article history:
Received 18 March 2011
Accepted 2 April 2011

Keywords:
Cold weather
Health effects
Temperature
Adaptation
Vulnerability
Winter

ABSTRACT

Winter weather patterns are anticipated to become more variable with increasing average global temperatures. Research shows that excess morbidity and mortality occurs during cold weather periods. We critically reviewed evidence relating temperature variability, health outcomes, and adaptation strategies to cold weather. Health outcomes included cardiovascular-, respiratory-, cerebrovascular-, and all-cause morbidity and mortality. Individual and contextual risk factors were assessed to highlight associations between individual- and neighborhood-level characteristics that contribute to a person's vulnerability to variability in cold weather events. Epidemiologic studies indicate that the populations most vulnerable to variations in cold winter weather are the elderly, rural and, generally, populations living in moderate winter climates. Fortunately, cold-related morbidity and mortality are preventable and strategies exist for protecting populations from these adverse health outcomes. We present a range of adaptation strategies that can be implemented at the individual, building, and neighborhood level to protect vulnerable populations from cold-related morbidity and mortality. The existing research justifies the need for increased outreach to individuals and communities for education on protective adaptations in cold weather. We propose that future climate change adaptation research couple building energy and thermal comfort models with epidemiological data to evaluate and quantify the impacts of adaptation strategies.

Contents

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doi:10.1016/j.maturitas.2011.04.004

1. Introduction

Many studies have provided evidence that morbidity and mortality increase in periods of cold weather. Overall, higher death rates are observed in winter compared to summer [1–3], which may be attributable in part to colder winter temperatures, in addition to higher rates of infectious disease (influenza), and higher air pollution. While cold-related morbidity and mortality do not increase dramatically during extreme cold weather events, as commonly seen during extreme heat events, cold remains a relevant concern for exposed populations. Understanding the complex and multi-factorial relationship between weather and health is increasingly important as climate models indicate that seasonal weather patterns and conditions will continue to vary from current climate conditions as average global temperatures increase.

This article presents an overview of climate models and winter storms, human physiologic responses to cold environments, epidemiologic studies of cold weather and health outcomes, and cold weather adaptation strategies for individuals, communities, and healthcare providers and policymakers. We discuss research needed to better understand and prevent cold weather health impacts, especially in the growing aging population.

2. Climate models and winter storms

Although it may seem counterintuitive, given the overall increasing trend in global temperature, climate change is expected to contribute to an increase in the intensity of winter storms. Climate scientists hypothesize that as average global temperatures increase, evaporation from Earth's surface will increase, adding moisture to the atmosphere and resulting in greater amounts of precipitation. In addition, wind speeds associated with winter storms are expected to increase [4]. These factors increase personal-level exposure to low temperatures through skin wetting and increased heat loss, but may also disrupt energy distribution for heating residential and commercial buildings [5,6].

General circulation models, such as those cited by the Intergovernmental Panel on Climate Change (IPCC) 2007 Assessment Report, build on knowledge of behavior of winter storms in current climate conditions to simulate winter storm behavior when climate conditions include higher concentrations of greenhouse gases [7,8]. Those models have indicated a trend toward more intense winter storms in the Northern Hemisphere, particularly in northwestern Europe and the Upper Midwest and Northeast of the U.S. [4,9].

3. Physiologic response to cold stress

Exposure to cold temperatures has long been a challenge for human survival. An individual's ability to thermoregulate protects him or her from ambient temperatures by maintaining a core body temperature of about 37 °C (98.6 °F). Exposure to cold temperatures and impairment of thermoregulation can lead to decreased core temperatures, direct effects such as hypothermia (core temperature below 35 °C), and indirect effects such as frostbite, pneumonia, and influenza.

Exposure to cold temperatures initiates a systemic response. First, vasoconstriction occurs in the skin of the extremities to conserve body heat by driving oxygenated blood to support vital organs in the core. As cooling continues and heat is lost in the periphery via radiation, the temperature gradient between the core and the periphery increases, redistributing heat to the periphery and reducing core temperatures. Muscle contractions, shivering, increased heart rates (tachycardia), and rapid breathing (tachypnea) occur, in an effort to generate heat [10–12]. Bronchoconstriction also occurs after inhalation of cold air.

Cardiac and cerebrovascular functions are most critically impaired as body temperatures fall below 35 °C. Both physical and mental impairment are symptoms of exposure to severe cold [13,14]. Cardiac irritability (e.g., cardiac arrhythmias, ventricular fibrillation, cardiac arrest) and cerebral insults (e.g., reduced cerebral blood flow and oxygen consumption) [12,15,16] occur after prolonged exposure to cold. Extreme cold conditions will eventually cause the cardiovascular system to shut down. Loss of consciousness, amnesic episodes, and ischemic stroke occur as a result of decreased oxygen to the brain in extreme cold environments.

Initial respiratory responses to cold weather are an increase in depth and respiration rate (hyperventilation), followed by decrease in respiration (hypoventilation); the respiration rate becomes shallow and erratic between core body temperatures of 25–30 °C [12,16].

Although most people exposed to cold weather will not experience hypothermia or an extreme decrease in body temperature, skin exposure to cold weather may render one susceptible to adverse health outcomes [16]. The cooling process can occur within a few minutes in extreme cases (e.g., submersion in cold water) or develop over several weeks (e.g., result of living in substandard conditions). People are regularly exposed to cold temperatures during daily behaviors such as commuting to work and outdoor activities. Whether the cooling experience is acute or chronic, people must protect themselves via physiological and behavioral adaptations.

4. The epidemiology of cold-related morbidity and mortality

4.1. Exposure metrics

Investigations of the relationship between human health and cold weather use a variety of metrics to characterize ambient temperature including daily mean temperature [14,17], daily maximum temperatures [18], temperatures lower than the 5th percentile [19], combined temperature and relative and/or absolute humidity [20–22], cold surges [23], indoor and outdoor temperatures [14] and a combination of measurements such as temperature, snow and rain precipitation [24]. One study concludes that different measures of temperature have roughly the same predictive ability for health outcomes [25], suggesting that measurement types should be determined based on availability and completeness. Often, measurements of temperature and other meteorological parameters used in health studies come from outdoor monitors (e.g., airport monitors) that take hourly readings; the exposures are typically assumed to apply to individuals living in the communities surrounding the monitoring station.

4.2. Cold-related health outcomes

Temperature-related mortality typically demonstrates a U-shaped response, in which mortality rates are highest at the colder and hotter extremes of the spectrum. All-cause mortality is associated with a decrease in ambient temperature [14,18,26,27]. The effects of cold temperatures on mortality can last for days, with the greatest association sometimes observed on the same day [28], and lasting up to 24 days after the cold weather. Air pollution [29,30] can modify the effect of cold weather with increasing associations between cold and mortality with higher pollution.

Cardiovascular-cause mortality is the most commonly identified health outcome associated with cold weather [14,15,17,24,30–34] and is generally observed shortly after cold weather events. Cold temperatures are associated with increases in blood pressure, cholesterol, fibrinogen and erythrocyte counts [35], which are