ARTICLE IN PRESS

Safety Science xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Safety Science

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

Are workers at risk of occupational injuries due to heat exposure? A comprehensive literature review

Blesson M. Varghese, Alana Hansen, Peng Bi, Dino Pisaniello*

The University of Adelaide, School of Public Health, Adelaide, South Australia, Australia

ARTICLE INFO

Keywords:
Environmental temperature
Occupational injuries
Health and safety
Climate change
Heat stress
Workplace heat exposure

ABSTRACT

Rationale: There is increasing concern about occupational illness, injury and productivity losses due to hot weather in a changing climate. Most of the current understanding appears to relate to heat-induced illness, and relatively little regarding injuries.

Objectives: This paper sought to summarise the evidence on the relationship between heat exposure and injuries, to describe aetiological mechanisms and to provide policy suggestions and further research directions.

Methods: A literature review was conducted using a systematic search for published and grey-literature using Embase, PubMed, Scopus, CINAHL, Science Direct and Web of Science databases as well as relevant websites.

Results and conclusions: There was a diversity of studies in terms of occupations, industries and methods utilised. The evidence suggests an imprecise but positive relationship between hot weather and occupational injuries, and the most likely mechanism involves fatigue, reduced psychomotor performance, loss of concentration and reduced alertness. The findings reflect an increased awareness of injury risk during hot weather and the economic benefits associated with averting injury, poor health outcomes and lost productivity.

Implications: More work is required to characterise specific injuries and the workers at risk. Policymakers and employers should be aware that heat exposure can lead to occupational injuries with information and training resources developed to aid prevention.

1. Introduction

Global average temperatures have risen about 0.85 °C over the last 100 years with temperatures further projected to increase by an estimated average of 3 °C by 2100 to reach 1.8–4 °C above pre-industrial times (IPCC, 2014). As a result, extremely hot days and warm nights have increased in number over recent decades and indications suggest that this trend will continue (IPCC, 2014; Steffen and Hughes, 2013).

In addition to the adverse effects of heat exposure on the general population, occupational health and safety is also affected (Song et al., 2017; Kovats and Hajat, 2008; Page et al., 2012). Workers in industrial sectors such as agriculture, forestry, fisheries and construction are exposed to outside temperatures and solar heat load making them vulnerable to the adverse health effects of heat exposure in hot weather (Lundgren et al., 2013; Heidari et al., 2015). Furthermore, those working in hot indoor environments without air-conditioning – such as manufacturing, smelting plants, bakeries, laundries, and restaurant kitchens can also be affected (Lundgren et al., 2013; Heidari et al., 2015; Health Council of the Netherlands, 2008). Heat-related illnesses (HRI) such as heat cramps, heat syncope, fatigue, heat exhaustion, heat stroke and heat shock are often the well-known and documented adverse direct effects of heat on health (Jackson and Rosenberg, 2010). These outcomes have been reported in the occupational setting among, for example, surface mine workers (Miller and Bates, 2007; Hunt et al., 2013), construction workers (Dutta et al., 2015), agricultural workers (Bethel and Harger, 2014; Kearney et al., 2016; Mirabelli et al., 2010; Spector et al., 2015) and radiation decontamination workers (Kakamu et al., 2015).

There is now increasing evidence that occupational heat stress is strongly associated with injuries, as an indirect effect of heat exposure (Tawatsupa et al., 2013; Morabito et al., 2006; Harduar Morano et al., 2015; Harduar Morano et al., 2016; Basu, 2009; Fogleman et al., 2005; The National Institute for Occupational Safety and Health, 2015). Work-related injuries/accidents in hot conditions can be caused by physical discomfort and altered behaviour, fatigue, declining psychomotor performance, loss of concentration and reduced alertness (Jackson and Rosenberg, 2010). However, the extent of injury occurrence in hot weather is poorly characterised and understood, and may represent a notable human and economic cost when combined with HRI.

* Corresponding author.
E-mail address: dino.pisaniello@adelaide.edu.au (D. Pisaniello).

https://doi.org/10.1016/j.ssci.2018.04.027
Received 1 August 2017; Received in revised form 14 March 2018; Accepted 30 April 2018

Please cite this article as: Varghese, B., Safety Science (2018), https://doi.org/10.1016/j.ssci.2018.04.027

In the United States, the National Institute for Occupational Safety and Health (NIOSH) estimated in 1986 that around 5–10 million workers worked in hot weather conditions for at least part of the year (Gubernot et al., 2014). According to the US Bureau of Labour Statistics (BLS) Census of Fatal occupational injuries report, 144 worker deaths and around 14,022 non-fatal work injuries and illnesses involving lost days of work were reported between 2011 and 2014 due to environmental heat exposure (Bureau of Labour Statistics, 2016). These figures provide little information about the scale of the problem and are also unlikely to include statistics on injuries that could be attributed to heat such as falls or traffic accidents. As a result, the relative incidence of heat-related occupational injuries is unknown.

In order to summarise current literature on hot weather and occupational injuries, a comprehensive literature search was conducted. Initially, we present a systematized review of studies on heat exposure and injuries, followed by a discussion of the potential pathways to injuries.

2. Methods

2.1. Search strategy

Published literature on heat exposure and injuries were obtained by systematically searching PubMed, Embase, Scopus, CINAHL, Science Direct and Web of Science databases. A search strategy using a combination of controlled vocabulary [Mesh, EMTREE] and key words was developed for each of the above databases (see Table S1-supplementary file for detailed search strategy). The following keywords along with their synonyms and closely related words were used: ‘heat’, ‘heat stress’, ‘hot weather’, ‘high temperature’, ‘climate change’; combined with ‘injury’, ‘occupation’, ‘workers’, ‘work-related’ and ‘epidemiology’. Searches were not limited to year of publication and references cited in identified papers were used as a further source of literature. Additionally, unpublished studies (articles/reports/academic-theses/conference presentations) were searched in internet search engines and web-based searches for ‘grey literature’.

2.2. Inclusion and exclusion criteria

The published studies included in the review met the following criteria:

- Original research articles in English published until 31st of January 2017.
- Studies which investigated the association between heat exposures and work-related injuries/accidents

Excluded were studies not focussing on injuries occurring in workplaces due to heat exposure, and literature reviews investigating the general population health impacts of heat. All titles and abstracts from the literature search were evaluated against the inclusion criteria for possible relevance and those references judged to be relevant were included as part of the review.

3. Results

Twenty-six studies (22 published and 4 unpublished) from 1922 to 2017 were selected as part of this review. Fig. 1 illustrates the study selection process for this review.

Fig. 2 shows the study location and design employed by the included studies. Most studies have been undertaken in developed countries such as North America and Australia, with fewer in developing and tropical parts of India and Thailand. The study populations were from general and specific occupational settings (n = 24) and the military (n = 2). The weather variables used in the studies included maximum temperature (T_{max}, n = 7), minimum temperature (T_{min}, n = 1), and indexes combining relative humidity and temperature, such as Apparent Temperature (n = 1), Heat Index (n = 1)), Humidex (n = 1) and Wet Bulb Globe Temperature (WBGT, n = 2). The methods to evaluate the association between heat exposure variables and the risk of occupational injury used in the studies were ecological time-series studies (TS, n = 5), case-crossover studies (CCO, n = 3) correlational studies (n = 10) and cross-sectional questionnaire surveys (n = 8). The TS/CCO and correlational studies involved both non-parametric regression models such as generalised estimating equations (GEEs), generalised additive models (GAMs) and negative binomial regression (NBR) and parametric regression models. The models of the TS and CCO studies were adjusted for key potential confounders such as relative humidity (n = 2), seasonal and long-term trends (day of week, year, month, n = 4), weekends and public holidays (n = 5) and used labour force estimates as offset (n = 1). However, none of the TS or CCO studies included effects of air-pollution, a variable normally included in the temperature-health relationship analysis models (Buckley et al., 2014). The summary of the included studies (study description, methods and key findings) is provided in Table 1.

3.1. Risk of accidents/injuries

The relationships between temperature and occurrence of workplace injuries/accidents have been examined by several studies. Consistent with the literature on heat effects on morbidity and mortality, this association between heat exposure and occurrence of injury/accidents is typically described as a U-, V-, or J-shaped curve whereby injuries increase up to a certain threshold (e.g. around 30 °C, depending on each individual study) following which they decline, possibly due to workers modifying work practices at extreme temperatures (Tawatsupa et al., 2013; Morabito et al., 2006; Fogleman et al., 2005; Xiang et al., 2014a; Adam-Poupart et al., 2015; Lao et al., 2016). The associations between heat and injuries among different occupational categories are discussed below.

3.2. Heat-associated injuries in the workforce

A relationship between heat exposure and occurrence of injury/accidents was first established by Osborne et al. (1922). They found that fewer accidents occurred in three British munitions factories when temperatures were around 19–20 °C, while higher frequencies of accidents occurred at both higher and lower temperatures (Osborne et al., 1922). However, in 1971, a study of 2367 accidents in four industrial workshops in the UK found no significant increase in accidents at higher temperatures while in half the workshops more accidents occurred at temperatures below 20 °C (Powell, 1971).

In a 2005 study by Fogleman et al. conducted at a US aluminium smelter, a significant increase in acute injury rates was observed (Odds Ratio (OR) = 2.3) when the heat index was above 32 °C (Fogleman et al., 2005). Bernard and Fogleman (Bernard, 2012) categorised ‘heat stress levels’ (HSL) as being ‘low’ when the WGBT was 0–3 °C above the threshold limit value (TLV) of 29 °C WBGT and ‘high’ when the HSL was 3 °C WGBT above TLV. They reported an increase in the rate of acute musculoskeletal disorders at both low and high HSL with corresponding ORs of 1.8 (95% CI: 1.1–2.9) and 2.4 (95% CI: 1.4–4.3) respectively (Bernard, 2012). Significantly increased rates of acute injuries were found at high TLV (OR = 1.7 95% CI: 1–2.9) compared to low TLV (OR = 1.4 95% CI: 0.9–2.2) (Bernard, 2012).

Moreover, in a study of hospital admissions in Tuscany, Italy, Morabito et al. (2006), found that the peak occupational accident rate occurred on days characterised by high, but not extreme thermal conditions (Morabito et al., 2006). No association was found for outdoor workers such as those employed in construction, land and forestry occupations but a significant increase in injuries occurred between the 10th and 90th percentile of temperature range (Morabito et al., 2006). Similarly, Xiang et al. (2014a) conducted a study assessing the