Review Article

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Heat exposure and workers' health: a systematic review

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Abstract

Objectives: Several studies on the health effects of heat exposure on workers have been reported; however, only few studies have summarized the overall and systematic health effects of heat exposure on workers. This study aims to review the scientific reports on the health status of workers exposed to high temperatures in the workplace.
Methods: We reviewed literature from databases such as PubMed and Google Scholar, using Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines to identify studies that address health effects of heat exposure among workers.
Results: In total, 459 articles were identified, and finally, 47 articles were selected. Various health effects of heat exposure on workers have been reported, such as heat-related diseases, deaths, accidents or injuries, effects on the urinary system, reproductive system, and on the psychological system.
Conclusions: Our review suggests that many workers are vulnerable to heat exposure, and this has a health effect on workers.

Keywords: health; heat exposure; high temperature; workers; workplace.

Introduction

Climate change is one of the most important threats to global health. As abnormal climate events that have not been reported in the past have recently been reported, interest in global warming is increasing. The most significant effect of global warming is the rise in average temperature. In the last 130 years, the world has become warm by approximately 0.85 °C [1]. Heat exposure causes heat-related diseases, and it has been reported to be associated with cardiovascular disease, increased mortality, incidence of injury at the workplace, and kidney disease [2–5].

The most important and effective way to prevent the occurrence of diseases caused by heat exposure is to reduce the heat exposure time. Workers are often exposed to heat because they do not have the authority to avoid exposure time or the place exposed to heat, depending on the work situation, making them a vulnerable population to heat exposure. Several studies have reported the effects of occupational heat exposure, which is characterized by a reduction in productivity; they have also reported the guidelines that prevent workers from leaving the workplace due to heat-related disease [6–8]. There are several individual reports that infectious diseases may increase according to environmental changes caused by temperature rise [9], and this rise in temperature also affects the eyes, skin [10], and mental health [11]. In addition, a systematic review of the literature on the most well-known

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problems regarding heat exposure, and injuries among workers, was recently conducted [12].

However, most studies on the association between heat exposure and health have focused on the general, young, or elderly population. Only few studies that summarize the overall and systematic health effects of heat exposure on workers are currently available.

This study aims to systematically review previous studies on the effect of heat exposure on workers' health. We demonstrated this effect according to human organ and disease characteristics among workers. This study will help to understand workers' health related to heat exposure and guide future research.

Materials and methods

Literature search strategy

We used literature search engines, such as PubMed and Google Scholar, to determine all published reports on the relationship between heat exposure and workers' health, according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines [13]. Literature search terms in PubMed were ((Hot Temperature [MeSH Terms]) OR (Extreme Heat [MeSH Terms]) OR (Heat Stress Disorders [MeSH Terms])) AND (worker* [Title/Abstract] OR occupation* [Title/Abstract]). We restricted the publication year to December 31, 2019 and applied the following filters; journal type: journal article, species: humans, language: English, and age: adults (19+ years). Google Scholar was used as a secondary search engine with similar search logic.

Criteria of article selection

We excluded studies that satisfied the following criteria: (1) study participants were not a working population, (2) the main exposure was not heat, (3) the effect was not on human health, (4) not an original article, or (5) the research was not reported in English in a peer-reviewed journal.

Article organization

The duplicate articles were removed after the initial search. We conducted an initial screening to select the relevant studies based on the criteria of article selection from titles and abstracts. The full-text of the remaining articles were assessed by all the authors to determine their eligibility. Consequently, quality assessments were conducted for eligible studies. Figure 1 demonstrates the flow of the article selection process. *In general, when humans are exposed to heat, heat-related illness occurs, and the nervous system may be damaged by protein denaturation. This can lead to injury and death, and it is known that kidney and urinary system damage due to dehydration can also occur. It can also cause reproductive toxicity, such as infertility.* We categorized the articles into seven groups that addressed the following health effects: (1) heat-related diseases, (2) death, (3) accident or injury, (4) effect on the urinary system, (5) effect on the reproductive system, (6) effect on the psychological system, and (7) others.

Results

Overall, 459 “Hot temperature” or “Extreme heat” or “Heat distress disorder”-related articles published until December 31, 2019, were found after excluding duplicates. About 348 articles were removed after further screening, as the quality and scope of these studies did not match that of the current study. Furthermore, 64 articles were excluded after full-text assessment because their study participants were not a working population (n=9), their main exposure was not high temperature (n=20), the effects were not on human health (n=14), they were not original articles (n=16), and they were not reported in a peer-reviewed journal (n=5). Finally, 47 articles were selected.

These 47 articles were divided into seven groups: 15 articles reported on heat-related diseases, five articles reported on the death effect, 10 reported on accidents or injuries, seven reported on the effect on the urinary system, five reported on the effect on the reproductive system, two reported on the effect on the psychological system, and three reported on the other effects of heat exposure among workers. We have described the studies included in detail.

Sixteen studies were conducted in North America, four in Central and South America, nine in Europe, 11 in Asia, two in Africa, and five in Oceania. By gender, 32 studies were conducted on both men and women, 14 on men only, and one on women only. Based on the study design, 18 studies used cross-sectional, 10 used case-crossover, seven used longitudinal, five used case-control, four used descriptive epidemiology, two used cohort, and one study used a quasi-experimental method. Twenty-five studies did not limit the age of the study participants, and 22 studies had an age range. Twenty-seven studies used heat exposure variables through measurement and calculation (including daily temperature, apparent temperature, heat

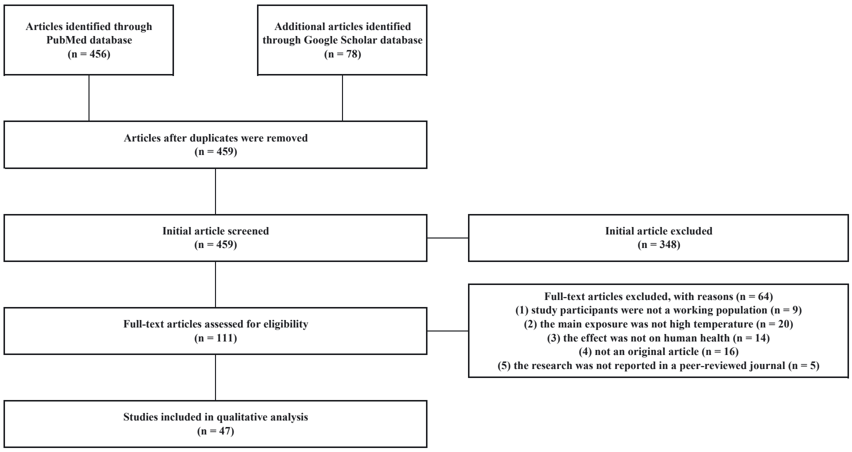

Figure 1: Flow diagram illustrating the article selection process according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines.

index, wet-bulb globe temperature [WBGT], humidex, heat waves), and 20 studies used unmeasured heat exposure variables (questionnaire, occupational or ambient heat exposure). We have described the studies included in detail.

Heat-related disease

Fifteen studies reported heat-related diseases among workers (Table 1). Occupational heat-related illness (HRI) emergency department (ED) visit rates were highest in males (RR=5.7, 95% CI 5.3–6.1) and minority workers (RR=1.4, 95% CI 1.3–1.5) that is, black and other races. Compared to whites, the HRI hospitalization rate was 1.5 times higher among blacks (95% CI=1.3–1.8) and 3.4 times higher among other minorities (95% CI 2.8–4.2) [14]. As the proportion of construction workers increased, the number of heat-related ED visits increased by 8.1% and the number of heat-related hospitalizations increased by 7.9%. Additionally, heat-related ED visits increased by 10.9% each time the proportion of workers in agriculture and related fields increased [15]. Moreover, for males, people living in rural areas, and residents aged 15–35 years, the highest incidence of HRI was observed [16].

The effect of three consecutive hot days was a 30% increase in the overall-cause mortality (RR=1.30, 95% CI 1.24–1.38), and the effect of heat on mortality was higher in manual workers (RR=1.25, 95% CI 0.96–1.64) [17].

Workers' questionnaire results showed that 35.6% of the participants reported HRI while working outside, and 13.9% reported HRI while working inside. Factors related to HRI while working outdoors included wet clothes and shoes [18]. Among forestry workers, one-third showed early heatstroke symptoms during summer, and variables such as frequency of urination, hotness, body mass index (BMI), and years of forestry work (standard coefficients: +0.229, +0.194, +0.280, and −0.162, respectively) were used for multiple regression analyses [19]. Among the 528 radiation decontamination workers, 316 (59.8%) experienced heat illness symptoms (213 at Grade I and 103 at Grade II) [20]. Among farmworkers, the number of heat-related symptoms at least once a week reported by each individual was higher in harvesters than in non-harvesters [21]. Two-thirds (72%) of the farmworkers experienced at least one HRI symptom when they worked outdoors, and one of the workers with three or more HRI symptoms was 72 and 27% [22]. The most frequently reported symptoms for farmworkers were sweating (66%), headache (58%), dizziness (32%), and muscle cramps (30%). In particular, females had three times the odds of experiencing three or more symptoms (OR=2.86, 95% CI 1.18–6.89) [23]. In another survey of farmworkers, heavy sweating (50%) and headaches (24%) were the most commonly reported HRI symptoms, followed by extreme weakness/fatigue (14%), and skin rash or skin bumps (10%) [24]. For the construction workers, the most reported HRI symptoms were sweating (100%), dizziness (98%), and muscle pain (82%) [25]. Among gold miners, 78.4% of underground miners and 69.6% of open-cut miners were reported to have moderate heat illness. High body temperature and hot and dry skin were the most commonly reported HRI symptoms [26].

The overall risk of occupational HRI was positively associated with the daily maximum temperature (T_{max}), especially when the threshold of 35.5 °C was exceeded. A 1 °C increase in T_{max} was associated with a 12.7% incidence (rate ratio=1.127, 95% CI=1.067–1.190). During the heat wave, the risk of occupational HRI was about 4–7 times higher than that in non-heat wave periods. Of the total occupational HRIs, 142 (46.4%) compensation claims were diagnosed as "heat stress/heat stroke," and 133 (43.5%)

Table 1: Summary of published studies meeting the inclusion criteria for heat exposure effect on workers' health.

First author	Year	Country	Study design	Heat exposure	Participants	Health outcome	Main results	Category
Kevin Riley	2018	US	Longitudinal	Heat events days of summer (May–September)	4,495,118 outdoor workers 16 years and over, 2012	Heat-related ED visits, hospitalizations, and deaths	IRR for construction workers ED visit 1.081 (1.051–1.112)/hospitalization 1.079 (1.022–1.138)/ death 1.091 (0.823–1.446)	Heat-related diseases
Takafumi Maeda	2006	Japan	Cross-sectional	Questionnaire (subjective report of workers)	Forestry workers (n=125, *M*=118, *F*=7)	Self-reported heat-related symptoms	1/3 of forestry workers developed symptoms of early heatstroke during summer	Heat-related diseases
Yihan Xu	2013	Spain	Case-crossover	Daily maximum ambient temperatures, three consecutive hot days	The Barcelona metropolitan area, 2,400,000 inhabitants, manual workers: 10%	Mortality	The effect of three consecutive hot days all-cause mortality RR=1.30 (1.24–1.38) manual workers RR=1.25 (0.96–1.64)	Heat-related diseases
Ariane Adam-Poupart	2014	Canada	Descriptive epidemiology	WBGT and relative humidity	259 heat-related illness compensated by the WCB of Quebec between May and September, from 1998 to 2010	Compensated heat-related illness	The pooled IRR of daily heat-related compensations per 1 °C increase in daily maximum temperatures was 1.419 (1.326–1.520)	Heat-related diseases
Jeffrey W. Bethel and Renee Harger	2014	US	Cross-sectional	Questionnaire (subjective report of workers)	Farmworkers of Oregon (n=100, *M*=60, *F*=40)	Self-reported heat-related symptoms	Heavy sweating (50%) and headache (24%) were the most reported symptoms	Heat-related diseases
Thomas A. Arcury	2015	US	Cross-sectional	Heat index	101 male farmworkers	Self-reported heat-related symptoms	35.6% participants reported heat illness while working outside, and 13.9% while working inside	Heat-related diseases
Jianjun Xiang	2015	Australia	Descriptive epidemiology	Daily maximum temperature	306 heat illness claims (*M*=248, *F*=58)	Compensated heat-related illness	12.7% increase in compensation case when 1 °C rises on a 35.5 °C basis IRR 1.127 (1.067–1.190)	Heat-related diseases
Takeyasu Kakamu	2015	Japan	Cross-sectional	Questionnaire (subjective report of workers)	528 radiation decontamination workers	Self-reported heat-related symptoms	Of the 528 workers, 316 (59.8%) experienced heat illness symptoms	Heat-related diseases
Jeniffer Crowe	2015	Costa Rica	Cross-sectional	Questionnaire (subjective report of workers)	106 male sugarcane harvesters, 63 male non-harvesters	Self-reported heat-related symptoms	Harvesters vs. non-harvesters For ≥1 symptom, 82 vs. 49% for ≥3 symptoms, 42 vs. 3%	Heat-related diseases
Laurel Harduar Morano	2015	US	Descriptive epidemiology	None	8,315 ED visits and 1,051 hospitalization for occupational HRI (2007–2011)	Heat-related ED visits, hospitalizations, and deaths	Occupational HRI ED visit male vs. female RR 5.7 (5.3–6.1) Black vs. white RR 1.3 (1.3–1.4) Occupational HRI IH Male vs. female RR 20.7 (15.0–28.5) Black vs. white RR 1.5 (1.3–1.8)	Heat-related diseases

Table 1: (continued)

First author	Year	Country	Study design	Heat exposure	Participants	Health outcome	Main results	Category
Laurel Harduar Morano	2016	US	Descriptive epidemiology	None	2,979 work-related HRI cases treated in ED, 416 hospitalizations and 23 deaths	Heat-related ED visits, hospitalizations, and deaths	Work-related HRI/100,000 worker-years there were 8.5 ED visits, 1.1 hospitalizations, and 0.1 deaths	Heat-related diseases
Gregory D. Kearney	2016	US	Cross-sectional	Questionnaire (subjective report of workers)	Farmworkers (n=158, *M*=154, *F*=1)	Self-reported heat-related symptoms	72% of farmworkers experienced at least one HRI symptom	Heat-related diseases
E. B. Meshi	2018	Tanzania	Cross-sectional	WBGT, relative humidity, air velocity	Gold miners (n=60, *M*=55, *F*=5)	Core body temperature, self-reported heat-related symptoms	78.4% of underground miners and 69.6% of open-cut miners reported to have moderate heat illness	Heat-related diseases
Dalia A. El-Shafei	2018	Egypt	Cross-sectional	WBGT	Construction workers (n=89)	Self-reported heat-related symptoms	The most reported symptoms of heat illness were sweating (100.0%), dizziness (98.0%), and muscle pain (82.0%)	Heat-related diseases
Abby D. Mutic	2018	US	Cross-sectional	Questionnaire (subjective report of workers)	Farmworkers (n=198, *M*=78, *F*=120)	Self-reported heat-related symptoms	Most frequently reported symptoms were heavy sweating (66%), headache (58%), dizziness (32%), and muscle cramps (30%). Females had three times the odds of experiencing three or more symptoms OR=2.86 (1.18–6.89)	Heat-related diseases
Pascal Wild	1995	US	Longitudinal	Underground work	French male potash miners (n=8,199)	Mortality for ischemic heart diseases	Mortality from IHD was higher for underground workers than for daylight workers (RR=1.6)	Death
Maria C. Mirabelli and David B. Richardson	2005	US	Cross-sectional	Annual summer temperature	Work-related fatalities (n=40, *M*=40, *F*=0)	Heat-related death	For each 1 °F increase in average summer temperature, the rate of heat-related death increased 59% in the total population RR=1.59 (1.36–1.87) and 37% in the working population RR=1.37 (0.99–1.90)	Death
Diane M. Gubernot	2014	US	Longitudinal	Heat	140,346,000 workers	Heat-related deaths	Between 2000 and 2010, 359 occupational heat-related deaths were identified in the US, for a yearly average fatality rate of 0.22 per one million workers	Death
Bandana Pradhan	2019	Qatar	Longitudinal	Monthly estimates of daily WBGT, for in-shade conditions	3,380,228 Nepali migrant workers from 2009 to 2017	Death certification	The average annual death rate for Nepali migrant workers in Qatar was 150 deaths/100,000. The major cause of these deaths was recorded as cardiovascular problems	Death

Table 1: (continued)

First author	Year	Country	Study design	Heat exposure	Participants	Health outcome	Main results	Category
Jongchul Park	2019	Korea	Longitudinal	Average maximum daily summer temperature	Outdoor workers (n=90,266)	MCR	MCR of outdoor workers was 1.17 and others was 1.10 above 35 °C (p<0.01)	Death
Marco Morabito	2006	Italy	Longitudinal	Apparent temperature (AT)	Hospital admission due to work accidents (n=835, *M*=711, *F*=124)	Number of work accidents	An average daytime AT value ranged between 24.8 and 27.5 °C were at the highest risk of work-related accident	Accident or injury
Ariane Adam-Poupart	2015	Canada	Cohort study	Daily hourly maximum dry bulb temperature	Injury compensated by the WCB database (n=374,078) 2003 to 2010 in Quebec	Daily counts of work-related injury compensations	IRR of daily compensations per 1 °C increase was 1.002 (1.002–1.003)	Accident or injury
June T. Spector	2016	US	Case-crossover	Maximum daily humidex	Traumatic injury worker's compensation claims (n=780,499)	Work-related injury claims	Traumatic injury OR was 1.14 (1.06–1.22), 1.15 (1.06–1.25) and 1.10 (1.01–1.20) for daily maximum humidex of 25–29, 30–33, and >33 °C, compared to <25 °C	Accident or injury
Rameez Rameezdeen	2017	Australia	Quasi-experimental	Heat waves	Compensation claims reported during 1 July 2002 to 31 June 2013 in South Australia for construction category (n=29,438)	Work-related injury claims	Civil engineering, old age, small-sized company workers are vulnerable to accidents and more likely to suffer higher severity of accidents	Accident or injury
Judith A McInnes	2017	Australia	Case-crossover	Ambient outdoor temperature	Worker's compensation claim for acute injury to a worker aged ≥15 years, during the period 2002–2012. (n=46,940)	Work-related injury claims	The strength of associations between injury risk and maximum daytime temperature for young workers, OR=1.008 (1.001–1.015) and male workers, OR=1.003 (1.000–1.006)	Accident or injury
Rongrong Sheng	2018	China	Case-crossover	Daily maximum temperature	Work-related injuries over the period of warm seasons (n=5,418)	Work-related injury claims	1 °C increase in maximum temperature was associated with a 1.4% (RR=1.014, 1.012–1.017) increase in daily injury claims 1 °C increase in minimum temperature was associated with 1.7% (RR=1.017, 1.012–1.021) increase in daily injury claims	Accident or injury
Judith A. McInnes	2018	Australia	Case-crossover	Daily maximum temperature	Acute injury claims in November to March 2002–2012 (n=65,487)	Work-related injury claims	Three consecutive days of high but not extreme temperatures were associated with the strongest effect, with a 15% increased risk of injury (OR 1.15, 1.01–1.30) observed when daily maximum temperature was ≥33.3 °C (90th percentile) for three consecutive days, compared to when it was not	Accident or injury

Table 1: (continued)

First author	Year	Country	Study design	Heat exposure	Participants	Health outcome	Main results	Category
Matteo Ricco	2018	Italy	Case-crossover	Daily maximum temperature, daily average temperature	Occupational injuries (n=7,325, *M*=6,241, *F*=1,084) 2000 to 2013	Occupational injury	The peak of work-related accidents occurred during heat waves (IRR=1.09, 1.02–1.17)	Accident or injury
Alessandro Marinaccio	2019	Italy	Case-crossover	Daily air temperature	Work-related injuries in the period 2006–2010 (n=2,277,432)	Occupational injury	RR of occupational injury for heat was 1.17 (1.14–1.21)	Accident or injury
Blesson M. Varghese	2019	Australia	Case-crossover	Heat waves	Workers' compensation claims and work-related ambulance callouts for the years 2003–2013	Work-related injuries and illnesses	Moderate heat waves in compensation claims made by new workers RR=1.31 (1.10–1.55)	Accident or injury
Haiming Luo	2014	China	Case-control	Ambient heat exposure (cumulative exposure time)	2003–2010 health check data of shipbuilding company (n=3,288)	Urolithiasis	Spray painters were most likely to develop urolithiasis (OR=4.4, 1.7–11.4) Workers with longer cumulative exposure time had higher risk for urolithiasis (OR=1.5, 1.2–1.8)	Effect on urinary system
Luiz Atan	2004	Brazil	Cross-sectional	Temperature greater than 45 °C	Industry's 10,326 employees	Urolithiasis	Of the 10,326 workers, 181 (1.75%) had presented with at least one episode of urinary stones. Of these, 103 were among the hot-area workers (8.0%) and 78 among the room-temperature workers (0.9%; p<0.001)	Effect on urinary system
Ramón García-Trabanino	2015	El Salvador	Case-crossover	Mean workday temperature	Sugarcane cutters (n=189, aged 18–49, male)	eGFR	There were statistically significant changes across shift. Serum creatinine, uric acid and urea nitrogen increased, while chloride and potassium decreased	Effect on urinary system
Catharina Wesseling	2016	Nicaragua	Cross-sectional	Heat stress	194 male workers: 86 were sugarcane cutters, 56 construction workers and 52 small-scale farmers	Biomarkers of kidney function and hydration	Reduced eGFR occurred in 16, 9 and 2% of sugarcane cutters, construction workers and farmers, respectively	Effect on urinary system
Sally Moyce	2017	US	Case-crossover	Heat strain	283 agricultural workers	Incident AKI over the course of a work shift	Workers who experienced heat strain had increased adjusted odds of AKI (OR=1.34 1.04–1.74)	Effect on urinary system
Jacqueline Mix	2018	US	Longitudinal	Heat index	192 immigrant agricultural workers	Hydration status and kidney function indicators	The odds of AKI increased 47% for each 5 °C (8 °F) increase in heat index	Effect on urinary system

Table 1: (continued)

First author	Year	Country	Study design	Heat exposure	Participants	Health outcome	Main results	Category
Jaime Butler-Dawson	2019	US	Prospective longitudinal cohort	WBGT	517 sugarcane workers	Kidney disease: improving global outcomes (KDIGO) criteria	Cumulative incidence of AKI was 53% in February, 54% in March, and 51% in April	Effect on urinary system
Joop S.E. Laven	1988	Netherland	Cross-sectional	Occupation (sitting or non-sitting), sleeping habit	56 males from infertile couples	Sperm quality	Occupational and living habits apparently through scrotal insulation can influence sperm quality	Effect on reproductive system
P. Thonneau	1997	France	Cross-sectional	Retrospective survey about occupation	402 fertile couples	Time required to achieve a pregnancy (TTP)	The TTP for the subgroups 'exposure to heat' was significantly longer (both $p<0.05$) than for the controls	Effect on reproductive system
Rima Dada	2003	India	Cross-sectional	Retrospective survey about occupation	122 infertile men (and 25 fertile controls)	Semen analysis	20 azoospermic and 14 oligozoospermic men had high testiculo epididymal temperatures, either due to occupational exposure to high temperature or varicocele	Effect on reproductive system
Gwendoline De Fleurian	2009	France	Cross-sectional	Retrospective survey about occupation	402 men consulting for couple infertility	Semen quality	Excess heat was associated with impaired sperm motility	Effect on reproductive system
Sylvia Guendelman	2017	US	Nested case-control study	Retrospective survey about occupation	580 employed women	Birth outcome	Exposure to extreme temperature had elevated odds of cesarean delivery. OR=1.46 (0.72–2.96)	Effect on reproductive system
Benjawan Tawatsupa	2010	Thai	Cross-sectional	Heat stress (questionnaire)	Workers (exclusion of missing response, non-worker, multi-hazard exposure) n=24,907	Overall health, psychological distress	Workers who often exposed to heat stress have poor overall health. OR 1.49 (1.32–1.66) psychological distress OR 1.84 (1.69–2.00)	Effect on psychological system
Adel Mazlomi	2017	Iran	Case-control	WBGT index	Foundry plant workers (n=70, heat-exposed=35, not exposed=35)	SCWT (for cognitive performance), stress hormones (cortisol, adrenaline, noradrenaline)	Heat stress leads to increase in the blood level of stress hormones, resulting in cognitive performance impairment	Effect on psychological system
R. Yasmin	2013	Bangladesh	Cross-sectional	Workplace temperature and humidity	200 workers of selected re-rolling mills	Eye problems (conjunctiva, itching, inflammation, condition of cornea)	Most of the complaints of eye were found to be associated with high temperature (more than 40 °C) at workplace	etc.
Katia Vangelova	2006	Bulgaria	Case-control	WBGT	Male industrial workers exposed to heat (n=102) and a control group of male workers (n=102)	Lipid profile	OR indicated higher risk in heat-exposed industrial workers of becoming dyslipidemic For TC OR=1.481 (1.097–2.002), for LDL-C OR=1.539 (1.123–2.111)	etc.

Table 1: (continued)

First author	Year	Country	Study design	Heat exposure	Participants	Health outcome	Main results	Category
Subhashis Sahu	2013	India	Case-control	WBGT	124 rice harvesters	Work productivity, perceived health problems, heart rate	The hourly number of rice bundles collected was significantly reduced at WBGT>26 °C (approximately 5% per °C of increased WBGT)	etc.

AKI, Acute Kidney Injury; eGFR, Epidermal growth factor receptor; ED, Emergency Department; HRI, Heat-Related illness; IH, In-Hospitalization; IHD, Ischemic Heart Disease; IRR, Incidence Rate Ratio; LDL-C, Low Density Lipoprotein Cholesterol; MCR, Mortality Change Rate; OR, Odds Ratio; RR, Relative Ratio; SCWT, Stroop Color Word Test; TTP, Time required to achieve a pregnancy; TC, Total Cholesterol; WBGT, Wet-Bulb Globe Temperature; WCB, Workers' Compensation Board.The confidence intervals not marked separately are 95% confidence intervals.

were diagnosed as "other unspecified diseases or injuries" due to the effects of weather, exposure, air pressure, and other external factors [27]. In another study conducted in Canada, the incidence rate ratio of daily heat-related compensations per 1 °C increase in $T_{\max}$ was 1.419 (95% CI 1.326–1.520) [28].

Death

In a cross-sectional study of annual summer temperature, for each 1 °F increase in average summer temperature, the heat-related mortality rate increased by 37% in the working population (RR=1.37, 95% CI 0.99–1.90), and it was 59% in the total population (RR=1.59, 95% CI 1.36–1.87) [29]. According to the fatality data from the Bureau of Labor Statistics in the US between 2000 and 2010, a yearly average heat-related fatality rate was 0.22 per one million workers, with the highest rates identified among Hispanics, men, agriculture and construction workers, and small business owners [30]. The mortality rate of outdoor workers exposed to heat above 35 °C was 1.17 ($p<0.01$) during the summer from 2007 to 2016 in Korea [31]. A strong correlation between average monthly afternoon heat levels and mortality from cardiovascular problems was shown in Nepali migrant workers in Qatar [32]. Moreover, among French male potash miners, the overall mortality rate was low (standardized mortality ratio=0.89), and it was lower in underground workers (age-standardized mortality rate=660 per 100,000 person-years) than in daylight workers (age-standardized mortality rate=710). Mortality due to ischemic heart diseases (IHD) was higher in underground workers than in daylight workers (RR=1.6) [33].

Accident or injury

As a result of an analysis of injury compensation cases in Canada from 2003 to 2010, the incidence rate ratio (IRR) was 1.002 (95% CI 1.002–1.003) at a 1 °C increase [34]. Based on the data from 2000 to 2013, the incidence of occupational injury occurring during the warm season in Italy Trento was 3.4 ± 2.3 events/day, and the incidence rate increased when heat waves occurred (IR=1.09, 95% CI 1.02–1.17) [35]. The highest risk of work-related accidents was observed from 24.8 to 27.5 °C for the average daytime apparent temperature (AT) value in Italy [36]. The OR of traumatic injury among workers was 1.14 (95% CI 1.06–1.22), 1.15 (95% CI 1.06–1.25), and 1.10 (95% CI 1.01–120) for daily maximum humidity of 25–29, 30–33, and ≥34, respectively, and it was strongly associated with their duties in June and July [37]. The RR of occupational injury under hot condition was 1.17 (95% CI 1.14–1.21), and construction workers had the highest risk of injuries on hot days [38]. Workers in lower civil engineering sectors were more vulnerable to accidents and injuries than those in building services and general construction workers, and factors such as old age and small-sized companies showed more vulnerability to severe construction accidents during heat wave periods [39]. Moreover, injury risk was strongly associated with maximum daytime temperature in young workers (OR=1.008, 95% CI=1.001–1.015) and male workers (OR=1.003, 95% CI=1.000–1.006) [40]. A daily maximum temperature increase of 1 °C was associated with a 1.4% increase rate (RR=1.014, 95% CI=1.012–1.017) of the daily injury claims, while a minimum temperature increase of 1 °C was associated with a 1.7% increase in the rate of daily injury claims (RR=1.017, 95% CI=1.012–1.021) [41]. Work-related compensation claims were positively associated with new workers (RR=1.31, 95% CI=1.10–1.55), workers in medium-sized enterprises (RR=1.15, 95% CI=1.01–1.17), indoor industries (RR=1.09, 95% CI=1.01–1.17), male gender (RR=1.13 95% CI=1.03–1.23), and laborers (RR=1.21, 95% CI=1.04–1.39) during moderate heat waves [42]. The increased risk of injury was related to 2–3 consecutive days of hot weather, and it became apparent at a daily maximum temperature of 27.6 °C (70th percentile). In addition, three consecutive days of high temperatures (not extreme) were related to the observed 15% increase in injury risk (OR=1.15, 95% CI 1.01–1.30) when the daily maximum temperature was 33.3 °C and above (90th percentile) [43].

Effect on the urinary system

Outdoor workers in China have been shown to be more likely to present with urolithiasis than indoor workers ($p<0.05$), and those with longer cumulative exposure times had a higher risk for urolithiasis (OR=1.5, 95% CI=1.2–1.8). In a study, spray painters were reported to be most likely to develop urolithiasis (OR=4.4, 95% CI=1.7–11.4) [44]. In a cross-sectional study of Brazilian workers, 1.75% of workers had presented with at least one episode of urinary stones, 8% of whom were "hot-area" workers, while 0.9% were room-temperature workers ($p<0.001$) [45].

Changes in epidermal growth factor receptor (eGFR) were statistically significant across shifts among sugarcane cutters, and these workers were more commonly reported to have heat stress, dehydration, and kidney dysfunction compared to other workers, such as subsistence farmers and construction workers [46]. In the USA, workers in hot conditions had increased adjusted odds ratio and a cumulative incidence of acute kidney injury (AKI) [47–49]. In particular, heat stress, dehydration, and kidney dysfunction were most common among sugarcane cutters compared to construction workers and small-scale farmers in Nicaragua [50].

Effect on the reproductive system

Several previous studies have suggested that heat exposure affects sperm quality and motility. Excess heat was associated with impaired sperm motility through scrotal insulation, which can apparently affect sperm quality [51, 52]. Moreover, 20 men with azoospermia and 14 with oligozoospermia in India had high testiculo epididymal temperature due to occupational high temperature exposure or variocele [53].

Exposure to extreme temperature had an elevated odds ratio for cesarean delivery (OR=1.46, 95% CI=0.72–2.96) [54]. The group exposed to heat had a significantly longer time to reach pregnancy than the control group ($p<0.05$) [55].

Effect on the psychological system

Heat stress has been shown to be associated with psychological distress and cognitive problems in some studies. Workers frequently exposed to heat stress had psychological distress (OR=1.49, 95% CI=0.72–2.96) in a Thai cohort study [56]. Moreover, cognitive impairment was observed in workers with increased stress hormones and dehydration symptoms caused by heat stress [57].

Other effects of heat exposure

Workers with heat exposure have been associated with dyslipidemia, eye, and cardiovascular problems in several studies. Most of the work-related complaints were eye problems while working under high temperatures [58]. An increased odds ratio of dyslipidemia was observed in heat-exposed workers with high total cholesterol (OR=1.481, 95% CI=1.097–2.002) and low density lipoprotein (LDL) cholesterol (OR=1.539, 95% CI 1.123–2.111) [59]. Among the rice harvesters in India, a slow recovery of heart rate, indicating cardiovascular strain, was observed in a case-control study [60].

Discussion

This is the review to assess the effects of heat exposure on workers' health. Exposure to heat was closely associated with increased risk of various diseases, injury, or accidents among workers.

Heat-related diseases accounted for most of the heat exposure-related health effects. It is well known that higher temperatures have increased workers' visits to emergency rooms and hospitalization rates related to heat-related diseases, and these characteristics have been observed in men and in people of color [14]. The most reported symptoms were sweating, headaches, dizziness, and muscle aches, as well as fatigue and skin rashes [24]. In a particular study, the proportion of women who reported three or more symptoms together were triple the proportion of men [23]. Regarding occupations associated with heat exposure, construction workers, manual workers, and farmers were frequently considered. Additionally, there were studies on miners, forestry workers, and radiation decontamination workers. A study showed that the industrial accident compensation for heat-related chronic diseases such as heat stress/heat stroke increases with each temperature rise and with heat waves [27, 28].

Just as the prevalence of heat-related diseases increased with temperature increase, so did the mortality rate. This trend has been consistently reported in many countries, including the United States [29, 30], Korea [31], Qatar [32] and France [33]. Heat-related deaths were higher in Hispanics, men, agriculture and construction workers, and in small-sized enterprises [30], and ischemic heart disease was reported as one of the possible causes [33].

Generally, groups vulnerable to heat exposure are known as older people. There are reports that the increase in temperature increases both cardiovascular and respiratory hospitalization rates and mortality rates for older people [61], and that policies such as improving housing structure are needed because older people have relatively little external activity [62]. Since workers' heat exposure is estimated to occur a lot in outdoor workers, customized support for workers may be needed, such as policies such as issuing heat wave-related alerts and measures to monitor body temperature.

In Canada [34], Italy [35], China [41], and Australia [42], when the temperature rises, it has been reported that the number of cases of injury-related claims and compensation increases. In addition to the average daily temperature, heat waves and peak temperatures for more than two consecutive days were also associated with injury risk [42, 43]. It was reported that construction workers had the highest risk of injury during heat waves [38], and male and young workers had a higher risk [40].

Outdoor workers exposed to hot temperatures have a high prevalence and risk of urolithiasis, high adjusted OR, and incidence of kidney dysfunction, including reduction of eGFR and AKI [44–50]. Dehydration caused by sweating is one of the main mechanisms inducing urolithiasis under heat exposure, and the chronic state of dehydration may change the renal tubules to an acidosis state [44, 63]. Urolithiasis is also associated with hypocitraturia, and it can cause hydronephrosis, pyelonephritis, and even kidney failure such as AKI and chronic kidney disease (CKD) [45, 64]. Moreover, daily exposure to heat stress and repeated dehydration may induce renal hypoperfusion, and rhabdomyolysis associated with excessive exertion may cause CKD due to inflammatory cytokines, oxidants, and uric acid [65, 66]. Hyperuricemia, a high-risk factor in CKD, was especially high in sugarcane cutters and construction workers [67]. Adaptation strategies and effective health precautions should always be considered and developed to cope with the occupational health effects caused by heat stress. In order to prevent the occurrence of urolithiasis, outdoor workers exposed to hot temperatures should reduce their workload during hot months and periodically measure their hydration status. Additionally, workers should consume sufficient water, such as electrolyte drinks, during the heat exposure period [44, 50, 68].

Heat exposure reduces the sperm quality and motility not only in workers but also in the general population, and it causes adverse effects such as delivery problems [51–55]. Previous studies have revealed that spermatogenesis requires scrotal hypothermia physiologically, and increasing scrotal temperature in men disrupts spermatogenesis and causes sperm abnormalities[51, 69, 70]. Infertility in male workers exposed to heat at their workplaces was reported in some studies, and the time to achieve pregnancy (TTP) was found to be relatively longer in women whose partners were exposed to occupational heat stress [71–73]. The p53 gene activation leads to cell cycle arrest, which prevents normal spermatogenesis with damaged DNA, and this is one of the mechanisms underlying the impairment of spermatogenesis under heat exposure and is related to quality control of sperm cells [53, 74–76]. Short-term heat exposure has a reversible effect on spermatogenesis; however, chronic exposure can lead to irreversible damage to the reproductive system, related to infertility.

In general, there are reports that exposure to heat during pregnancy can cause congenital malformation [77, 78], and in the case of the paternal system, exposure to heat increases the likelihood of certain brain tumors in the child [79]. However, in the case of groups of workers, the relevant literature was insufficient. Reproductive toxicity has significant ethical implications, requiring further relevant research.

Psychological distress and cognitive impairment were observed in workers exposed to heat stress [56, 57]. In a cohort study, workers who experienced heat stress at work had higher odds of psychological distress in Thai (adjusted OR=1.84, p<0.001) [56]. In theory, decline in cognitive function due to heat stress is related to complex mechanisms in the body. Interaction between stress hormones, such as cortisol, adrenaline, and noradrenaline, and cognitive function has been demonstrated in previous studies [80, 81]. Exposure to heat increases the concentration of stress hormones [81, 82] thus, cognitive performance impairment has been observed [57]. Heat stress with other environmental stressors can negatively affect workers' mental health and cause occupational accidents by reducing workers' concentration. As mentioned earlier, cognitive impairment is associated with complex physiological mechanisms; therefore, proper recognition and control of the mechanisms can prevent the adverse effects of heat stress on the psychological system.

There are reports [83, 84] that exposure to high temperatures not only decreases cognitive function but also increases hospitalization for actual mental illness. Suicide attempts have also been reported to increase [85], and mortality rates have increased 2–3 times in patients with mental illness [86, 87]. In the case of outdoor workers, depending on the country, there is a possibility that they are elderly or marginalized from public health. However, research on mental disorders of workers is insufficient, and additional related studies are needed.

Eye problems, dyslipidemia, and cardiovascular strain have also been reported to be affected by heat exposure in other studies [58–60]. Regarding eye problems, the occurrence of thermal cataracts has long been well known as an occupational affliction. Conjunctival inflammation was significantly associated with workplace heat exposure among re-rolling mill workers in Bangladesh through a cross-sectional study (p<0.001). Infrared and ultraviolet rays emitted from the workplace environment may also cause many eye problems to heat-exposed workers [58]. Meanwhile, the specificity of a country in the development stage, such as Bangladesh, and a lack of awareness of personal protective equipment (PPE) should be considered for eye problems. The risk of dyslipidemia was higher in heat-exposed workers, as shown by the odds ratio, with significance depending on the shift schedule, workload, and psychosocial factors [59]. The level of cholesterol is also related with the secretion of cortisol and catecholamine, which increase under stress conditions [88, 89]. Similarly, cardiovascular strain is associated with cortisol secretion under heat exposure [90, 91]. The lipid profile of heat-exposed workers should be screened regularly, and since cardiovascular strain is also associated, the recognition of heat exposure effect will be important for workers.

We classified the health effects of heat-exposed workers into seven categories: (1) heat-related diseases, (2) death, (3) accident or injury, (4) effect on the urinary system, (5) effect on the reproductive system, (6) effect on the psychological system, and (7) other effects, considering disease mechanisms. Although the working population tends to be relatively young and healthy, which is not considered the most important factor in studies related to heat exposure, generally known heat-related health effects have been consistent with those reported in workers. In particular, outdoor workers (e.g., construction workers, agricultural workers, and forestry workers) have been reported to be at risk of HRIs, injuries, and deaths, in several studies. In addition, men were more susceptible to heat-related health effects than women; younger workers under 30 years of age were also as vulnerable as the elderly population. The literature analyzing industrial accident compensation system data focuses only on the relatively developed countries, and large-scale research in low-income countries is relatively scarce. Given that more heat exposure-related diseases will occur in developing countries, more research on industrial accident monitoring systems in low-income countries is needed to establish appropriate prevention strategies. On the contrary, studies have shown that non-white people suffer more heat-related injuries or deaths than white people. Although socioeconomic factors appear to act as confounding variables, studies on relatively large Asian or African populations are currently lacking. Diseases of the urinary system due to heat exposure have been actively studied recently, but there is no large-scale analysis of their social burden. Most urinary stones are cured. However, as there are cases of deaths due to urolithiasis even in developed countries [92], the burden on workers in low-income countries is likely to be greater, but the research effort is insufficient. Relatively unknown health effects, such as dyslipidemia or increased eye disease, have been reported. Further follow-up studies to prove the causality in these cross-sectional studies would be helpful in devising strategies to prevent excessive health care costs and improve the health of workers exposed to high temperatures.

Our review demonstrated that workers exposed to heat could be a vulnerable population in terms of health and safety at the workplace. Further research, including a longitudinal design and assessing the dose-response relationship and summarized effect, should be conducted to examine more closely the links between heat exposure and workers' health.

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