COMMENTARY

Re-evaluating Occupational Heat Stress in a Changing Climate

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ABSTRACT

The potential consequences of occupational heat stress in a changing climate on workers, workplaces, and global economies are substantial. Occupational heat stress risk is projected to become particularly high in middle- and low-income tropical and subtropical regions, where optimal controls may not be readily available. This commentary presents occupational heat stress in the context of climate change, reviews its impacts, and reflects on implications for heat stress assessment and control. Future efforts should address limitations of existing heat stress assessment methods and generate economical, practical, and universal approaches that can incorporate data of varying levels of detail, depending on resources. Validation of these methods should be performed in a wider variety of environments, and data should be collected and analyzed centrally for both local and large-scale hazard assessments and to guide heat stress adaptation planning. Heat stress standards should take into account variability in worker acclimatization, other vulnerabilities, and workplace resources. The effectiveness of controls that are feasible and acceptable should be evaluated. Exposure scientists are needed, in collaboration with experts in other areas, to effectively prevent and control occupational heat stress in a changing climate.

RE-CONTEXTUALIZING OCCUPATIONAL HEAT STRESS

Heat stress in occupational populations is a moving target. Global climate change, which includes both changes in mean weather conditions and the frequency and intensity of extreme weather events (IPCC, 2013), will change the pattern of occupational heat stress risks over time. Workers in tropical and subtropical regions, many of whom are involved in heavy physical work outdoors or indoors without effective cooling, are at particularly high risk (Kjellstrom et al., 2013). Unacclimatized workers in temperate regions are also at increased risk of heat stress, especially during heat waves (Adam-Poupart et al., 2013). Workers in large cities may experience greater heat exposures, relative to their rural counterparts, as a result of urban heat island effects (United States Environmental Protection Agency, 2014).

A complex picture emerges when work is viewed in the context of climate change. Heat stress risk will vary by industry and occupation over time not only as a result of spatiotemporal changes in weather conditions...
but also as a result of personal and work characteristics that themselves may be influenced by climate change. Outdoor industries, such as construction, agriculture, forestry, fishing, and mining (Bonauto et al., 2007; Centers for Disease Control and Prevention, 2008; Schulte and Chun, 2009; Jackson and Rosenberg, 2010; Adam-Poupart et al., 2013), and certain indoor industries (Favata et al., 1990; Srivastava et al., 2000; Schulte and Chun, 2009) have already been identified as high risk for heat stress. This risk will increase further, particularly if there develops a confluence of (1) local increases in mean temperatures and/or frequencies of heat events, (2) lack of controls such as shade, fans, air-conditioning, and other adaptive capacities, (3) more intense physical work demands and/or fewer rest breaks, and (4) workforces that are more susceptible to internal heat retention such as unacclimatized workers.

Although successful control of occupational heat stress begins with the early identification of high-risk workers, this task is not straightforward. Industries and workforces will change over time, including in response to climate change (Schulte and Chun, 2009; Adam-Poupart et al., 2013; IPCC, 2014a). Increased heat stress is projected to affect productivity, economic development, and job security, which could in turn affect the underlying health and susceptibility of workers to heat stress health effects (Kjellstrom et al., 2011a; Rhodium Group LLC, 2014). Interdisciplinary and collaborative work, including between exposure scientists, other occupational and environmental health professionals, atmospheric scientists, biological scientists, labor studies experts, and economists, in industry, labor, and academia, is needed to effectively predict and control occupational heat stress.

**IMPACTS OF OCCUPATIONAL HEAT STRESS IN A CHANGING CLIMATE**

In addition to heat-related illnesses, which can be fatal, several studies have reported relationships between occupational heat stress and increased injury and accident risk (Fogleman et al., 2005; Morabito et al., 2006; Tawatsupa et al., 2013). The interaction of occupational heat stress and certain chemical exposures may impact the absorption and metabolism of chemicals and thermoregulatory responses to heat exposure (Bourbonnais et al., 2013). Heat stress is also hypothesized to contribute, in conjunction with other factors such as pesticide exposure, to chronic kidney disease in sugarcane workers (Raines et al., 2014). Climate change will increase the risk of these heat health effects in workers.

The impacts of occupational heat stress extend far beyond exposed workers. Heat stress is estimated to lead to decreased work productivity (Kjellstrom et al., 2011a) by triggering the body’s natural response to reduce physical work intensity and internal heat generation and also through deliberate efforts to adhere to heat stress exposure limits (Lundgren et al., 2013). Heat stress may also serve as an indicator of other climate change-related occupational hazards and health effects that impact work productivity. For example, certain agricultural workers exposed to heat stress may also be affected by new or increased exposures to water- and vector-borne diseases and pesticides given their direct contact with irrigation water and associated disease vectors, and the emergence of new pest-control issues in a changing climate (Sareen and Nagata, 2011). Air pollution and ultraviolet radiation exposures also relate to heat stress levels (Lundgren et al., 2013). Although quantitative exposure–response relationships are not available for all heat health effects, work has been done to evaluate the effect of heat exposure directly and indirectly (e.g. via changes in air pollution) on such outcomes as cardiovascular and respiratory diseases, and on mental health (Kjellstrom, 2009; Berry et al., 2010). Productivity losses from these and other health conditions are estimated to cost US employers alone $225.8 billion annually (Stewart et al., 2003).

The consequences of occupational heat stress in a changing climate, and its associated hazards, on workers, workplaces, and global economies provide strong motivation for a re-evaluation of occupational heat stress assessment and control strategies. Further, the International Organization for Standardization (ISO) 7243 (1989) hot environments standard (ISO, 1989) is undergoing revision (d’Ambrosio Alfano et al., 2014), so a re-evaluation of heat stress assessment and control is timely.

**RE-THINKING HEAT STRESS ASSESSMENT**

A multitude of empirical (Bedford, 1946; McArdle et al., 1947; Yaglou and Minard, 1957) and rational (Belding and Hatch, 1955; Vogt et al., 1981; Malchaire,
heat stress indices have been developed, each with different strengths and limitations. The High Occupational Temperature, Health, and Productivity Suppression (Hothaps) Program is an international effort aimed at quantifying the extent to which workers are affected by, and adapt to, heat exposure, and the effect of climate change on these estimates (Kjellstrom et al., 2011b). One aim of the Hothaps program has been to develop improved methods for human heat exposure assessment. The following characteristics of optimal occupational heat stress assessment methods, in the context of a changing climate, have been described (Kjellstrom et al., 2009; Lemke and Kjellstrom, 2012; Parsons, 2013).

Practical

The need for a practical and economical heat stress assessment method, given greater projected impacts of climate change on workers in low- and middle-income countries, raises three important considerations: (1) the level of detail of the assessment method; (2) the anticipated audience of the method; and (3) the actual measurement method. The ISO scheme for heat stress assessment includes the use of a relatively simple index (ISO, 1989) and, when needed, more sophisticated resource-intensive methods (ISO, 2004a,b). The focus for high-risk areas of the world that have not yet been extensively studied should be on the optimization of a simple index, using more detailed assessments in later stages as needed. The rationale for a simpler, more practical index includes the need for use by workers, managers, and other key stakeholders in areas where access to advanced training may be limited, and the lower cost of a simpler approach (Parsons, 2013).

The practicality of the actual measurement method must also be considered. The wet bulb globe temperature (WBGT) instrument, which measures natural wet bulb temperature, globe temperature, and air temperature, indirectly captures information about radiant temperature, air velocity, and humidity. The WBGT itself is really a measure of heat exposure and not heat stress unless considered with activity and clothing (Parsons, 2013), as in ISO standard 7243 (1989) (ISO, 1989). As D’Ambrosio Alfano et al. (2014) point out in this issue, the WBGT has a number of limitations, including limited use in high humidity, low air movement environments, lack of a direct measure of air velocity, and a lack of standardization of instruments to measure WBGT. However, its relative ease of use and widespread adoption are advantages (Parsons, 2013).

An alternate approach is to estimate WBGT from standard meteorological data (Lemke and Kjellstrom, 2012). Two such methods were reported by Lemke et al. (2011) to meet pre-specified criteria for a “valid” method: Bernard’s empirical method for indoor WBGT estimation, which does not incorporate solar data (Bernard and Pourmoghani, 1999), and Liljegren’s rational method for outdoor WBGT estimation (Liljegren et al., 2008). These methods have the capacity to incorporate climate change models to estimate future WBGT values (Lemke and Kjellstrom, 2012).

There are several important limitations of the use of meteorological data to estimate WBGT. First, these methods are limited in environments where there is a large differential between local work conditions, for example, near an indoor heat source such as a smelter, and ambient outdoor conditions. Estimation of WBGT from meteorological data is more likely to be useful in outdoor workplaces or indoor work environments where outdoor conditions consistently approximate indoor conditions, such as those without heat sources and air-conditioning and with open windows, a common scenario in low-income countries (Lemke and Kjellstrom, 2012). Second, data from weather stations may not correspond to specific workplace conditions, depending on the proximity and elevation of the weather station in relation to the worksite. If traditional WBGT meters, which cost thousands of US dollars, are too expensive and not feasible, cheaper hand-held electronic meters and data loggers could be considered for use at the workplace if certain assumptions are met (Lemke and Kjellstrom, 2012; d’Ambrosio Alfano et al., 2014). Although heat stress assessments using estimates from weather station data or hand-held devices may not be as accurate or detailed as traditional methods, these methods may be useful for initial assessments of heat stress risk, particularly in settings with limited resources.

Automated

Assuming adequate computing power and/or access to internet-based calculators, simple indices need not be simple in their approach, but only simple from a practical standpoint. For example, one limitation of the WBGT, as applied in the ISO standard 7243 (1989)
(ISO, 1989), is its adjustment for clothing properties (d'Ambrosio Alfano et al., 2014). More sophisticated clothing adjustment models could be incorporated into existing methods, using an automated tool that computes an index and provides an interpretation, given the necessary inputs. The Universal Thermal Climate Index provides an automated approach to incorporate complex physiological models but is limited in its assessment of metabolic rate and occupationally relevant clothing (Bröde et al., 2012).

Valid in high-risk zones
An ideal occupational heat stress index should apply in a variety of climates and contexts, including moist tropical climates, where the risk of occupational heat stress is projected to become dangerously high (Lemke et al., 2011). In these climate zones, limitations in cases of high humidity may preclude direct measurement using traditional approaches (d'Ambrosio Alfano et al., 2014), and alternative methods will need to be developed and validated.

Interpretable and translatable outputs
Outputs should have meaningful interpretations and be translatable into heat stress control strategies. One limitation of the WBGT, as applied in ISO standard 7243 (1989) (ISO, 1989), is that in high-risk hot countries, where conditions will become even more extreme over time, WBGT values are close to or exceed reference values (Parsons, 2013). Although preferable in extreme conditions, follow-up with detailed heat stress and strain assessments may require more expertise and resources than are currently available in certain settings. Further, ISO standard 7933 (2004), which uses information about heat transfer between workers and the environment to predict likely heat strain, only considers standard subjects in good health that are fit for work (ISO, 2004a). Workforces in different geographical areas, climates, and workplaces likely differ in levels of acclimatization and prevalences of other factors that may increase the risk of heat strain. Further work is needed to determine how this information could inform the interpretation of heat stress assessment method outputs and control recommendations, when individual heat strain monitoring is not possible, so that work is not completely restricted but health remains protected.

Technological developments may allow for cheaper and more efficient physiological monitoring of groups of workers in the future (Parsons, 2013). Individual heat strain monitoring will be particularly useful in groups of workers with variability in heat strain risk. If workplace physiological monitoring becomes more prevalent, further work on how best to translate these physiological data into useful control recommendations will be needed (Parsons, 2013).

Acceptable and accessible
Global acceptability of an occupational heat stress assessment method is likely related to its practicality and cost. Accessibility is aided by infrastructure such as the ISO, which helps distribute standards to key stakeholders. An affordable price to access these standards, however, is needed to ensure accessibility (Parsons, 2013).

An acceptable and accessible universal index is a first step toward generating large-scale heat stress databases that address high-level trends as well as local heat stress risks (Kjellstrom et al., 2011b). Such an index could have various levels of inputs, from individual workplace to regional data. Inputs could include basic parameters and, when possible, more detailed workplace-level data could be added. Data could then be collected and analyzed centrally for climate change impacts assessments and adaptation strategy planning, an aim that has been articulated by Hothaps (Kjellstrom et al., 2011b).

LIMITATIONS OF HEAT STRESS CONTROLS IN A CHANGING CLIMATE
The climate change community has outlined a need for both mitigation, or slowing, of climate change (IPCC, 2014b) and adaptation, or actions that can be taken to reduce heat stress and associated health effects (IPCC, 2014a). Mitigation is outside of the scope of this commentary. However, awareness of the negative effects of potential control strategies, such as traditional air-conditioning, which can involve burning of fossil fuels to produce electricity and greenhouse gases and worsen climate change, is critical.

There are a number of limitations of elements of the traditional hierarchy of heat stress controls in the context of climate change. Although elimination or reduction of heat exposure, including through the design of workplace buildings, the use of trees for shade, and
the reduction of heat island effects (Lundgren et al., 2013), may be the ultimate goal for climate change adaptation, these longer term adaptations require substantial resources and planning. Yet, sufficient resources may not be available in high-risk, low- and middle-income countries, where the majority of the global population lives and works and where the risk of heat stress is projected to increase (Kjellstrom et al., 2013). Engineering controls such as job automation and cooling systems may also not be available in these settings. Reliance may instead be on administrative controls, such as organization of work around cooler periods of the day and season and work-rest regimens. Unfortunately, cooler periods may diminish with climate change, and there are barriers to effective work-rest regimens, particularly in settings where workers are incentivized per unit of work (Lundgren et al., 2013). Further, work-rest regimens have implications for productivity. Current efforts to understand the relationship between heat stress, acclimatization, heat-related health effects, productivity, and economic impacts may help inform the development of region- and industry-specific work-rest recommendations (Kjellstrom et al., 2009).

The confluence of globalization and climate change will lead to increasingly diverse working populations being exposed to more varied and extreme climates (Parsons, 2013). If climate change leads to increased chronic disease risk, affected workers may become more vulnerable to heat stress effects. Control strategies such as education programs, early warning systems, and hydration schemes may show different effectiveness in different populations, depending on cultural beliefs and other barriers and facilitators (Lam et al., 2013; Stoecklin-Marois et al., 2013), even when incorporated into regulations (California Division of Occupational Safety and Health, 2006; Washington State Legislature, 2012). Certain workers whose home and leisure circumstances do not facilitate cooling outside of work may be vulnerable to heat effects at work despite workplace controls (Quandt et al., 2013). Controls may need to be tailored to specific working populations.

Finally, climate change may create more profound “competition” between hazards. For example, changes in crop pests and increases in pesticide impermeable personal protective equipment use may occur in increasingly hot environments (Sareen and Nagata, 2011). Overall, although workplaces should aim to follow the hierarchy of controls, practicality limitations of certain approaches may preclude their implementation.

**CONCLUSIONS AND FUTURE DIRECTIONS**

In summary, climate change will affect occupational heat stress risk, particularly in low- and middle-income tropical and subtropical regions. The potential for profound consequences of occupational heat stress on workers, workplaces, and economies in a changing climate merits a re-evaluation of heat stress assessment and control strategies. Future efforts should build upon relatively straightforward and accepted heat stress indices such as the WBGT, as applied in an improved ISO standard 7243, to generate economical, practical, and universal approaches to heat stress assessments. Limitations of existing methods should be addressed, and the possibility of including inputs of varying levels of detail, depending on resources, should be incorporated. Validation of these methods should be performed in a wider variety of contexts, including high-risk climate zones. Heat stress data should be collected and analyzed centrally for both local and large-scale hazard assessments and to guide heat stress adaptation and control efforts. Although workplaces should aim to follow the hierarchy of controls, flexibility should be built into the interpretation of heat stress standard recommendations to allow for variability in worker acclimatization, other vulnerabilities, and in workplace resources, while still protecting health. The effectiveness of controls that are feasible and acceptable should be evaluated. An ultimate goal should be to prevent heat stress through the design of workplaces and communities for longer term climate change adaptation. Occupational exposure scientists should play a key role in these efforts, in collaboration with experts in other disciplines.

**DISCLAIMER**

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**REFERENCES**


