MANAGING CLIMATIC HEAT STRESS IN SINGAPORE: STATE OF THE PRACTICE AND WEARABLES ON SITE

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Climatic heat stress is a prominent risk to safety and productivity of construction projects. In Singapore, the tropical climate pattern made wearables a cost-efficient safety measure to prevent heat injuries on site. A concurrent study was designed to understand the ecology of managing heat stress in Singapore's construction industry. This involved an experimental study to test the effectiveness and usability of a commercial water-cooling headgear with a sample of 30 rebar and carpentry workers amid everyday practice on site. Participants' body temperatures with and without the water-cooling headgear were recorded with a thermal imagery to avoid interfering with the work. In parallel, ethnographic data were collected through observation and six focus groups. Paired-sample t-test between the experimental group and the control group turned a result of significant difference; the ethnographic data analysis confirmed its use is consistent with local coping convention. The research provides a first snapshot of Singapore's state of practice of managing heat stress in the construction industry. It contributes to the knowledge of designing wearables for on-site heat stress mitigation and establishes thermal imagery as a useful non-intrusive approach to heat strain monitoring on site.

Keywords: Singapore; health and safety; climatic heat stress

INTRODUCTION

Climatic heat stress is a growing health and safety risk with potential life-threatening consequences to the people working on sites (Hesketh *et al.,* 2019). In countries that defined heat related injury as occupational safety incidents, construction industry is among the highest number of workers' compensation cases (Bonauto *et al.,* 2007). This risk is aggravated by the effect of climate change (Hesketh *et al.,* 2019; Gasparrini *et al.,* 2017). In Singapore, a city country located around the equator, the heat hazard is further elevated by the urban heat island effect. Construction workers particularly suffer from exposure to the high uniform temperature and high humidity in the tropical climate in Singapore, as shelter and work-rest regimen cannot make much difference to their thermal condition. Wearables or PPEs in this environment become a more effective and economical choice, contrary to what is normally believed by the Hierarchy of Control. Recent years have seen an increase in the development and test of wearables for heat stress control, focusing on scientific test of

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the product (Yi *et al.,* 2017; Edirisinghe and Jadhav, 2017). However, the systemic and cultural context of construction work, the ecology of which the wearable will become part of, has not yet been given much research attention. In an absence of systems thinking in risk assessment (Goh, 2020), PPEs often end up preventing one hazard but introducing another. For example, Jia *et al. (*2016) reported a temperature of up to 11.5°C higher within worker's safety helmet than the air temperature around. Wearables interact (or interfere) with existing patterns of work activities and impact on the cultural-cognitive institutions espoused by front-line workers, the outcome of which could invalidate the product or introduce new hazards (Rowlinson, 1997). This study aims to bridge these gaps by taking an anthropological approach to in general review the practice of managing heat stress in Singapore's construction industry, and in particular, evaluate the effectiveness of a water-cooling head gear used by workers in mitigating heat risk on site.

Theoretical Perspective

Climatic heat stress of different climate zones differs in the combination of ambient temperature, humidity, solar radiant heat and wind speed. Human societies and communities accordingly respond with a diversity of institutional infrastructures and local methods to cope with the risk. In Middle Eastern countries such as Qatar and the United Arab Emirates, regulations exist to stop outdoor work between 11:30 and 15:00 during the hottest months of the year. However, driven by many different motives, illegal labouring during the restricted work hours becomes a norm, resulting in high heat-induced fatality rates (Amnesty International, 2013).

The issue of heat stress risk in the construction industry also distinguishes itself from that of the general public by the characteristics of its population base. The population entering and remaining in the construction workforce has been selected over time by its heavy physical work nature, and the remaining workforce share some common lifestyle, work habit, coping styles and career entry/exit pattern. For example, Jia *et al. (*2016) found the most vulnerable age group among construction workers is 26-35, rather than higher, while in the general working population of all industries, vulnerability to heat steadily increases with age (Xiang *et al.,* 2014).

Local traditions and coping conventions are cultural-cognitive institutions as part of the system fabric that work for a specific population in a specific natural and social historical environment (Goh, 2020). Safety regulations configured against local culture are least effective in achieving its goals (Ju and Rowlinson, 2020). Previous studies in Hong Kong identified a vernacular Herbal Teas as a local coping tradition (Jia *et al.,* 2017). The low-cost drink used to be contractor's free provision to workers on site. When it was replaced by vending machines selling bottled drinks, the cost was multiplied and shifted to the workers, which not only restricted their opportunity of heat dissipation, but also introduced a health risk in vending the artificially flavoured, heavily sugared drinks. Studies in southwest China identified employers' provision of a traditional medicine Ageratum Liquid as a local coping convention, recognising its effect of improving human body’s immune system and calming down the vomiting digestive system (Jia *et al.,* 2019). Study on acclimatisation in Australia found workers coming from a different climate zone took longer time to adapt to the hot and humid weather on site, mainly due to adjustment of personal life routines (Jia *et al.,* 2020).

These observations and contrasts suggest the necessity of a more delicate study on the ecology of the cultural-cognitive institutions espoused by the target population which could offset, counter or enable the top-down regulative or technological initiatives (Rowlinson, 1997). An anthropology approach is needed to parallel scientific experimental test of the new intervention, in this case, wearables, with ethnographic study of the work ecology where the construction workers are embedded.

The Ecology of Heat Stress Risk in Singapore

The local climate

Geographically 1.5 degrees north of the equator, Singapore has a tropical rainforest climate characterised by high and uniform temperatures and high humidity (MSS, 2020). Recent national study on climate change projected a steady increase in ambient temperature in years to come (Marzin *et al.,* 2015). Daily mean temperature is projected to increase approximately 2-4°C for the end century period (2070-2099), warm days and warm nights throughout February to September. Extremely hot weather is predicted to occur with increasing frequency and intensity.

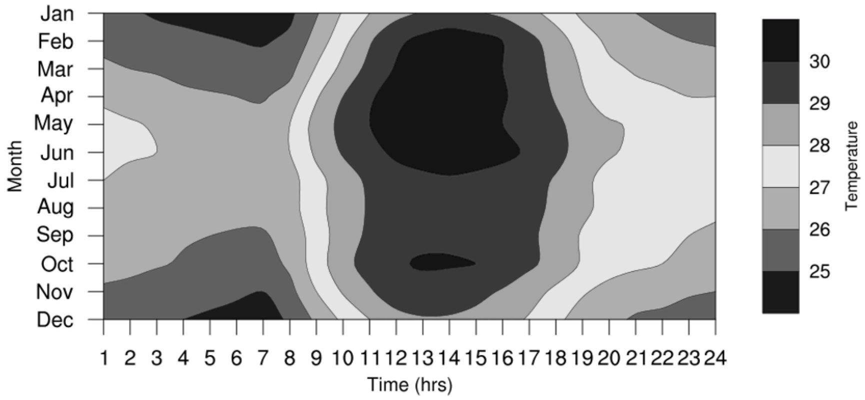

Fig 1: Hourly variation of temperature in Singapore (1981-2010) (Source: MSS, 2020)

On top of the natural heat, as a city state, Singapore further suffers from Urban Heat Island (UHI) which can elevate air temperature up to 7°C in the urban commercial area (Chow and Roth, 2006). While there are no distinctive wet or dry seasons, the highest number of warm days occurs during February to May; the highest number of warm nights from June to September. Hourly mapping by Meteorological Service Singapore (MSS) indicates the highest temperature zone is between 11 AM and 4 PM of the day during February to mid-June of the year (Fig 1).

The institutional context

Singapore is one of the few countries with an elaborate preventive action plan for heat stress control, employing the use of WBGT and Heat Stress Index as the main indices to alert employees of the hourly weather readings. Heat stress as an occupational hazard is protected by the Workplace Safety and Health Act and further under the Workplace Safety and Health (General Provisions) Regulations, under which the employer has a general responsibility to protect workers from 'excessive temperature and harmful radiation'(MOM, 2012). Under the WSH (Risk Management) Regulations, employers are required to conduct risk assessment to eliminate or reduce the risk of heat stress on workers. In guiding practice, Work Safety and Health Council first published workplace heat stress management guidelines in 2010, updated a first revision in 2012 and a second in 2020 (WSHC, 2020). Employers are required to report heat stroke cases to MOM's online reporting system. Preventive measures include acclimatization, drinking facilities, a balanced work schedule, shaded areas and appropriate work clothing. The current guideline recognises three purposes for heat stress management: protection against heat injury, accident prevention and sustained productivity. A key development in the 2020 guidelines is it recognises that 'exertional heat stroke' can happen even in cool environment, due to the accumulation of a large amount of metabolic heat from physical activities beyond human body's capacity of dissipation (WSHC, 2020, p. 5). Existing research on heat stress has been focused on the environmental heat but not given enough attention to metabolic heat which in fact accounts for the major amount of the heat load on human body, a potential area for future research. In terms of acclimatisation, MOM recommend a 14-day acclimatisation protocol, during the work-in-heat duration is to be increased from 2 hours per day to routine practice. Re-acclimatisation is required after a prolonged leave, but no exact number of dates is specified. Hydration is specified, where supervised drinking or "water parades" are recommended to ensure workers are properly hydrated. More specifically, WHSC suggests a WBGT-based threshold system for evaluation of risk levels, i.e., less than 31°C, low risk; 31 - 31.9°C, moderate risk; over 32°C, high risk. The thresholds give some certainty in risk assessment, but it is difficult to implement or act on, as accuracies of WBGT metres available in the market range from +/- 0.5°C to +/- 2°C, and the thermal environments on construction site are too diverse to monitor and respond respectively. The regulation provides reference values for protection but cannot practically work for an economy in a tropical climate, practical development in Singapore for managing heat stress are focused on wearables and technological innovation.

The working population of the construction industry in Singapore

The working population of Singapore's construction industry is characterised by a large amount of international migrant workers from China and Southeast Asia due to Singapore's skill shortage particularly for unskilled workers (Huang and Yeoh, 2003). Migrant workers are reluctant to see a doctor or notify their supervisors on their latent health conditions, due to their job arrangement which pushes the cost of sick leaves to individuals, uncertainties in their health insurance or fear of losing their job (Lee *et al.,* 2014). They also need to cope with precarity and discrimination in the work environment (Hamid and Tutt, 2019), as well as communication and cultural barriers (Dutta, 2017). Yeoh *et al. (*2017) report that international construction workers in Singapore are required to long work hours without the power of negotiation, constrained by their time-bound work visa which often deprived them certainty and mobility. Their off work living spaces are lack of legal protection, confronting them with personal security issues (Huang and Yeoh, 2003). Thus, at times of conflicting commitments, they are left vulnerable to fatigue, distraction, pressure and mistakes, therefore more vulnerable to accidents. However, not all international workers are having the same extra issues to cope with. Ling *et al. (*2013) examined international workers of different home countries and their patterns of handling conflicts and disputes within the top-down regime of Singapore. They found workers from Thailand had least issues; Chinese workers suffered from poor safety awareness and inability to solve disputes, while worker from India were found lack of initiative (p.25). These extra issues and patterns compound heat stress confronting workers on site.

The official record of Singapore's Ministry of Manpower (MOM) marks six or less heat-related injury cases every year. However, in 2012 alone, Singapore General Hospital reported around 150 heat stroke cases. Such contrast indicates a potential gap of underreporting heat related incidents. A review of practice is needed for comprehending how frontline staff are coping with heat stress and making sense of relevant regulations or supplementing them with bottom-up self-initiatives.

RESEARCH METHODS

Based on the contexts reviewed above, wearable personal protective equipment (PPE) was identified as a useful approach to tackling heat stress on site in Singapore. A concurrent study was designed to test the effectiveness of a commercial water-cooling headgear used amid daily on-site practice (Fellows and Liu, 2015). An experimental study was designed to test the effectiveness of a commercial water-cooling headgear applied in daily practice on site. For conducting the experimental study without interfering with the ongoing practice, the research team explored options of non-intrusive technologies for monitoring and measuring relevant parameters. In parallel, ethnographic study was conducted on the participating sites to understand local work context and tradition of coping styles.

The water-cooling headgear

The water-cooling headgear under test is a commercially available heat prevention headgears that protect the user's neck from harmful ultraviolet rays of the sun, preventing sunburn while keeping the head cool. Its flap can be detached from the cap and immersed in cool water, or rotated for targeted cooling (Fig 2). The headgear is made of superabsorbent fibre which is light-weighted and soft, effective in absorbing and keeping water. The fibre has anti-static and antibacterial properties which is highly suitable for physically strenuous and sweaty exertions. Innovations of this product include utilisation of water evaporation effect, UV protection and its self-cooling textile. The lifespan of the fibres is limited to 100-120 number of times of wash, which means 3- 4 months of continuous usage.

Fig 2: Headgear tested in the experimental study

Research design

A total of 35 participants (healthy rebar and carpentry workers) were randomly selected among the outdoor workers on a construction site in Singapore to participate in the experimental study for two weeks in June 2018. Five of the participants dropped out during the study, the data of whom were thus excluded from the analysis. The participants were divided into an experimental group (wearing the water-cooling headgear at work) and a control group (normal work without extra headgear) in Week 1 and switched groups in Week 2 so that each participant had a chance to wear the water-cooling headgear once. Thus, in data analysis, the control and experimental groups were the same people with and without the headgear at different days of the study period. The participants' body temperature (face) was assessed every 30 minutes during 13:00 to 14:30. WBGT on the site was recorded at five-minute interval using a thermal imagery EXTECH HT30.

The most direct measurement for heat strain is body core temperature. Ingestible telemetric pill seemed to be a popular means for measuring body core temperature (Notley *et al.,* 2018), but it is intrusive and associated with health risks on the participants. A non-intrusive technology, thermal imaging, as it has lowered price for lay people usage, was thus adopted in this study. Thermal imagery Fluke Thermal Imager TiR32 was used for measuring heat strain on site (Fig 3). The validity of taking body temperature with thermal imaging was recently recognised by the World Health Organisation.

Fig 3: Taking participants' body temperature using thermal imagery

Concurrent to the experimental study, ethnographic data was collected by the first author through on-site observation and six focus group discussions, each involved approximately 5 participants. The sessions were conducted during their tea break time at 3pm. All focus groups were conducted in the local language (Hindi, Chinese, and Tamil) with the help of the bilingual participants and site coordinator. The focus groups explored usability of the headgear, including its comfort, ease of usage, durability, acceptability and effectiveness. General background information of the work team such as workers' socioeconomic status, health protective resources, their perception of exposure to hot environments, experience of heat related disorders, and health measures adopted to cope with hot environment, was also explored through the discussions. On-site observations took notes on local wearables adopted by other workers in coping with heat stress.

Data analysis

First, the mean WBGT of the workplace environment in the two study sessions were calculated respectively. An independent sample t-test was conducted to check if the two days can be assumed to be a thermal environment of the same level. Second, body temperature data was treated and compared. Each individual participant in each study session had four measures of body temperature. The mean value of the four readings was calculated as a data point for further analysis. A paired-sample t-test was then conducted to test the statistical significance of the mean body temperature between the experimental group (with the cooling headgear) and the control group (without the cooling headgear). Third, a content analysis on the ethnographic data was conducted to contextualise the quantitative data analysis results. Fourth, a broader document search was undertaken to ground the findings into Singapore's existing policies, regulations and legislative context.

RESULTS

The Sample

The demographic information of the sample is summarised in Table 1. On average, the workers work 8-10 hours per day. 20 (66.6%) participants report that they are fully aware of the heat prevention measures adopted on site, 18 (60%) are very satisfied with the measures.

Table 1: Demographic information of the participants

	Mean (SD)	
Age	35.5 +/- 8.5	
Body height (cm)	167 +/- 8.7	
Body weight (kg)	64.3 +/- 8.8	
Years of working in construction	6.7 +/- 7.4	
Smoking/drinking habits	10 (33.3%) smoking	7 (23.3%) drinking
Trade	15 (50%) rebar	15 (50%) carpentry
Education	26 (86.7%) secondary	4 (13.3%) tertiary

Result of the Experimental Study

Mean WBGT of both study days were calculated as 26.4°C in Week 1 and 27.0°C in Week 2. Independent sample t-test comparing between the two weeks' data turned out no significant difference, indicating that heat stress levels of the two weeks can be assumed as the same. This condition ensures the levels of heat strain between the experimental group and the control group are comparable.

Body temperatures with and without the headgear are shown in Fig 4. The drops of temperature were observed in 29 (96.7%) of 30 within the experimental group. Significant differences in body temperature ($p < 0.01$) were found between the experimental group (M=34.8 ± 0.712) and the controlled group (M=35.2 ± 0.693). The results indicate the water-cooling headgear has a significant cooling effect.

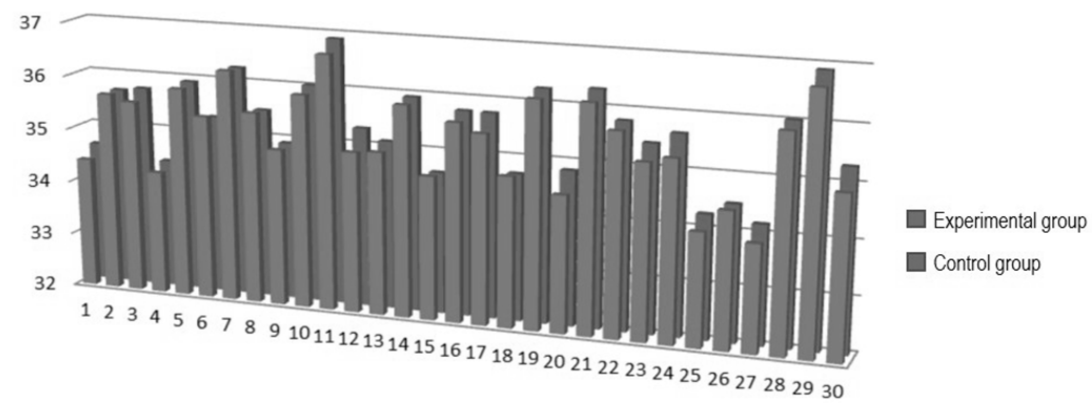

Fig 4: Comparison of body temperature data between the experimental and control groups

Results of the Ethnographic Study on Site

General issues and practices on site

Workers perceived a trend of increasing number of hot days in Singapore. They described their jobs as strenuous and physically demanding, with most of their time spent outdoors under direct sunlight or underground in confined spaces. The compulsory personal protective equipment, including hard hats, safety shoes, gloves, harness, safety vests, contributed to the overall heat load on workers; and this is associated with the sensation of hotness and dehydration. A quarter of the participants reported musculoskeletal pain from all the heavy works and early heat stress symptoms from working outdoors over the past few months during work. This number is likely to be higher, as the participants were filling the pre-intervention questionnaire at the presence of their supervisors, a constraint of this on-site study. Reported syndromes included rashes, flushed dry skin, dizziness, weakness/fatigue, nausea, loss of appetite, dark urine, headaches, blurred vision. Some complained of being light headed, irritable and exhausted.

Some of the workers made personal adaptation by wrapping towels and cloths underneath their helmets to protect their eyes against sun exposure or surrounding their necks with wet towels for cooling purpose. A notable observation when walking around on site was the presentation of similar cooling headgears that workers bought on their own accord which functioned similarly to the commercial headgear used for this study, which could be as simple as a towel or piece of cloth soaked with cool water. This pattern indicated that the mechanism of the water-cooling is aligned with local knowledge and work habits. 36.7% of participants found the headgear very effective in combating heat stress. One participant found it uncomfortable to wear.

Eye strain caused by sun exposure is another issue associated with heat stress, on which workers perceived that the provision of sunglasses would have protected their eyesight. However, management decided not to provide on concerns that it might hinder workers view at work. The workers were reluctant to report injuries to their supervisors for three reasons: (1) they perceived injury was part of their job; (2) they feared negative consequences from the employer; (3) taking leave from work meant lost wages and reprimanding in their work environment. Thus workers tend not to report or discuss their heat stress experience with their supervisors for fear of consequences on their employment.

Perception of the water-cooling headgear

The water-cooling headgear was perceived as heavy and inconvenient. Its effectiveness is dependent on the frequency of rewetting which is once every 2-3 hours. This could potentially create interference and distraction for the work on a construction site. When wetted, the headgear has a weight of approximately < 0.4 kg was reportedly heavy for the workers. Participants indicated neck strain caused by wearing the headgear. Therefore, the headgear helped mitigate the heat risk but brought in some ergonomic risk which takes more systematic assessment and planning. In spite of this risk, it is notable that 96.7% of participants agreed with permanent implementation of the headgear. Another concern by the workers was the cost of the headgear multiplied by its relatively short lifespan. Workers nominated alternatives of lower cost, such as a towel or those sold at sports retail outlets.

CONCLUSIONS

This study embedded an experimental test of a cooling headgear in a practice-as-usual site context and paralleled it with an ethnographic study to understand local tradition and vernacular patterns of coping with heat stress in Singapore. The results of the experimental study indicate that workers have significantly lower body temperature when using the water-cooled headgear as compared to a scenario without it. Results of the ethnographic study suggests that the headgear is consistent with local conventions of heat stress mitigation and therefore, as also verified by the quantitative study results, effectively fits for its purpose. The only factor for the adoption of the product would be a competition of price in the market. However, the frequent soaking needed for the headgear, which was found to interfere with the work, suggests such technology needs to be automated. The implication of this study is limited by the accuracy of the measurement instruments and the small sample size. In spite of the limitation, it is the first study to establish a realistic understanding of what’s going on in terms of heat stress management on construction sites in Singapore. The study has also tested the usability of thermal imagery for monitoring heat strain in human body. Although the accuracy of such device is to be improved, the study indicates it is a usable, non-intrusive, efficient and effective approach to instant monitoring of body temperature that can help ensure workers' safety in heat. This study serves as a pilot study on the review of heat stress management practice in Singapore's construction industry. Next steps of this series of study will focus on a full-scale review of the industry practice, as well as identifying appropriate technologies for automating the cooling heat gear.

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