Tuning into Heat: Acclimatisation on Construction Site and Horizontal Integration in Major Project Management

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Abstract

Acclimatization is a process in which human body adapts to a hot environment by developing capacities of more efficient heat dissipation and electrolyte retention. International heat stress management standards specify thresholds of up to 5 °C-WBGT difference for acclimatised and non-acclimatised populations, and a 3-14 days' period for newcomers to take up full workload. Such protocols if literally practised in construction projects would have a massive impact on productivity, and would particularly suffer major projects for uneven work pace and discorded team rhythms. Thus it takes a systemic tune-up to address it in major project delivery. The aim of this research is to explore the actual process of acclimatisation in the complex systemic context of major project delivery. Data were collected through an ethnographic study on a remote site of a megaproject in Australia. We found that inadequate acclimatisation as a major causal factor to heat related incidents on site, but not until added by poor individual situation awareness and behavioural response patterns. On this empirical basis, we attempt to redefine an extended concept of acclimatization for a working population embedded in the work context and personal histories and lifestyles outside of work. From a human-based systems thinking perspective, we further discuss the necessity of horizontal integration in major project delivery where safety is essentially an authentic approach of managing people in projects. We then define a broader concept for OHS management as *the preservation of human lives at work, including quality of life*. With this definition, we can take safety, health, wellbeing and fulfilment on the job under a single care and safety as an attribute of the complex project management system.

KEYWORDS: acclimatization, adaptive opportunity, heat stress, horizontal integration, major projects, systems thinking.

Introduction

The disruption of COVID-19 has forced a shift of thinking in many knowledge domains. To our field, the Hierarchy of Control (HOC) underlying OHS management practices (e.g., Safe Work Australia 2015) is turned upside down. HOC suggested a sequence of prioritizing hazard control choices from elimination, substitution, engineering controls, administrative controls, to PPE as the least effective measure and the last resort. Acting on this belief, initial governmental responses to the pandemic

hazard was lock-down and social distancing rules, legitimated by expert advice against wearing a mask. Four months down the path, the economic consequence of shutting down businesses and production activities has been catastrophic, which will eventually impact on the safety and health of a growing jobless population left in idling and isolation. Thus governments turned around to mandate the wearing of masks in order to keep the society running and people economically engaged. The upside down HOC now sees PPE as the most effective control in that it enables businesses operating in hazardous conditions. For OHS management in construction, such a learning curve implies that we need to be freed up from a single-disciplinary safety focus to embrace a broader safety concept, which takes a tune-up of the whole project delivery system. In this study we seek to understand construction workers' heat acclimatization in the complex system of project delivery and its implication on horizontal integration in major project management.

Heat stress on construction workers is a systemic issue for the construction industry (Tymvios et al, 2019). Over the past decade, empirical studies on managing heat in construction projects were undertaken, in which an important step for managing heat stress, acclimatization, has been underexplored. Acclimatization is human body's adaptation process of developing a stronger heat dissipation capacity and therefore more tolerance to heat stress. Acclimatisation is an effective approach to improve safety and productivity in heat, and the lack of it is a major factor accountable for heat illness incidents in construction projects (Jia et al., 2016b). International heat stress standards such as ISO 7243 and ACGIH ©TLVs prescribe environmental thresholds of up to 5 ^{o}C-WBGT difference between acclimatized and an unacclimatized working populations. For the construction workforce, 5 ^{o}C-WBGT difference will have a massive impact on labour productivity. Acclimatization protocols suggested a period of 3-14 days for a newcomer to take up the full workload. Whether this protocol works or not in construction practice, and how, is yet to be explored. In the context of major projects, the project as a complex system would find itself interrupted by uneven work pace and dissonant team rhythm. Through exploration of workers' acclimatization experiences in a megaproject in a hot and humid climate zone in Australia, we redefine an extended concept of acclimatisation, taking into account of adaptation behaviour, to address the embeddedness of the workers in the physiological context of their workplace. We then discuss the systemic tune-up needed for complex project management in trying to manage acclimatisation effectively.

Horizontal fragmentation and the systemic perspective

Fragmentation has been a long-standing characteristic for construction project delivery whereas safety management has particularly suffered from the invisible walls between organisations and professions in a project lifecycle. The OHS professionalism, the legal systems developed on it and the resulted project governance structure fan the flames of horizontal fragmentation (Smyth et al, 2019). As such, safety is educated as a separate discipline and practiced as 'another' job of construction projects, somewhat alienated from the project business (Lingard et al 2019; Jia et al 2017). Fragmentation between organisations in projects and its effect on safety has been indicated in Lingard et al (2011)'s survey in an Australian sample which found principal contractor's supervisors' decisions did not have a direct influence on subcontractors' workers' safety behaviours but through a path via subcontractors' supervisors. As an explanatory note to this survey result, the authors' field work on a megaproject site in Australia observed that a manager came across a worker engaging with unsafe behaviours, only to find himself unable to intervene due to the fact that they belonged to different companies. Similar phenomenon was observed by the first author with an experienced regulator in

varied types of projects in Australia, suggesting this is a rather normal construction management practice.

Armchair professor might find such observations hard to believe and argue that since WHS has been so well regulated in Australia, all parties should have been highly motivated to act proactively upon witnessing any unsafe practice on site. Interestingly, such fragmentation is exactly the outcome of the highly developed formal institutional systems in developed countries, where all parties for compliance's sake try to adhere to their own legal obligation and avoid taking up the extra risk of acting beyond it (c.f. a more detailed discussion in Jia et al 2017). In contrast, more holistic managing and caring practice was found in developing countries where formal institutions were not yet developed to the level of mediating how people make sense of safety in their work context (Jia et al 2019b). At this point, developed countries have something to learn from developing countries. An anthropologic approach is needed in construction safety research to reflect more fundamentally on how systemic improvement can be made in managing complex projects.

Acclimatization as a physiological adaptation process

Acclimatization is a heat adaptation process that involves a series of physiological adjustment within the human body. An acclimatized body has an improved ability in dissipating heat through more sweat, better retention of electrolyte and reduced arousal in Plasma renin activity and aldosterone concentration levels (Finberg and Berlyne 1977). Earlier physiological studies found that acclimatization makes human blood able to carry more oxygen (King et al., 1985) and more fluid (Bonner et al. 1976). King et al (1985), for example, found that after 8 days' acclimatization, human body developed an enhanced physical capacity by reducing muscle glycogen utilization. They conclude that acclimatization changed fuel selection within the body during submaximal exercise. Acclimatization can be automatically triggered when a person is exposed to a hot environment or climate, but not always. Physical activities must be carefully controlled during the period of acclimatization to prevent the occurrence of heat illness. In athlete training, artificial acclimatization is sometimes deliberately used to improve the body's functioning in performing highly intense exercises (King et al. 1985). Occupational hygienists typically suggest an acclimatization protocol a period of 3-14 days' gradual increase in exposure to the target level of heat stress (e.g., MOM 2012, AIOH 2013, ISO 7243: 2017). It is also known that acclimatization starts losing after 4 days' away from the exposure and is completely lost after 3-4 weeks (ACGIH 2015: 218).

Acclimatization and thermal thresholds

ISO 7243 (2017) gives separate sets of reference values for acclimatized and unacclimatized workers, e.g., up to 5 ^{o}C-WBGT in the 'very heavy' workload category. The ACGIH (2015) provide Threshold Limit Values (TLVs) for acclimatized workers and the Action Limits for unacclimatized workers, up to 3 ^{o}C-WBGT difference between the two. In the current construction practice, the work rules are treating all workers as fully acclimatized, although a formal acclimatisation protocol is rarely in use (Arbury et al. 2014, Dong et al. 2019).

Table 1. Threshold values for acclimatized and unacclimatized workers (Unit: ^{o}C-WBGT)

Workload [Met (W)]	ISO 7243 (ISO 7243, 2017: 7) Reference values: acclimatized / unacclimatized	ACGIH (2015: 222) (TLV / Action Limit)
Light (180)	30 / 29	31 / 28
Moderate (300)	28 / 26	28 / 25
Heavy (415)	26 / 23	- / -
Very heavy (520)	25 / 20	- / -

Adaptation: physiological, psychosocial and behavioural

There has been a long debate between the rational and the adaptive approaches to modelling thermal comfort (Fanger 1993, Baker 1996, Humphreys and Nicol 1996, Nicol 2004, Candido et al. 2015, de Dear et al. 2018). The rational approach (Fanger 1970; ISO 7730: 2005) assumes a tight coupling between thermal environment and human sensation and satisfaction. It assumes thermal balance within the human body leads to dissatisfaction associated with non-neutral thermal sensation. However, Baker (1996) argues that such deterministic logic only exists in a highly controlled environment such as a climate chamber, where people's adaptive opportunity is deliberately eliminated. In contrast, the natural human being in a free-running building environment will be prompted by any sense of discomfort to take a range of adaptive actions to create and modify their immediate thermal environment. Occupants' adaptive actions include, for example, modification of clothing, change in work pace and therefore metabolic rate (Nikolopoulou et al., 2001), hydration (Baker and Standeven, 1997) and interaction with the physical environment to construct a better local environment (Nicol 2004). Such adaptive actions are almost simultaneous to the perception of the environment, thus become intertwined with the environment itself.

On this basis, the adaptive school lays stress on the embeddedness of the perceiver in his environmental and psychosocial context, and the coupling of adaptive actions altering the perceiver's immediate environment. Humphreys (1978) shows that the perception of indoor thermal comfort is associated with the monthly variance of outdoor temperature. Baker (1996) suggests behavioural and psychological factors play a more important role in thermal comfort than the four environmental factors do; while small adaptive effects add up to make a significant difference on the overall thermal environment that is being sensed and perceived. Baker and Standeven (1996: 176) put forward a model that explains how thermal environment is interrelated with thermal sensation through modification actions that are almost simultaneously prompted by the actors' perception and preference of the thermal environment. The key factor to comfort is thus the presence and extent of 'adaptive opportunity' in the specific environment. Actors' thermal sensation of their local condition is mediated by posture, adjustment of metabolic rate and clothing. The model also shows that thermal sensation does not necessarily lead to satisfaction; the path is moderated by psychological factors.

Relevant to the outdoor environment of a construction site in this study, we are reminded that, between the workplace environment and human thermal sensation, workers are situated in a 'local condition' that varies spatially on site and temporally over the project lifecycle and by seasons, days, hours and minutes. Such differentiation is captured by a socio-ergonomic grounded theory (Jia et al., 2016b) which draws a distinction between 'heat hazards' (heat in the natural and work environment) and 'effective heat risks' (heat at one's immediate environment) (Jia et al., 2016b: 29). Effective heat risks lead to the onset of heat illness, followed by more serious consequences and fatality. This phasing of the heat illness development process allows intervention measures to be mapped into the right timing in their best effectiveness. The model highlights that thermal sensation may not work as a signalling mechanism in the extreme situation of heat stress on construction site where adaptation opportunities are constrained by the work regime. In a structured work setting, thermal sensation is competing with sensations of many other stimuli for actors' attention to trigger adaptive actions. How thermal sensation wins or loses the competition is largely determined by the prevailing institutional logic in the psychosocial environment. Jia et al (2019) found when the whole project team was

preoccupied by progress pressure, the warning signals related to personal safety are likely to be overlooked or ignored. In such situation, heat illness incident happens.

Research Methods

The research took an ethnographic approach (Hammersley and Atkinson, 2007) with fieldwork from a megaproject on a remote site in a hot and humid climate zone in Australia. Through triangulation of findings from mix-methods, we try to re-construct an authentic reality on the gestalt of acclimatization through exploration of construction workers' experiences on site. The ethnographic study was conducted by the first author over a period of two weeks in the summer of 2015 and 2017, respectively. The fieldwork generated a large amount of data including on-site heat stress recording, project documents, field notes from interviews and observations. The second author, who was working on the project for long term, did verification on the observation and validation on the authenticated cases. In both field studies, heat stress data were recorded at typical workplaces. Year-round temperature and humidity record from the nearest Bureau of Meteorology (BoM) station was purchased from BoM. After triangulation of multiple sources of data, a grounded theory approach was employed to identify key concepts that explain the data. Some of the findings have been reported in separate papers (Jia et al., 2016a, Jia et al., 2018, Jia et al., 2019a). In this paper, we focus on findings on acclimatization issues.

Results

The megaproject is an LNG onshore facilities construction project, located on the seaside in around 45 minutes' drive from Darwin City in Northern Territory (plus another 45 minutes from site entrance to the project office). At the time of the field studies, there were about 8000 workers working on site daily under 99 subcontractors' project organizations. Except a few local workers, the majority of the workforce worked in a fly-in-fly-out (FIFO) mode, on a roaster of 4-weeks-in-1-week-out. The on-site heat stress level is far over the limit recommended by ACGIH, ISO 7243 or AIOH, and a gap of up to 7.7 ^{o}C between the local temperature and that recorded in the nearest station of Bureau of Meteorology (details reported in Jia et al., 2018). If these standards were literally implemented, there should have been no work activity going on in most of the days in this region. However, the project was implementing a 58-hour working week at the time of study. The gap between the reality and the standards indicates the effect of human adaptation activities. Common to a task-oriented construction site elsewhere in the world, frontline staff's first perception about heat was the operability of the construction material (e.g. the China cases in Jia et al., 2017, 2019b). Similar observations were made by several managers and foremen in this Australian project, "When the weather is too hot, the material (the metal scaffold) can't touched. We must wear gloves." The major strategies of controlling heat stress on site are two folds: provision of cool water and entitlement of 'heat break'.

Is the week-out a source of de-acclimatization?

Initially, the researcher was concerned that the monthly week-out might be a source of de-acclimatization that leads to heat illnesses on site. The ethnographer thus explored around this inquiry with the workers and managers on site.

Ethnographer: *Any issue with the one-week-off when people just come back to work?*

Foreman: *No. Because you know to work slower. Don't keep up on the first day. It took around 2-3 days back to full workload*.

Lack of acclimatization as a cause of heat illness

However, acclimatisation was indeed a major cause of heat illness on site. A foreman stated: "*We got most of these issues with the new guys. They were vomiting.*" An old worker reported that he had heat illness on the third day of coming on site.

Why newcomers are vulnerable to heat illness? A few observations and interpretations were made by foremen, senior management and safety advisors. An immediate observation was:

- "*They were not drinking enough water*."

This was related to a range of off-work activities:

- *"I would mention about afterwork contributing factors of Alcohol consumption and personal activities sports, football, tennis, swimming pool laps …ect and food diet*."

Furthermore, there was psychosocial pressure of working in a team on site:

- "*Newcomers try to prove themselves*."
- "*Newcomers wanted to impress the crew*."
- "*They don't want to be left out. They want to keep up to prove they are productive*."

An overweight worker mentioned that when he was a newcomer, he once fell, lost consciousness:

Ethnographer: *How long did it take you to fully recover?*

Worker: *I recovered at that night. I took fluid and monitor. Then the next day I tried not to keep up. After that I knew the limit of my body. I work slower. Don't rush. It was a lesson to learn. It took 2-3 days back to full workload*.

Time scale for full acclimatization

Exactly how long does it take to develop a full acclimatization to adapt to this hot and humid work environment? A worker suffered from heat illness at 2 pm on a Friday of Week 5 on his commencement of work on site (date: 20 January 2017). Two weeks later, the incident occurred to him again.

thnographer: "*How long does it take to adapt to heat?"*

Foreman: "*Back from the one-week-off, it took 1-2 days to adjust*."

Safety Advisor: "*Newcomers took 2-3 weeks to adapt. They complained about the heat*."

A worker from Sydney: "*Three months*."

A worker from Melbourne: "*I'm here for two years, still not used to it*."

A worker having lived in Darwin for 12 years: "*It took me six years to really adapt to Darwin's climate. It is not only about the body, but also about your life habit, how you eat, and how you respond*."

Safety Advisor: "*Living here for 25 years will be classified as local*."

It was evident that acclimatization did not work as the physiological model suggested. Full acclimatization was achieved in a wide variety of time scales, ranging from zero day to six years. The FIFO workers' one-week-off following every four weeks' on-site work did take re-acclimatization, but was not a major factor to cause heat illness, given conscious self-management was practised.

Psychosocial acclimatization

A worker from Sydney mentioned that he had a heat illness incident at around mid-day, right after lunch, in August. "*I hit the wall, flat out. I was carrying some loads*."

When the ethnographer explored his activities before the incident, he mentioned that he drank overnight. "*For breakfast, I only had coffee and nothing else. I was quite young and fit. I had done this way all the time. Now I work a lot slower to adapt*."

Does this worker have a lifestyle peculiar from the majority of the construction workforce? The answer is NO. When the ethnographer mentioned this to the Project Director, who was from Melbourne, the Project Director said,

"*I did the same, for many years*."

– which indicates the worker's lifestyle is rather an industry norm than an exception.

A young worker from Kent (a dry hot climate zone) was in his Week 3 on site:

"*No heat stress yet. I had once fell down. From that I learned the lesson. I must drink a lot of water*."

In this case, the worker kept himself safe in this environment where many newcomers had acclimatization issues because he had learned a lesson from his 'thermal history'.

A team of three workers formed a buddy group to stay safe in heat, "*We watch each other. If anyone is not right, we tell him to sit down have a shade break*." In this case, the workers adapted to heat through a social approach.

Discussion

Acclimatisation in the psychosocial context of construction work

A number of recently developed scales measure thermal environment with psychometric tools. Isotherms, such as Effective Temperature (ET*) or Standard Effective Temperature (SET), indicate that human sensation genuinely synthesizes aspects of the thermal environment around and adjusts one's expectation on temperature or humidity according to the level of other parameters (Zanni, 2016). The adaptive thermal comfort theory (Nicol and Humphreys, 2002) recognizes that people react to feelings of discomfort to restore their comfort. We shall be aware that within the individual body, the sensation that needs to be mobilized to trigger adaptive action is different from the sensation needed to perceive comfort. Working on a construction site under strong sunlight in a hot weather is hardly comfortable, e.g., as data shown from the same construction site reported in Jia et al (2018), the WBGT values recorded on site far exceeded the action triggering threshold prescribed by ACGIH or ISO 7243 in a normal working day. There is no adaptive opportunity for workers to stay comfort by avoiding physical activities in their designated workplace. On the site of a major project, how effectively can workers mobilise their sensation to respond precisely to a personal safety threshold condition on top

of a sensation of discomfort? This is closer to the situation of athlete training or competition (Coris et al., 2004). The population of a certain occupation have more or less collective lifestyle and response pattern, such that the findings of occupational heat illness causalities are different from what was expected from a general public population. Furthermore, we shall be reminded that a large part of human behaviour is rational and nominal (Jia et al., 2017). A person's rational decision of action is constrained by his/her scope of attention, driven by his/her intention and preference (Fishbein and Ajzen, 2010, Goh et al., 2018, Jia et al., 2019a). Thus embedding into construction context, as reported in Jia et al (2016b), people's adaptation behaviour is so intertwined with their psychosocial environment such that some factors, e.g., age, may not predict the same heat strain outcome in a work setting as they do in a laboratory environment. This study sheds more light to the collective characteristics of construction workforce differentiated from that of a general public population; as can be seen from our findings, the lifestyle of having coffee only for breakfast for the morning shift was shared by both the workers and senior management.

Redefining acclimatization

Findings of the study confirm our proposition that acclimatization is a complex adaptation process that needs holistic adjustment in response to climatic, physiological and psychosocial stimuli. The difference between the climate zone where the worker is brought up and the climate zone where the worker works is a factor to be considered. Nonetheless, the adjustment in lifestyle and behaviour is more important than physiological acclimatization. Acclimatisation involves adaptation of personal life habits and response patterns to various stimuli in a holistic situation. Human activity of changing clothing is one of the behavioural responses to thermal discomfort. While physical activity itself will influence the amount of metabolic heat generated within human body and therefore the heat load on human body. Comfort, or even health, is a dynamic equilibrium between the people and their environment. Each person has a calibrated line of a personal thermal neutrality. Acclimatization happens within human body, but if we treat patterns of decisions and actions as part of one's personality, we may extend the periphery of acclimatisation to include adaptive actions. Early research has found that in an environment of ample adaptation opportunities, through adaptive activities, the natural human being makes himself a thermal environment of 1.5 ^{o}C-ET lower than the average of the ambient environment (Haigh, 1981). Taking cold drinks as an adaptation habit takes away 10% of the total metabolic heat at the hottest time of a day (Haigh, 1981), which is also reported in research in more extreme hot conditions by Miller and Bates (2010). Hydration is clearly a major coping strategy adopted by this megaproject. Engaging the psychosocial context, we can define acclimatization as *the personal equilibrium of preserving self-safety in a hot environment, which is adaptable within a range of behavioural freedom*.

Systemic adaptation for PPE

The development of smart cooling vests (e.g., Yi et al 2017) has promised a PPE solution which might enable the workforce to proceed their work without dealing with the acclimatization issues. Related to our findings that workers' personal heat histories and geographical origins that lead to diversity in their acclimatization needs, personalised fitting will be a major challenge for the new PPE to be successfully integrated into construction practice. The fitting work will also need to involve a comparative assessment of local climate and that of the workers' geological origin, incorporated in training for workers alertness at work in wearing the new gears, new hazards incurred by the change

and subsequent control measures. That is, the application of the new smart cooling vest in major project delivery will take a systemic tune-up in the project organisation.

Implications for major project management

The exploration into the complexity of acclimatization on construction site brings us back to the origin of safety management in construction projects: effective project management starts from a healthy and productive workforce (Duryan et al, 2020). Project safety management need to start from understanding the total worker (c.f., a recent reference of this concept may be found in Dennerlein et al, 2020). Safety in construction is essentially about a human centric approach of managing people in projects, by which we see the necessity of horizontal integration in delivering major projects (Rowlinson, 2020).

In the safety engineering literature, a socio-technical perspective of systems thinking was developed from experiences in aviation, patient safety, oil & gas, nuclear or chemical safety management, which have a liner engineering process as the core system (e.g., Dekker 2011; Leveson, 2016; Leveson et al 2020). These models no doubt offer great clarity and enhance safety as a discipline, but they may or may not reflect the nature of the system of construction projects. Jia et al (2019b) attempted to draw a distinction between the assumed 'system' based on an engineering core from the complex systemic context where construction safety is operated in, which is more akin to a socio-political system with an uncertain and ambiguous core of human-to-human interaction. A highly realistic depiction that unpacks the complexity of such human-based system of construction practice is found in Sherratt (2016). The findings of this study contribute to our understanding of a human-centred construction practice system, played out through numerous individuals of diverse life styles and personal histories. With this understanding, from an integrated perspective, occupational health and safety in construction may be more broadly defined as *the preservation of human lives at work, including quality of life*. With this definition, we can take safety, health, wellbeing and fulfilment on the job under a single care, and construct safety management as an integrative attribute of the project management system.

Conclusion

This research explores workers' heat acclimatization in the complex systemic context of major projects. Specifically we explored the diversity of individual acclimatization processes in a megaproject organisation in a remote location in Australia, which required 8000 workers rotating in a FIFO mode. Our finding suggests that effective intervention should start from understanding the multiplicity of personal historical contexts and project systemic contexts where the total workers are situated in. Embedded it into personal and organizational contexts, we suggest to redefine acclimatization as *the personal equilibrium of preserving self-safety in a hot environment, which is adaptable within a range of behavioural freedom*. At project level, the results suggest that a single disciplinary approach does not work effectively to ensure workers' safety and health under climatic heat stress, making a case of necessity for horizontal integration in major project management. A well developed and implemented acclimatisation protocol on site would reduce injury and improve productivity on site, but it will take a systemic tune-up for the complex project organisation to make it work. From an integrated perspective, we suggest OHS in construction may be more broadly defined as *the preservation of human lives at work, including quality of life*.

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