Adaptation of Local Communities to Climate Change

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Abstract

While we continue to develop policies to address the risks of climate change at the population level, it is no less necessary to address the issue of how to optimise the adaptive capabilities of communities. The uncertainties associated with the various putative climate change models suggest that attainment of adequate adaptive responses might well require specific strategies for achieving (a) greater understanding of the nature of the risks to communities and individuals from environmental stressors, and their likely impacts, and (b) improved resilience to the effects of these and other phenomena thought to be associated with climate change. The paper briefly suggests some ergonomic and educational principles thought to be useful and effective for this purpose. A specific example concerning the issue of outdoor work in increasingly hot climates is used to outline some specific strategies which can be applied for maintaining heat balance in respect of the 'adaptation phase' in the example stress response model. The potential for degenerative heat stress effects resulting from working in hot climates may thus be reduced, suggesting the possible application of such strategies for improving community adaptation.

Keywords: climate change, risk models, uncertainty, stress response, heat balance, resilience, ergonomics, adaptation.

1. Introduction

Communities require relatively stable environments to remain extant and to be productive. Such environments are characterised by *certainty*, with regard to seasons, production cycles, leisure activities and so on. Uncertainty undermines the sense of predictability with respect to the organisation of human activities. At the community and organisational level, for example, we can consider unpredictable weather patterns, production losses, changing regulatory of environments etc, each with concomitant economic effects. Other, entirely different risks to communities from climate change may arise from possible disruption of the complex ecological systems that determine the geography of vector-borne infections (malaria; dengue fever etc) (Beaglehole, 2003). This paper briefly discusses some pertinent physiological and psycho-physiological issues which suggest that adaptive strategies at the individual and community levels are important, as enabling mechanisms, for assisting adaptation of such communities to the uncertainties of climate change. In any case, whether we consider the effect of such uncertainties at the individual, organisational or community level, there is a specific, individual, psycho-physiological *stress response* involved, whose effects and influences must be recognised and understood in any attempt at mitigating a maladaptive response. We should firstly be clear about what we mean by *adaptation*: a dictionary biological definition describes it as 'any alteration in the structure or function of an organism or any of its parts that results from natural selection and by which the organism becomes better fitted to survive and multiply in its environment,' or 'the ability of a species to survive in a particular ecological niche.' From a purely physiological perspective, this ability relates to 'a *decrease in response* of sensory receptor organs, which include those of vision, touch, temperature, olfaction, audition, and pain, to changed, constantly applied, environmental conditions.' This is useful in understanding what is required for adaptation from individuals within human communities, but tells us little about the process of adaptation, which should also include other factors, such as psycho-social.

2. The Nature of Risks as Stressors Associated with Climate Change

It is firstly necessary to consider some characteristics of the problem of climate change. What is the nature of this problem and the type of risks apparently associated with the phenomenon? Hollnagel (2008) considers that the construction of realistic and effective risk assessment models for climate change critically depends upon our ability to *imagine what can possibly go wrong,* in which case it is therefore necessary to adequately understand the nature of the phenomena generating the risks. According to this author, there are three essential steps to address in relation to this ability:

a) *Confirming that there is actually a problem at all (ignoring influencing factors such as economic interest or political expediency).* This is not as simple as it may sound, however, as evidenced in the disparity of opinions among the scientific community in advanced Western societies;

b) *Understanding the possible mechanisms by which adverse outcomes may arise*. This requires, among other things, extrapolation of results from theoretical climate change modelling, which we cannot be absolutely sure of;

c) *The difficulty of thinking of ways to reduce the risk or the outcomes*. This is one of the most contentious issues at present, given the critical reliance to the economies of many countries upon fossil fuel energy sources.

In relation to b), it may be that the matter of <u>understanding</u> the nature of an event or phenomenon is the most important of the three propositions. It is also essential to the adaptation process, which, when successful, involves changes to the entire functional capacities of the human organism, according to the physiological definition of adaptation given above. We may understand climate change as a phenomenon arising from changes in the atmosphere attributed to rising carbon dioxide levels (from the continued exploitation of fossil fuel reserves) which affect the surface temperature of our planet. This is not a new understanding, however, but has been described as a phenomenon (at least within scientific circles), as long ago as 1895, when the Swedish scientist Svante Arrhenius presented a paper entitled 'On the influence of carbonic acid in the air upon the temperature on the ground' (Hollnagel, 2008). Understanding a phenomenon suggests knowing what to do about the information we have about it, particularly if it involves possible risks to our health, safety or well-being. One thing we can be reasonably certain of about climate change is that it involves associated potential and actual *risks*. According to Hollnagel, we can consider possible risk scenarios as being either *tractable* (manageable) or *intractable* (unmanageable) to a defined extent, and *coupled*, meaning that the elements within the system are somehow linked to a given extent. Thus we may consider as *tightly coupled* a system in which an event upon one element transmits to all other elements in the system (Hollnagel, 2008b). What is becoming apparent in climate change modelling is that we are dealing with a system (the ecosphere) which appears to be:

(a) *intractable*, meaning that we cannot manage the system effectively, and

(b) *tightly coupled*, meaning that the components of the earth's biosphere are inextricably linked (also a characteristic of the human body), so that anything we do to one part of the system has consequences (generally incompletely understood) which are transmitted to all other parts.

Both aspects of our putative models presently reflect a degree of uncertainty with respect to our current understanding of risk assessment in climate change. Such uncertainty usually carries implications of likely adverse consequences adding to the familiar array of other problems which currently beset human societies. However, this is not the only difficulty we encounter, as we also need to understand the 'mechanisms' by which adverse outcomes may arise, and how to eliminate the risk, or at least to protect ourselves against adverse consequences (Hollnagel (2008b). The latter statement-protecting ourselves against adverse consequences-is certainly central (and critical) to the adaptation process, and may be in the short term the only realistic thing we can do, given the intractable, tightly coupled nature of this phenomenon of the ecosystem. The following immediate aspects of the situation therefore should be noted:

a) the need to understand the nature of risks as *stressors*,

b) the need for specific approaches, both physiological and psychosocial, to facilitate adaptation processes in individuals;

c) The importance of *resilience* and *self reliance* as factors contributing to the adaptation processes of a community.

3. Risks as Stressors: The Non-Specific Nature of the Human Stress Response

Risks can be understood as *possibilities of harm* arising from exposure to a hazard. Such exposure functions as a *stressor*, which arouses a characteristic physiological *stress response* in vertebrates. The presence of risks to health, safety and well-being therefore has important physiological consequences to individuals. As stress is ubiquitous in association with human activities, especially in the current context, how might we define it? This is one of the most researched areas in the psychological and physiological disciples. Welford (1973) regards stress as *arising when there is a departure from optimal environmental conditions.......which the individual is unable to correct*. Another extensively researched approach was developed by Hans Selye (1907-1982), an endocrinologist, who suggested that all stimuli are 'stressors' that produce a general response of 'stress' in the affected person (he later preferred the more appropriate term 'strain syndrome'). With important implications for adaptation, he defined stress as *the non-specific response of the body to any demand, whether caused by, or resulting in, pleasant or unpleasant conditions*. Stress as such, like temperature, is all-inclusive, embodying both the positive and the negative aspects of these concepts. An individual's inability to 'cope adequately' with stressors results in various 'diseases of adaptation.' This phenomenon, which he called the General Adaptation Syndrome, comprises 3 phases: alarm, resistance and exhaustion, as summarised in Figure 1. In the first stage (*alarm*), the muscles become tense and heart rate, breathing and perspiration increase, generally preparing the body for the well-known *fight or flight* response. The second stage (*adaptation*) prepares the body for longer-term functioning in the continued presence of the stressor. In other words, the body *adapts* to the situation via its physiological mechanisms, *while continuing to manifest the response of the first stage* (emphasis added). However, if this adaptation phase is prolonged, without relaxation and rest to counterbalance the effects of the stress response, the overuse of the body's defence mechanisms eventually leads to the third stage (*exhaustion*), whereby resources (as reserves of energy) have been depleted, and actual illness or even death may result. In summary, the body's capacity to resist stress, and hence its ability to adapt to changed circumstances, diminishes over time if unaddressed. The p*erception* of what constitutes a stressor also plays an important role in the excitation of the human stress response, confirming its *psycho-physiological* nature.

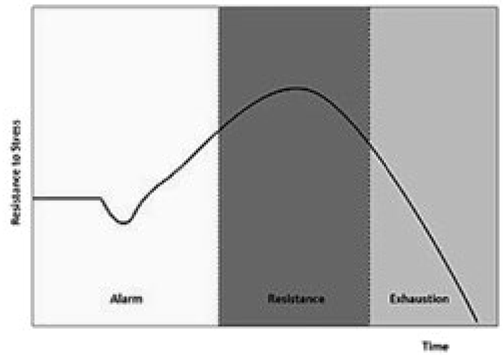

Figure 1 The three stages of the Selye General Adaptation Syndrome .

4. Stressors Associated with Climate Change

What types of stressors might we expect to be associated with climate change, causing excitation of the stress response? As discussed previously, lack of predictability with respect to human activities and environments constitutes an important stressor, that of *uncertainty*, being the result of the combined influence of the perceptual elements of risk, uncertainty and surprise, as reflections of our knowledge with respect to outcomes and probabilities (Schneider & Turner, 1994). A particularly potent stressor which produces pronounced physiological effects relates to working in (increasingly) hot environments. Physical work in such environments may lead to heart problems (because of the increased demand arising from the dual requirement to move blood from the body core to the peripheral vessels to regulate heat balance as well as maintaining gaseous exchange), increased accident proneness (as peripheral perception is reduced in the midst of multiple stressors), reduced *performance capacity* in work (because of *physiological over-arousal*; see Figure 2) and reduced capacity for *responsiveness* and *flexibility*, two elements essential for the individual adaptation process (because of reduced proprioception to the CNS as a result of the effects of the stress response (Selye). (These are only briefly mentioned here).

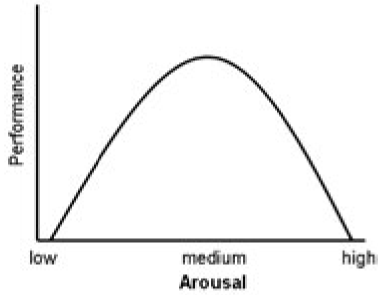

Figure 2 With respect to work activity, the Yerkes-Dodson (1908) Law links task performance with the state of arousal, or the state of physiological activation.

5. Outdoor Work in Hot Climates

Outdoor work is a significant contributor to the national economies of Southeast Asian countries, which have warm to hot climates which are possibly susceptible to exacerbation attributable to the effects of climate change. As well as its economic importance, outdoor work carries a significant risk in the form of increased exposure to outdoor heat, leading to some of the stress effects described above, which result in a form of perceived stress called heat stress. While few studies addressing climate change issues for these countries are available, a recent paper by Kjellstrom *et al* (2009) concerning the problem of outdoor work in hot developing countries (Southeast Asia in particular) suggests that...'increasing heat exposure due to local climate changes is likely to create occupational health risks and to have a significant impact on the productivity of many workers, unless effective preventive measures reducing the occupational heat stress are implemented. This ...... is much more difficult for outdoor environments (and) eventually will hamper economic and social development in affected countries unless appropriate preventive measures are taken in the planning processes for workplaces and urban development' (Kjellstrom *et al,* 2009).

Before addressing specific adaptation measures, we briefly consider the nature of specific problems associated with outdoor work in hot climates. As described earlier, these may occur at the physiological and psycho-physiological (as perception of heat stress effects) levels. Simply stated, the central problem is how to minimise heat accumulation in the human body. Much useful work has already been done in formulating strategies for reducing this problem, and recommendations formulated accordingly (eg NIOSH). These usually address external, environmental factors. This paper and this example concerns itself principally with some intrinsic physiological factors which contribute to the production of heat within the human body, as *metabolic heat*, in contradistinction to the heat acquired from the environment. As homeotherms, humans react to thermal environmental stimuli in a manner which attempts to preserve their internal body ('core') temperature within an optimal range of around 37°C. To ensure this, heat *inputs* to the body (from within and without) must therefore balance heat *outputs*, as expressed in the following heat balance equation proposed by Parsons (1995):

$$M \pm C \pm R \pm K - E = S$$

With respect to the terms of this equation, heat transfer can occur by conduction (K), convection (C) radiation (R) and evaporation (E), and if the net heat storage (S) is zero (S=0)) then the body may be said to be in *heat balance* and hence internal body temperature can be maintained (Parsons, 1995). Conduction, convection and radiation are factors which can vary within wide limits, and may be either positive or negative. Evaporation, however, is always negative, while metabolic heat (M) (produced by muscular work, ATP and oxygen metabolism etc) is always positive. While discussion and quantification of these parameters (eg use of whirling hygrometer, WBGT etc) are outside the scope of this brief paper, it is generally accepted that there are six important factors essential to the body's response to the effects of thermal (hot and cold) environments, these being temperature, air velocity, radiant temperature, humidity, clothing and the activity of the human occupants of the environment. While protective measures to optimise the effectiveness of these have been long established, clearly some difficulties arise (for example, for effective evaporation (E) in hot climates, exposed surface area of the body should be maximised, while it should be minimised to reduce UV exposure, and *some* exposure is preferred to allow the metabolic synthesis of Vitamin D). While much has been written concerning the role of evaporation in heat loss (involving values for the so-called *heat index*, a measure of subjective sensation of heat discomfort), and appropriate recommendations formulated (NIOSH, OSHA etc), the following discussion considers some aspects of heat production, as *metabolic heat*.

Metabolic heat production cannot be avoided, as it is the result of all (chemical and mechanical) processes within the living human body, but it can be minimised. Its effects are increased in the presence of *activity*, one of the six factors mentioned as important in the response to thermal environment. The second law of thermodynamics dictates that heat is the inevitable consequence of muscular work, as chemical energy (mediated by ATP, or adenosine triphosphate, which contains two usable high-energy phosphate bonds which are metabolised to provide required mechanical energy, at the same time increasing the *entropy*, or state of disorder, of the biological systems) converts to mechanical energy in muscles. The maximum efficiency of a contracting muscle lies between 18-25% (a surprisingly low figure, perhaps, but due to the fact that about 40% of available energy is required for ATP metabolism and catabolism, the rest for overcoming inherent mechanical properties and factors such as tissue viscosity, joint inertial effects and the various kinematics of limb trajectories, with actual muscle work eventually converting to heat within the interstitial tissues. This heat is removed by the general circulation, eventually transferring to the body periphery by the activity of the heart, which therefore performs a dual role both in maintaining circulation for respiratory and metabolic processes and by removing heat from the body core. Apart from formulating guidelines and recommendations for work hours, clothing, rest breaks, hydration etc, what else can be done, therefore, to assist physiological adaptation in individuals working outdoors in hot climates? The following considerations pertaining to some aspects of muscle physiology from the perspective of ergonomics are relevant:

a) The force exerted by a muscle is a function of its cross-sectional area, which suggests that the largest muscle groups possible should be engaged in the performance of a given work task;

b) The maximal active force of a muscle (producing the most efficient performance in terms of work output for a given energy expenditure) is generated at sarcomere (individual muscle fibre) lengths of about 1.2 times the natural, physiologically determined resting length (eg within the range 2-2.35 mm: the resting length of a muscle lies close to the mid-point of this range). Strategies to encourage chronically contracted muscles to release residual tension (as rest and specific exercises) would therefore be desirable to promote this condition;

c) If contraction of a muscle is too rapid, large proportions of energy are used to overcome inherent viscous friction within the muscle tissue itself, which reduces the efficiency of contraction and generates excess metabolic heat. Ordinarily, maximum efficiency is developed when the velocity of contraction is 30% of maximum (Guyton & Hall, 1997); Work should therefore proceed more slowly in hot outdoor work environments, suggesting that community involvement is desirable;

d) Muscular co-contraction represents a hidden form of static work - hence a loss of efficiency. It refers to the simultaneous contraction of agonist / antagonist muscles on either aspect of a relevant joint: ie *triceps* and *biceps bracchiae* around the elbow joint, for example, so that the force exerted by a contracting biceps muscle is opposed by contraction of the antagonist triceps muscle, referred to as internal loading, which reduces the maximum useful force exerted by the biceps, since energy is being expended in overcoming the opposing force of the triceps. If work is static and not dynamic, it is not being efficient. In general we should expect working techniques which minimise internal loading to maximise physiological efficiency (Pheasant, 1991). Skilled workers are much less prone to this type of inefficiency, therefore experience and training are important;

e) A generally unrecognised phenomenon concerns that of unconscious *postural set*, which constitutes a form of internal loading quite different from that of muscular co-contraction. As such, it can significantly lower efficiency. This is more difficult to address, requiring special training;

f) When excessive muscular tensions are released, there is increased blood flow to the periphery, so that heat loss via the mechanisms (convection, evaporation) is improved.

6. Community Adaptation: Resilience, Self Reliance, Judgement and Self Efficacy

Having discussed approaches to address the specific problem of physiological adaptation, what sort of psychosocial attributes might be required? People need to be able to demonstrate *resilience* against the coming challenges of climate change: (a 'resilient system' is one able to 'adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations even after a major mishap or in the presence of continuous stress' (Hollnagel, 2008). We may also loosely define it as an individual's ability to recover from, or adjust to, misfortune or change. There can be no doubt that personal qualities have an important influence upon the adaptation process. One of these, *self reliance*, is a major factor in determining the nature of one's responses to environmental influences, including stressors. A famous essay written in 1847 by the American writer R W Emerson describes such an individual as 'one who has the *capacity* to attempt a succession of enterprises (which may or may not fail)....' Self reliance, which the dictionary defines as '*the ability to do things and make decisions by yourself, without needing other people to help you...'* is extremely useful to the adaptive responses required with climate change phenomena. Self reliance is no mere psychological or psychosocial construct, but a reflection of a *state of development* of individuals which reduces dependence upon others, with implications for reductions in the stress response. We would expect the ability to *learn and profit* from our experiences to be a significant factor in developing self reliance, given the inevitable confrontations with our life experiences, climate change included, and communities should therefore encourage its development. A community comprised of such individuals is more resilient and therefore more adaptable to environmental changes, principally because stressors do not have such an impact that the adaptation phase of the Selye stress response model is excessively prolonged, with serious consequences for health.

7. Conclusion

This short paper is intended to be a relatively non-technical overview of the effects of environmental stressors upon human adaptation capacities, both physiological and psycho-physiological. The uncertainties associated with climate change present new challenges to human communities, and the more people are exposed to the effects of environmental stressors, the more salient becomes the need to effectively adapt to these relatively unpredictable phenomena. The approaches so briefly discussed here are among those thought to have the potential to contribute to enhancement of attributes enabling successful community adaptation to climate changes. It is worth emphasising that one of the most important requirements for enhancing the adaptation process undoubtedly involves achieving greater *understanding,* via education, of the phenomenon of climate change. If combined intelligently with the various approaches as described, the result will potentially lead to stronger, more cohesive and resilient communities having a greater capacity to meet the coming challenges.

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Methodological Issues in the Quest for Resilience Factors