Effects of Thermal Stress on Psychological Functions and Performance

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MEASUREMENT of cockpit temperature confirms the existence of significant heat stress in flight. In summer, fighter cockpit temperatures commonly exceed 50°C. Even though it may be technically possible to achieve comfortable cockpit temperatures to overcome this problem, the operational role of the aircraft precludes installation of a heavy cooling system and therefore a pilot is liable to be subjected to severe thermal stress. Flying is a complex psychomotor task requiring a high degree of alertness, mental function, muscular coordination and is adversely affected under heat stress.

There are several mechanisms through which heat stress might be expected to affect human performance capability. The primary mechanism is a rise in internal body temperature with resulting increase in the rate of neural activity. Other mechanisms are far more tentative and subjective. It is expected that initial exposure to elevated temperature would cause an increase in the general level of arousal resulting in improved performance. With continued exposure it is followed by feeling of discomfort, lassitude, subjective fatigue, inconvenience and distraction caused by sweating.

Performance is related to core and skin temperature. Allnut (1969) reported that when the core temperature was raised by seating the subject in hot environment under high radiant heat and then the skin was cooled rapidly by the use of liquid cooled suit, the subject had a high core temperature together with a low skin temperature and that under these conditions the subject felt comfortable. The increase in rate of performance was the same as it had been in an equivalent hot environment, but while performing a task, error rate was reduced, implying possibly that the temperature of the core determines the speed of performance, whereas skin temperature (or comfort) determines the error rate.

Certain factors enhance or lessen the thermal stress :

(a) *The severity of the stress.* The effects not only depend upon its physical intensity, but also on the individual's tolerance to heat.

(b) *The rate of application* influences the effect of thermal stress. Edoholm (1963) found that on-site acclimatisation improved physical performance though mental performance remained relatively unaffected.

(c) *The duration of the stress.* When the environmental temperature exceeds comfort levels, the physiological compensatory mechanisms come into play to maintain stable internal body temperature. If the heat input exceeds the heat dissipation capabilities of the body, the internal temperature will slowly rise. Longer the duration of exposure more is the heat accumulation and consequent stress.

Blockley et al (1954) suggested that performance decrement occurs significantly at a body heat storage level about 70% of that at tolerance limit. In well acclimatised tropical subjects the level of heat storage at tolerance point as calculated by Verghese and Sinha (1969) is about 110 Kilocals and a performance decrement occurs when about 70 - 80 Kilocals are accumulated.

Wing (1965) in his review of fourteen experiments conducted in various laboratories, assessed the effects of high thermal stress on mental performance. The experiments were conducted at different combinations of exposure time and effective temperatures. The results of these studies indicate that upper thermal limit for unimpaired mental performance varies significantly with exposure durations. The lowest test temperatures yielding statistically reliable decrements in mental performance declined exponentially as exposure durations were increased to four hours. It was confirmed that human performance deteriorates before physiological limits are reached. In studies of less than one hour duration, decrements in performance occurred at 38.1° C. The values for 2, 3 and 4 hour exposures were 31.7°C, 30.9°C and 30.6°C respectively.

(d) *The presence of other stresses.* Most real life or operational situations concern multistress environment. Broadbent (1963) suggested that the effect of two stresses together might be indifferent, additive or deductive and the same holds true for heat. Dean and Mc Glothen (1962) found that heat and hypoxia had an additive effect on primary task and greater than additive effect on secondary task whereas heat and noise had less than additive effect on secondary task. Heat together with noise and hypoxia had less than additive effect on a primary task and an additive effect on a secondary task. Allnutt (1969) found that heat and hypoxia in isolation increase the number of errors made on a standard intelligence test and that the two in combination have even greater effect. Whereas heat speeds up performance this effect disappears when hypoxia is added to the environment.

(e) *Man.*

i. *Physical conditions* The degree of acclimatisation and fitness have important psychophysiological effects on performance when exposed to thermal stress.

ii. *Intelligence.* Blockley and Lyman (1950) generalised that the more intelligent the man is, the better will he be able to cope with thermal stress and generally be able to generate more possible solutions to a problem.

iii. *Personality.* It could be argued, for example, that introverts require more training and reassurance than extroverts when they are exposed to a novel situation and more neurotic subjects may tend to be more upset by the experimental environment. Wearing a liquid cooled suit or waiting to go into the hot cockpit may be anxiety provoking long before heat is added to the situation.

Human performance tests used in heat stress research have been grouped into five broad classes, viz., neural activity rate, reaction time, vigilance and monitoring, tracking and cognitive functions. It is important to know what kinds of human performance are affected by heat and at what temperature levels impairment of performance is severe enough to be of practical concern in critical situations. Zone of maximum comfort ranges between 22° C and 24° C. Until about 1964, work on thermal stress was confined to studies in which performance was related to ambient thermal environment, but more recent studies have usually attempted to relate performance to body temperature.

Body Temperature and Neural Activity Rate. A direct physical effect of ambient heat exposure is elevation of body temperature. Because of its effect on metabolism, the elevation of body temperature would increase the speed of nerve conduction, with possible effects on performance. Hoagland (1933) showed that the speed of counting increased when body temperature was elevated. He interpreted these results in terms of " internal chemical clock" that speeded up as body temperature was raised. More recently other investigators have shown a consistent relation between elevation of body temperature and such tasks as estimation of time duration, speed of counting at 1/sec rate, and speed of tapping.

Reaction Time. Any speeding up of neural activity caused by heat exposure would result in shorter latencies in simple reaction time measurements. Kleitman et al (1938) showed that reaction times were shorter when persons were at peak of their diurnal temperature cycle. They observed that heat exposure speeded up simple reactions while causing slower performance on more complex reaction time tasks.

Vigilance and Monitoring. Vigilance and monitoring functions have in common the watching or listening for certain prescribed events. Vigilance tests involve the detection of near threshold events, usually in a single display. Monitoring involves scoring at multiple display tasks in which the events to be detected are considerably above threshold. Observations by various workers suggest that vigilance is best at an environmental temperature of 26.7°C.

Tracking. Performance changes hover around zero until the environmental temperature reaches about 29.4°C, but at higher temperatures the general trend is downward.

Cognitive Functions. The type of tests covers a broad range of complex tasks. All of them involve considerable amount of reasoning, judgement or other kinds of central nervous activities. Cognitive performance scores remain approximately normal or even surpass normal levels, until environmental temperature exceeds 29.4°C and above this temperature the trend is downward.

Conclusions

The problem of thermal stress is encountered in a wide variety of operational situations. Several mechanisms come into play as the environmental temperature is raised, some of these being beneficial and others harmful to human performance. Beneficial mechanisms are the speeding up of neural activity, increased level of general arousal and increased motivation caused by the subject's desire to "prove he can taket it". On the other hand, one can postulate mechanisms that will cause decrements in performance. These are internal physiological stresses, subjective feeling of discomfort, fatigue, inconvenience and distraction caused by sweating.

It is not necessary to eliminate completely heat induced psychophysiological strain so long as it does not induce decrement in performance. Cooling measures which extend tolerance time by delaying acquisition of heat storage and limiting it below critical levels at which performance decrements occur, should be aimed at.