Temperature Induced Changes in Neuromuscular Function: Central and Peripheral Mechanisms

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ABSTRACT

Two fit male subjects each performed three series of experimental tests in both an elevated or depressed thermal condition. Tripartite series consisted of whole body immersion excepting the head; whole body immersion excepting the head and response limb; and discrete response limb immersion. Measures of physiological and behavioural response were made at sequential \(6^\circ\)C changes during whole body immersions and approximately \(5^\circ\)C changes between the limb only manipulation. Results suggested that nerve conduction velocity decreased with thermal depression. Premotor, motor, simple, and choice reaction times varied differentially as a function of the hot and cold conditions. Implications of these differential effects on neuromuscular function are examined with respect to person-machine performance in artificially induced or naturally occurring extremes of ambient temperature.

INTRODUCTION

The human operator is exposed periodically to non-optimal work conditions and on such occasions impinging environmental stressors can radically affect capability. One of the most frequently occurring and disruptive of these stressors is extremes of ambient temperature. Perturbations from normative or comfortable thermal values may be due to geographical location or the artificially generated by-product of manufacturing or storage processes. Depending upon their severity, such extremes may induce variation in either the peripheral or peripheral and deep body temperature of the exposed individual. While the physiological effects and potential thermal health hazards have been fairly well documented, concomitant variation in cognitive and psychomotor performance has remained a largely confused area of investigation. Recently, empirical analyses of these latter effects have been reported, with particular reference to efficiency in person-machine systems (Aird, Webb, & Hoare, 1983; Hancock & Dirkin, 1982). The present paper seeks to extend upon such research and reports on variation of neuromuscular performance under systematically driven increments of both thermal elevation and depression.

The effect of temperature upon simple neuromuscular abilities may be dichotomized into central (CNS) and peripheral (limb) components. The central element includes capacities such as signal detection, information processing, and response selection. Increases in CNS temperature results in enhanced brain blood flow, higher nerve conduction velocity (CV) and elevated metabolic activity. Moderate changes in CNS temperature may heighten behavioural arousal which has been suggested as the mediational process involved in performance enhancement under such thermal conditions (Poulton, 1976). Further deviations from normal CNS temperature require thermoregulatory action and this process has been postulated as demanding attentional resources. Consequently, less resources are available in thermal extremes for task performance and the capability of the individual suffers (Bell, 1981; Horay, 1979).

The peripheral component of a response mechanism is composed of motor neurons, the neuromuscular junction, and characteristics of the muscle, tendons, and joints of the biokinetic links utilized for action. Nerve conduction velocity varies as a function of temperature above the blocking threshold noted in the range \(5-10^\circ\)C (Paintal, 1973). In addition to changes in peripheral neural transmission, differences in limb temperature affect components of muscle and associated structures.

The effects of such temperature variation or components of simple neuromuscular function should be manifest in measurable changes in tasks such as simple and choice reaction time (RT) and movement time (MT). However, because of the piecemeal nature of previous research, no overall pattern or results has emerged. Many studies have reported facilitation (e.g., Kleitman, Titlebaum, & Feveson, 1938; Lovingood, Blyth, Peacock, & Lindsay, 1967), decrement (e.g., Fraser & Jackson, 1955; Shvartz, Meroz, Mechtinger, & Birnfeld, 1976), and no change (e.g., Peacock, 1956; Teichner, 1954) in performance. These rather diverse results are not due to simply experimental error. Rather, they reflect certain complex interactions between differing elements of the individual, the specific RT task, and the operational environment. In addition, many studies have confounded both temperature and performance variables, making viable cross-study comparison an arduous task. One of the most important omissions from many investigations has been the recording of peripheral and core body temperature changes of the active human respondent.

In consequence, the present study employed an indwelling thermocouple to measure limb temperature as well as temperature at the rectal and tympanic site to index changes in central temperature. In contrast to previous
research which has taken limited observations at operator temperatures governed by environmental conditions. The present work utilized a regime whereby observations were taken at increments of deep and peripheral body temperatures across a wide range of the continuum of supportable thermal levels. Four hypotheses concerning performance in such manipulations were advanced. They were first, that small variations in core temperature would result in decreased RT and choice RT due to elevated arousal. Second, large changes (greater than 1°C) would be associated with increased premotor and total RT due to the competition for attentional resources from thermoregulation resulting from the stressor. Third, nerve CV will vary with temperature of the response limb and finally, under elevation of limb temperature motor RT will decrease, while an increase in motor RT will follow limb cooling.

METHOD

Experimental Test Facility

All procedures took place at the Environmental Physiology Unit, Simon Fraser University.

Experimental Design

Two right-handed adult male subjects were exposed to three manipulations. First, whole body immersion in a water filled tub (AIBI). Second, whole body immersion except the right arm (AIOBI), which was maintained at initial temperature level and finally, discrete immersion of the right arm (AIROBI) with no change in whole body temperature. All conditions were repeated when the water temperature was either hot or cold. This created a 2 x 6 repeated measures design which was preceded by five pilot immersions to determine the relationship between rate of temperature variation and optimal water temperature necessary to cause such a change.

Experimental Task

The RT/MT task consisted of response to a visual stimulus by a 35 mm extension movement of the right index finger. Both simple reactions, consisting of ten trials with the right hand, and choice reactions consisting of ten trials with each hand were elicited. The hands rested on an aluminum bracket at chest height. The index fingers rested on rectangular pressure switches which were 60 mm apart horizontally. Upon illumination of the light stimulus, the subject responded as rapidly as possible with finger extension which closed a microswitch 35 mm above each response finger. Both RT and MT were consequently recorded.

Experimental Procedures

Subjects, clothed only in swimming trunks were instrumented in a pre-experimental room, where ambient temperature ranged from 20-22°C. In whole body immersions, the subject sat in a cedar tub 121 cm in depth, which was water filled to a level of 100 cm.

In the first condition, the whole body was immersed to neck level. In the second condition the response arm was not immersed but remained outside the tub and was maintained at pre-immersion temperature by the use of a warm or cool cloth. Discrete limb immersion was achieved in a ceramic coated steel sink with a depth of 21 cm. During whole body immersion, physiological and behavioural measures were taken at 0.4°C increments of deep body temperature as recorded at the rectal site. When the limb only was immersed, measures were taken at every 4°C change in heating and every 5°C change in cooling (39°C minimum and 12°C maximum). The following measurements were taken: temperatures (rectal, tympanic, muscle, skin and water), reaction time, movement time and heart rate. In addition, nerve CV was measured both pre and post immersion. Rectal temperature was recorded from YSI thermistor inserted 15 cm past the anal sphincter and tympanic temperature was recorded from a tympanic thermostor positioned alongside the tympanum. Intramuscular temperature was taken by a wire thermocouple inserted to a depth of 12 mm beside the extensor digitorum longus in the forearm of the response limb, while skin temperature was derived from a mean of four measures at chest, arm, thigh, and calf (cf., Ramanathan, 1964). Similar measures were elicited in the condition which required only discrete limb immersion.

The measure of nerve conduction velocity (CV), stimulation was applied to the ulnar nerve at the wrist (styloid process) and elbow (proximal to the internal humeral condyle). The action potential of the adductor pollicis was observed on a storage oscilloscope. Electromyographic (EMG) recordings from adductor pollicus were utilized for this measure, while activity in extensor digitorum longus was recorded for use in analysis of the premotor reaction time.

RESULTS

Physiological Measures

Deep body temperatures followed patterns typically expected in cold and hot water immersion conditions. In the cold condition, a period of inertia in rectal temperature was followed by an approximately linear decrease until termination at the 35°C level. Inertia was less evident in hot immersions where rectal temperature rose progressively to the 39°C termination level. The alternate measure of deep body temperature at the tympanic site followed this general pattern but exhibited slightly higher absolute values and contained an apparent lag with respect to the rectal measure. In discrete limb immersions, there was no change in either of the measures of deep body temperature.

Skin temperature also followed an expected pattern, whereby during whole body immersions average skin temperature rapidly stabilized to within 1-2°C of the water temperature. In discrete limb immersion, mean skin temperature did not change except for one subject in a high, 48°C water
The body despite the thermoregulatory actions by the nervous system, has little temperature exposure. In a wetter environment, the body has a higher temperature at the skin level. This can result in overheating and core temperature increase. In cold water exposure, core temperature decreases in the presence of peripheral vasoconstrictions and sweating. Decrease in skin temperature increases the perception of coldness. In cold environments, peripheral vasoconstriction and sweating are reduced, leading to an increase in core body temperature. This can be seen in the presence of peripheral vasoconstrictions.

DISCUSSION

Figure 1. Simple and choice motor RT for age at different ages.

Behavioral Measures

Temperature was reduced.

Two methods were used to measure motor RT: choice and simple.


g = (simple RT & choice RT)

Figure 2. Simple and choice motor RT for age at different ages.

Behavioral Measures

Temperature was reduced.

Two methods were used to measure motor RT: choice and simple.


g = (simple RT & choice RT)

Figure 3. Motor and choice RT at different ages.

Behavioral Measures

Temperature was reduced.

Two methods were used to measure motor RT: choice and simple.


g = (simple RT & choice RT)
such as peripheral vasodilation and sweating. These latter effects accompany an increase in heart rate as observed in the present work. In total immersion as indicated, the only possible heatsink is the non-immersed head, however, effector action at this location is insufficient to rid the body of heat from the water and core temperature rapidly rises. Skin temperatures tend to asymptote toward the ambient water temperature, while intramuscular temperature exhibits the same tendency but less dramatically due to overlying subcutaneous adipose tissue.

Nerve conduction velocity appeared to decrease as muscle temperature was depressed. This followed the general hypothesis. However, at elevated limb temperatures this tendency was less obvious. Such equivocal questions the validity of the measurement technique applied to the ulnar nerve or alternatively suggests readings from the thermocouple inserted in the extensor digitorum longus were not truly reflective of ulnar nerve temperature. In either case this indicates the necessity to pursue more elegant measures of nerve conduction velocity in vivo, during such thermal variations.

The general tendency of reaction time and movement time data suggest an intricate relationship between central, peripheral, and temperature factors exists. With the body immersed and the limb at normal temperatures, there is no competition for attentional resources from thermoregulation. However, when the limb and body are immersed, attention is directed toward thermoregulation as evidenced by the increase in premotor RT. Increments and decrements in simple and choice RT are also elicited with limb only immersions. If the arm is heated, RT decreases as intramuscular temperature rises due to a decrement in motor RT. In contrast to heating, cooling the limb causes an increase in RT due to the decrement of premotor RT. Accurate description of behavioural changes to temperature stress can only achieved by examining both the central and peripheral components of a response.

SUMMARY

The present study extends some recent work (Aird, Webb, & Hoare, 1981; Hancock & Dirkin, 1982), which has begun to examine performance variation in more controlled circumstances. The experiments reported induced a systematic change in temperatures, with peripheral and deep body temperature independently manipulated. Measurement of behavioural responses at systematic increments of such temperature provided information toward the contribution of central and peripheral temperatures to performance variation. These results hold importance for those concerned in the design and use of complex systems where the human operator is vulnerable to the effects of the thermal environment in inducing either deep and/or peripheral body temperature change.

ACKNOWLEDGEMENTS

This research was supported by a grant from the Natural Science and Engineering Research Council of Canada.

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