The Effect of Heat on Psychomotor Efficiency with particular reference to Tropical Man.

A

THESIS

presented in accordance with the regulations governing the award of the Degree of Doctorate of Medicine in the University of Liverpool.

October, 1956.

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CONTAINS PULLOUTS

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Explanatory Note.

The experimental work in this thesis was undertaken while the author was working for two years at the Hot Climate Physiological Unit of the Colonial Medical Research Council at Oshodi, Nigeria, as a seconded R.A.M.C. Graded Specialist in Physiology.

(1) Introduction & History.

(a) Long term effects of heat.

The effect of heat on Man's physiology and psychology has long been the source of much speculative, and sometimes erroneous thinking but it is only in recent times that the problems of human adaptation to heat have been put to experiment. Of these two branches of knowledge concerning human performance in hot climates, the study of physiology has attracted the most attention and, apart from repeated discussion of the concept of tropical mental fatigue and neurasthenia, comparatively little work has been done on psychological or psychomotor reaction to heat. Considering the pathological effects of hot climates on Europeans, Masters, as recently as 1920, states that "neurasthenia" is almost universal", and that "loss of memory is common, especially on the West Coast of Africa where it is known as 'Coast Memory'. He states also that acclimatisation for permanent residence of Europeans in the tropics does not take place, and that such residents are expecially liable to disease from diminished resistance of both mind and body. This emphasis on the sapping of mental vigour by heat is further extended by quoting Anderson's views (1908) on the subject; the latter's opinion seems a quaint mixture of dogma and colonialism and is summarised as follows:-

(1) When a white species is well adapted to the conditions which environ it, it flourishes; when imperfectly adapted it decays; when ill adapted, it becomes extinct.

(2) When a white man, a native of the temperate zone, goes to the tropics there occurs a biological reaction of his system to the new environment and a readjustment of co-ordination between his vital processes.

(3) In the tropics the white man individually can exist; racially he cannot.

(4) Acclimatisation is not possible.

(5) No superior race can successfully govern an inferior race superior in numbers, with equality before the law.

(6) Only by partial enslavement of the coloured natives, superior in numbers, can the white man rule and govern the tropics, and it is only by relays of fresh representatives that he can continue his sovereignty.

(7) No colony of northern origin has ever been able to lead a permanent and independent existence in the tropics."

These possibly irrelevant statements are used to show that although not explicit, it is implicit that in some way tropical man is much better suited to his tropical clime than is the temperate flower, wilting far from home. The main preoccupation is with the deterioration of the white man, and no attention is directed to the effect of heat on the native. This "tropical fury of Phehn" which assails the white man consists of "diminished vigour, general debility, anaemia, irritability, nervous depression, and sleeplessness" and is ascribed by Masters to "slowing of the pulse and slight impairment of respiration by which the heart's action is weakened and the vital organs are less well nourished." Similar views concerning deterioration of the white man in the tropics were expressed by Huntington (1924), and have been repeated since (Lukis & Blackham 1931; McCartney, 1943).

In the spate of research emanating from the war years (1939-1945) some of these misconceptions have been laid to rest. For example, criteria have been laid down as to what constitutes physiological acclimatisation to heat, and evidence has been accumulated to show how acclimatisation is acquired. Ladell (1950-1952) has shown for example that temperate climate man in the tropics and tropical man, are capable in the extreme of reaching a similar standard of acclimatisation to heat, and that individual acclimatisation is dependent on individual activity and circumstances, rather than on racially acquired characteristics. Similar findings have been obtained by Weiner (1949) in the Bantu mineworkers, and by Adam, Ellis & Lee (1953) in Asians. Also the neurasthenia of the tropics, so common to Europeans, is common among Europeans in similar conditions in non-tropical exile, as studies upon the reactions of sailors in isolated stations in Iceland and elsewhere have shown, (Critchley 1945). Tropical neurasthenia has been studied by Macpherson (1944) in New Guinea, and by Carpenter (1949) and Ellis (1952-1953) in Malaya, and has been shown to depend more on circumstances and the frustrations of isolation than on the actual climatic conditions. Trenchard (1946) showed, that of the cases of psychoneurosis invalided home from R.A.F. stations in the Far East, there were few that were not ascribable to a definite cause such as personal, domestic, or service stress, and that the climate per se could not be incriminated. Macdonald Critchley (1945) laid down stringent conditions against which assessment of climatic effects must be considered, before being held responsible for psychoneurotic disorders in the tropics. Thus the concept of "tropical" neurasthenia has fallen somewhat into disrepute, and Lee (1946), referring to the confusion of thought and superficial reasoning concerning effects of tropical climate, reasserted the principle of continuous adaptation to environment expressed by Cilento (1933) regarding the efficiency of settlement of the white man in tropical Australia. Cilento maintained that given suitable amenities and facilities, permanent settlement could be attained.

On the other hand, in the wider philosophical sense, the climate has often been advanced as explanation for tropical man's backwardness, and for the consequent lack of development and economic inferiority of the tropical parts of the world. Mills (1942) elaborates this theme in an interesting and peculiar book, and illustrates it by reference to the learning abilities of rats reared from birth at three different temperature levels-, 65°F, 76°F, 90°F. Unfortunately the experiments quoted are performed by a scientific friend who is unnamed, so few details are available. Mills indicated, however, that tests of learning ability were made on the group of rats as young adults, and that rats reared in the cool climate required 12 trials to learn their way through a labyrinth to find food, rats reared in moderate warmth required 28 trials, and those reared in tropical heat found great difficulty, and either gave up the unequal struggle or required an average of 48 trials before success. The cold room rats after learning did not forget, even after a three month rest interval, but those from the warm and the hot climes made frequent errors, and after three months rest interval, retained no knowledge of the former experiment, and had to relearn all over again. Mills enlarges, by reference to his personal experiences of human races who exist in differing climates but who are not racially dissimilar. His impression of greater intellectual alertness and vigour in the members of the same race living in climatically cooler conditions, is one common amongst observers in the tropics (Critchley 1945). No scientific analysis is offered, but as an example, Mills cites the effect of air conditioning on the productivity of one hundred Philippine women who worked in a bubble-gum factory. Increase of efficiency by 30% was found when the factory ambient temperatures were lowered from 95°F to 65°F by air conditioning, and the women competed with each other in order to work in the cooled sections of the factory. Similar conclusions concerning the impairment of efficiency by heat were obtained by Huntington (1924), who investigated the effect of climate and season on the productivity of American factory workers, and produced clear evidence of reduction of activity in the warmer climates during the summer i.e. the warmest time of the year.

Maximum productivity occured in the mid-winter amongst these workers, who were variously, cotton operatives, carpenters, and cigarmakers. Mills concluded that cool temperatures, 35-60°F, "push man into an energetic ruthlessness, and that human energy and initiative rise to the highest level". This is held to account, in part, for the world dominance of North America and Western Europe, which contain one third of the human population. Another third of mankind, writes Mills in Africa and South America, "are held captive by the insurmountable difficulty of losing body heat in persistent tropical temperatures." But however, he claims, at times in highland regions within the tropics, which offer a temperate climate, e.g. the Andes and the highlands of Abyssinia, man has done well. The final third, Asia, China, and the Mediterranean countries, which have hot summers and cold winters are destined, according to Mills to pursue a middle course in world affairs and domination, "by a climate which holds them to a neutral course." Recent world events have indicated that such a viewpoint can no longer be held.

In a much more convincing study, Markham (1947) elaborates the role played by climate, and its control on world civilisation and history. It is pointed out that the "Theory of climatic pulsation" in history is by no means a new one, and that Aristotle, Hippocrates, and Herodotus ascribed the success of the Greek civilisation to the excellence of its climate. This approach is adopted by Huntington in his "Civilisation and Climate", and later Markham attempts to correlate the rise of civilisation to the isotherm approximating to the ideal working climate, 60-76°F. The 70° annual isotherm is traced across the globe and it is pointed out, that before clothing and heating became developed, civilisation developed along this line. Thus the earliest civilisations occured in the southern Mediterranean, Mesopotamia, and Asia Minor, for example, those of Egypt, Babylon, Assyria, and Sumeria. Traced eastward, this isotherm crosses through India, along and across the Indus, where the former centres of Indian civilisation were sited, and then South Eastern China, across to Mexico and Guatemala. Wherever this line coincides with moderate humidities, civilisation has advanced. Elsewhere in desert or jungle no great development occurred. However, with the discovery of a means of heating, superior to the open fire, civilisation moved to cooler regions with the development of the hypocaust. Thus Greece and Rome rose, and the Romans rapidly became the world's supreme heating engineers with their hot air distributing system.

But subsequent to the decline of Rome, the centre shifted back to the original isothermic line areas in Arabia and Persia, when once again climatic control was abandoned. Among the countries around the Mediterranean, Spain was late in its development, and did not take eminence until the 10th century, and then, beset by internal strife with the Moors, did not spread its empire until the fifteenth century. In the Americas likewise, the Aztec and Inca civilisations arose in elevated regiohs, enjoying a "most salubrious" climate (60-70°) and the Mayan civilisation in Yucatan sprang from the central Americal highlands along the 68° isotherm. The upsurge of civilisation again in Europe after the dark ages, was helped by the rediscovery of brick making, window and glass making, coal, and the invention of the fire grate and chimney, in the eleventh, twelfth, and thirteenth centuries. Thus with the acquisition of climatic control, world dominance came for the first time to Western Europe and Britain. The point emerges that whereas climes, colder than the ideal isothermic region, may become civilised by the development of climatic control, the hotter parts of the world remain unorganised, for no simple solution was procurable for its climatic adjustment.

Alternatively, Markham assesses the effect of hot climates, on the members of developed races from temperate zones who take up permanent residence in the tropics, where the temperature is greater than 75°F. for a considerable part of the year. He points out the remarkable degradation of the so-called "Poor Whites" in the Southern States of America, the West Indies, and South Africa "out of 2,000,000 whites, no less than 300,000 are "Poor Whites." It is pointed out, however, that in other tropical areas, where the European returns home for frequent periods of leave, for example the Far East and West Africa, the problem of the poor white has not risen to the same extent.

To summarise these general remarks it can be said that in the twenty years, between 1920 and the war years the following viewpoints were held concerning the long term effects of climate on man's development and behaviour:

(1) Civilisation developed, geographically, economically, and physiologically, in the most suitable climatic regions.

(2) In other regions, colder or hotter, little or no advance was made, except in colder regions with the development of climatic control. As no simple method of climatic control is feasible for hot regions, these

have remained undeveloped.

(3) The long term effect of unrelieved tropical heat on the developed races is intellectual and moral decay. Since the war, critical examination shows that the evidence upon which climate, per se, has been incriminated, is fallacious.

(4) While tropical heat is held to be responsible in part, for tropical man's backwardness, little or no attention has been paid to the effect of climate on tropical man, except in so far that general observations suggest an improvement in efficiency in cooler climatic conditions.

(b) Short term effects of heat.

For a variety of reasons, in the last fifteen years remarkable impetus has been given to the study of the effect of hot situations on the mental efficiency of man. This has stemmed chiefly from the war years, and the necessity for conducting and controlling complicated machinery in industrial and military circumstances in tropical parts of the world. Men of the armed forces have been required to perform their duties efficiently in conditions of great heat. Critchley (1945) paints a vivid picture of "a rating in the tropics" trying to maintain vigilance while crouched in a minute compartment with a dry bulb standing at 95°F (or up to 110°F.) and a wet bulb at

85°F. - "naked except for shorts..., body streaming with sweat, probably covered with the rash of prickly heat...but he has to cope with an exacting, boring, but highly important task." Similarly with the increasing and necessary industrialisation of developing tropical countries, analogous circumstances begin to involve tropical man and have involved the temperate zone worker, both in industry outside the tropics and, more recently, in the tropics as well. Although, as long ago as 1915, it was observed that climate could exert an influence on efficiency in industry (Huntington 1924), in 1927 both Sundstroem and Bazett drew attention to the paucity of information concerning the function of the nervous system in hot climates. Among the earliest references to the effect of heat on efficiency, are those observations quoted by Bedford (1934) and made by Weston (1922) concerning the output of linen weavers, and its relation to climate. This observer found, as did Wyatt (1926) for cotton weavers, that the adverse physiological effect on the workers of wet bulb temperatures greater than 73°F, more than counterbalanced the decrease in warp breakages due to the increased humidity, and consequently overall output declined. Barcroft, in 1934, drew attention to heat effects on mentality, and experiments are described in which dogs, (Rice and Steinhaus

1931), and rabbits, (Marsh 1930), were exposed to high temperatures and their mental reactions observed, before unconciousness supervened due to hyperpyrexia. Later in 1938, Barcroft in "The Brain and its Environment" quotes in full the observations of Sutton (1909) who, stimulated by J.S. Haldane, studied the effect of heat on a healthy person's mental processes. External heat was produced by exposure in hot vapour baths, and the investigator's findings are stated as follows:-

"The general condition of the subject, especially the mental phenomena seem to bear a close relationship to the rise of internal temperature. In later experiments a tolerable guess as to its height could thus be made. The marked sensation of heat, felt on entering the hot room soon passed off on resting quietly, and was replaced on the occurrence of free sweating by a relaxing and not unpleasant sensation of warmth. Dilatation of the vessels and relaxation of muscular tone was marked, and still more marked was the sensation of sleepiness, which often times became quite overpowering. This condition, however, only existed during the stage of compensation when the body temperature was stationary or only beginning to rise gradually. The organism seems to reduce its energy to a minimum, and so muscular and mental effort are practically abolished. This state lasted during these experiments for half an hour or so, for as soon as the rise of body temperature became at all definite, this was associated with quite another set of sensations. Sleepiness disappeared, and the complete muscular idleness passed off and was replaced by a marked and increasing irritability. The change from drowsiness to wakefulness and irritability was comparatively abrupt, and occured quite constantly at about 99.5°F. Once the rise of rectal temperature was fairly marked, (2-3°F.), the continuance of any employment, such as reading a book or sitting in one position, became intensely tiresome. For example, the attempt to learn by heart a short vocabulary of German words proved a complete failure. To remain at rest required a marked effort of will, and the only approach to comfort was obtained by lounging about, so as continually to change one's position. Later on the body temperature rose to over 103°F., and any irritation, however slight, became not merely tiresome, but actually annoying and trying to one's temper. This irritability - a preliminary sign of early exhaustion of the control nervous system - is thus closely associated with rise in body temperature

Immediate relief was felt on reaching the cool external temperature and this was accompanied by a rapid fall in internal temperature, (2-3^{o}F.) in ten to fifteen minutes." Anyone who has experienced great heat can testify to the accuracy of these observations. Barcroft (1938) concludes from this, and his own experiments involving mental reaction to cold, that raising body temperature results in "excitement complex", while lowering temperature results in "Depression complex." Thus body temperature becomes, along with oxygen, glucose, and carbon dioxide, one of the factors requiring control for the fixity of the internal environment of Claude Bernard for the proper functioning of the higher qualities of the brain.

By the late 1930's although it was agreed that heat, by raising body temperature, could impair mental processes, no exact measure of impairment had been made, although some attempts had been made to define the limit of heat which was tolerable before deterioration occurred, in some industrial situations. These observations suffered from the naturally different circumstances of type and condition of occupation, and also different methods of recording the climatic conditions were used. Thus, using the Dry Bulb figure alone as an indication of heat Huntington (1924) defined the optimum temperature to be 60-65°F. and Bedford (1948), records the finding of the New York State Commission on Ventilation 1923, that "men performing weight lifting did 15% more work at a temperature of 68°F. than at 75°F."

Using the Wet Bulb figure, Weston (1922) and Wyatt (1926) noted decrement above 73°F. and the Cotton Cloth Factory Regulations (1929) fixed an upper limit of 80°F. (wet bulb) above which all work must stop. However, with the more widespread introduction of the Effective Temperature Scale,* better standardisation of climatic measurement became possible, but the widely differing industrial activities still rendered recognition of a critical level of temperature an impossibility. Thus the following different levels were found, above which decrement in efficiency resulted; Vernon and Bedford found a 50% reduction in efficiency, in coal miners between temperatures of 66°F. and 81°F. Other workers found a 50% reduction in efficiency occuring between 91° and 97°F. (Lieberson and Marques), and 70° and 93°F., (Yaglou.). Yaglou (1937) gave limits of effective temperature depending on activity as follows, for light work 90°F. and for heavy work 80°F. This type of industrial observation could only lead to confusion, for differing activities combined different proportions of physical and mental work and so were probably

* See footnote.

liable to decrement at different levels due to different factors. Concerning purely mental work the only observations to hand were those mentioned by Barcroft (1934 & 1938), Huntington (1924) and Kuno (1934). Huntington found the scholastic performance of American cadets was reduced in hot weather, while Kuno (1934) mentioned that mental work was especially tiring in hot weather due to sweating being inhibited by mental exertion, thus producing more stress.

It is proposed in the next section of this thesis to discuss in detail the literature of the last fifteen years, which describes finite attempts to determine the effect exerted by heat on mental efficiency, and the temperature or climate at which decrement in efficiency appears.

Footnote. The Effective Temperature scale (Houghton and Yaglou 1923) was originally a subjective scale, but was subsequently given objective validity. The scale takes into account temperature, humidity and air movement, and indicates the temperature of still air saturated with water vapour in which an equivalent sensation of warmth would be obtained, and, in which similar physiological reactions would be produced. Two scales are available, namely "Basic" for subjects stripped to the waist, and "Normal for subjects dressed in light clothing.

(2) Review of Literature, (1940-1955) on the short term effects of heat on Temperate Climate Man.

The first reports of the impairment of skill by heat came from America in 1942. Houghton, Stacey, Urdahl and Watt, investigating the effect of heat on the skill of unacclimatised young men for the U.S. Navy, found that reduced output and accuracy were not observed at effective temperatures of 73°F. and 80°F., but did appear when the effective temperature was raised to 87°F.

At about the same time, Bartlett (1941) in a study of fatigue in elaborate and highly skilled work, drew attention to the type of changes to be expected in heat. Quoting from a series of experiments in which subjects were required to produce a co-ordinated response of eyes, hands, and feet, to stimuli from a set of control instruments and lights, Bartlett found that with time, the standards of response acceptable as satisfactory by the central nervous system deteriorated. Operator error increased, though the operators felt they were performing more efficiently, and the amplitude and limits of error also increased progressively in the two hour exposure. The chief source of error at first, was in timing of the response, and the correct actions were taken in reply to a stimulus but, at the wrong time.

Subsequently errors in judgement appeared, and the wrong actions were taken. With time, the subjects projected their errors on to extraneous causes and objects, and blamed the controls or interference by other subjects. Distracting stimuli e.g. noise, or heat, or even proprioception from body attitudes, had an increasing powerful interference effect with time, and subjective symptoms and complaints appeared. It was also found that in the pattern of multiple stimuli requiring consideration before the response, that with time, stimuli from the margin of the pattern and not closely organised in the central field were forgotten or ignored, with resultant lapses. From these results Bartlett considered that in situations in which an organised pattern of stimuli require a co-ordinated response of the central nervous system fatigue is manifested by the central control expanding "its indifference range." The threshold for central influences from the stimulus pattern rises, while a constriction of the field receipt from marginal to central influences occurs. Consequently distracting stimuli increase in interference effect, and as a result, inaccuracy of timing and dissociation of performance appear, with ultimate failure of response to the stimulus. Subjectively, irritability appears, unreliability of assessment of performance becomes manifest, and the subjects become possessed by physical discomfort, with projection of their shortcomings on to the instruments or their companions. These changes have been likened to the impairment of performance by anoxaemia and carbon dioxide poisoning (Critchley 1945).

Following this work, research was stimulated and directed towards observation of decrement in less complicated situations, to attempt an analysis of the processes involved in complex stimulus-response mechanisms. Weiner and Hutchinson (1945) were among the earlier experimenters along these lines, and in 1943 investigated the effect of heat on the performance of a motor co-ordination test by laboratory workers and service men. The test was, in effect, of manual dexterity and involved manipulation with forceps of small steel ball bearings from a rotating gramophone disc. The balls were moved between two sets of holes on the rotating disc and performance was measured as the time taken to complete the given number of manipulations. Ball bearings which dropped fell on to a collecting tray, and had to be retrieved and placed in the appropriate holes before the manoeuvre was held to be complete. The number of balls dropped, also afforded an index of dexterity, and the total times taken for the test, divided by the number of balls moved plus the number of balls dropped, gave the time per movement per ball as yet another index. Three series of experiments were formed, two were acute exposures to heat in (a) unacclimatised, and (b) acclimatised subjects, and the third involved performance of an unacclimatised subject in a prolonged exposure to heat in the climatic chamber. In the first series, four subjects, who had three weeks practice at performing the test at ordinary room temperature, performed the test nude, in the climatic room, after a two hour exposure to an effective temperature of 91°F. Subsequently, on the same day or within a few days, control performances were done at ordinary room temperatures (dry bulb 68-65°F.). Despite no increase in rectal temperatures during the hot exposure, manual dexterity, was said to be impaired because an increase of the total test time of 8% was found.

In the second series of experiments after differing lengths of practice at room temperatures, six clothed acclimatised subjects performed the test in the climatic chamber, after an hour's rest following step climbing at an effective temperature of 91°F. Control experiments at room temperatures following step climbing, were performed later. Upon comparing the series of tests following work in the hot room with the series of tests without work in the cool, it was found that the total test time was 14% longer at 91°F. effective temperature than at room temperature. This was statistically significant. The number of balls dropped, and the time per movement per ball, were also statistically greater in heat than in cold. Exposure to heat, in fact, caused a reversion in performance to the standards shown in the early practice performances. In the hot experiments the rectal temperatures of the subjects were above 101°F. but this did not seem to increase materially the decrement.

In the third experiment involving prolonged stay in the hot room one unacclimatised subject, after ten days' practice of the test at room temperatures, lived in the hot room for thirteen days. Each day, during this period, he performed the test in the mornings at 82°F. effective temperature, and again in the afternoons after step climbing at 86°F. effective temperature. During the mornings his rectal temperatures were normal, but in the afternoon tests his rectal temperature averaged 103.2°F. At the end of thirteen days he left the chamber and performed the test in room temperature on six subsequent days. His performances for the last four days before entering the room, were compared with those of the first four days in heat, and also the performance of the last six days in heat were compared with the final six days in room temperature. All three indices of dexterity were greater in the heat both for morning and afternoon performances, so it can be seen that rectal temperature does not specifically affect performance. Once again it was found that the performance, in the first four days in heat, reverted to the standard of the early practices in room temperatures. The total test time was 11% greater in the first four days in heat than the last four days before entering the chamber. However, while the subject was in the heat, his performance improved, and in the last six days in the heat, was almost as good as before entry into the room.

Thus, Weiner and Hutchinson concluded that in all three groups of subjects heat resulted in a deterioration in performance, which was independent of body temperature rise. The deterioration was mainly due to slowness of movement and inaccuracy in handling the balls, due to impairment of motor co-ordination. That these conclusions, as based on these experiments, are open to criticism is obvious and more will be said on this point later.

In the years 1946-50, further experimental evidence, demonstrating impairment of skilled and semi-skilled abilities by heat, became available.

Viteles and Smith (1946) found in a variety of tasks, ranging from mental arith-metic to lathe operation, that young naval ratings showed a deterioration in performance at effective temperatures above 80°F. During the last few years of the war, Mackworth, at Cambridge, had been engaged on an exhaustive survey of the effects of environment on a variety of skills, and with the end of the war, this work was released from security. The full reports were published in 1950, and comprise the most comprehensive conclusions as yet in this field of research. Mackworth investigated the effect of heat on four types of activity:-

(1) A simple form of muscular work - "the pull test."

(2) A test involving heavy effort with accurate muscular control - "the pursuitmeter test."

(3) A semi-automatic high speed mental task - Wireless telegraphy reception.

(4) An intellectual task - "the coding test."

As Mackworths' results and conclusions are of great interest in comparison with the experimental work in this thesis, it is of importance that they be considered in detail here.

(1) "<u>The pull test</u>."

In this test the subject, seated at a table, had to raise and lower a 15 lb weight each second, by bending and straightening his arm in time to a metronome. The weight was suspended over a pulley on the end of a table by a wire, and the subject held the wire by means of a handle. The subject was asked to continue to lift the weight up and down till he was exhausted, and could not raise the weight from the floor. At each lift the weight had to be raised from the floor to a given marked height, normally two feet, so that 30 ft-lbs of work was done for each lift.

The subjects were well practised at this test before the experimental series, and, in addition, were physiologically acclimatised by daily acclimatisation exposures for two weeks to temperatures of 91°F or 97°F. effective temperature. The test was scored by means of a tape measure band, passing round two pulleys, which moved two inches for each pull, and could be screened from the subject or not as required. The number of inches moved by the tape for each attempt divided by ten, constituted the score in arbitrary units. Thus either the subject could see how he was performing and be encouraged also by a running commentary on his accomplishments, or, if the tape was screened, he could be held in complete ignorance of his result. Two levels of incentive were consequently available and were used by Mackworth, to see if incentive could alter the effect of heat. The subjects were exposed for one hour, before performing the test, to the particular climate of the six test climates used, which were 61°F., 69°F., 79°F., 83°F., 87°.5°F., and 92°F., effective temperatures. Mackworth found that at both levels of incentive, performance suffered with the hotness of the climate. Working with a high incentive produced overall better performance than working with low incentive, and in fact, working with high incentive, even in heat was as efficient as working with low incentive in the cool temperatures. Nevertheless, the performance curves were similar, though placed at different levels and attempts were made to define the critical level of temperature above which deterioration became significant. It was found that if the performance at 61°F. effective temperature, was taken as the standard, then the first statistically different performance was at 83°F. effective temperature, for both high and low incentive tasks. However, if the performance at 79°F. effective temperature was accepted as the standard, (and this itself did not significantly differ from that at 61°F.E.T.) then the temperature at which a significantly different performance was obtained was found to be 87.5°F. effective temperature. Incentive difference, it was found, produced a statistically significant difference in performance at all temperatures, except 87.5°F. effective temperature and 92°F. effective temperature; thus with rise in environmental tamperature, incentive produced less effect on performance, and despite high incentives, decrement in efficiency resulted in the performance of this simple task. Mackworth also investigated the effect the level of ability of the subjects, as defined arbitrarily from the performances at 61° and 69°F. effective temperature, had on the reaction to heat. It was found that the "good subjects," or the men who were working hardest, suffered a greater fall in efficiency than the "average subjects." This is a point of some importance.

(2) The pursuitmeter Test.

The pursuitmeter is an apparatus designed to test the ability of a subject at "tracking," attempts are made to follow an electrically driven, erratically moving pointer, with another pointer which the subject controls by means of a weighted lever. It thus provides a test of accurate muscle control involving hand-eye co-ordination, and requires intermittent physical effort and constant attention and concentration. Errors in alignment between pointers are summed on a recording dial and constitute an error score. If the error score obtained by a subject exceeds an arbitrary score, predetermined by running the machine without anyone at the controls, then the subject's attempt can be deemed a failure. If the error score be less than the machine score, the attempt is a "pass."

Mackworth used this test to observe the effect of heat on acclimatised sailors in three hour exposures to climates of 79°F., 83°., 87.5°F., 92°F., and 97°F., effective temperatures. Each of the ten subjects performed the test fifteen times per session. Mackworth calculated the results in terms of Percentage Failure Rate/session, obtained by summing the total number of failures in each session and finding its percentage in terms of total number of attempts made (usually 150). As shown below the results indicated that performance deteriorated with rise in environmental temperature, both for overall performance per session, and for the performance in the third hour of each exposure:-

Effective temperature, °F.	79	83	87.5	92	97
Failure rate(%) Overall.	14	19	21	35	62
Failure rate(%) Third hour.	14	18	26	38	76

Thus for the climates up to 87.5°F. effective temperature, performance was of the same order, but above this temperature the failure rate rose steeply. Mackworth inferred that a logarithmic relationship existed in this test between deterioration and atmospheric temperature and derived a theoretical curve for the percentage incidence of failure occuring in the last hour of exposure viz:-

$$\log y = 0.9176 + 0.1794\ x$$

where y = % rate of failures, and x = atmospheric temperature. From this, calculation was made to find at what temperature significant deterioration from the standard performance at 79°F. effective temperature would appear. This was found to be 86-7°F. effective temperature.

(3) <u>Wireless Telegraphy Reception</u>.

In this test eleven acclimatised and experienced wireless operators were required to receive Morse code messages in the following different atmospheric temperatures- 79°F., 83°F., 87.5°F., 92°F., and 97°F., effective temperatures, during three hour exposures. The messages consisted of 1250 mixed letters and numbers each, and three messages were relayed in each of the three hours of exposure. The operator's attempts were then marked, and any message containing five or more missing or incorrect symbols were regarded as faulty; the percentage incidence of faulty messages for each session was thus found. The results showed that a decline in performance resulted with heat:-

Effective temperature °F.	79	83	87.5	92	97
Percentage Incidence Faulty messages	18	18	22	33	40

A logarithmic relationship was again suggested by these figures for deterioration with rise in atmospheric temperature, and the following equation derived for the performance curve, viz:-

$$\text{Log } y = 1.1077 + 0.0957\, x$$

where y = % age incidence of faulty messages, and x = atmospheric temperature. From this it was deduced that the critical temperature for accuracy was between 87.5 and 92°F. effective temperature.

In addition to this, Mackworth analysed the results by considering the actual average error score per hour for each session, and by this method found that the critical temperature level was 87.5°F. effective temperature. The results were also considered in terms of the operators ability as judged by their performances at 79°F. effective temperature and the men were split up into "Exceptionally skilled," "Very good," and "Competent" categories. It was found that the "Very good" and "Competent" groups showed a marked deterioration in heat, whereas the "Exceptionally skilled" men showed little deterioration. This may be interpreted as showing that the more automatic or "Highly skilled" a worker may be in this type of work, the less decrement he shows, or alternatively that the harder a man has to work to attain a standard, the more liable he is to show deterioration in adverse circumstances. Mackworth also found that with time the hourly error scores within a session increased except in the hottest climate, when in the first hour of exposure an already increased number of errors were made.

(4) The Coding Test.

This was the most intellectual task investigated in Mackworth's survey, and the twelve subjects were required to arrange on a peg-board, a set of small squares of two sizes, according to a coded series of instructions. The correct squares had to be selected and then arranged in a particular way; in addition, the large and small squares had to be arranged in combination, and orientated in a definite way. The subject worked through as many of the boards as possible within the test time of three hours, and all had had adequate practice on the test before the climatic series was attempted. Mackworth used the same test temperatures as before, 79°F., 83°F., 87.5°F., 92°F., and 97°F., effective temperatures, and the performances of the subjects was measured as the average number of mistakes per hundred boards. The following performances were obtained and a logarithmic relationship was once again deduced.

Effective temperature °F.	79	83	87.5	92	97
Average mistakes	20.9	22.0	28.5	33.5	42.7

The equation of the curve was found to be:-

$$\text{Log } y = 1.2136 + 0.0803\ x$$

where y was the incidence of mistakes, and x the atmospheric temperature. From the performances the critical level of temperature for deterioration was 87.5°F., effective temperature and from the theoretical curve 90°F., effective temperature.

From these four experiments Mackworth (1950), drew the following conclusions which still form the basis of present day thought concerning heat and efficiency:-

(1) There is a critical region on the atmospheric temperature scale, above which most acclimatised men will not work efficiently. This

region lies between the effective temperatures readings of 83°F., and 87.5°F., and this conclusion applies to all forms of intensive work, both physical and mental.

(2) The accuracy of very highly skilled men is not affected as much as that of less skilled workers, because skilled men require less effort to complete a given task. It is men who are putting the greatest effort into doing their work, who deteriorate most in the heat. Thus in a physical task those working hardest suffer most, whereas in a mental task it is the men who are straining their resources, who suffer most i.e. the less skilled men.

(3) In three entirely different performance tests, the index of deterioration bore a logarithmic relationship to the atmospheric temperature. This logarithmic relationship is most valuable to the organism because it allows a remarkably effective compromise between two conflicting biological requirements. Mackworth states that "Man must be able to respond in two different ways to environmental change: he must be able to ignore minor variations in his surroundings but he must be very much aware of potentially harmful extremes." Mackworth also draws attention to the general physiological principle mentioned by Barcroft (1934) that the logarithm of the degree of activity of a vital process often correlates with the

temperature at which it takes place.

(4) There is no direct relationship between rise in rectal temperature and the incidence of mistakes; the association is non-causal being dependent on the common factor of room temperature.

It is to be noted, that although in all the tests, the experimental subjects were stripped to the waist, Mackworth used the Normal scale of effective temperatures to determine the effective temperature represented by the particular atmospheric conditions of the test climates instead of the more appropriate Basic scale.

Since 1950, evidence has been obtained which throws doubt upon some of the conclusions made by Mackworth. It will be remembered that Mackworth's researches were made in England upon young British men, artificially acclimatised to heat by repeated daily exposures in a climatic chamber.
The question rose as to whether his results were applicable to temperate climate subjects who had been living in the tropics for some time, so that not only were they locally and naturally acclimatised to heat, but were in fact residing between experimental exposures in tropical conditions. Consequently, Pepler,

in Singapore, instituted a long series of experiments designed to test this point, and during the years 1950-1953 investigated heat effects on the following abilities:- wireless reception, pursuitmeter performance, and some "intellectual" and vigilance tasks. It will not be necessary to consider in detail all Pepler's experiments, but the important work relevant to the thesis will be discussed, and the general conclusions compared with those found by Mackworth.

Pursuitmeter test.

Pepler (1953 a) found that his tropically acclimatised subjects, when exposed to climates of 66°F., 76°F., 84.5°F., and 91.5°F., on the Basic effective temperature scale, performed better at 66°F., and 76.2°F., effective temperatures than at the higher temperatures. The difference between performances at 76.2°F., effective temperature and 84.5°F., was significant, and "performance in the warmer climate was more erratic, less accurate, and generally rather disorganised." Performance was measured by Pepler in terms of a Total Error Score by means of an electrical scoring device fitted to the pursuitmeter, and also by using the Total Error Score obtained by summing the angular errors recorded on the machine error dial. The pass-or-fail method of scoring was not used, and because of this, an important point was brought to light, for Pepler found that at 91.8°F. effective temperature, although performance was worse than at 84.5°F. effective temperature, the difference was not significant. However, he concluded that the effect of heat on tracking by locally acclimatised subjects was similar to that found on artificially acclimatised subjects in England. Later, in a larger experiment, Pepler (1953 b) again found that performance deteriorated with heat, and observed a significant change in Error Score from 79.5°F. effective temperature to 84.5°F. effective temperature. But performance at 92.5°F. effective temperature, although worse than at 84.5°F. effective temperature, was not significantly different. These observations in two experiments, Pepler concluded, "although not disproving Mackworth's general hypothesis of a logarithmic relationship between the index of deterioration in performance and the room temperature, do not, however, support it." In the second experiment, Pepler applied the pass-or-fail scoring method to some of his results and found the failure rate to be increasing from 79.5°F. to 84.5°F. effective temperature, and then to 92.5°F., "in line with Mackworth's results." It was felt that the measure of agreement obtained by this manoeuvre in combination with the observations on Total Error Score, provided some evidence that the logarithmic relationship suggested by Mackworth was due largely to the influence of certain specific conditions in the experiment, among which the relative difficulty of the task was of prime importance. On neither method of calculation did the results show a relationship between performance and simple physiological measures. Some evidence was found however, that the standard of tracking in moist climates (80% Relative humidity) deteriorated over a lower range of effective temperatures than in dry climates, (20% Relative humidity).

Morse Code Reception.

In his investigations of wireless reception, Pepler (1953 c) met considerable difficulties and obtained somewhat confusing results. Twelve subjects who were fully trained operators, and who had been resident in Singapore for at least six months, underwent an intensive period of training at receiving morse before taking part in the experiment. They were then exposed to the test climates, either in morning or afternoon test sessions, each of which lasted three hours. The climates used were 71°F., 76°F., 81°F., 86°F., 91°F., and 96°F., effective temperature on the Basic scale. Twelve Morse Code messages, each of 250 groups symbols, were relayed in each session, and performance was measured as the average number of errors per message at each climate. Rather strangely, the results obtained for morning and afternoon sessions varied from each other. In the morning session performances at 71°F., 81°F., and 86°F., effective temperature were similar, but at the higher temperatures 91°F., and 96°F., effective temperature, the performances were significantly poorer. At 76°F., effective temperature in the morning sessions, performance was also poor, but Pepler ascribed this to the behaviour of some of the operators who were in a light-hearted mood, and did not concentrate on the task as consistently as usual. In the afternoon sessions, performance at all climates was better than in the mornings, but performances at 81°F., 86°F., and 96°F., effective temperatures were of the same order. The worst performances were at 71°F., and 91°F., effective temperatures, and the best at 76°F., effective temperature.

Pepler felt that these findings were due to the large measure of uncontrolled variability of the operators, but in view of his criticism of the light-hearted operators, and because elsewhere he states that some of the data had to be rejected because one of the operators was drunk in the climatic chamber and had to be excluded, it appears that the operators did not take the experimental series very seriously, and this may well explain their variability. That this may have been due to boredom, following the prolonged pretest training they underwent is likely.

Nevertheless, Pepler thought that there was some evidence, that men accustomed to living in the tropics could maintain their efficiency better over the range of climates, than did Mackworth's artificially acclimatised subjects. When performance was considered in terms of ability, he found that highly skilled men were able to maintain their level of accuracy despite the hottest climate. Deterioration in accuracy, with time, within sessions, was found for all sessions and all operators. Once again no direct relationship was found, between accuracy of performance and measure of sweat loss, or increase of rectal temperature. However, in view of the circumstances of this experiment, it is obviously difficult to put any undue weight upon any of the results.

It will be of value to mention one more of Pepler's experiments at this stage, before considering his general conclusions. This experiment is concerned with visual vigilance (Pepler 1953 d), and consisted of two series of climatic exposures, in which subjects performed the "Clock Test," devised at Cambridge by Mackworth (1950). In this test, the subject watched a pointer moving round a circular scale, graduated into a hundred divisions. The pointer usually moved one division per second, but at irregular intervals of time it would move double this distance, thus providing a stimulus to which the subject was required to respond by pressing a key. Performance was measured by the number of signals missed per climatic session of two hours. Pepler found in his first series that performances at 66°F., effective temperature and 92°F., effective temperature were better than at 82°F. effective temperature, but in his second series, which in contrast to the first was short and compact, the reverse result was obtained. Deterioration with time within sessions, was marked after the first half hour of the two hour exposures. This experiment indicates the difference in results obtained in the same circumstances on different occasions, and in this case the difference was held to be due to prolonged length of the first series, during which the subjects lost interest, while in the second series the subjects maintained a high level of interest and effort. In addition, the second series of this experiment indicated that a deterioration in performance occured with change in temperature in either direction from the climate to which these subjects were most nearly accustomed i.e. 82°F., effective temperature. More attention will be paid to this point later, as Pepler's later work provides some confirmation of this finding.

Pepler (1953 e) summarising his views, maintained that the reaction to heat of young men from temperate climates, living in the tropics did not differ from those of artificially acclimatised subjects in England. However, criticism was made of Mackworth's concept of a critical temperature range in view of the marked variability in performance which may result from difference in motivation and ability of the subject. Finally, doubt was also cast on the logarithmic relationship of performance to temperature, in view of Pepler's failure to find a logarithmic fit to either the wireless reception, or the pursuitmeter results. General confirmation was found for Mackworth's findings concerning the effect of ability, and also for the deterioration in performance with time within test exposures.

In 1953 also a negative result for the effect of heat stress on a mental test was reported. Bartlett and Gronow (1953) used a test designed to assess the effect of heat on anticipatory perception and judgement. The subjects were given in succession squared cards upon which were marked symbols representing aircraft. It was to be imagined that the aircraft on a given card would move over the card in certain directions determined by rules of movement and indicated by the symbols particular situation on the card. The subject was required to assess whether collision would occur between the aircraft. Four climates were used to observe heat effects, namely 60-70°F., (dry bulb); 80°F. (dry bulb), 70°F. (wet bulb); 90°F. (dry bulb), 80°F. (wet bulb); and 100°F. (dry bulb), 90°F. (wet bulb), and the subjects were exposed for half an hour, and then performed the test in the second half hour of the hourly exposure. No effect on performance was found; it should be mentioned that the subjects were, in fact, research workers at the Institute of Aviation Medicine and corresponded to "Exceptionally skilled workers." Thus no deterioration might be held to be likely on this count and also, in view of the shortness of exposure and the probably high motivation of the experiment, it was unlikely that decrement would be found.

Later, in 1953, Pepler published the results of further investigations on some of the points raised by his earlier work. With regard to the effect of motivation, he performed two experiments in which the level of incentive was varied. In the first (1953 f) the subjects' pursuitmeter performance was observed over a climatic range of 76°F., 81°F., 86°F., and 91°F., effective temperatures when they were given no information about their performance, and no encouragement, and also when full information and encouragement were provided. Pepler found that the best performances at both incentive levels were at 81°F., effective temperature, and that at higher temperatures, performances were worse, despite high incentive. Like Mackworth (1950) he found that even at high temperatures, performance with high incentive was better than the best performance without incentive. Performance at 76°F., effective temperature, at both incentive levels was not as accurate as that at 81°F., effective temperature; this provided more evidence to support Pepler's finding in the vigilance test that alteration of climate in either direction might affect performance in subjects adjusted to the small temperature range of ambient conditions in the tropics. Pepler's second experiment (1953 g) with incentive level variation was a more complex mental test, in which subjects were required to note discrepancies between paired symbols printed on cards. Once again either no information, or full information with encouragement concerning the standard attained, represented the incentive levels, and the same test climates as above were used, namely 76°F., 81°F., 86°F., and 91°F., effective temperatures. The most accurate performances were at 81°F., effective temperature at both incentive levels; below and above this climate performances were significantly worse. In this experiment also the speed of card presentation to the subjects was varied from fast to slow, at both incentive levels. It was found that the results were similar for slow speeds at both incentive levels over the range of climates. But at fast speeds with increase in temperature, deterioration was greater at the high incentive level than it was at the low incentive level - this is in agreement with Mackworth's general conclusion that the subjects who try the hardest deteriorate the most. In a larger experiment, using the same test and climates

Pepler (1953 h), confirmed that performance was most efficient at the climate nearest ambient i.e. 81°F., effective temperature, at any of three different rates of working, when no incentive was offered. Thus Pepler (1954) concluded:-

(1) Men do not work as efficiently at 86°F., effective temperature, as they do at 81°F., effective temperature, under differing incentive conditions and at different speeds. The effect of heat was deterioration, independent of incentive, knowledge of results or standard achieved. However, high incentive at the worst climate may provide a better performance than low incentive at the ideal climate.

(2) Men used to a small range of climate variation, work best at the climate nearest ambient, and may be less efficient at cooler temperatures. In three tests, performance at 76°F., effective temperature was poorer than at 81°F., effective temperature. This may be due to the subjects becoming more sensitive to climatic change, owing to the narrow range of ambient conditions.

(3) Progressive deterioration in performance at temperatures above 86°F. effective temperature, was not evident except in the mental task at high speeds of

working, and in the tracking task at low incentive level. These results once again, do not favour Mackworth's finding of a logarithmic relationship between performance and temperature.

The popular concept of incentive under special conditions, staving off physical and mental deterioration, has long been considered possible, and the evidence accumulated by Mackworth and Pepler tends to its support. Blockley and Taylor (1954) drew attention to experiments performed earlier which provide striking confirmation of this phenomenon under the most adverse physical circumstances. Blockley and Lyman (1950 & 1951) found that in exposures up to one hour at very high temperatures, subjects could maintain their psychomotor standard for 60-90% of their "physiological tolerance time". The psychomotor tests used were addition and number checking tests, and also a task simulating complicated instrument flying. The "physiological tolerance time" was reached at the onset of the first symptoms of collapse such as complaint of intolerable stress, faintness, nausea, paraesthesia, mental confusion, compulsive restlessness, dyspnoea or a tachycardia greater than 140 beats per minute. The temperatures used for these flight simulation experiments were 160°F., and 200°F., and tolerance times were of the order of 30 minutes for the very high temperature, while psychomotor deterioration only showed at 21-29 minutes, but rapidly became complete. Two subjects who were particularly well motivated performed more nobly than the others, but all were experienced pilots, whose reactions represented an "emergency maximum duration of stress which could not be used as a design value for routine flight plans." Blockley and Taylor, after stressing the importance of motivation, maintain that usually, however, psychomotor performance fails long before physiological collapse threatens, and that 2-4 hours is the maximum psychological tolerance time, even in only uncomfortable temperatures, when the physiological tolerance time is much greater. Pepler (1956 a) has confirmed that in 20-30 minute exposures to high temperatures (dry bulb 116°F., wet bulb 105°F.), well motivated subjects maintained their pursuitmeter performances almost until physical collapse.

Negative reports of the effect of heat on some abilities appeared in 1954, from Teichner and Rohles. Teichner (1954) in a review of studies of simple reaction time concluded that ambient temperatures (- 50°F. to + 117°F.) have little or no effect on simple or complex reaction time.

Rohles (1954) studied the effect of temperatures of 70°F., 60°F., 50°F., 40°F., 30°F., on "serial discriminative responses" as manifested by typing. He found the best performances of the 25 subjects as indicated by the least errors and the least time taken to complete a given work, were made at 60°F. Above and below 60°F., and 50°F., more time was required but little change in number of errors was found until the temperature was below 40°F., In a further experiment, temperatures of -55°F., to 110°F., at 15° intervals were used, and the subjects performed manual dexterity, pursuit and co-ordination tests. Analysis of variance of the results showed temperature to have been ineffective as a cause of variation in performance, but the statistical manipulation of the results seems to be based on peculiar premises. Performances from climate to climate were compared with each other by student's "t" test and then the number of significant "t's" for each climate was then used to perform an analysis of variance.

Fraser and Jackson (1955) failed to support Teichner's finding in their study of the effects of temperatures 90°F., to 104°F., (90-95% saturation), on serial reaction time. The subjects were required to perform the Cambridge visual vigilance test and the mean reaction times to the serial stimuli were measured electrically before entry into the heat, and after one and two hours exposure. The rise in reactinn time in heat was found to be significant and they conclude that it offers a clear cut index of psychomotor change in heat stress of the temperatures used.

Finally Pepler (1956 b) in a summary of the position, points out that in a variety of tasks, performance is less efficient at 86°F., effective temperature, than at 81°F., effective temperature, and draws attention to the fact that man becomes less efficient at carrying out a skilled task within the first few minutes in the heat, particularly if it is humid heat. While pointing out that man is, or may be able to compensate for adverse climate, under certain conditions, Pepler asserts that this may be potentially dangerous, in that other features of the situation may temporarily be regarded as unimportant.

Before closing this review of relevant literature, it is worth while to note the efforts that have been made to correlate mental impairment with physical or physiological measures. Mackworth (1950) and Pepler (1953 a,b,c,e,) have found that performance could not be correlated either with sweat rate or rise in rectal temperature. Both relate the onset of impairment to the effective temperature of the atmospheric conditions, rather than to any physiological measure of the subject. Physiologically, the upper desirable level of warmth has been defined by means of the predicted four hour sweat rate, or P4SR - as determined from a empirical nomogram, combining energy expenditure of the subject, clothing worn, air temperature, humidity, and speed. This conclusion was reached by McArdle et al. (1947), after a long series of observations, and these observers considered the threshold for intolerance was reached by hyper-acclimatised subjects at a P4SR of 4.5 litres. Ellis (1953a) maintains that for everyday practice, the level should be 3.5 litres in the Far East, and 3.0 litres on ships at sea. An extension of this line of thought by Williams (1955) using Mackworth's results as a basis, places the upper limit for continued efficiency in psychological performance at P4SR 0.7 litre. Blockley and Taylor (1954), tackle the problem in a different manner, by plotting the psychological tolerance time, as determined in their flight simulation task, against the heat storage rate of the individual, as found by calculation from the rate of rectal temperature rise. Because their results only deal with exposures up to

30-60 minutes, extrapolation was used, based on the results of other workers, to derive a curve for larger tolerance times, both physiological and psychological, against Body Heat Storage rate. That extrapolation is a hazardous procedure in these circumstances must be remembered, so that the chief value of this curve is confined only to similar or the particular circumstances of its derivation i.e. in heat exposures less than one hour and in the same conditions of subject ability and motivation. It must also be remembered in terms of assessing decrement by physiological measures, that as Pepler (1956 b) has pointed out, impairment is obvious within the first few minutes of exposure to a hot atmosphere before any considerable heat storage could take place, before in fact, the rectal temperature rises, and before the subject has had opportunity to start to sweat at a rate commensurate with a predictable loss of 0.7 litres in four hours.

General Conclusions.

(1) Evidence is overwhelming, that psychomotor efficiency is impaired at effective temperatures in the region of 86°F., for artificially and tropically acclimatised temperate climate subjects. Dispute exists as to whether progressive deterioration with temperatures above this limit is real, and logarithmic

in nature, or whether it is the result of specific factors in the experimental method.

(2) Subjective ability or skill, incentive, interest or boredom, and motivation may determine or alter reaction to heat.

(3) No general physiological measure has been found to predict the onset of impairment, and the best indication is the physical measure of the effective temperature of the specific atmospheric conditions in relation to previous experience and observations.

(3) <u>The Short Term Effects of Heat on Tropical Man</u>

All the work discussed in the section 2, has been performed using men normally from temperate climates as subjects, and up to date few laboratory observations have been made on tropically indigenous subjects. Wyndham et al (1951-1953) have investigated the effect of heat on the "Arm ergometer performance" of African gold mine recruits. The ergometer test was, in fact, a muscular pull test similar to that used by Mackworth (1950), and the subjects were exposed to climates of 82° to 96°F., effective temperature. These observers found that working efficiency deteriorated at temperatures above 86°F., effective temperature. The fact that temperate climate man's reactions to heat of short duration is of importance, has been emphasised both for work in the tropics (Crowden 1949, Mole 1952), and also in specialised situations in temperate climates (Mole 1952), (Blockley, McCutcham & Taylor 1954). The necessity for considering whether the results obtained on temperate climate man can be used for anticipating the effects of heat on tropical subjects, does not seem to have been investigated. That tropical workers are sometimes exposed to temperatures above those generally accepted as being "critical" for temperate workers has, however, been pointed out. Reddy (1947) drew attention to this problem, and quoted results obtained by Bedford (1946), in a survey of industrial conditions in India. Bedford found cotton factory temperatures reading 90°F., and occasionally 105°F., with high humidities, even though the hot season of the year was not at its height. Concerning efficiency, Bedford revealed that production per man was often only $\frac{1}{4}$-$\frac{1}{2}$ of production in Western European cotton mills, and he felt that high environmental temperatures might account for $\frac{1}{3}$ of the loss in efficiency, although other causes of inefficiency were present. Caplan and Lindsay (1947) investigated the effect of high temperatures on the efficiency of Indian workers in deep mines. The subjects worked nude, at hand-drilling granite blocks for three hour exposures, and the index of performance was the number of inches drilled per hour. For comparison, the amount of work done was expressed as a percentage efficiency figure, 100% representing the average, done under the most favourable conditions during the first hour of a test. Caplan and Lindsay found that the rate of working declined with time, and that in the hotter places efficiency was lower than in the cooler parts. The best conditions experienced was a wet bulb temperature of 83°F., and this performance was taken as 100%. At wet bulb temperatures of 89.5°F., 88.2°F., and 86.6°F., during the first, second and third hours respectively, efficiency was 80%. Only 50% efficiency was found at wet bulb temperatures of 94.4°F., 93.0°F., and 91.3°F., during first, second and third hours of exposure. They concluded that below wet bulb temperatures of 85°F., no serious diminution of work was found, but at 90°F., only 60% efficiency can be expected. At 93°F., they felt that hardly any satisfactory work can be found, after two hours, and that none could be expected after the third hour. They state that the apparent high efficiency at wet bulb temperatures of 83°F., compared with those found for Europeans, were due to the Southern Indian labourer adjusting his basic rate of working to that demanded by tropical conditions. Bedford (1951) also referred to the apparent higher efficiency of coloured workers at wet bulb temperatures of 84°F., but ascribed this to the probability that "the European sets himself a relatively much higher standard in a cooler environment." Robinson et al, earlier in 1941, found that Negro workers were mechanically more efficient than white workers in the Southern States of America, and concluded that this was because the Negroes had a better temperature regulating mechanism. In hard physical work of this nature, however, differences in acclimatisation may have been responsible for the results.

Experience in West Africa shows that environmental temperature in mines, industrial situations, and even operating theatres, may exceed the upper desirable level of warmth. Ladell (1953) found basic effective temperatures in a gold mine to be 91.5°F.-93°F., Watkins (1955) in an investigation of conditions at working sites in the railway engineering workshops, found the following maximum temperatures on days at the beginning of the cool season.

Foundry during smelting	104.4°F. (dry bulb), 86.6°F. (wet bulb)
Boilershop during welding	97.1°F., (dry bulb), 84.5°F. (wet bulb)
Smithy near a furnace	97.8°F. (dry bulb), 83.2°F. (wet bulb).

As the air movement was generally less than 50 ft/min these temperatures represented effective temperatures of 90°F., 87°F., and 86°.5F., respectively on the Basic scale. From the observations it was concluded, that as conditions in the workshops exceeded outside temperatures by definite increments, the following maximum temperatures at various working sites were to be expected on hot days (i.e. when outside temperatures are dry bulb 95°F., wet bulb 80°F.,).

	Dry bulb°F.	Wet bulb°F.	E.T.°F.
Foundry-near furnaces	103	84	88
-when metal pouring	113	88	93
-in the shop generally	99	82	85.5
Smithy -near furnaces	106	85	90
-in the shop generally	100	83	87
Boilershop -in boilers during welding	105	84.5	89.5

Thus effective temperatures in most situations would be expected to be above 85.5°F., and certainly above the "critical level."

Ellis (1953) mentioned in his Hunterian lecture, the possibility that temperatures in operating theatres may conceivably exceed the warmth limit tolerable for optimim efficiency of surgical teams. Watkins (1955) in an operating theatre in West Africa, found the following conditions:- 86-87°F., dry bulb; 84-85°F.,wet bulb; Relative humidity 86-94%; with air movement of 10-22 ft/min; when outside temperatures were only dry bulb 84-87°F., wet bulb 80-81°F. These conditions represented effective temperatures 85-86°F., and it is small wonder that the surgeon complained that on hot days he could pour out sweat from his rubber boots, and that after 1-2 hours operating he found concentration and fine manipulations difficult.

It must be concluded therefore, that high effective temperatures above the level defined by Mackworth, frequently occur in the tropics in a variety of situations. Some evidence has been accrued that tropical subjects suffer impairment with heat but these observations are few and mainly industrial in nature; it was for these reasons that the experimental investigations in this thesis were undertaken.

(4) <u>The Scope and Plan of Experimental Work</u>.

The following questions were designed to be answered by the results of these investigations.

1) Do tropical subjects deteriorate in psychomotor efficiency in heat?

2) At what climate does impairment, if any, result, and to what extent is the decrement?

3) What comparison can be made with the

results of Mackworth and Pepler on the temperate climate subject?

4) What abilities or skills suffer, if any?

5) Can any further information be derived from this work concerning the logarithmic relationship of performance to atmospheric temperature?

It was decided therefore, to perform experiments at three levels of intellectual and motor "skills":-

(a) a simple manual dexterity task.

(b) a psychomotor task.

(c) an "intellectual" task.

For comparison with the work of Mackworth and Pepler, and also because facilities were easily available for performing pursuitmeter and wireless reception tests, these were chosen to fulfil the requirements of (b) and (c), and for (a) it was decided to perform the manual dexterity test used by Weiner and Hutchinson (1945). From an earlier section of this work it has become obvious that for psychomotor tests to have any significance, strict control of conditions and circumstances must be exercised. Motivation and level of incentive must be defined, and boredom or loss of interest on the part of the subjects must be avoided. It is considered that lengthy experiments based on

Latin square designs as used by Pepler tend to negate subject interest, and consequently a different design of experiment was used to this end. In none of the experiments were the subjects informed of their performances, as in most industrial situations today incentives for the most part are low and information concerning individual output is not available except in piece work situations.

The details and results of the three experiments outlined above are described in Part II of the thesis.

Part II

Section A.

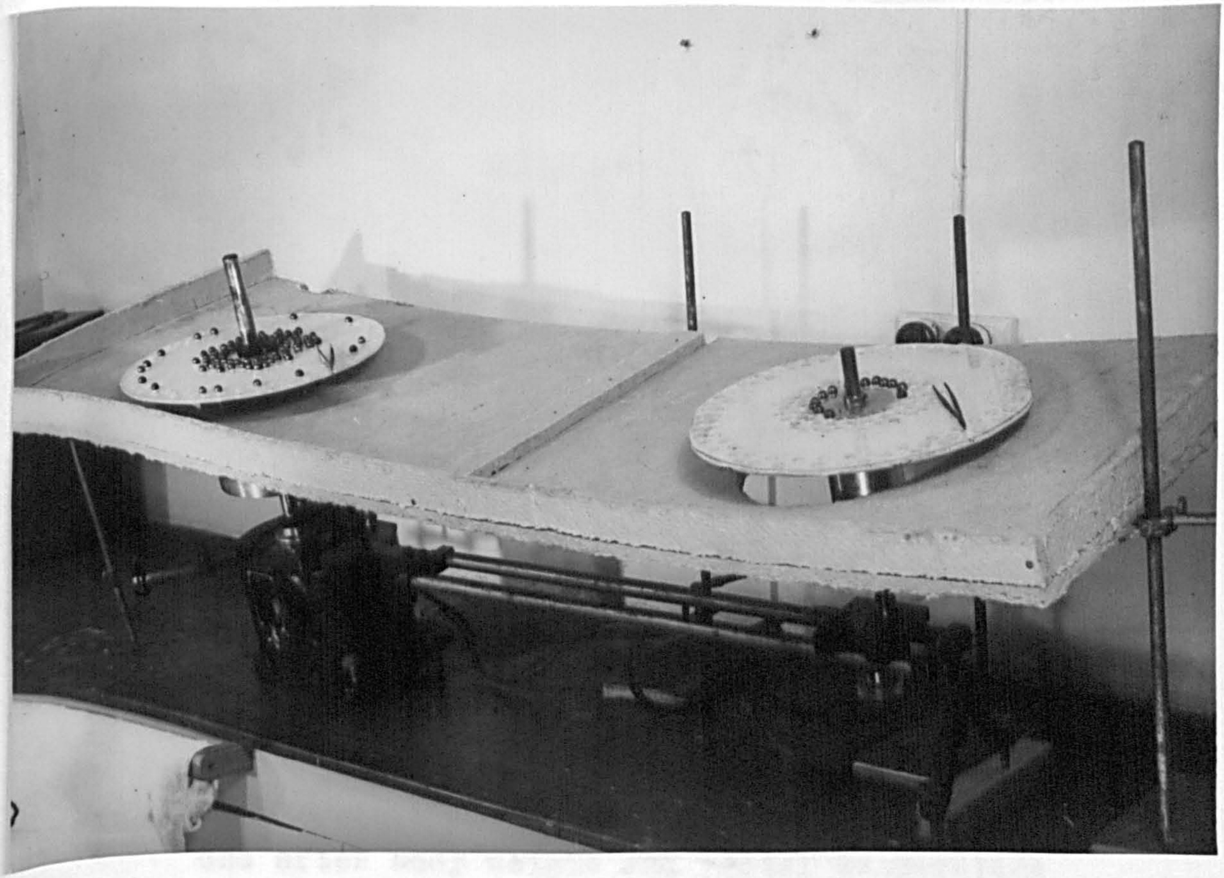
Manual Dexterity Test.

METHODS - (a) Experimental subjects

When this test was carried out by Weiner and Hutchinson (1945) in Britain, the subjects used were ordinary service men and laboratory workers. In Nigeria, however, it was found that the skill required, which involved fairly high speed fine repetitive movements with considerable motor co-ordination, was not developed in those ordinary Nigerian working men tested in preliminary experiments. In order to save time, it was decided to use subjects, whose everyday jobs involved sorting small articles at considerable speed and with accuracy. Storekeepers, who sort ammunition and small replacement spares at the Command Ordnance Depot of the Royal West African Frontier Force were considered suitable, and four of them, all African N.C.O's volunteered as subjects for the test. These men, 28 - 32 years old, had been soldiers since their late teens.

(b) The Test.

The apparatus used in this test was slightly modified but essentially the same as that described by Weiner and Hutchinson. It consisted of two rotating perspex discs (diameter $12\frac{1}{2}$ inches) mounted and driven by a kymograph motor at 5 revs/min. One of the discs was mounted on the top of the kymograph drum itself, and the other on the pilot drum which rotated at the same speed. By this means two subjects could do the test at the same time. The discs were drilled and recessed in two sets of perforations, each 84 in number; one set was disposed at random in a ring around the centre of the disc, and the other set in a ring round the periphery of the disc. Into each of the 84 holes of the inner ring was placed a $\frac{3}{8}$" steel ball (ball bearing); the test consisted of transferring these balls, with forceps, to the outer series of holes and then, when this was completed, transferring them back again to the inner ring, as quickly as possible, while the discs were rotating. The apparatus as a whole was mounted, so that the discs were inclined at 13° to the horizontal, and any balls which were dropped or misplaced, fell and rolled down the slope onto collecting trays placed under the discs. These dropped balls, which were counted by the observer, had to be retrieved by the subject, and properly placed in vacant holes of either the outer or inner ring, according to which half of the test was in progress. All balls had to be properly placed, before the test was completed. A photograph of the apparatus is shown on the next page.



The time taken by the subject to perform this double manoeuvre was recorded with a stop watch, and the total number of balls dropped was noted. This complete manoeuvre, performed three times, with a two minute rest between the first and second attempt, and a fifteen second rest between the second and third attempt constituted a "run". The sum of the times taken for the three successive attempts was taken as "the run time", and the sum of balls dropped, constituted the "total balls dropped per run". "Mean time per ball movement" was also calculated from the ratio:- total time for run (in seconds) divided by total movements (given by 6 x 84 plus total balls dropped).

(c) The Daily Routine.

The routine for the experiment was as follows. The subjects, dressed only in shorts, entered into the climatic chamber in which the test was carried out, two at a time, the second pair 30 minutes after the first. The time table was then as follows:

Time (minutes)	
0	2 subjects (P.O.) enter climatic chamber; rectal temperatures (R.T.) and body weights (Wt.) are recorded and the subjects rest.
30	P and O perform run 1. Subjects E and I enter, and after body weight and rectal temperature observations, rest.
60	E and I perform run 1. P and O R.T. and Wt. observed, rest.
90	P and O perform run 2. E and I " " " " "
120	E and I " " 2. P and O " " " " "
150	P and O " " 3. E and I " " " " "
180	E and I " " 3. P and O after observation of R.T. and Wt. leave room.
210	E and I after observation of R.T. and Wt. leave room.

Each man thus performed a run once in the second half hour of each hour of his three hours climatic exposure.

From the changes in body weight and the observed fluid intake and output, hourly sweat rates could be calculated. Rectal temperatures were measured with clinical thermometers.

(d) Experimental Plan

After a preliminary training period in which the subjects carried out the test in the climatic chamber at "normal" Lagos ambient temperatures (82-89°F Dry bulb, 76-84°F Wet bulb) they then performed the routine in test climates arranged as follows :

Climatic	Days	1 & 2	Effective	temperature	76°F	(Basic scale)
"	"	3	"	"	86°F	"
"	"	4	"	"	96°F	"
"	"	5	"	"	81°F	"
"	"	6	"	"	91°F	"
"	"	7	"	"	76°F	"

By having days 1 and 2 the same temperature, it was possible to confirm that a flat part of the learning curve had been reached, and by repeating this temperature on day 7, any further improvement due to learning could be detected. The order of the temperatures for days 3 to 6 inclusive, was determined by strict randomisation. In both the training and climatic runs, the air movement was 100 feet per minute. Finally a more severe test of the same nature was performed by doubling the number of runs attempted per session; thus in the second half hour of each hour of exposure, each subject performed two runs, and so, in a complete session, handled 3024 balls (plus any dropped), instead of 1512 (plus the number dropped) as in the main series. This severe test of manual dexterity was performed in two climates, first at 81°F effective temperature, then at 91°F effective temperature, on days 8 and 9 of the climatic tests, and performance was measured by the "double run" time.

RESULTS.

The detailed daily scores and observations are shown in the Appendix section A. For convenience the results are discussed under three headings :-
(1) Performance during learning (2) Performance during the climatic tests, and (3) Performance of the severe test.

(1) Performance during learning.

"Learning" of the test was rapid and successive performances of a "run" took less time to complete. The "run times" for the learning period are shown in Table I in order of performance, and it can be seen from Figure 1 that if mean time per run is plotted against run number in consecutive order, a typical learning curve is obtained. The individual learning curves are shown in the Appendix.

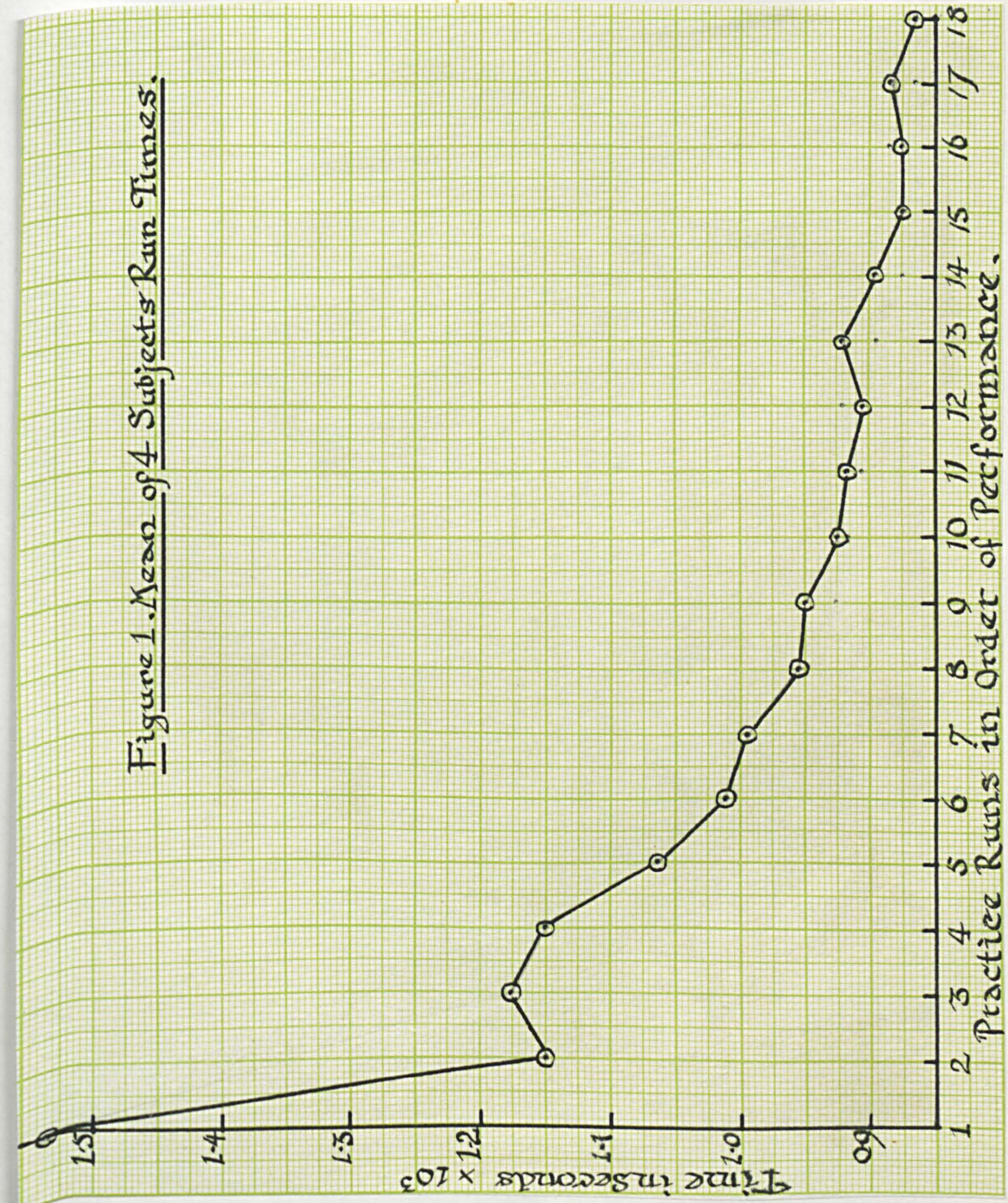


TABLE I

Individual Performances of Subjects During Learning Period.

Practice Day	Run. No. in order	Run/Time (seconds)				Number of Balls Dropped/Run			
		Subjects				Subjects			
		P.	O.	E.	I.	P.	O.	E.	I.
1	1	2222	1340	1088	1491	162	104	92	71
	2	1224	1110	958	1310	42	52	60	77
	3	1376	1118	978	1218	63	56	31	67
2	4	1357	1004	1139	1118	80	51	42	56
	5	1131	1015	1001	1116	61	48	37	59
	6	1099	914	1008	1026	72	43	54	61
3	7	1009	918	1029	1026	77	56	78	45
	8	1008	934	962	933	78	69	62	38
	9	981	914	944	976	62	56	68	48
4	10	1048	850	859	943	84	45	30	24
	11	967	882	882	934	76	53	48	20
	12	905	854	916	935	66	43	43	28
5	13	939	834	901	1013	76	39	27	24
	14	923	837	832	996	71	53	23	18
	15	919	801	847	938	111	58	31	24
6	16	896	839	845	925	80	62	42	31
	17	839	828	868	1021	73	76	56	27
	18	828	898	818	917	78	83	39	30

During the learning period, the "total balls dropped per run" became fewer, although there was still some variability. Similarly, the individual run times showed some variability even at the end of the learning period. However, at the end of six training days, the learning curve for "mean run time" had flattened out, and by then, the subjects had also become familiar with the climatic chamber, the experimental routine, the fan noise, and the observers. The improvement in overall performance during learning as shown by the daily means of time per run, number of balls dropped, and time per movement can be seen in Figure 3.

Consequently it was judged that learning was virtually complete at the end of the sixth training day, and the climatic test series was begun on the next day. It must be remembered that in all tests once the initial learning, which is rapid, is acquired further slight improvement in performance may be expected for a considerable time.

(2) Performance during the climatic tests.

The individual performances during the climatic tests are shown in Table II. The first two days were performed at the same effective temperature and it can be seen that results were substantially the same. When the mean time per run for successive runs on these days are considered, (see Figure 2), it is confirmed that the results were similar, and that learning was sufficiently complete to proceed with the other climatic tests.

TABLE II

Individual Performances of Subjects During Test Climates.

Climate Effective Temperature	Run Number	Time/run (seconds)				Number of Balls dropped per Run.			
		P.	O.	E.	I.	P.	O.	E.	I.
E.T. 76°F	1	816	789	815	881	93	58	30	24
	2	834	846	796	853	59	63	32	12
	3	779	796	824	892	82	65	37	20
E.T. 76.5°F	4	819	784	824	887	77	56	43	18
	5	768	793	788	847	76	71	40	26
	6	768	755	789	835	106	68	57	53
E.T. 86°F	7	735	770	759	818	63	77	56	48
	8	714	723	773	798	94	60	35	38
	9	687	799	717	782	73	94	37	47
E.T. 96°F	10	739	755	760	787	84	84	51	25
	11	735	733	758	755	59	80	72	44
	12	728	715	715	713	102	85	58	32
E.T. 81°F	13	657	696	757	745	42	56	43	29
	14	630	730	730	760	51	76	61	44
	15	634	689	693	762	47	77	56	38
E.T. 91°F	16	703	664	713	729	83	69	48	33
	17	662	683	652	782	63	79	53	46
	18	593	659	653	710	52	75	57	38
E.T. 77°F	19	623	682	699	784	47	78	56	50
	20	615	675	632	720	49	79	53	41
	21	590	676	655	715	61	89	55	37

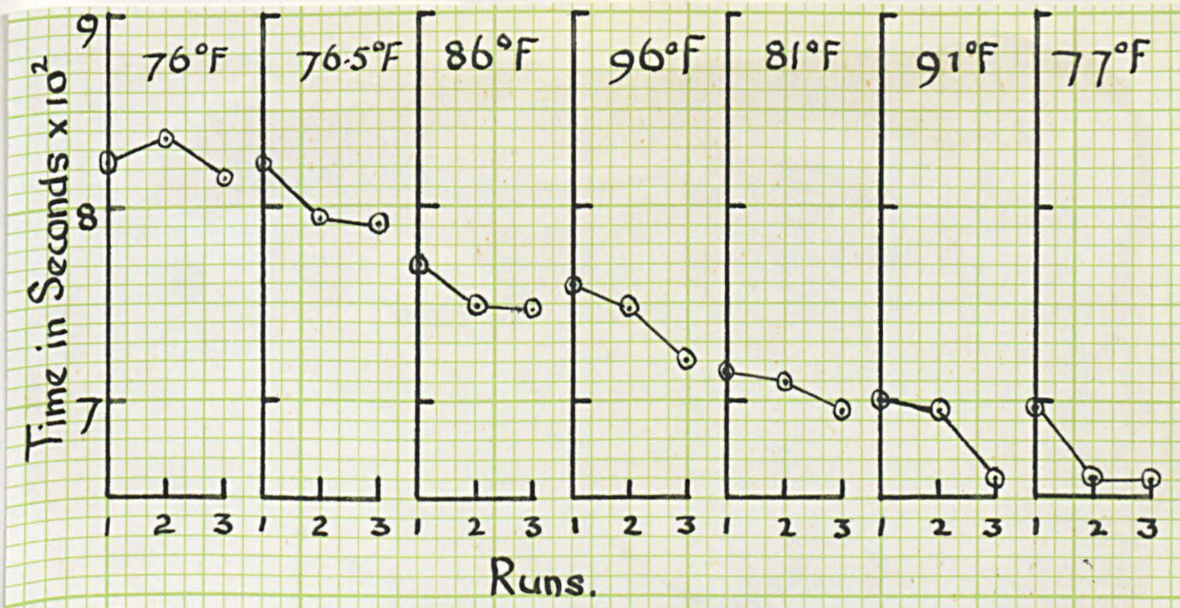


Fig. 2. Means of 4 Subject's Run Time for Climatic Tests.

However, further inspection of Table II clearly indicates that individual performances did not appear to be markedly affected by raising the effective temperature. The mean run time for successive runs during the climatic tests, shown by Figure 2, continued to decrease slowly.

The overall daily performances are shown in Table III and it can be seen that from the first to the last sessions at 76°F effective temperature the daily mean time per run improved slowly and there was no interruption of this improvement at the intermediate hot climates.

TABLE III

Overall Mean Performances per Session

Session	Run Time or Duration of Mean Time/Run/ Daily Session in seconds (each mean is mean of 12 runs)	Mean Time per movement (Seconds) (Mean of 12 runs)	Mean Balls Dropped per run (mean of 12 runs)	
Practice Day 1	1286.08	2.229	73.00	t
" " 2	1077.33	1.926	55.33	to be signi-
" " 3	969.50	1.715	61.41	ficant
" " 4	914.58	1.661	46.66	"t"
" " 5	898.33	1.632	46.25	must be greater than or
" " 6	876.83	1.564	56.75	equal to 2.074
Effective Temperature				
Climate of 76°F ET.	826.75	1.497	47.91	
" 76.5°F E.T.	804.75	1.433	57.58	0.907
" 86°F "	756.25	1.340	60.16	0.268
" 96°F "	741.08	1.303	64.66	0.473
" 81°F "	706.91	1.272	51.66	1.552
" 91°F "	683.58	1.216	58.00	0.972
" 77°F "	672.16	1.196	57.91	0.013

Similarly, the mean time per movement showed a gradual though slight improvement throughout all the exposures (see Figure 3). There was thus, a slow continuation of learning, uninterrupted by exposure to high temperatures as shown by these two measures of performance.

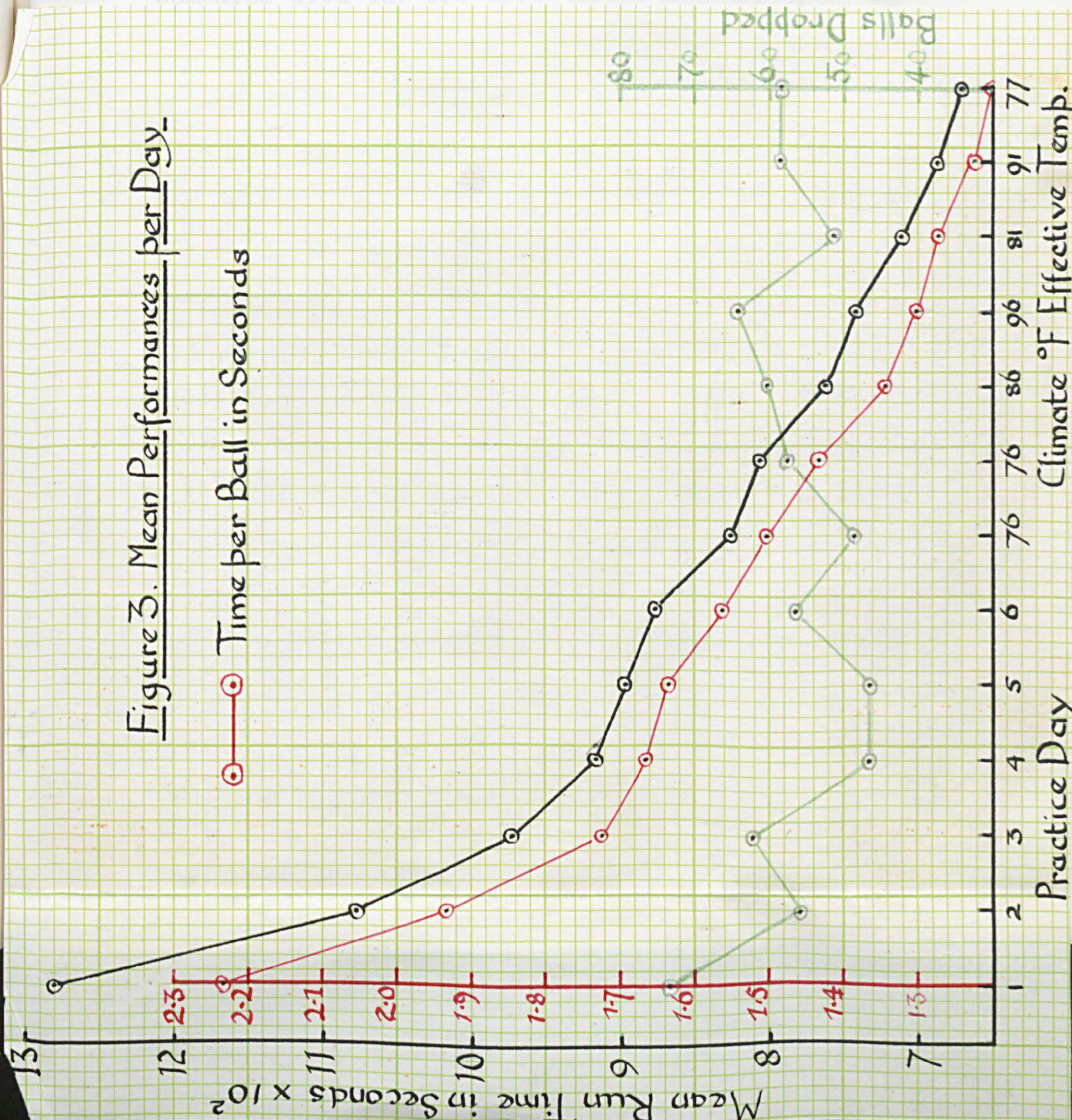


Figure 3. Mean Performances per Day.

The number of balls dropped per run by the subject continued to be variable in the climatic tests. (Table II). The daily mean of balls dropped per run was likewise variable, and differed between successive tests at the same effective temperature (Table III), and throughout the series there was no overall decrease of this measure. There was an apparent decrease in the mean balls dropped at an effective temperature of 81°F, compared with the preceding daily mean at 96°F, and the succeeding daily mean at 91°F. This decrease was of the order of a difference in the mean of either 7 or 13 balls. However, a change of similar order in the mean was noted between successive daily performances at 76°F, 76.5°F and 86°F effective temperature. Such a change of about 13 out of approximately 560-570 balls handled, constituted only 2%, but in order to prove that this is not a significant change, the "t" values for differences between the means are shown in Table III. The maximum difference between the means i.e. from performance at 96°F effective temperature and 81°F effective temperature, is not statistically significant, "t" = 1.552 (in order to reach significance at the 5% level, "t" must equal 2.074). The differences between the mean balls dropped at other climates are likewise not statistically significant.

Despite these day-to-day variations in number of balls dropped, the daily improvement in mean time per movement was always sufficient to give a steady slight decrease in daily mean run time (see Figure 3).

The daily atmospheric temperature means, subjects' mean sweat rates and rectal temperatures are shown in Table IV. At 76°F effective temperature, rectal temperatures were steady or fell slightly, and sweat rates were less than 1 ml/min, but at the highest temperatures, rectal temperatures were increased by up to 3°F, and sweat rates were more than 10 ml/min. However, at no time was there any deterioration in efficiency in successive runs as body temperature rose, in the course of an exposure. In fact mean run time for the second and third hour of exposure, was generally better than during the first hour, even when the rectal temperatures were rising (see Figure 2). Performance was thus not only independent of body temperature rise, but also did not deteriorate with time within a session. Absence of "fatigue" was, therefore, a consistent feature in all the tests, assuming that "fatigue" would be represented by a falling off of manual dexterity towards the end of a session.

TABLE IV

Bodily Changes and Climates (in order of performance)

Effective Temperature °F		76°F	76.5°F	86°F	96°F	81°F	91°F	77°F	81°F	91°F
Mean Rectal Temperature on entry (°F)		99.40	99.12	99.33	99.25	99.15	99.35	99.22	99.02	99.05
End of 1st hour	Mean RT. (°F)	99.12	98,97	99.68	100.32	98.97	99.62	99.05	99.15	99.35
	Mean sweat rate (grams)	43.70	47.50	176.20	588.25	110.00	265.00	50.00	86.25	258.75
End of 2nd hour	Mean RT. (°F)	99.02	98.97	99.53	101.27	99.02	100.12	99.07	99.40	99.92
	Mean sweat rate (grams)	45.00	60.00	172.50	728.75	123.70	297.50	55.00	116.25	318.75
End of 3rd hour	Mean RT. (°F)	98.92	98.90	99.65	102.07	99.00	100.20	99.12	99.42	100.12
	Mean sweat rate (grams)	55.00	54.50	185.00	623.50	120.00	272.50	53.70	105.00	291.25
Climate Means.	Dry Bulb (°F)	83.06	84.13	95.01	105.07	90.03	100.06	85.08	90.02	100.02
	Wet Bulb (°F)	75.89	76.17	85.06	95.03	80.03	90.02	76.46	80.07	90.01
	Air movement (Ft/min)	100	100	100	100	100	100	100	100	100

RT. = Rectal temperature (°F)

(3) Performance of the severe test.

The results of this test are shown in Table V. Even though a very large number of ball bearings had to be handled as quickly as possible by the subject, raising the effective temperature from 81°F to 91°F did not impair performance. In fact all three indices of performance were improved during the test at 91°F effective temperature, compared with the test performances at 81°F effective temperature. Thus mean double run time, and mean time per movement were less at 91°F effective temperature, and fewer balls were dropped. Handling a larger number of ball bearings did not cause a falling off of performance with time within a session, and double run time was less during the third hour than it was during the first hour at both these effective temperatures. Table V is shown on the next page.

TABLE V.

Individual and Mean Performances for Severe Test.

Individual Performances		Time/Double Run (Seconds)				Balls dropped/ Double Run.				Mean Performances.		
Climate Effective Temperature	Run No.	P.	O.	E.	I.	P.	O.	E.	I.	Mean time per run (secs)	Mean time per movement	Mean Balls dropped/ run
	1	1276	1238	1329	1466	90	127	111	78			
81 °F. E.T.	2	1291	1272	1285	1442	96	151	78	63	1306.5	1.180	98.9
	3	1205	1224	1265	1385	105	151	81	56			
	1	1288	1178	1311	1428	63	116	66	61			
91 °F. E.T.	2	1164	1134	1282	1354	69	111	61	41	1256.1	1.159	75.6
	3	1158	1151	1246	1380	75	118	67	59			

DISCUSSION.

It is clear from the results that manual dexterity was not impaired by heat in these experiments. This finding contrasts so markedly with the results of Weiner and Hutchinson, that it is necessary to examine both experiments critically. A difficulty which occurs in both series is that the performance of this test by an individual is subject to considerable variability, even on consecutive attempts. It can be seen from Table II and Table III, that the time taken per run varied by as much as 60-100 seconds from run to run for some subjects, even on the same day. Similarly, in the work done by Weiner and Hutchinson, variation of the same order occurred, as shown by the results of the prolonged exposure, given by Ladell (personal communication 1956), who was in fact the subject in the exposure. The details of this test are shown in the Appendix, and variations in time per run were up to 105 seconds. It is necessary, therefore, that to provide a reliable index of performance, the "mean time" used should be the mean of as large a number of runs as possible. In the present series, the mean was the mean of twelve run times in each session, and this was the maximum possible in the circumstances. In the work done by Weiner and Hutchinson, the results were based on the performance of the test once, by four subjects in the preliminary test, and by six subjects in the main series. In other words, the index was the mean of four run times, or the mean of six run times. The increase in run time which were significant were 8% or 14%, yet variations of the same order in the performance of the test could arise without any extraneous cause. This criticism is particularly apposite in the preliminary series of Weiner and Hutchinson, for in addition, the authors do not specify the exact relation of the controls to the experimental test. They state that the controls were "done ..... within a few days of the hot room test", without further information as to whether this was before or after, and, as the learning curve for these subjects is not shown, it is not possible to be assured that proper comparison could be made. The fact that the subject in the preliminary series were unacclimatised to heat, further weakens the results based on this test. Similar criticism can be applied to the experiment involving prolonged stay in the heat, for only one subject was used, the test was performed only twice each day, and this subject was also unacclimatised. The psychological effect of the prospect of such a prolonged stay in heat, when the subject was unused to the conditions may also have affected the motivation of the test.

However, the main strength of Weiner and Hutchinson's results lies, not in the preliminary or the long stay experiments, but in the main experiment, in which six acclimatised subjects performed the test. Unfortunately, consideration of the results is complicated by the experimental design; these subjects performed the test:-

(a) in the cool without prior step climbing

(b) in the heat after step climbing

(c) in the cool after step climbing.

Because the learning curves of these subjects were at different stages in (b) and (c), Weiner and Hutchinson could not compare these two conditions directly. Instead, they demonstrated that performance in the cool, after step climbing, was not statistically different from performance in the cool without prior work. In view of this it was held to be justifiable to compare performance in the heat after step climbing, with performance in the cool without prior work, and a significant difference was found. However, to assume that work would make no difference in heat, because it did not do so in the cold, would seem unwise. Although it appears that rectal temperature rise does not influence performance, and, therefore, step climbing cannot exert an influence by this means, this does not exclude the possibility that work itself in the heat might act detrimentally. Pepler (1956 - personal communication), believes that increased muscle tension may impair psychomotor performance in heat, and therefore, it may be that prior work did influence performance in Weiner and Hutchinson's experiment.

One more point arising from Weiner and Hutchinson's work remains to be considered. In the prolonged stay in heat experiment, it was found that the single subject showed rapid improvement with successive tests in heat. It was suggested by these authors, that this may have been a form of motor acclimatisation to heat. Ladell (1956 personal communication), suggests that if this process is analogous to acclimatisation, the absence of deterioration followed by improvement in tropical subjects' performance might indicate that these men had an inherent acclimatisation to heat for motor co-ordination of about the same intensity, i.e. about three days, as that already found for heavy work in the heat in the indigenous West African, (Ladell 1950). This superficially attractive concept involves, not only acceptance of Weiner and Hutchinson's work, but also acceptance of a specific phenomenon which is abstract and indefinable, namely "acclimatisation for motor co-ordination". In addition it can be pointed out, that in Weiner and Hutchinson's main experiment, the subjects were physiologically acclimatised to heat, and hence physically, were in much the same state as the tropical subjects, and quite possibly should have also acquired "the acclimatisation for motor co-ordination". Nevertheless, it is claimed, they showed deterioration in heat.

The position concerning the effects of heat on manual dexterity is, therefore, complicated. The evidence upon which is based the belief that temperate climate man suffers an impairment has been shown to be unsatisfactory. Little other evidence is available on temperate climate man, concerning such a simple automatic high speed test; much of the other work done on simple skills, involves more complex situations, such as lathe operation (Viteles and Smith 1946), and this work showed that deterioration results with heat. Rohles (1956), in an unspecified manual dexterity test, claimed heat to be without effect, but his results are open to doubt. The necessity for more experimental work to be done to clear up this point is obvious. It is difficult to say, therefore, that tropical man differs from temperate climate man in the effect of heat on manual dexterity, when the evidence concerning temperate man is unsound or conflicting. It is possible to criticise the present work by saying that these tropical men did not show a deterioration for either or both of the following reasons :-

(1) that they were better or more highly trained, than were the temperate climate subjects, and corresponded to "exceptionally skilled workers".

(2) that they performed the test in pairs, and competed with each other, and were thus highly motivated.

In answer to the first criticism, it can be said that the abilities of the subjects differed. Subject I was not as skilled as Subject P, yet both showed similar lack of reaction to climate. In addition, on the whole the subjects had had less practice at the test than Weiner and Hutchinson's subjects, and performed the test generally more slowly. It should be noted that the subjects showed gradual slight learning through the tests and cannot therefore on this count be considered "exceptionally skilled". The opposite criticism might be applied that no decrement was found because they were still learning and opposite effects might have cancelled out, but the slight improvement due to learning would surely have been more than counteracted by a significant impairment by heat. It is held, therefore, that subjects were sufficiently trained to have shown a heat effect if there was one, but were not so skilled that they could have resisted any impairment as might "exceptionally skilled" workers. Secondly, although they performed the test in pairs, owing to their differing abilities, once the run attempts had started, the two subjects rapidly became out of step in time, and consequently, neither could judge his own performance relative to the other, either in time, or in number of balls dropped.

CONCLUSIONS AND SUMMARY.

(1) When four tropical climate subjects were exposed to a series of climates, ranging from 76°F to 96°F effective temperature, no deterioration in the performance of a manual dexterity test was detected, contrary to previous findings on temperate climate subjects.

(2) The fact that this is a real difference to the previously reported deterioration in temperate climate subjects is refuted, in view of the unsatisfactory evidence of the earlier work.

(3) More work under carefully controlled conditions of experimental design is necessary to establish the effect of heat on the manual dexterity of temperate climate subjects.

(4) The inherent variability of performance of the manual dexterity test used, is emphasised, and possible criticisms of the design of this experiment mentioned, in particular in relation to the state of "learning of the test" acquired by the subjects.

Section B.

Pursuitmeter Test.

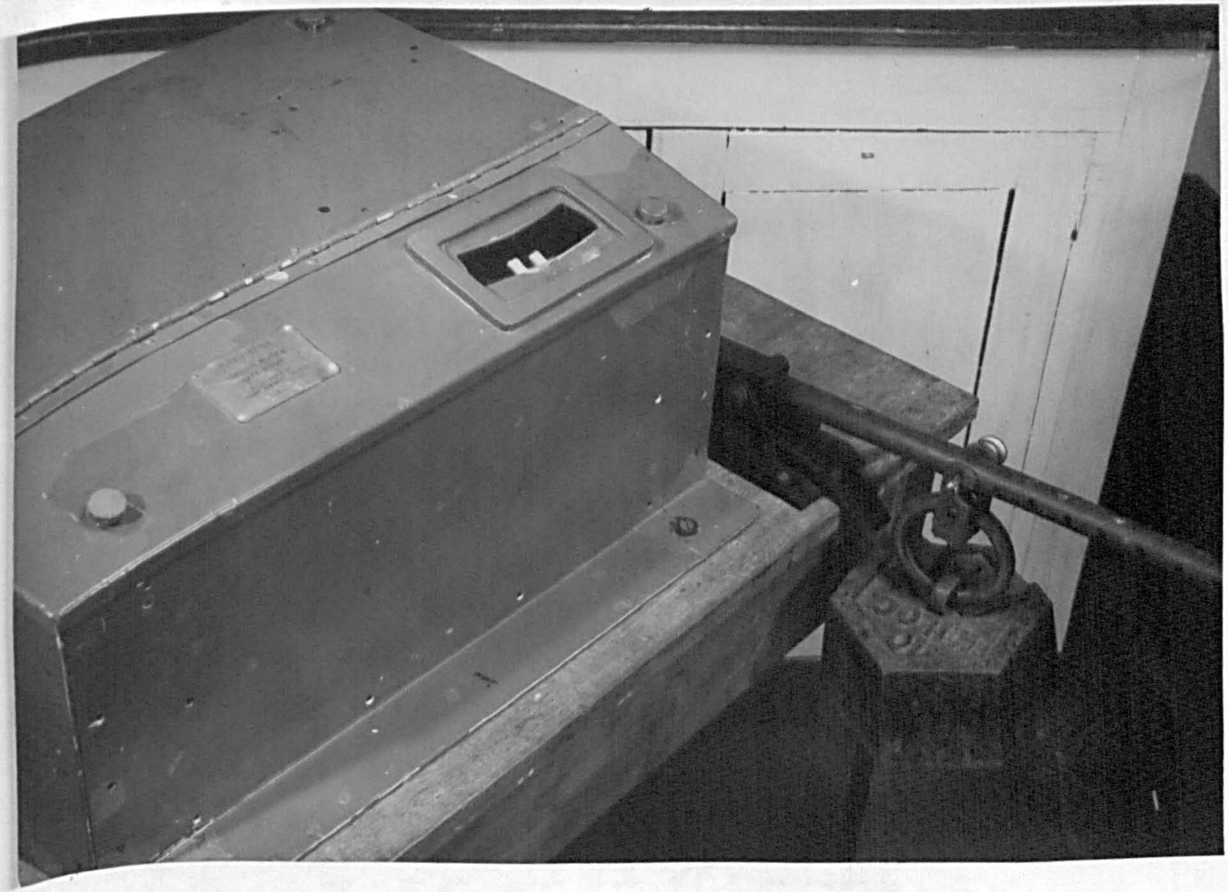
METHODS - (a) Experimental Subjects.

In view of the past experience of Section A, it was felt that the subjects should possess some degree of the skill under scrutiny, and Nigerian Army lorry drivers were thought to be the most suitable subjects available for a tracking experiment. Four African volunteers, aged 20 to 30 years were obtained from the driver pool of the Command Ordnance Depot, Yaba; all were willing and enthusiastic, and had been in the army from 1 to 14 years.

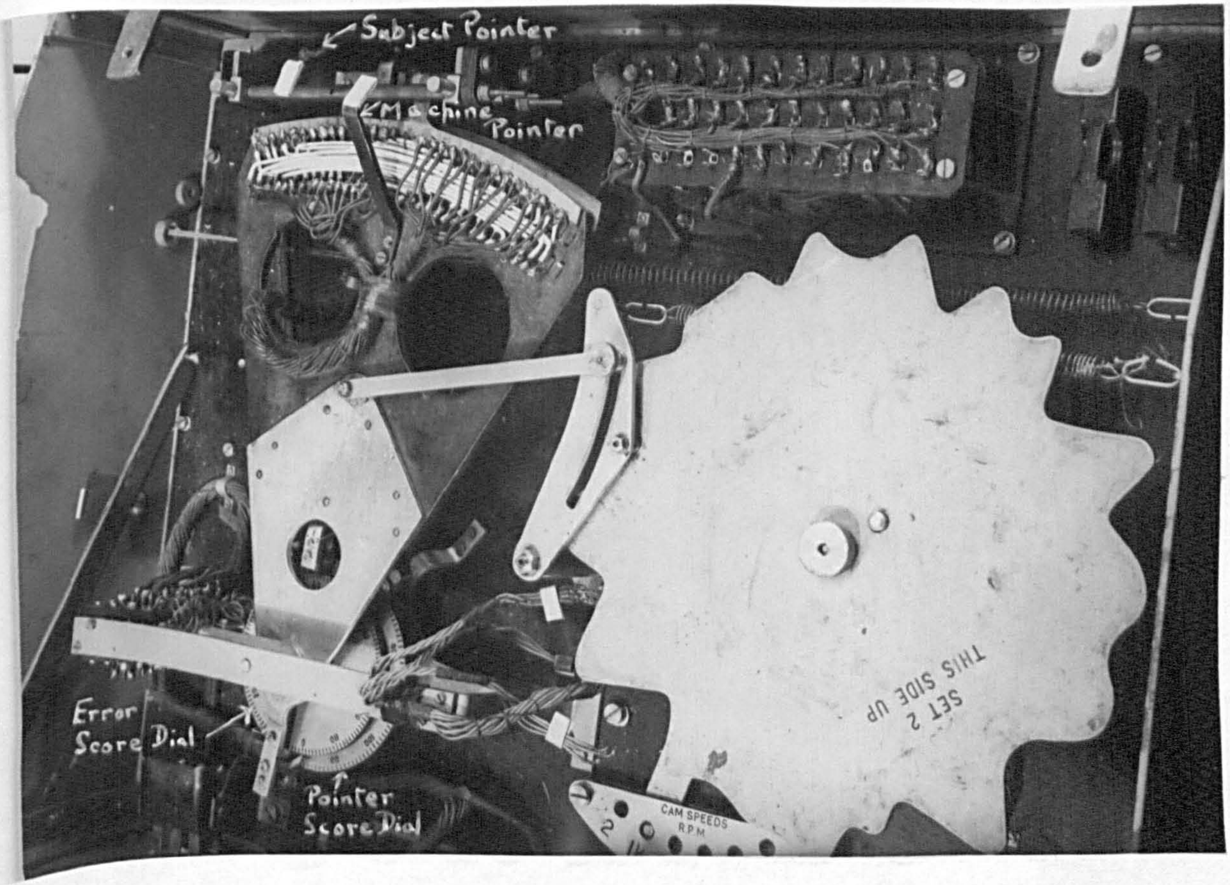
(b) The Test.

The apparatus used was the heavy pursuitmeter with a mechanical scoring device of the same type used by Mackworth and Pepler. The principle of the test is that the subject controls the movements of a pointer by means of a weighted lever, and attempts to track accurately the movements of the machine pointer, (see on next page).

The machine pointer moves to and fro erratically, and is operated by an electrically driven irregularly-shaped cam. The mechanical scorer sums the angular discrepancies between the subject's pointer and the machine pointer, (error score), and also records the total angular movement of the subject's pointer (pointer score).



The total angular discrepancy and the total subject pointer movement scored are noted for each test on the machine, and to duplicate Mackworth's experimental conditions, the machine was set so that in three minutes the maximum error that could be made if the subject's pointer was not moved at all was 176. By this means, an arbitrary fail score can be used, and all attempts which produce an error score of 176 or more, can be classed as "failures".



It is important also in this test to observe total subject pointer movement, for by remaining comparatively still, the test can be rendered spurious, and an error score less than 176 may result without a genuine attempt to track the machine pointer. Under perfect conditions, without any angular discrepancy between machine and subject pointer, the subject's pointer should score 176 (i.e. the same as the maximum error score when the machine was run and the subject's pointer was not moved at all), and the error recording dial should score 0. By thus recording subject activity score the spurious attempts at tracking can be detected.

(c) The daily routine

During each daily session, each subject had 15 three-minute runs on the pursuitmeter during the three hour exposure. The subjects, wearing only shorts, entered the climatic room at three minute intervals, and on entering were weighed and had their rectal temperatures taken. Subsequently, they each performed five runs in the first hour of exposure; and then were weighed and rectal temperatures measured after one hour of exposure. The same routine was then followed for the second and the third hour of the session. As each subject performed the test five times per hour at twelve minute intervals, there was thus time for the other three subjects each to perform the test between two successive tests of the first subject. The hourly routine was thus :-

	Time of performance of runs (minutes)			
	Subject A.	Subject B.	Subject C.	Subject D.
Rect.Temp.& Wt.	0	3	6	9
Run 1	3	6	9	12
" 2	15	18	21	24
" 3	27	30	33	36
" 4	39	42	45	48
" 5	51	54	57	60
Rect.Temp.& Wt.	60	63	66	69

Fluid input and output was recorded, and the hourly sweat rates were calculated from the changes in body weight.

(d) Experimental Plan.

The subjects underwent a training period with the pursuitmeter in the climatic chamber under exactly the same conditions, except for temperature, as in the test experiments. The same routine was followed in both training and test sessions, and interruptions were avoided during the session; the subjects were not informed of their scores for any of the tests.

For the first two days practice the lever of the pursuitmeter was loaded with an 11 lb. (5 Kg.) weight mounted 1.5 ft. (45.8.cm.) from the fulcrum, so that the work done to move the lever was 16 ft. lbs. As the lever is 2ft. long, this load was equivalent to an 8 lb. weight mounted at the handle end of the lever. For the third day and all the subsequent days, once the subjects had grasped the principle of tracking, the weight was increased to 22 lbs. (10 Kg), so that the load was equivalent to a 16 lb. weight at the handle end. This weight was adopted for the test because Pepler (1953 b) has shown that for British subjects the maximum efficiency at tracking was obtained with a 16 lb. load at the handle.

The first five days practice was performed at ambient temperatures for Lagos (dry bulb 82-89°F, wet bulb 75-83°F), and air movement of 100 ft. per minute. On the sixth and seventh days, the climatic chamber was run at the same effective temperature of 77°F, to see if learning of the test was complete. If this appeared to be so, the climatic tests were to be performed in the following randomised order of effective temperature, 86°F, 96°F, 81°F, 91°F, 77°F, ending with the cool climate effective temperature 77°F, again to observe any overall learning effect of the test during the climatic exposures.

Climatic	days	1 & 2	Effective	temperature	77°F	(Basic	scale).
"	"	3	"	"	86°F	"	"
"	"	4	"	"	96°F	"	"
"	"	5	"	"	81°F	"	"
"	"	6	"	"	91°F	"	"
"	"	7	"	"	77°F	"	"

It is necessary to point out that owing to partial failure of the air conditioning plant in the climatic chamber, it was impossible to maintain effective temperatures of 77°F. on the second and seventh days of the climatic tests. The effective temperatures were in fact 77.5°F and 78.5°F, respectively on these days. This level of climatic error, however, does not affect the significance of the result, and did not necessitate repetition of the experiments on those days.

RESULTS.

The detailed daily scores and observations are shown in the Appendix section B. The results are considered in two ways, firstly in terms of successful or failed attempts using the machine score per run of 176 as the arbitrary level for a failed attempt. Secondly, the results are considered in terms of error score; this method allows also the necessary assessment of activity score.

(1) Performance as judged by failed attempts.

In Table VI are set out the individual and total failure rates for each session including the training days. Total failures became fewer on consecutive days with the heavier handle load. On the second day at effective temperature 77.5°F, the failure rate was greater than on the first day at 77.0°F indicating that the subjects had reached the flat part of the learning curve, and that it was safe to proceed with the other climatic sessions.

Exposure to climates of 91°F and 96°F effective temperature, resulted in a marked rise in the total number of failures per session, compared with performance at all other climates.

TABLE VI.

Individual and Total Failure Rates/Session with Pursuitmeter

Training Days	Subjects' Failed Attempts/Session. E.	L.	S.	N.	Total failures out of 60 runs.
1	4	4	0	0	8
2	0	0	0	0	0
3	0	3	5	1	9
4	0	8	0	0	8
5	0	4	0	1	5
Climatic Test days. Effective Temperature					
E.T. 77°F	0	1	2	1	4
" 77.5°F	0	2	2	2	6
" 86°F	0	2	1	3	6
" 96°F	0	9	10	8	27
" 81°F	0	1	3	0	4
" 91°F	0	8	10	2	20
" 78.5°F	0	1	4	0	5

Subject E was notable in that he did not score any failures during all the tests, except on the first training day, but examination of his total error score per session (see Table VIII) shows that he did in fact deteriorate in tracking efficiency at these high temperatures.

In Table VII the failures for each hour of the climatic session are shown, it can be seen that at 91°F. and 96°F. effective temperature, an increased number of failures was made from the beginning of the exposure before the subjects' body temperatures rose. This deterioration in performance then persisted for the remainder of the exposure. In the other sessions there was no appreciable increase in percentage incidence of failures with time.

TABLE VII.
Percentage Incidence of Failures/hour and Session for the Pursuitmeter Tests.

Climate Effective Temperature	Day	1st hour	2nd hour	3rd hour	Overall % age failure
E.T. 77°F	1	0	15	5	6.6
" 77.5°F	2	25	0	5	10
" 78.5°F	7	20	0	5	8.3
" 81°F	5	15	0	5	6.6
" 86°F	3	20	0	10	10
" 91°F	6	40	35	25	33.3
" 96°F	4	45	40	50	45

Generally performance in the third hour was better than in the first, and in some sessions performance during the middle hour was better than during either the first or the third.

The Logarithmic Relationship of Performance to Atmospheric Temperature.

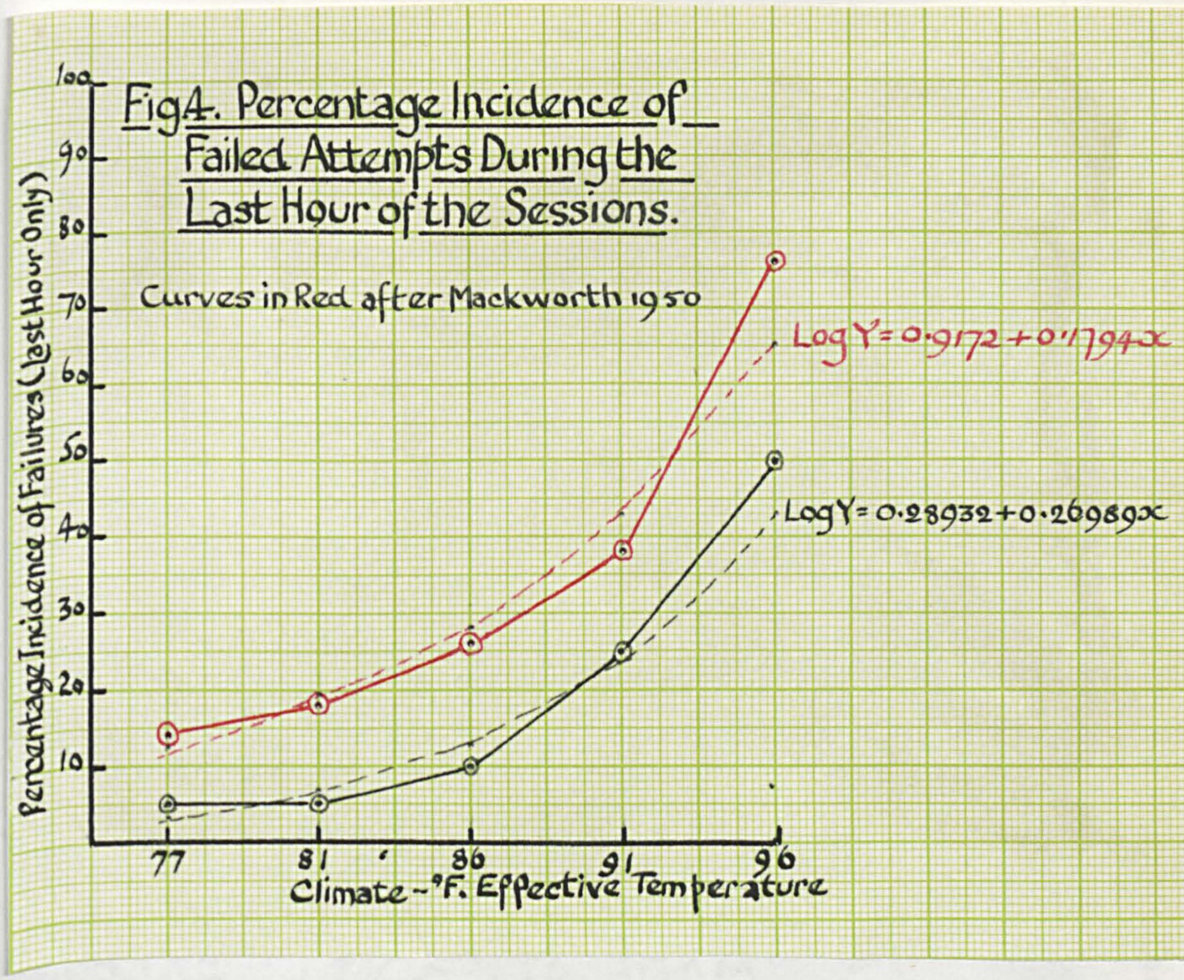
In Figure 4, the percentage incidence of failures in the last hour of each exposure, is plotted against climate and for comparison Mackworth's results are shown on the same scale. The two lines are very similar in general appearance, and the inflections of each curve are situated at the same place. If a logarithmic expression be fitted to the results obtained in this experiment the following equation is derived.

$$\text{Log } Y = 0.28932 + 0.26989 X$$

The goodness of the fit of this equation was confirmed by the Chi square test, $x^2 = 0.67$ ($p = 0.99$).
Mackworth's equation of the logarithmic relationship obtained in his experiments was

$$\text{Log } Y = 0.9172 + 0.1794 X$$

The regression coefficient of this equation and that obtained in the present series, are not statistically different ($t = 0.4778$).



(2) Performance as judged by error score.

The individual error scores per session and the total and mean error scores per session are shown in Table VIII. The significance of the differences between the daily mean error scores was tested by Student's "t" test, and the "t" values are shown.

TABLE VIII

Individual, Total and Mean Scores/Session.

Day	Total Individual Score (15 runs) E(15)	L(15)	S(15)	N(15)	Total Score/Day (60 runs)	Mean score (60 runs)	t significance
1	2516	2553	2398	2372	9839	163.9	For significance
2	2183	2084	2389	1887	8543	142.4	at p = 005
3	2245	2494	2576	2374	9689	161.5	t must be
4	2188	2670	2484	2210	9552	159.2	equal to or greater than
5	2096	2622	2372	2352	9442	157.4	1.980.
Climate °F							
E.T. 77	1964	2392	2423	3326	9105	151.7	1.082 n.s.
" 77.5	1938	2442	2440	2489	9309	155.1	0.437 n.s.
" 86	1923	2525	2492	2461	9401	156.6	3.81 +++p0.001
" 96	2158	2664	2695	2641	10158	169.3	7.05 +++p0.001
" 81	1909	2415	2458	2105	8887	148.1	4.92 +++p0.001
" 91	2082	2625	2721	2423	9851	164.2	5.02 +++p0.001
" 78.5	1798	2450	2539	1876	8663	144.4	

E.T. = Effective temperature. +++ Highly significant. + Just significant.
n.s. = not significant.

Overall Mean Score for Performances at 77°F, 81°F, 86°F = 151.2

Significance of Difference between performances at 91°F t = 5.61 +++, p=0.001
" " " " " " 96°F t = 8.07 +++, p=0.001
" " " "1st & last " " 77°F t = 2.00 + , p=0.05
" " " "performances at 91°F & 96°F t = 1.578 n.s.

During the learning period, the individual and the total error scores became smaller, until the second climatic test day, when for the first time the scores became larger, indicating that learning was nearly complete. The performances on the first and second climatic test days at effective temperature 77°F and 77.5°F, were not significantly different ($t = 1.082$). Nevertheless, during the remaining climatic tests, there was still a slight overall learning effect, the difference between the mean scores for the first and the last performances at effective temperature 77°F and 78.5°F was just significant ($t = 2.0, p = 0.05$).

The effect of heat on error scores was marked and exposure to effective temperatures of 91°F and 96°F caused a rise in these measures of performance and the total error score reverted to figures larger than even those of the first training period. These results are shown in Figure 5 in order of performance. The individual error scores on these hot days increased from the beginning of the exposures, and this increase was reflected by the increase in failure rate (Table VII) and the increase in total error score (Table X) in the first hour of these exposures.

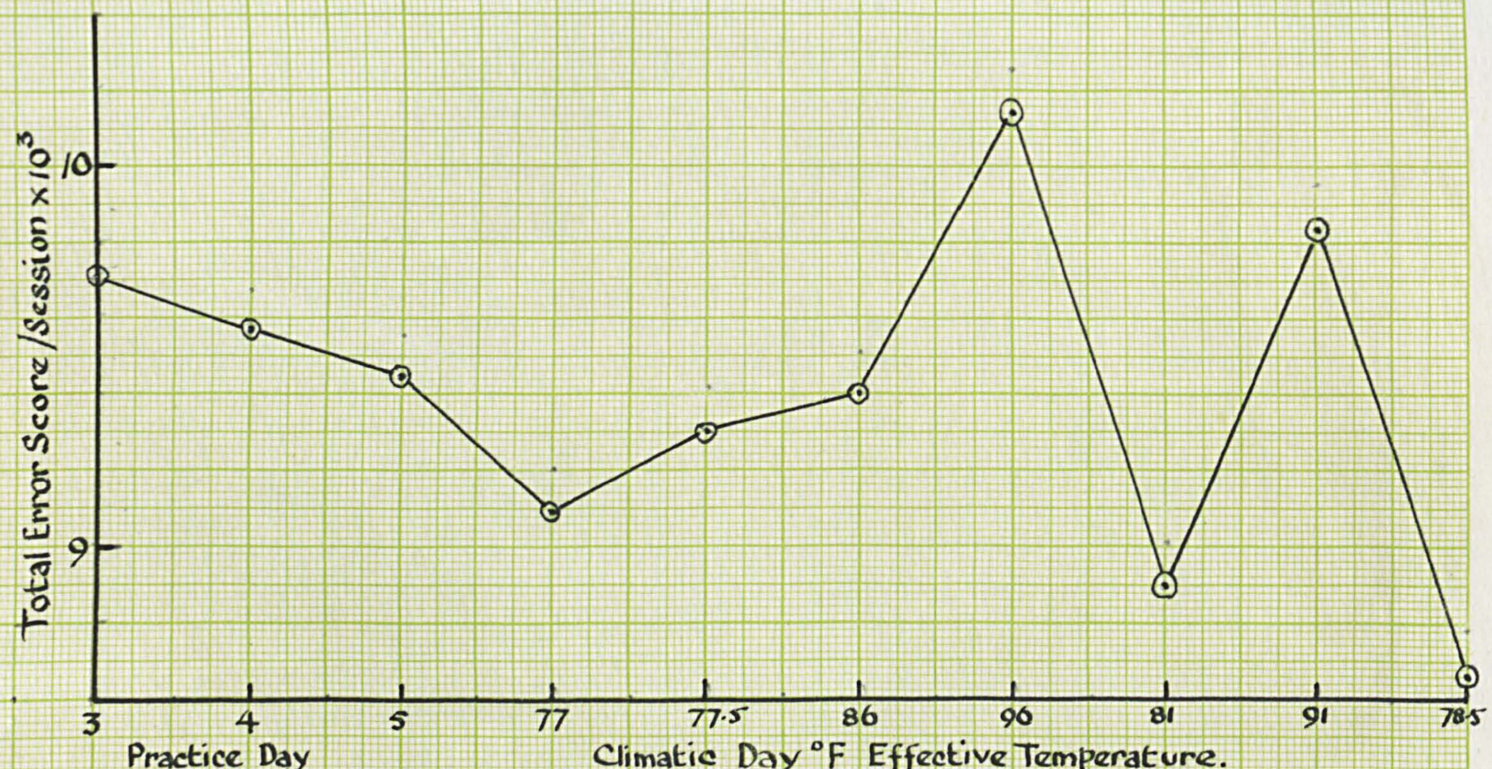


Fig.5. Total Error Score/Session in Order of Performance.

In Figure 6, the total error scores are plotted against climate, all three performances at the coolest climates are shown to indicate the extent of the overall training effect. The performance curve under these circumstances is not logarithmic.

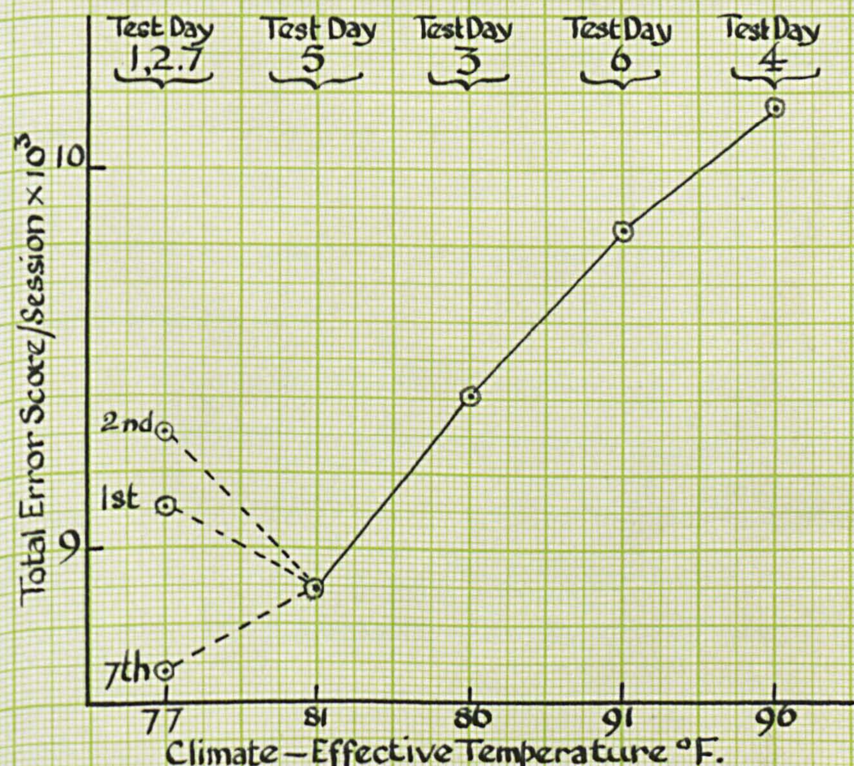


Fig. 6. Total Error Score/Session.

When the mean run scores per session are considered statistically, performance at 91°F effective temperature, and 96°F effective temperature were significantly worse than the overall mean performance of all other climates (for 91°F, $t = 5.61$ and for 96°F, $t = 8.07$). Mean scores at these high temperatures were also significantly different from the mean scores for the cooler days preceding and succeeding these hot sessions (see Table VIII). Mean error scores at 91°F. and 96°F. were not significantly different from each other ($t = 1.578$).

It can also be seen from Table VIII that subject E who was failure free on the machine score rating did in fact have more errors at 91°F and 96°F than at the cooler climate before and after these temperatures.

In order to strengthen the statistical significance of these results an analysis of variance was done on the performances of the last five climatic days, taking days as synonymous with climate and pooling each subject's error for the day as one single total. The F ratio for days was significant confirming that a significant difference of performance between climates existed.

	No.	Degrees of freedom.	Total Sum of Squares	Mean Square
Days	5	4	395,996	98,999
Subjects	4	3	1138,380.4	379,460.1
Discrepancy		12	186,063.6	15,505.3
Total	20	19	1720,440	

F (days) = 98999 divided by 15,505.3 = 6.3848 ($p=0.01$)

The individual climate scores compared with each other by the analysis of variance and the "t" values are shown in Table IX. Performances at 96°F and 91°F were both significantly worse than those at 81°F and 78.5°F but were not statistically different from the performance at 86°F. However, the performance at 96°F and that at 91°F were similar, while those at 86°F, 81°F, and 78.5°F were not significantly different to each other. These figures place the level of temperature for decrement in efficiency between 81°F and 91°F effective temperature. As the performance at 86°F was not significantly different to that of any other climate it seems that this temperature on the effective temperature scale is probably "the critical level" based on this method of error scoring. It appears from these results that while raising the effective temperature from 81°F to 91°F did impair efficiency, the deterioration detected did not follow a logarithmic relationship to atmospheric temperature because there was no significant difference between performances at 78.5°F and 86°F. or between 86°F and 96°F. Similarly, the performance at 96°F was not significantly worse than that at 91°F so that heat above 91°F effective temperature did not produce significantly more deterioration. This too negates a logarithmic relationship.

TABLE IX

Significance of Difference between Daily Mean Performances.

To be significantly different	p = 0.01	t = 3.055
	p = 0.05	t = 2.179

Effective Temperature °F	Score Mean	Difference From	Effective temperature °F 96	81	91	78.5
86	2350.25	"t" value =	2.149	1.459	1.277	2.106
96	2539.50	" " =	-	3.609	-	4.24
81	2221.75	" " =	-	-	2.717	-
91	2462.75	" " =	0.883	-	-	3.373
78.5	2165.75	" " =	-	0.63	-	-

Table X shows the hourly scores; an apparent tendency for performance in the second hour to be the best in a session as indicated by the failure rate, could not be confirmed by consideration of the total error score per hour per session. Analysis of variance of the hourly scores showed that there was no significant difference between hours.

Table X

Table Scores/hour/Session.

Day	1st hour	2nd hour	3rd hour
1	3366	3298	3175
2	2789	2805	2949
3	3274	3217	3198
4	3120	3180	3252
5	3178	3145	3119
E. T.°F 77	3005	3062	3038
" 77.5	3284	2984	3041
" 86	3253	3071	3077
" 96	3411	3332	3415
" 81	3045	2914	2928
" 91	3383	3298	3170
" 78.5	2963	2884	2816

ANALYSIS OF VARIANCE.

No.	Degrees of Freedom	Variance	Mean
Days 12	11	645,249.465	58,659.04
Hours 3	2	43,155.175	21,577.58
Total 36	35	1,071,708.105	
Discrepancy	22	383,303.465	17,422.885

Hours F. equals 21,577.58 divided by 17,422.885 = 1.238 not significant.

Examination of the individual subject pointer scores for each run (see Appendix) showed that there had been no spurious attempts at tracking in the climatic tests. During the training period, some of the subjects erred on the side of too little pointer movement, but, once this was explained to them, they corrected this defect, and the extreme range during the climatic test was 120 - 230, which is roughly ± 33% error in activity.

In Table XI, the hourly sweat rates and changes in body temperature are shown for each climatic session and also the mean dry and wet bulb temperatures, and corresponding effective temperatures.

At 77°F effective temperature, rectal temperatures fell slightly and sweat rates were about 1 ml./min. but at higher temperatures, once again rectal temperature increases up to 3° F were found with sweat rates of 10 ml./min. indicating that the subjects were under climatic stress.

TABLE XI

Bodily Changes and Climates (In order of Performance)

Effective Temperature °F		77.0°F	77.5°F	86°F	96°F	81°F	91°F	78.5°F
Mean Rectal Temperature on entry °F		99.15	99.00	99.20	98.72	98.85	98.77	99.02
End of 1st hour	Mean R.T. °F	99.12	98.85	99.30	99.55	98.97	99.00	99.00
	Mean S.R. (gr.)	78.75	81.25	172.50	588.75	125.00	287.50	73.75
End of 2nd hour	Mean R.T. °F	99.00	98.72	99.22	100.90	98.77	99.25	98.97
	Mean S.R. (gr.)	75.00	73.75	168.75	695.00	130.00	260.00	76.25
End of 3rd hour	Mean R.T. °F	98.72	98.65	99.16	101.60	98.82	99.40	98.97
	Mean S.R. (gr.)	73.75	71.25	170.00	512.50	110.00	226.25	83.75
Climate Means	Dry Bulb °F	85.11	85.29	95.07	105.02	90.13	100.06	86.10
	Wet Bulb °F	76.40	77.31	85.01	94.96	80.15	90.04	78.03
	Air Movement ft/min.	100	100	100	100	100	100	100

R.T. = Rectal temperature °F. S.R. = sweat rate in grams

DISCUSSION.

The similarity of these results and those obtained by Mackworth (1950), on temperate climate subjects is striking. This can be attributed in most part to the fact that the experimental design scoring and conditions of this series was deliberately made similar to that of Mackworth's to obtain as close a comparison as possible with this worker's results. However, as has been pointed out by Pepler (1953 a & b), the method of scoring, experimental design and individual ability may be responsible for the specific inflection of the curve defined by Mackworth and for the logarithmic relationship of performance to room temperature. In this series duplication of the condition plus similar behaviour reactions on the part of the subject, have indeed reproduced a similar curve and relationship, so that under given standard circumstances a reproduction of Mackworth's findings was obtained.

However, the pass-or-fail method of scoring against an arbitrary score is obviously coarse, and may tend to exaggerate the effects of any deterioration due to climate. For example, it seems unfair to class an error score of 176 a failure and an error score of 175 a successful attempt, for the two performances are obviously alike. On Mackworth's method of scoring, the difference between these two error scores would represent a deterioration which is not real. It is also difficult, to understand what rationale determines the level that an error score must not exceed, in order to be a successful attempt. In both Mackworth's and this series the score produced on the error dial when the pursuitmeter was run without control, was regarded as the arbitrary level. In order to obtain a successful attempt the subject was required, therefore to produce a score, a little better than that produced by the machine when uncontrolled. That this is not a logical basis upon which to assess performance, is clear, and any other figure could be selected,with as little justification, which might completely alter the results. Thus it is necessary in the last analysis to consider the results in terms of total error score, and here Pepler's findings (1953 a & b) are confirmed as being applicable also to the tropically indigenous subject. In terms of total and mean error score it was found that increase in room temperature from 77°F to 96°F effective temperature produced a deterioration in tracking performance. Performances at 77°F, 81°F and 86°F were similar and performances at 91°F and 96°F were likewise similar to each other, but placed at a lower level of efficiency than the cooler climates. The performance curve on this method of scoring was not logarithmic in nature, and the absence of a logarithmic deterioration in performance based on error score has been confirmed statistically. In Pepler's work (1953 a & b), evidence was found to suggest that the logarithmic relationship defined in Mackworth's test was imposed by the method of scoring and the relative abilities of the subjects. In the present experiment, consideration of the results in two ways shows that the logarithmic relationship is indeed dependent on the scoring method.

Confirmation of Mackworth's (1950) and Pepler's (1953 a & b) previous findings concerning the independence of performance from body temperature was obtained in this series. In addition, there was no performance deterioration with time within sessions, even on the hot days. During the first hour of performance at 91°F and 96°F effective temperature, both the failure rate and the error score was increased compared with the cooler days and this increase persisted throughout the remainder of the hot sessions. It appears that decrement in efficiency results from the beginning of exposure to heat and Pepler (1956) also reported that man becomes less efficient at carrying out a skilled task within the first few minutes in the heat.

CONCLUSIONS AND SUMMARY.

(1) As compared with other climates exposure to high effective temperatures of 91°F and 96°F, produced a deterioration in the tracking performance of four tropical climate subjects on the pursuitmeter.

(2) When the derived method of pass-or-fail scoring was used, performance bore a logarithmic relationship to atmospheric temperature and the inflection of the performance curve was placed at 86°F effective temperature.

(3) Error score at 86°F effective temperature was not significantly different to that at 76°F effective temperature.

(4) Error score at 96°F effective temperature, was not significantly different to that at 91°F effective temperature.

(5) When the absolute error scores are considered instead of the derived scores, performance did not bear a logarithmic relationship to atmospheric temperature.

(6) The lack of dependence of performance on body temperature was confirmed.

(7) An immediate onset of decrement in tracking efficiency was found on exposure to heat.

Section C.

Morse Code Reception Test.

METHODS. - (a) Experimental Subjects.

The subjects in this series were African volunteers from the Nigerian Signals Squadron of the West African Frontier Force. Twelve men were selected, aged 26 to 40 years, who were all operational wireless receptionists, and who were in daily practice at a standard rate of eight words per minute, and had been so for some months, hence a prolonged preliminary learning period was not considered necessary or advisable, in view of the possible loss of interest with time which results from repetition of training sessions.

(b) The Test.

In order to obtain as close a comparison as possible with the results obtained by Mackworth (1950), the experimental design in this series was made similar to that of his series. Certain changes were necessary, namely in length and speed of wireless messages, because of the different standard of the ability of the subjects. Nine wireless messages were recorded on tape, each message was of approximately 180 groups of 5 symbols, so that about 900 symbols of mixed letters and figures were transmitted for each message at a speed of transmission of 12 words per minute (60 symbols per minute). Although the length of the individual messages and the fact that they were in cipher precluded the subjects' learning the symbols, the messages were relayed in the following mixed order so that the effect of time within a session could be considered on the efficiency of reception. This procedure was adopted in case some messages were easier to receive than others, as slight variations in length and speed existed from message to message. Three tapes were required upon which to record the nine messages, and the order of transmission was randomised from session to session so that the following order resulted :-

MESSAGE ORDER

Session 1	7,8,9	1,2,3	4,5,6
" 2	4,5,6	1,2,3	7,8,9
" 3	7,8,9	4,5,6	1,2,3
" 4	1,2,3	7,8,9	4,5,6
" 5	1,2,3	4,5,6	7,8,9

Symbols omitted or incorrect were scored as errors, and the subjects were not informed of their scores for any of the tests. Messages containing five or more errors were regarded "failed messages" similar to Mackworth's method of scoring.

(c) The Daily Routine.

During each test session which lasted three hours, the subjects received, via headphones from a tape recorder, three messages in each hour of exposure. The subjects' rectal temperatures and body weights were measured on entering into the climatic chamber, and subsequently after every hour. In each hour men were given messages at 10, 27 and 45 minutes; as each message lasted 15 minutes there was a 2 minute interval between the first and second message, and a 3 minute interval between the second and the third, and then a 10 minute rest before the next series of transmissions started. Fluid intake and output were recorded and hourly sweat rates calculated, from the changes in body weight.

HOURLY ROUTINE

0	Subjects enter, rectal temperature and body weight observations
10	First message commences.
25	Two minutes rest.
27	Second message commences.
42	Three minute rest.
45	Third message commences.
60	Rectal temperature and body weight observations.

(d) Experimental Plan.

The twelve subjects were divided at random into three groups of four each, and each group attended once weekly for a test session. Their normal duties forbade the subjects attending at shorter intervals than this, but nevertheless as on the intervening days they were employed receiving Morse Code their abilities were being maintained. The subjects attended two test practices at Lagos ambient temperatures (82-89°F dry bulb, 76-84°F wet bulb) in the climatic chamber, to familiarise themselves with the routine and the surroundings, and then one practice session at effective temperature 92°F before exposure to the higher temperature test began.

The temperatures used for the climatic tests were the same as those used in Sections A and B, and the subjects were exposed to the following randomised order of climate :-

Week 1	Effective	temperature	81°F	(Basic	scale)
" 2	"	"	96°F	"	"
" 3	"	"	76°F	"	"
" 4	"	"	86°F	"	"
" 5	"	"	91°F	"	"

RESULTS.

The detailed daily observations are shown in the Appendix Section C. The results are considered in two ways, firstly by terming a message "failed" if it contains five or more incorrect symbols, and secondly by counting the actual total number of incorrect symbols per session.

(1) Performance as judged by failed messages.

The individual performances per climate are shown in Table XII. The total number of failed messages per climate are shown as total percentage error, and it can be seen that the best performance occurred at 76°F effective temperature, and the worst at 96°F effective temperature. Intermediate climates produced immediate scores in terms of percentage error but at 81°F effective temperature, a higher error resulted than at 86°F or 91°F effective temperatures. This was no doubt due to the fact that the session at 81°F effective temperature was the first actual climatic test and, despite the precautions which had been taken, the subjects were nervous.

In addition the overall percentage error change from climate to climate in Table XII is small, the reason for this is manifest when the actual individual symbol error scores are considered (Table XIII). From this table it becomes obvious that some operators were constantly making so many errors that they failed nearly every message or a nearly constant number of messages, despite climate (see Table XII). This reduces the percentage change resulting from the changes due to the operators who performed differently.

TABLE XII.

Faulty Messages per Session, Individual and Total.

Effective Temperature (°F)	76°F	81°F	86°F	91°F	96°F
Subject					
Nw.	0	0	0	1	0
Mb.	7	9	7	7	8
Ob.	9	9	9	9	9
Iw.	0	1	0	0	0
Ep.	1	1	3	2	6
Er.	3	4	2	2	6
Ok.	6	5	6	5	7
Osi.	4	8	6	6	9
Osg.	0	0	0	1	1
Okek.	0	1	0	2	3
Eg.	1	1	1	0	2
Cai.	3	7	4	7	3
Total/session out of 108.	34	46	38	42	54
Percentage error	31	43	35	39	50

(2) Performance as judged by the actual symbol error score.

In Table XIII are shown the numbers of incorrect symbols made in each session.

TABLE XIII.

Individual and Mean error Scores per Session.

Week Order	3	1	4	5	2
Effective Temperature (°F)	76°F	81°F	86°F	91°F	96°F
Subject					
Nw.	4	5	6	12	9
Mb.	163	159	99	82	143
Ob.	251	373	268	284	297
Iw.	6	15	6	7	18
Ep.	19	19	28	29	78
Er.	27	38	23	22	68
Ok.	106	48	85	67	77
Osi.	53	83	67	74	83
Osg.	13	13	16	23	18
Okek.	13	25	14	20	33
Eg.	8	14	11	9	33
Cai.	42	61	54	116	39
Mean/session	59	71	57	62	75

Scrutiny of Table XIII shows that two patterns of response emerge, four operators (Mb. Ob. Ok. Osi.) scored many more errors consistently at all temperatures than the other operators and two of them (Mb. Ob.) were clearly learning at some stages of the tests. Of the remainder, seven made less errors in the cool climates than in the hot climates. These operators, even at the high temperatures made fewer errors than did the previous group. Finally the remaining operator (Cai.) performed very variably, and as it happened that this man was extremely difficult to handle as a subject, differences in his motivation or "interest" may have accounted for his variability. As a result, the overall mean total error per climate is loaded heavily in favour of the men who made a lot of mistakes and, consequently, the mean performance pattern is confused by learning and other effects. Nevertheless the worst mean performance resulted at 96°F effective temperature and the best at 76°F and 86°F effective temperatures. Performance at 91°F effective temperature was similar to that at 76°F and at 86°F effective temperatures, but performance at 81°F effective temperature was worse than at any other climate except 96°F effective temperature. The high mean total error at 81°F effective temperature was in part loaded by the very bad performance of Ob. On this the first actual climatic test day, this operator and several others were, despite precautions, nervous and apprehensive. These difficulties necessitate consideration of operators' results in classes defined by ability.

Results in terms of ability.

Mackworth (1950) has emphasised the importance of the ability of the subject as a factor in the reaction shown to climate. He classed his operators into "exceptionally skilled", "very good", and "competent" categories on an arbitrary scale based on the order of competence at the coolest climate. If a similar classification be applied to the operators in this experiment based on the error score at 76°F effective temperature, the following classes emerge:-

less than 10 errors - 3 men - Nw. Iw. Eg. - "Exceptionally skilled".
" " 30 " - 4 men - Ep. Er. Osg. Okek. - "Very good."
" " 90 " - 2 men - Osig. Cai. - "Competent."
more than 90 " - 3 men - Ob. Mb. Ok. - "bad".

It should be noted that this error incidence happened to lend itself to a roughly similar classification to that of Mackworth's based on error score, in that in his series the mean errors of the classes for the coolest session were "Exceptionally skilled" 8.7, "Very good" 18.6, and "Competent" 92.7.

The mean performances of the different classes are set out in Table XIV as Mean Errors/man/session.

TABLE XIV.

Class performances - Mean errors per man per session.

Effective Temperature (°F)	76°F	81°F	86°F	91°F	96°F
Class					
Exceptionally skilled	6.0	11.3	7.6	9.3	20.0
Very good	18.0	23.75	20.25	23.5	49.25
Competent	47.5	72.0	60.5	95.0	61.0
Bad	173.3	193.3	154.0	144.3	172.3
Class performance as %age of Performance at 76°F.E.T.					
Exceptionally skilled	100	188	125	155	333
Very good	100	132	112	130	273
Competent	100	151	127	200	127
Bad	100	111	89	83	100

When these results are plotted in order of performance, and expressed as percentage of the class error score of the coolest climate (Figure 7), it can be seen that the "bad"operators were learning while the "competent" group performed variably due to the presence of operator Cai. The"exceptionally skilled" and the "very good" operators, on the other hand were less efficient at 96°F effective temperature than at the cooler climates.

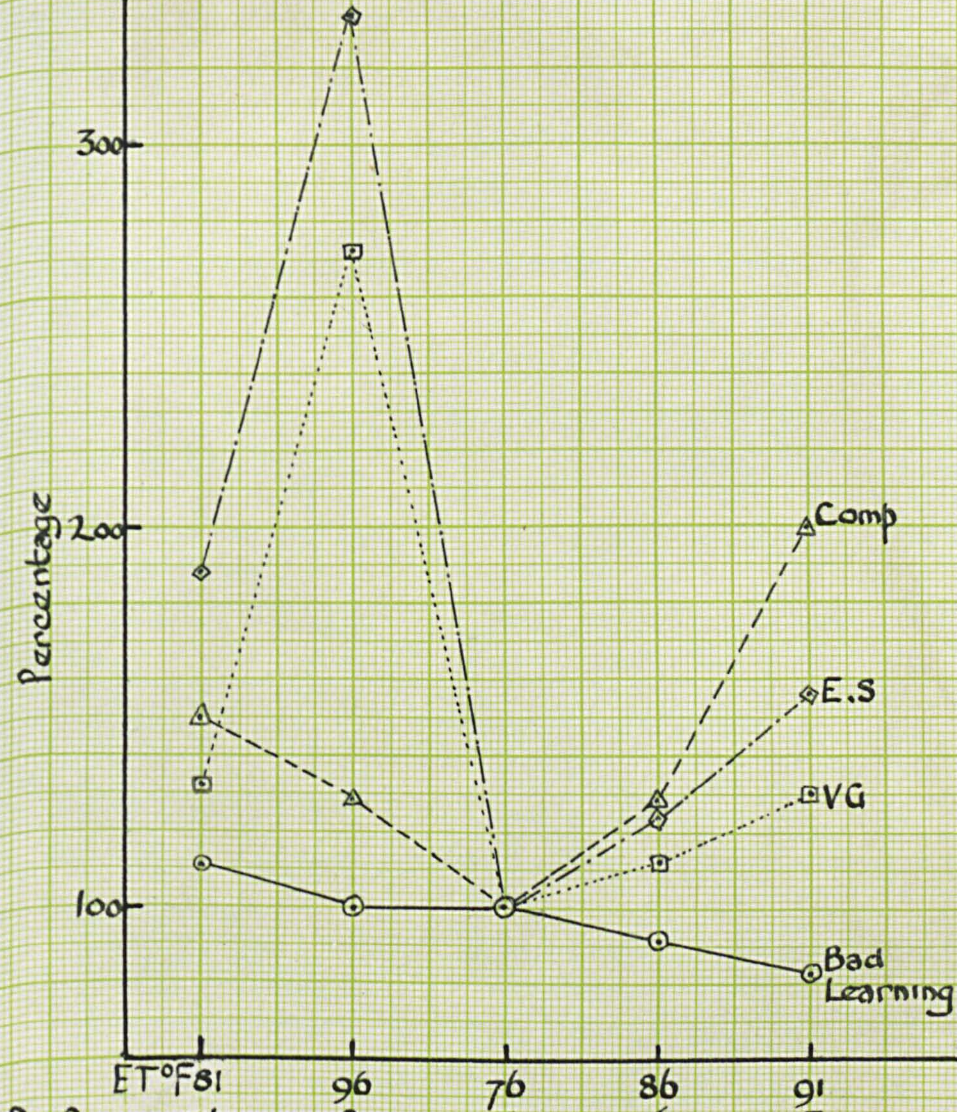


Fig. 7. Mean Error Score/Man/Class Expressed as a Percentage of Performance at 76°F. E.T. and Plotted in order of Performance.

If the seven operators who did deteriorate at 96°F effective temperature are considered together as a class and their results assessed by the pass-or-fail method, it can be seen (Table XV) that the hot climates resulted in an increased percentage of failed messages as well as an increase in mean error score.

TABLE XV.

Mean Total error score and Total Failure Score of the seven Operators who deteriorated in heat.

Effective Temperature (°F)	76°F	81°F	86°F	91°F	96°F
Mean error score/man	12.8	18.4	14.8	17.4	36.7
Failed messages (out of 63)	5	8	6	8	18
Percentage Incidence of failed messages	7.9	12.7	9.5	12.7	28.5

In Figure 8 these results are shown graphically and on the same scale Mackworth's results are plotted. Similar logarithmic curves may be fitted to both Mackworth's and to the present results. The equation derived for the present results is shown below :-

$$\text{Log } Y = 0.6957 + 0.1271 X$$

The goodness of the fit of this equation to the results was confirmed by the Chi Square Test, $x^2 = 0.036$ ($p = 0.99$). Mackworth's equation of the logarithmic relationship was :-

$$\text{Log } Y = 1.1077 + 0.0957 X$$

The regression coefficients of these two equations are not statistically different ($t = 0.21$).

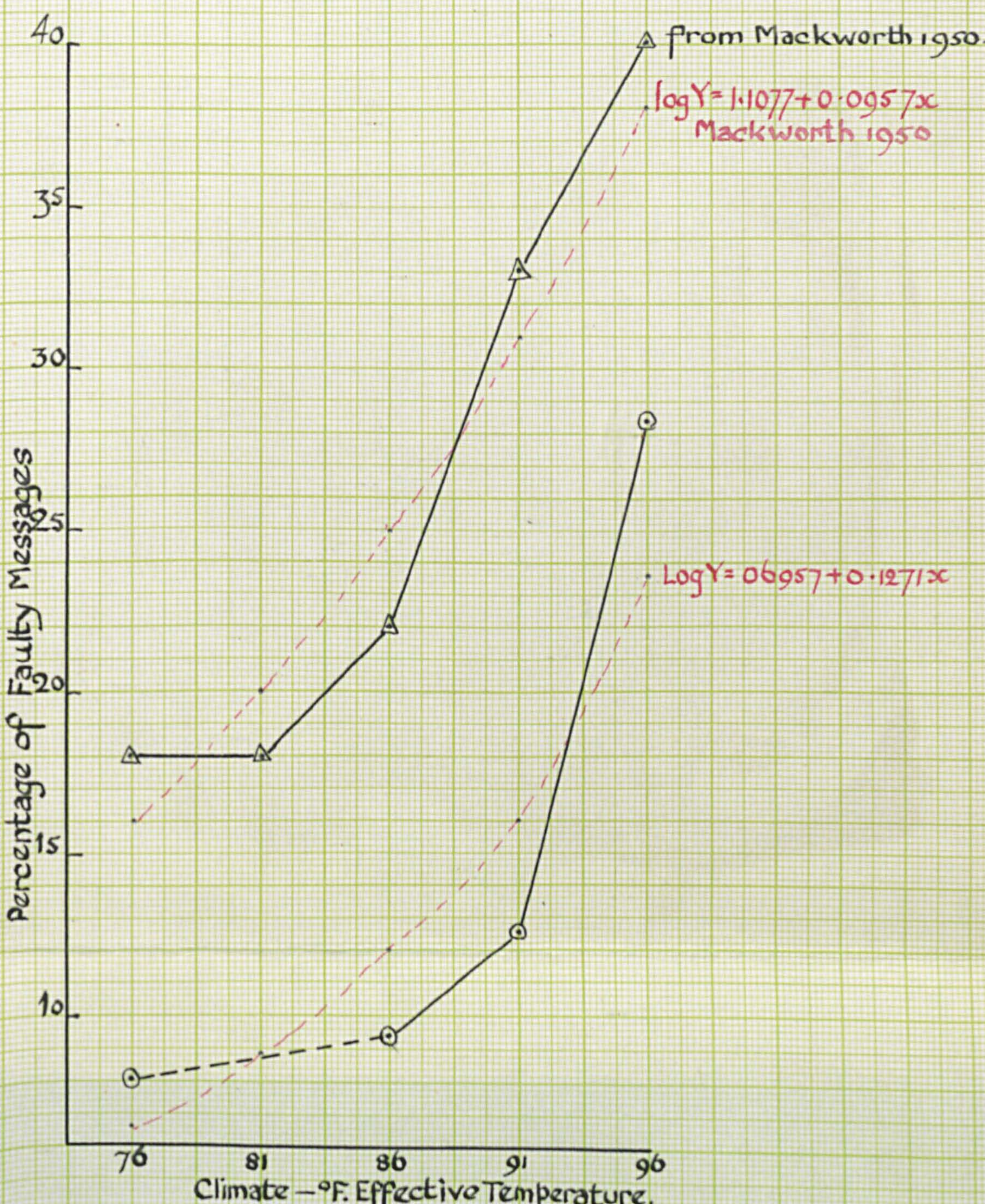


Fig.8. Percentage Incidence of Faulty Messages With Climate and Logarithmic Curves of Performance Compared on the Same Scale.

Using this method of scoring, performances at 91 ^{o}F and 96^{o}F effective temperatures were worse than performances at the lower temperatures, and this places the critical level for deterioration at the same level as that defined by Mackworth. In Table XVI are shown the number of faulty messages per hour for all operators and also for the "exceptionally skilled" and "very good" classes of operators combined. The number of failures was greater in the second and third hours than in the first hour for all operators in all sessions except that at 96^{o}F effective temperature. At this climate the failure rate had already increased during the first hour before subjects' body temperature rose thus confirming the previous findings that deterioration is independent of increase in rectal temperature.

TABLE XVI

Total Faulty Messages per hour.

Effective Temperature (^{o}F)	76^{o}F	81^{o}F	86^{o}F	91^{o}F	96^{o}F	Total
First Hour	9	13	8	11	19	60
Second Hour	10	15	13	13	17	68
Third Hour	15	18	17	18	18	86
Faulty Messages per Hour for "E.S" and "V.G" Operators combined						
First Hour	2	1	1	2	8	14
Second Hour	0	3	2	2	4	11
Third Hour	3	4	3	4	6	20

For the combined group of "skilled" operators the number of failed messages likewise increased with time at all temperatures except 96°F effective temperature, when an already increased number of failures were made during the first hour of exposure. On either basis, therefore, decrement in heat was manifest early in exposure.

Performance judged by error score.

Table XV shows that mean error score for the combined group of "exceptionally skilled" and "very good" operators was greater at 96°F effective temperature than at other climates. Performance at the other climates was of a similar order. To determine the statistical significance of the impression gained from the mean figures, analysis of variance was performed on the daily scores of these seven operators. This showed that the F ratio for climates was significant and the change in error score due to climate was significant statistically :-

	No.	Degrees of freedom.	Total sum of squares.	Mean square.
Climates	5	4	2,561.1	640.27
Subjects	7	6	3,750.3	625.05
Discrepancy		24	2,298.5	95.80
Total	35	34	8,609.9	

F (climates) = 640.27 divided by 95.8 = 6.68 (p = 0.01)

The mean scores at the climates were compared with each other by the analysis of variance, and "t" values obtained are shown in Table XVII. Significant differences between the means existed only between the mean score at 96°F effective temperature, and all other mean performances. The mean scores at 76°F, 81°F, 86°F and 91°F effective temperatures were not different to each other. This method of scoring, therefore, places the level of deterioration at 91°F effective temperature, and the uniformity of performance between other climates below this level indicates that a logarithmic relationship did not hold between performances and atmospheric temperature.

TABLE XVII

Significance of Difference between Error Means.

To be significant at p = 0.01 t must = 2.797
" " " " p = 0.05 t must = 2.064

Effective Temperature °F	Error score Mean	Table of "t" values			
		96°F	91°F	86°F	81°F
76 °F	12.8	4.56	0.87	0.39	1.07
81 °F	18.4	3.49	0.19	0.68	-
86 °F	14.8	4.18	0.49	-	-
91 °F	17.4	3.68	-	-	-
96 °F	36.7	-	-	-	-

Consideration of the hourly error scores (Table XVIII) for all operators shows that deterioration with time occurred in all climates except 96°F effective temperature. At this temperature the error score in the first hour was of the same order as the subsequent hours, and this was because in the first hour the error rate had already increased compared with other days. No further significant increase in error resulted at this temperature, despite rise in subject's body temperature later in the session.

In Table XVIII the hourly error scores of the combined group of "exceptionally skilled" and "very good" operators are also shown. The total error score for this group was highest in the third hour of all sessions, while at 96°F effective temperature the scores during the first and second hours were already higher than usual compared with the performance at cooler climates.

Analysis of variance of the error scores for the combined group shown in Table XVIII, was undertaken to determine the statistical significance of the apparent deterioration with time.

TABLE XVIII

Total Error Score per Hour.

Effective Temperature (°F)	76°F	81°F	86°F	91°F	96°F	Total
First hour	162	261	216	238	294	1171
Second hour	258	276	211	257	300	1302
Third hour	285	316	260	250	302	1413
Hourly Error Score of "E.S" and "V.G" Operators						
First hour	26	34	28	24	82	194
Second hour	22	46	34	38	75	215
Third hour	42	49	42	60	100	293

The F value for hours was significant, indicating that deterioration with time was significant :-

	No.	Degrees of freedom	Total sum of Squares	Mean square
Climates	5	4	5,944.2	1,486.05
Hours	3	2	1,088.4	544.2
Discrepancy		8	383.8	47.97
Total	15	14	7,416.4	

F (hours) = 544.2 divided by 47.97 = 11.343 (p = 0.01)

The bodily changes and climates for these experiments are shown below in Table XIX.

TABLE XIX.

Bodily Changes and Climates
(In order of Performance)

Effective Temperature °F		81°F	96°F	76°F	86°F	91°F
Mean R.T. on Entry (°F)		99.21	99.23	99.03	99.17	99.33
End of 1st hour	Mean R.T. (°F)	99.42	100.43	99.03	99.34	99.64
	Mean sweat rate (grams)	119.16	580.83	67.50	166.25	276.25
End of 2nd hour	Mean R.T. (°F)	99.30	101.44	99.00	99.35	99.81
	Mean sweat rate (grams)	138.25	653.33	77.83	190.00	293.75
End of 3rd hour	Mean R.T. (°F)	99.30	102.05	98.86	99.26	99.86
	Mean sweat rate (grams)	131.66	517.08	75.75	178.16	281.66
Climate Means	Mean D.B. (°F)	90.03	105.03	84.87	95.08	100.06
	Mean W.B. (°F)	80.06	95.02	75.22	84.99	90.01
	Air Movement Ft/Min.	100	100	100	100	100

R.T. = Rectal temperature (°F) D.B. = Dry Bulb °F
W.B. = Wet Bulb °F.

Table XIX shows that at 76°F effective temperature, body temperatures fell slightly and sweat rates were in the region of 1 ml/min. while at 96°F effective temperature, temperature increases of 3°F were seen with sweat rates in the region of 10 ml/min. indicating that the subjects were under climatic stress.

DISCUSSION.

Mackworth (1950) emphasised the necessity for the consideration of individual ability in assessing reaction to climate. Pepler (1953 c) showed how wide variation in subject ability could so complicate the picture of reaction to climate that he could draw no very firm conclusions from his results. He found, for example, that in the afternoon sessions, his operators performed more efficiently at 96°F than they did at 91°F effective temperature; at 96°F their performances were within the same range as those at 86°F and 81°F effective temperatures, and considerably better than the performance at 71°F effective temperature.

The same difficulties have been met with in this series, and it has been shown that the results of five operators who performed consistently badly or variably could mask the reaction shown by the better operators. However, when the performances of the latter are considered the effect of heat was to impair efficiency, and when the results are scored by the pass-or-fail method, remarkable similarity to Mackworth's earlier results was found. This is to some extent due to the similar experimental design, and these similarities result in the inflection of the performance curve being placed at 86°F effective temperature and also in the logarithmic relationship of performance to atmospheric temperature.

When the analysis of variance of the results of the seven "better" subjects, considered in terms of actual error score, is used to assess performance, all scores except at 96°F effective temperature were in the same range thus placing the inflection of the performance curve at 91°F effective temperature. Below this latter temperature the performance curve was more or less horizontal for a range of climate of 15° effective temperature. This shows that the site of the performance curve inflection and the logarithmic relationship clearly depend on the scoring method. These results, however, agree with Mackworth's findings when he used actual symbol error score. The performances of his "exceptionally skilled" and "very good" groups did not deteriorate then until the temperature was above 92°F effective temperature (Normal scale). Similarly in his "competent" group, performances at 87°F and 92°F were about the same. Figure 9 shows Mackworth's results as mean errors per man per hour, and on the same scale the results of the present experiment (see next page). The remarkable deterioration of Mackworth's "very good" and "competent" classes at the hottest climate is shown. Pepler (1953 c) has drawn attention to the fact that Mackworth's results included the scores of some operators who performed very variably at the hottest temperature. Pepler cites the example of one operator, who was one of the three in Mackworth's "competent" class, who on two occasions at 97°F effective temperature produced respectively error scores of 2,527 and 34. This operator, on the occasion of producing 2,527 errors, in fact scored only 14 errors in the first two hours of the session but scored 2,513 errors in the third hour, owing presumably to impending physical collapse. Pepler has stressed that the inclusion of results of this variation cannot be allowed for in the tests of significance and therefore complicate their interpretation.

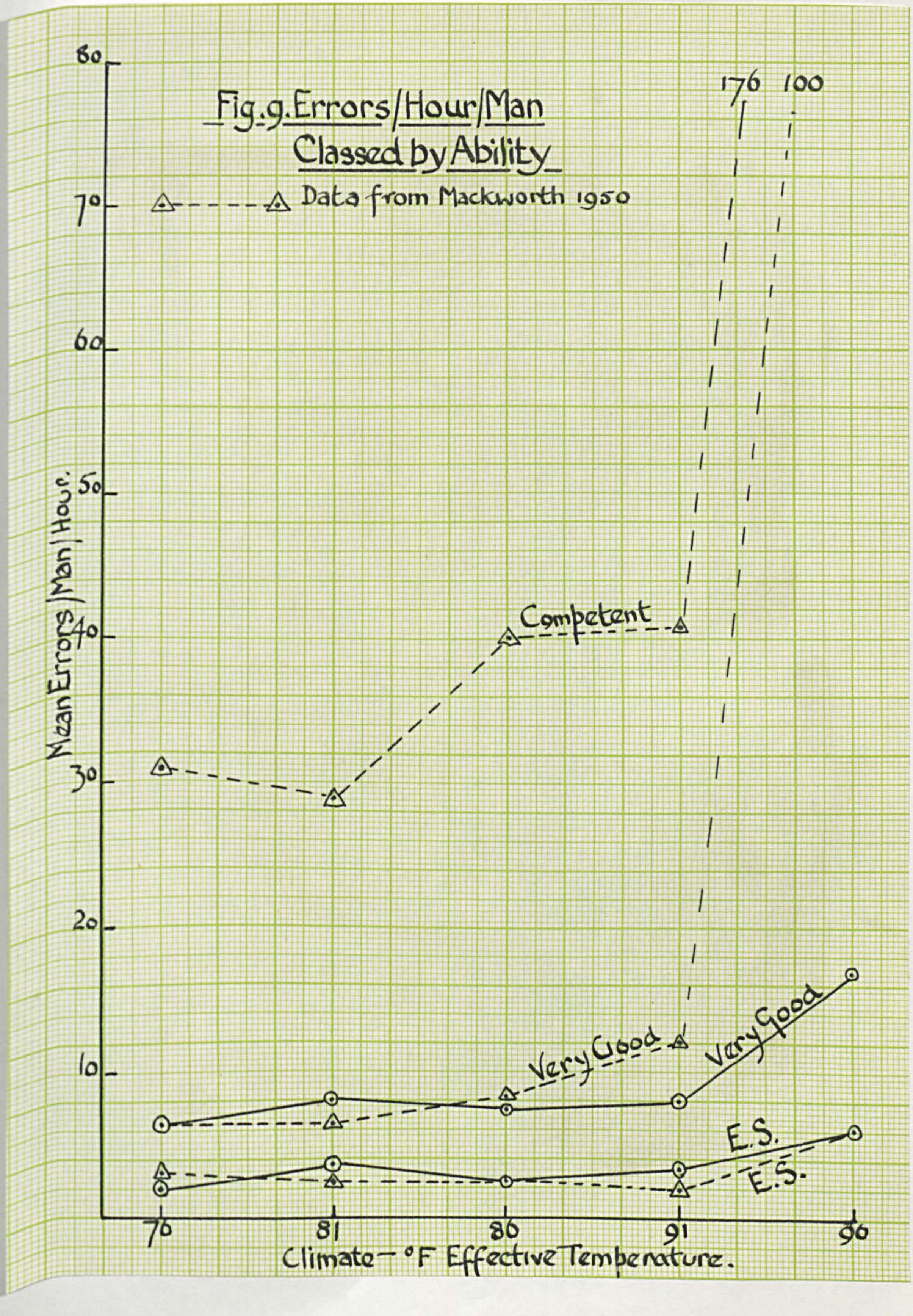


Fig.9. Errors/Hour/Man
Classed by Ability
Data from Mackworth 1950
176
100
Competent
Very Good
Very Good
E.S.
E.S.
Mean Errors/Man/Hour.
80
70
60
50
40
30
20
10
70
81
86
91
96
Climate — °F Effective Temperature.

In the present series further evidence was obtained which indicates the independence of psychomotor deterioration from body temperature. This confirms both Mackworth's and Pepler's earlier work. An immediate deterioration in heat in the first hour of exposure was found both in terms of failed messages and error score for all operators and for the combined group of "skilled" operators. Finally, performance deterioration did occur with time in this series, confirming Mackworth's and Pepler's earlier findings.

CONCLUSIONS AND SUMMARY.

(1) Twelve tropical climate subjects received Morse Code messages under differing climatic conditions, ranging from 76°F to 96°F effective temperature.

(2) When the results were considered as a whole, the poor performances and variability of some operators masked the deterioration shown by other operators.

(3) When the results were marked by the total errors per operator, seven operators were found to deteriorate considerably at a climate of 96°F effective temperature. Below and including 91°F effective temperature, performances were within the same range of efficiency.

(4) When the results of these seven operators are marked by a pass-or-fail method, a logarithmic relationship of performance to atmospheric temperature was obtained, and the inflection of the performance curve was placed at 86°F effective temperature.

(5) Deterioration in efficiency with time occurred in all sessions, except at 96°F effective temperature, when an immediate onset of decrement resulted in the first hour of exposure.

(6) Deterioration in efficiency was once again found to be independent of body temperature.

Part III

General Discussion.

Before discussing some of the general points which arise from work of this nature, it is logical first to consider the results in the light of the questions which, it was hoped, this experimental work might answer.

The results of the pursuitmeter and Morse code reception tests indicate that these tropical climate subjects did suffer deterioration in performance in heat. This evidence, in combination with that obtained by Wyndham et al (1953) concerning "the pull test," shows, therefore, that heat affects the efficiency of tropical subjects at performing three of the activities which formed the basis of Mackworth's original survey on temperate climate man. Wyndham et al (1953), found that the level above which further heat caused the onset of deterioration in the "pull test" was 86°F., effective temperature (Basic Scale) when the work was mild (100 Kg Cal/m^2/hr) or 82°F., effective temperature when the work was moderate (150 Kg Cal/m^2/hr). The first climate i.e. 86°F., is in agreement with that found by Mackworth to be the "critical level" when the performance at 79°F., was taken as the standard. Mackworth's figure was 87.5°F., effective temperature (normal scale) but from the dry bulb and wet bulb temperatures, and the air movement of his experiment (namely 95°F. dry bulb, 85°F. wet bulb, air movement 100 ft/min), this climate was, in fact, 86°F., effective temperature (Basic Scale.).

Similarly, when the results of the pursuitmeter and Morse reception tests are considered in the same way as Mackworth considered his results, the climatic level above which deterioration was marked was 86°F., effective temperature, and the rates of decrement with further elevation of the temperature were similar to those exhibited by temperate climate subjects, and appeared to depend on similar logarithmic relationships to atmospheric temperature. Thus, in relation to "critical" climatic level and extent of decrement, the effect of heat on tropical man is identical with that on artificially acclimatised temperate climate men, as defined by Mackworth.

However, if the concept of "critical" climatic level be re-examined, it is seen that Mackworth's definition (1950) was "there is a critical region on the atmospheric temperature scale, above which most acclimatised men will not work efficiently ......this conclusion applies to all forms of intensive work, both physical and mental." The operative words here are "most" and "efficiently." The first implies that some can still work efficiently, and evidence has been related to show that under some circumstances, "exceptionally skilled" or very highly motivated workers can work without decrement, (Mackworth 1950, Bartlett & Gronow 1953, Blöckley & Taylor 1954, Pepler 1956). The second operative word in the definition is "efficiently", and here a very vexed question arises, for the difficulty of assessing efficiency is generally recognised. In work of this nature the index of performance or efficiency is necessarily arbitrary, and Pepler (1953 e) drew attention to the fact that the nature of the scales of measurement in performance indices is such, that fitting of mathematically constructed curves to the performance scores is a very uncertain procedure. Treatment of the results of the present experiments in two ways brings out this point effectively, and it can be seen that both the "critical temperature" and the rate of decrement above this zone can differ with the performance index. Thus, using basic error score instead of a derived method of pass-or-fail scoring, the "critical" level is altered from 86°F., to 91°F., effective temperatures for the Morse code reception test, and in both this and the pursuitmeter experiment, the logarithmic relationship no longer holds.

In the pursuitmeter test, the scores at 96°F., and 91°F., effective temperatures, were not markedly different to each other, Pepler (1953 b) also found a similar apparent stabilisation of error score at the high temperatures (Pepler 1953 a), as did Carpenter earlier (1950). Wyndham et al., (1953) also found in the "pull test" that at temperatures above 90°F. effective temperature, performance reached a minimum steady level. Therefore, both for temperate climate man and tropical climate man, decrement may not continue to increase with atmospheric temperature after the initial deterioration, provided the subjects' state is physiologically satisfactory, and collapse is not imminent. The reactions of tropical climate man then, on the whole, do not appear different to those of tropically acclimatised temperate climate man, as described by Pepler (1953 a,b,c,e). Finally, the findings of both Mackworth (1950) and Pepler (1950 a,b, c,e) on the independence of deterioration from body temperature rise, and the findings concerning deterioration with time have been confirmed, while the immediate onset of deterioration in heat within a few minutes of exposure noted by Pepler (1956 a & b) was also found.

Briefly then, four of the questions posed have been answered by the experimental evidence as follows:-

(1) Tropical subjects show deterioration in psychomotor efficiency in heat.

(2) The figure for "critical" climate resulting in impairment depends, amongst other factors, on the manner in which the evidence is manipulated, as does also the apparent extent of decrement. The "critical level" may thus be 86°F., or 91°F., effective temperatures, depending on the task and the method of assessing performance.

(3) Close agreement has been obtained with the results of Mackworth (1950) for artificially acclimatised temperate climate subjects, and Pepler (1953 a,b,c,e) for tropically acclimatised temperate climate subjects. The effects of heat on tropical man's efficiency appear similar to the effects on temperate man's efficiency.

(4) Evidence has been shown that tropical man's efficiency at the following tasks is impaired by heat:-

a) Simple muscular work-pull test (Wyndham et al 1953)

b) Heavy physical work with accurate muscle control - the pursuitmeter test.

c) Semi-automatic high speed mental work Morse code reception.

(5) The apparent logarithmic relationship of performance to atmospheric temperature, depends on

specific factors in the experimental method.

However the answer to question (4) is complicated by the absence of deterioration shown by the subjects in the manual dexterity test in this series, and possible criticisms of the design of the experiment which may have been responsible for this, have been mentioned. Nevertheless the evidence at hand (Weiner & Hutchinson 1945) concerning the detrimental effect of heat on the manual dexterity of temperate climate subjects, has been shown to be unsatisfactory.

Mackworth (1950) stated that deterioration occured "in all forms of intensive work both physical and mental." He found, however, a difference in reaction between some psychomotor tests. For example, the "clock" and the "pull" tests differed from the pursuitmeter and wireless telegraphy tests, in that errors did not follow a logarithmic trend. He ascribed this difference to the extreme psychological simplicity of the former tests, and suggested that the resemblance of the performance curves of the latter tests was due to the common factor of "speed stress." The validity of the logarithmic relationship has now been shown to be suspect, but nevertheless the concept of the psychological simplicity, or otherwise, of a test affecting the reaction to heat, is worthy of consideration

The similarity of reaction in the pursuitmeter and wireless tasks was the result, Mackworth thought, of the necessity for immediate, accurate, and continuous response to a very rapid succession of signals. In the other tests, response was either discontinuous (clock test), or mechanical and regulated by the subject (pull test). This line of thought may possibly be extended to explain why the tropical subjects showed deterioration in the pursuitmeter and Morse code tests, and not in the manual dexterity test. It can be said, for example, that the task in this test was discontinuous compared with tracking or receiving Morse signals, and that the speed of performance was imposed by the subject, and not by extrinsic control, such as pursuitmeter cam speed or Morse code speed.

Mackworth (1950) and Pepler (1953 f.g.h.) have shown that results may be modified in the same test by the level of incentive provided by giving the subjects information concerning the progress of performance, scores made, and encouragement. In Mackworth's "pull" test, information was given visually by a gadget which indicated progress. Thus in some way, information may facilitate efficiency and alter decrement, and the knowledge of the amount of work remaining may also spur on the subject to greater effort. In the manual dexterity test, in this series, it could be said, that at every stage of a "run", the subject had immediate knowledge of errors, with the opportunity to make compensatory bursts of speed, and also the knowledge of how much work remained to be done. These differences in the nature of the tasks may have accounted for the difference in reaction in this test. In addition, apart from the fact that in the pursuitmeter and Morse code reception tests no information is inherently available concerning standard achieved or progress of the test, the nature of the "mental" components tested are somewhat different. The manual dexterity test is essentially sensori-motor, and involves comparatively short periods of "conscious attention" with little intellectual complexity, for the problem posed is merely the moving balls from A to B and back, as quickly as possible. On the other hand, in the pursuitmeter and Morse code tests, "conscious attention" to the incoming stimuli is essential, and rapid response is necessary after the receipt and interpretation of the stimulus, whether it be visual (the ceaseless movement of the machine pointer), or auditory (Morse code).

It becomes evident to the critical observer at this stage of the discussion, that the field of observation is rapidly being left behind with the introduction of generalities in terms such as "conscious attention" and "mental components." Nevertheless while remembering that "generalisations are dangerous in proportion to their value unless constantly correlated with the facts of observation" (Walshe 1942), it becomes necessary to introduce such terms on the grounds that no more precise terms are available to express the functions and concepts involved, and to attempt to relate these generalisations to the experimental work available. Strengthened also by Whitehead's (1929) assertion that "true discovery is like the flight of an aeroplane. It starts from the ground of particular observation: it makes a flight in the thin air of imaginative generalisation......", it becomes necessary to define, so far as possible, the terms used. Hebb (1949) defines attention as a selectivity of response to some event in the environment, instead of to another event, which could be responded to (or noticed) just as well. It means, therefore, that the activity which controls the form, speed, strength, and duration of response to a stimulus, is not the immediately preceding excitation of receptor cells alone, but that a central process, partly autonomous or non-sensory, exerts a modifying influence on response. With this definition in mind, then, one can return to the influence of "attention" in the psychomotor tests under discussion.

Siddall and Anderson (1955), studying "fatigue" in a simple tracking test demanding continuous attention, claimed that as the task was simple enough to be error free for runs of up to ten minutes duration, any subsequent errors would be due to inattention to the display. The hypothesis was that with time, mental blocks or gaps in perceptual response would occur, causing tracking to become momentarily uncontrolled. The results showed that after a relatively long time, errors appeared, and increased in incidence with time. It is inferred that this "fatigue" was due to increasing decay of attention with increasing "perceptual blocking" resulting. The task involved tracking a target which moved in a constant direction at a constant rate, and to keep the target aligned, required cranking a handle at a constant rate. Thus the situation involved less discontinuity of stimulus or response than most situations, and it was supposed that in these circumstances, the limited variation of sensory input and information or monotony, would lead to inattention and "blocking."

Bartley and Chute (1947), in a consideration of the phenomenon of "blocking," state that a subject may pause for an unusual length of time before giving a response during a mental performance, or may interject an interval of no response in the middle of a response series. They quote Bills' (1931) definition that a block is " a pause in the responses, equivalent to the time of two or more average responses," and also point out that while Bills considered blocking periods as rest periods for the nervous system, they consider "blocking" to represent a type of momentary unfruitful organisation of activity. It is also pointed out that "blocking" is related to the rate of working, and that frequency of "blocking" increases with rate of response, until at very high rates, continued "blocking" may result with total ignoring of the stimulus to response.

That "interest," "incentive," or "motivation" may stave off deterioration has been shown earlier, and Hebb (1949), and Siddall and Anderson (1955) maintain that the level of "sensory input" is of importance in determining the onset of impairment. Some experimental evidence of a simple nature may support these theoretical considerations. Brozek (1943) describes an example of "sensorimotor synthesis" from an experiment by Lieberson (1939); subjects were required to move the index finger as quickly as possible, and the frequency attained and the onset of decrement was observed under two sets of circumstances. Firstly in air without the finger touching anything, and secondly when the finger just touched a pliable sheet of paper which did not offer resistance. In the latter circumstances, a higher frequency was obtained and decrement occured later. Thus sensory influences obtained in the second set of circumstances appeared to improve performance.

Gibbs (1954) observed the difference in tracking performance of subjects, when the control handle was used isotonically or isometrically by means of a pressure control on the handle. In the latter circumstances, normal subjects showed much superior performances, due presumably to increased kinaesthetic impulses or "feed back." Tabetic subjects, who performed the test under the same sets of conditions, showed no difference in performance standard attained. This evidence implies that increased kinaesthetic feedback in a tracking situation, by continuous monitoring, caused improvement in performance.

Thus in terms of current neuropsychological thought, it is possible to distinguish the effects of environmental heat on the manual dexterity task, and the pursuitmeter and Morse code reception tasks. In the former, the activity was discontinuous, yet with a high "perceptual feedback" as to progress and standard attained, the subject worked at his own speed for relatively short times and was perhaps well motivated, and under these circumstances deterioration is unlikely.

However, in the pursuitmeter and Morse reception tests, the activity was continuous with no perceptual feedback as to standard attained or progress, and no information or incentive was supplied. Performance required "continuous attention," and hence was liable to decrement due to perceptual blocking in these circumstances. Thus "fatigue" would be expected in normal climates for the wireless telegraphy test, but for the pursuitmeter test, as performance of the test was once every twelve minutes, less decrement might be expected in normal climates.

But exposure to heat in both resulted in impairment from the start of the exposure. Bartlett (1941) has indicated that "fatigue" and decrement due to heat may be expected to show the same characteristics. It may be that heat acts by accelerating the onset of decrement in some way, or that impairment by heat and decrement due to fatigue operate similarly. The fact that decrement in heat appears within a few minutes of exposure, suggests a rapidly operating mechanism, and implies a nervous basis, but more will be said on this point later.

Finally the effect of ability on staving off impairment may be interpreted in current concepts by consideration of Hebb's views (1949), on the basis of learning a response to a stimulus. Hebb considers that "a frequently repeated particular stimulation will lead to the slow development of a 'cell assembly,' a diffuse structure composing cells in the cortex, diencephalon, and perhaps the basal ganglia, capable of acting briefly as a closed system delivering facilitation to other such systems, and usually having a specific motor facilitation." This is termed a phase sequence, and such an "assembly" action may be aroused by a preceding assembly, by a sensory event, or both. On this assembly (or assemblies), the influence of "attention" or the central autonomous process is exerted. In 1884 Hughlings Jackson stated "less consciousness attends activities of nervous arrangements the more organised and automatic they are or have become." It is feasible that the less skilled a man is, the more "attention" he must pay to the task, and the less autonomous are the functions of the phase sequences involved in the task. The onset of decrement in Bartlett's sense (1941), if it be mediated through "blocking"-Siddall and Anderson (1955)-then is likely, for "attention" must be exerted continuously by an unskilled man, and it may follow that such a subject will show decrement when a more skilled man, with possibly less "attention" to his task, will not suffer impairment. This hypothesis presupposes that impairment is indeed the result of interference with the central autonomous process in some way by heat influences. It is of considerable interest therefore, to discuss in the next section the possible ways that the detrimental effect of heat is exerted, and to consider the causes of decrement.

Causes of Decrement in Heat.

This is a topic about which relatively little information exists in the literature, despite the amount of attention that has been paid to the study of decrement and fatigue in general. What does exist consists mainly of mere smatterings of articles, but nevertheless, the almost mystic effect of heat on function, and the rapidity of its exertion offers an interesting field for speculation.

Barcroft (1938) considered that in heat, it was the rising of the body temperature which threw out of gear the proper functioning of the higher qualities of the brain. While it must be conceded that this is so, the onset of impairment of these functions before measurement of body temperature, as we know it, reveals an increase, seems to indicate that other factors may be operating, unless neurones are exceptionally sensitive to minimal temperature change. This point is capable of resolution if the sensory and peripheral effects of heat could be eliminated, and the function in subjects with only a raised body temperature investigated e.g. due to fevers etc. This possibility seems to have crossed Barcroft's mind, for in considering the effects of raised body temperature, he mentions pyrexial effects but warns that the effect of circulating toxins could not be ignored. Barcroft then, considered the effects of heat by raising body temperature as one of the factors disturbing the fixity of the internal environment. Oxygen, for perfect cerebral function, is another factor, and it has been suggested by Ellis (1953 a) that heat may act by diverting blood flow to the periphery with a resultant reduction in cerebral blood flow and possible cerebral anoxia.

That anoxia can cause impairment of pursuitmeter performance, similar to that caused by heat, has been shown by Shephard (1956) and earlier, Critchley (1945) has mentioned the similarity of the effects of anoxaemia and carbon dioxide. However, in the absence of any experimental evidence it cannot be visualised that cerebral blood flow would suffer so acutely from the onset of heat, while it has been shown that subjects nearing circulatory collapse in intense heat could still maintain their performance standard, (Blockley & Taylor 1954, Pepler 1956 a). Ellis (1953 a) maintained that although there was no evidence of a direct effect of heat on the central or peripheral nervous system, decrement might be due partly to distraction or changes in incentive associated with thermal discomfort or sweating.

Mackworth (1950) on the basis of the logarithmic change in performance with temperature, contemplated a biochemical explanation. He suggested that some substance which might slow nerve transmission at synapses, might be produced in the body by heat, and by its cumulative effect increasing disorganisation. However, the fact that increase in body temperature did not act as an intermediary in causing decrement, he considered, was a telling point against this explanation, apart from the different effects that incentive exerted on the results.

The immediate onset of decrement in heat, it has been suggested earlier, implies a rapidly acting mechanism and a nervous basis may well account for the phenomenon. The fundamental nervous response to heat is mediated in the hypothalamus in the heat regulating centres. In view of the proximity of this region to the hypothalamic "sleep" centre it is not surprising that a hypothesis incriminating irradiation from one to the other centres with setting in motion of the sleep arousal mechanism (Kleitman 1939) has been posed. Thus Lee (1950) invokes this explanation as assisting in the production of feeling of lassitude, drowsiness and inattentiveness in heat, and this may well cause interference with the maintenance of the necessary "conscious attention" in psychomotor skills. In addition evidence exists as to the interdependence of hypothalmic and cortical relations (Murphy & Gelhorn 1945, Ward & McCulloch 1947), and also thalmic and cortical activities (Dusser de Barenne et al. 1937, 1938, 1941) through the "suppressor strips." Hypothalmic firing in heat might thus spread its influence over widespread areas of the cortex and interfere with "inte-grative" functions and "conscious" activity. While considering the possible ways in which nervous influences may be exerted it is worthwhile to pay more attention to the possible role of heat as a distracting influence. Pepler (1953 f,g,h,) has shown that men usually used to a remarkably constant climatic environment may show deterioration in performance when the temperature is lowered only a few degrees (from 81°F., to 76°F., effective temperature) as well as when it is raised. In 1954 Pepler said that this effect might be because the subjects became more sensitive to climatic change owing to the narrow range of ambient temperatures. He hastened to add that this was not an argument against air conditioning, for in time a new level of performance might be established at the cooler climate which would be more efficient. Generally in the tropics where the ambient range is small, the indigenous subjects may become excessively sensitive, physiologically, to lowering of atmospheric temperature (Ladell 1954), and psychologically one has observed peculiarities of behaviour and judgement by tropical men on "cold" days in the tropics. That this cooling may act as a distractor as well as heat is possible, if the distracting influence is mediated by discharge from cutaneous receptors and fired by the temperature gradient. Pepler (1956 b) believes that when other stressful stimuli e.g. glare, noise, or controlling a dummy handle are combined with heat, the decrement in pursuitmeter performance may be greater than in their absence. It is on this basis that in the next section a hypothesis is evolved for the cause of decrement in heat. It is fully realised that the experimental work in this thesis provides no information upon which to base a hypothesis for decrement in heat, and indeed there is little experimental evidence at all upon which to base speculation. Nevertheless speculation may be permissible in that, even if wildly incorrect it is stimulating, and provided that one remembers the observation of Trotter (1913) and his warning that "In dealing with theoretical considerations concerned with the physiology of the nervous system one is exceptionally liable to be misled by preconceived or introspectively evolved notions as to how sensory and perceptive processes may be supposed to act....... and we tend to drift into the error of supposing that conceptions which are clearcut, easily comprehensible, and "reasonable", acquire by that very fact an increased probability of being accurate expositions of the physiological processes they profess to explain."

A Neuropsychological Hypothesis for the Cause of Decrement by Heat.

Various authorities have stressed the importance of input, and feedback or servo mechanism in many problems of nervous organisation relating both to physiological and psychological functions (Weiner 1948, Hebb 1949, Hebb 1954).

Weiner (1948) mentioned that in situations where response is called for by stimuli displayed in time the problem becomes related to time series studies, and has discussed the mathematics involved in interference between two stimuli. For example, if "u" is a message and "v" a noise then in the absence of noise the information carried by the message is infinite. However in the presence of a noise, the information becomes finite and rapidly approaches zero as the noise increases in intensity. Weiner also draws attention to the complex assembly of neuronic chains involved in the performance of complicated behaviour by man. It is pointed out that this is analogous to multiple switching or staging in a communication system, the delicacy of which increases with its complexity, while at the same time the multiplication of stages for efficient performance continually demands a higher level of successful and controlled activity at each stage, to render the ultimate function a probability. Such a system can be overloaded by an excess of traffic, by a physical removal of channels for carrying traffic, or by the excessive occupation of such channels by undesirable systems of traffic. In all these cases, Weiner points out, a point will come when breakdown occurs. Weiner elsewhere discusses the influence of feedback in electronic machines, and indicates that breakdown of control is manifested by oscillation or hunting of the machine.

It is conceivable that for any organised communication system such as a cerebral neuronal net, there is an optimum input which is limited to a considerable amplitude of input for efficient control. If input falls below a critical level disorganisation may result (Hebb 1949, Siddall & Anderson 1955) and it is analogous that input above a critical order may also create disruption - for example, sensory input above a certain level may produce pain from the cutaneous special sense receptors when hyperstimulated, and Bartley and Chute (1947) point out that excessive rate of stimulation may result in complete "blocking". If a neuronal net is bombarded by a set of impulses -

thus becoming overwhelmed - then disorganisation may result; that "blocking" may be analogous to the hunting of the electronic apparatus, as representative of momentary disorganisation, springs to mind. It is conceivable that if a distracting influence reaches the same central integrative level as a co-existing input stimulus, then it may overload the neuronal net mechanism, as may the "undesirable systems of traffic" in communication chains. Pepler (1956 b) states that heat decrement in pursuitmeter performance may be greater in the presence of other stressful stimuli e.g. glare from a light, heard irrelevant but audible speech, or even extraproprioception produced by the inactive arm holding a dummy control arm loaded with 16 lbs. This may well be objective evidence in support of the above hypothesis. If heat decrement is considered in this light, then it is necessary to consider at what level of nervous activity heat influences are perceived, and whether the situation visualised can arise. Presumably the ultimate fate of the electrical impulses passing from cutaneous receptors in the skin will be the cortex, and it may be at this level that interference will act. However, recent advances in neurophysiology may incriminate a lower anatomically but functionally higher level than the cortex. Penfield (1954) proposed that the highest level of neural integration of the total activity of the nervous system is situated in the centrencephalic system which lies in the reticular formations of the diencephalon, mid-brain & pons. Magoun et al (1954) have shown that the activity of this formation reacts to auditory and tactile stimuli and that its activity can cause the "arousal reaction" or desynchronisation of the electro-encephalogram with disappearance of the alpha rhythm. This arousal reaction occurs also when "attention" is directed consciously to particular fields. Here then lies a neuranal net system responsive to exteroception and involved in "conscious activity;" Jasper (1954)has drawn attention to his hypothesis that it is in this centrencephalic system that the signal to the whole system to respond is evoked by a pattern of stimuli. Jasper (1954) adds that "this (neural) pool will only receive a limited input and competing impulses cannot reach it."

Heat could conceivably act in a similar way to other distractors, by overloading the neuronal net and interfering with the central autonomous process with resultant "blocking." Bartlett (1941) in his study of "fatigue" found that an increasingly powerful interference effect resulted with time from a variety of distracting stimuli. Noise, heat, or even proprioception from body attitude, were among the distracting stimuli offered; that these different influences operate through the same mechanism seems possible.

Consequently, abilities not primarily requiring close central control may be less interfered with by an excessive sensory input of heat stimuli. Thus the more automatic an activity, the less likely it will suffer decrement. This might explain the apparent heat insensitivity of the manual dexterity test, while tests requiring cortical integration and involving the participation of the central autonomous process, would respond to heat interference. An extension of this hypothesis may also explain the oft repeated observation concerning ability, that the most skilled workers suffer less decrement - Mackworth (1950) noted that very skilled operators could carry on a conversation yet receive Morse code accurately at the same time, a remarkable example of automatism.

In very adverse circumstances during high motivation, sensory input can sometimes be ignored by the individual, for example, pain in battle. Heat influences may perhaps be similarly disregarded in some circumstances to the benefit of performance, as in

Blockley & Taylor (1954) and Pepler's (1956) experiments, but only by conscious striving.

Finally, if it be considered that the central organiser mechanism is faced with different inputs which are vying for treatment, and that in certain conditions potentiation of one might lead to partial or complete extinction of the other's effect, it may be possible to understand the beneficial result of gaining information concerning performance either from an observer or from the nature of the task:- e.g. in the pull test or in the ball picking test. These conditions may result in the dominance of the feedback influences over the interfering phenomena; this implies a potential selectivity of the control mechanism, or a differentially applied influence of feedback mechanism. The following situations and results might result on this hypothesis and may explain some of the past anomalies.

Processes Involved	Influence	Anticipated decrement		
Feedback	Low	No information	→ High	Pull test (Low incentive)
Central facilitation	Low	Automatic task		
		or (E. skilled men)		
Feedback	High	Information available	→ Low	Man. dexterity & Pull test (High incent.)
Feedback	High	Information available	→ Less	Pursuitmeter
Central facilitation	High	Interpretive continuous task	→ High	Morse, vigil. Coding, Pursuitmeter.
Feedback	Low	no information		

Thus a central nervous interference effect may explain that

(1) The onset of decrement is immediate in heat-neuronal in nature and speed.

(2) The decrement is not related to body temperature, as it is the immediate result of exteroceptor interference which may not be conscious but is capable of extinction in some circumstances of motivation, skill, or high feedback in particular tasks.

Summary of Psychomotor Work.

Three psychomotor experiments of differing complexity were performed, using tropical climate subjects, to investigate the effect of raising the environmental effective temperature on the efficiency of performance.

In all three experiments the subjects were given a preliminary opportunity to become familiar with the experimental routine and conditions, or to become trained performing the particular test. The experimental routine in each test was so designed that hourly sweat rates and rectal temperature changes could be observed for each of the particular climatic exposures, each of which lasted three hours. The same range of climatic conditions was imposed in all the experiments, and as the air movement in all tests was 100 ft/min. exposures to dry and wet bulb temperatures of:-

$$\frac{DB}{WB}\ \frac{85}{75}{}^{o}F.,\ \frac{90}{80}{}^{o}F.,\ \frac{95}{85}{}^{o}F.,\ \frac{100}{90}{}^{o}F.,\ \frac{105}{95}{}^{o}F.,$$

gave a range of effective temperatures of 76°F., 81°F., 86°F., 91°F., 96°F., The order of exposure was randomised.

(a) Manual Dexterity.

This was the simplest test and involved high speed repetitive movements. The four subjects were required to manipulate with forceps 84 steel ball bearings and to transfer them from one site to another and back, as quickly as possible. The ball bearings were carried on a rotating tilted circular disc to make the test more difficult; the time taken to complete the task was the measure of performance. In addition, any balls dropped had to be replaced before the test was completed, and the number of mishandled balls offered another index of performance. The final index was the time/movement, which was obtained by dividing the time taken per test by the total number of balls handled (including those dropped). It was found that during the preliminary period, typical learning curves were obtained for these indices except the number of balls dropped which remained variable all the time. Exposure to hot climates did not result in any impairment of performance normally, or even when the severity of the task was doubled. In fact, the time per test and time/movement continued gradually to be more efficient from day to day throughout the tests despite climate or raised rectal temperature.

(b) <u>The Pursuitmeter Test</u>.

In this experiment attempts are made by the subject to follow the erratically moving machine pointer (controlled by an electrically driven irregularly shaped cam), with a pointer controlled by the subject by moving a heavily weighted lever. Angular errors between the two pointers are summed on an error scoring dial within the machine, and performance can be assessed either in terms of absolute error, or in terms of failed attempts at tracking if the subject exceeds an arbitrary error score. Four subjects performed this experiment, and it was found that on either method of scoring, performance became poor at climates of 91°F., and 96°F., effective temperatures even before the rectal temperatures rose. Performances at other temperatures were within the same range. In terms of failed attempts, a logarithmic relationship between performance and atmospheric temperature was obtained, and the "critical level" of climate was found to be 86°F., effective temperature. These findings are similar to Mackworth's findings on temperate climate personnel. However, consideration of performance in terms of error score, instead of a derived system of scoring, indicated that a logarithmic relationship does not hold, and that the latter is due principally to the scoring method. The critical level of temperature however, remained the same for performance based on error score. Performance was independent of body temperature; time within a session did not impair performance, but at 96°F., effective temperature the onset of impaired performance was immediate.

(c) Morse Code Reception

This test represented the highest plane of mental activity investigated, and involved little motor component. Twelve subjects received cipher Morse code at the speed of twelve groups, each of five symbols, per minute for 45 minutes, in each hour of the three hours exposures. The result was marked in terms of actual number of errors made, and also as failed messages if five or more symbols were missing or incorrect. Variability and poorness of some of the operators rendered interpretation of the results difficult; however, the "better" operators showed deterioration at 96°F., effective temperature, and also with time within any session on the former method of scoring. When the derived method of scoring was used, the results bore a logarithmic relationship to atmospheric temperature, and the critical temperature for deterioration was placed at 86°F., effective temperature; results were thus similar to those of Mackworth. However, the fact once again that these relationships do not hold for performance when the error score was used, indicate their dependence on the scoring method. In terms of failed messages, performance deteriorated with time within sessions, and onset of decrement at 96°F., effective temperature was immediate.

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Acknowledgements are due and are sincerely tended to the following:-

(1) To the subjects who suffered the exposures.

(2) To the Army authorities in West Africa, in particular to Major Kennet of the Nigerian Signal Squadron and to Major Brett and Major Preston of the Royal Army Ordnance Corps who co-operated in the provision of the subjects.

(3) To the Applied Psychology Unit of the Medical Research Council for the loan and use of one of their pursuitmeters, and more recently for the facilities afforded me when I visited the Unit earlier this year.

(4) To Dr. Mackworth, Mr. Pepler, Dr. Ladell and Dr. Horne for discussing my results with me, and to the latter also for invaluable statistical advice.

(5) To Mr. E. A. Oshinyemi, Chief Technical assistant at the Hot Climate Physiological Research Unit who was my assistant in performing the experimental observations.

A P P E N D I X

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APPENDIX. Section A.

Results of Manual Dexterity Test.
Practice Run Results

Subject		P Time m. s.	P B.D.	O Time m. s.	O B.D.	I Time m. s.	I B.D.	E Time m. s.	E B.D.
Run 1.	Attempt 1	16.17	82	8.43	50	9.33	30	6.55	48
	" 2	11.30	44	6.44	25	7.45	21	6. 0	29
	" 3	9.15	36	6.53	29	7.33	20	5.13	15
Run 2.	Attempt 1	7. 2	11	6. 7	21	7.57	33	5. 5	16
	" 2	6.49	17	5.49	14	7.10	21	5.18	24
	" 3	6.33	14	6.34	17	6.43	23	5.35	20
Run 3.	Attempt 1	8.16	19	7.24	18	6.32	29	5.17	13
	" 2	7.48	26	5.42	23	7.35	26	5.26	7
	" 3	6.52	18	5.32	15	6.11	12	5.35	11
Run 4.	Attempt 1	8.50	34	6. 2	19	5.57	10	6.18	18
	" 2	7.45	22	5. 7	16	6.24	21	6.40	13
	" 3	6. 2	24	5.35	16	6.17	25	6. 1	11
Run 5.	Attempt 1	6.33	28	5.15	9	6.27	26	5.57	13
	" 2	6.18	19	5.25	14	5.48	11	5.18	11
	" 3	6. 0	14	6.15	25	6.21	22	5.26	13
Run 6.	Attempt 1	6. 4	24	5. 9	17	6. 0	36	6.50	19
	" 2	5.45	16	5.10	14	5.37	10	4.58	20
	" 3	6.30	32	4.55	12	5.29	15	5. 0	15

Times were recorded in Minutes and Seconds for convenience in these tests and later converted to seconds for the final analysis.
B.D. = Balls dropped.

Practice Run Results (continued)

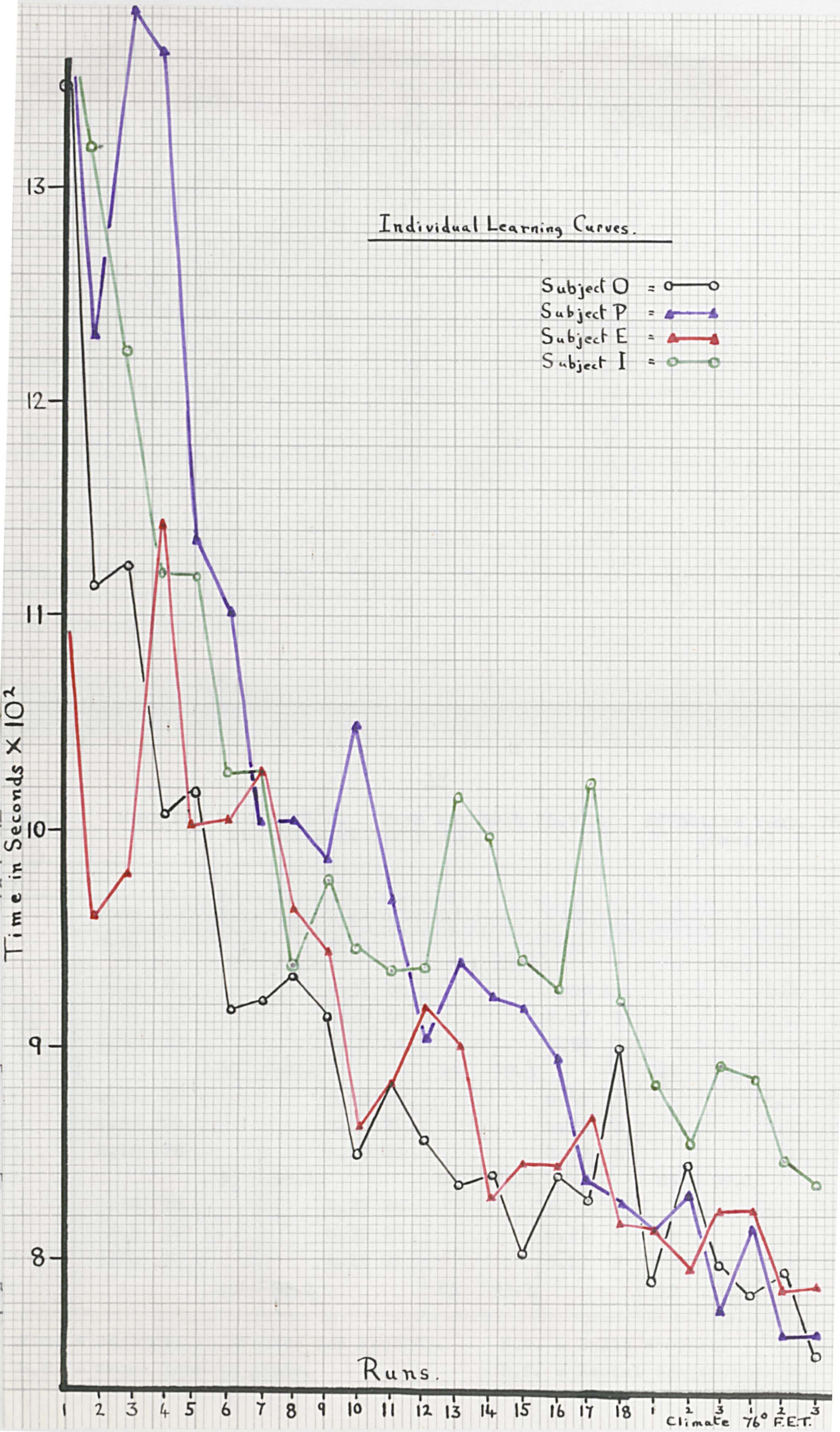
Subject	P		O		I		E	
	Time	B.D.	Time	B.D.	Time	B.D.	Time	B.D.
	m. s.		m. s.		m. s.		m. s.	
Run 7. Attempt 1	5.22	26	5. 5	15	6. 0	19	5.15	23
" 2	6.14	32	5.37	26	5.11	15	6. 5	25
" 3	5.13	19	4.36	15	5.55	11	5.49	30
Run 8. Attempt 1	5.26	33	5.42	31	5.15	13	6. 7	25
" 2	5.50	27	5. 7	21	5. 6	6	5.25	21
" 3	5.32	18	4.45	17	5.12	9	4.30	16
Run 9. Attempt 1	4.56	17	4.35	16	5.43	21	4.59	16
" 2	5.48	26	5.32	19	5.29	17	5.19	24
" 3	5.37	19	5. 7	21	5. 4	10	5.26	28
Run 10. Attempt 1	6. 0	29	4.49	20	5.34	15	5. 2	6
" 2	5.49	23	4.53	15	5. 0	5	4.37	12
" 3	5.39	32	4.28	10	5. 9	4	4.40	12
Run 11. Attempt 1	5.43	27	5. 3	20	5. 2	5	5.14	15
" 2	5. 7	21	4.38	15	4.57	8	4.55	19
" 3	5.17	28	5. 1	18	5.35	7	4.33	14
Run 12. Attempt 1	4.56	11	4.50	20	5. 0	9	4.42	14
" 2	4.56	21	4.53	12	5.11	9	4.49	10
" 3	5.13	34	4.31	11	5.24	10	5.45	19

Time = recorded in minutes and seconds. B.D. = Balls dropped.

Practice Run Results (continued)

Subject		P		O		I		E	
		Time	B.D.	Time	B.D.	Time	B.D.	Time	B.D.
		m. s.		m. s.		m. s.		m. s.	
Run 13.	Attempt 1	5.25	19	4.51	18	5.27	9	5. 0	9
	" 2	5.24	26	4.32	8	6. 0	11	4.56	10
	" 3	4.50	31	4.31	13	5.26	4	5. 5	8
Run 14.	Attempt 1	4.22	16	4.43	19	5.27	7	4.42	7
	" 2	5.22	34	5.18	23	5.40	2	4.27	9
	" 3	5.41	21	3.56	11	5.29	9	4.43	7
Run 15.	Attempt 1	4.35	26	4. 0	17	5.17	11	4.55	12
	" 2	5.35	51	4.32	20	4.57	4	4.26	9
	" 3	5. 9	34	4.49	21	5.24	9	4.46	10
Run 16.	Attempt 1	5.19	32	5.20	22	5. 7	11	4.56	18
	" 2	5. 0	25	4.27	20	4.55	4	4.28	10
	" 3	4.37	23	4.12	20	5.23	16	4.41	14
Run 17.	Attempt 1	4. 9	13	4.37	32	5.41	8	4.56	19
	" 2	4.53	31	4.23	21	5.36	11	5. 8	21
	" 3	4.57	29	4.48	23	5.44	8	4.24	16
Run 18.	Attempt 1	4.11	14	4.52	25	4.51	13	4.52	14
	" 2	4.44	31	4.48	26	4.59	4	4.11	9
	" 3	4.53	33	5.18	32	5.27	13	4.35	16

Time = recorded in minutes and seconds. B.D. = Balls dropped.



Individual Learning Curves.
Subject O =
Subject P =
Subject E =
Subject I =
Time in Seconds × 10²
13
12
11
10
9
8
Runs.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 1 2 3 1 2 3
Climate 76° F.E.T.

limatic Day 1. Mean Dry Bulb 83.1°F. Mean Wet Bulb 75.9°F. Effective Temp. 76°F.
Air movement 100 ft/min. (Basic)

Subject	P				O				I				E			
	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.
	m. s.				m. s.				m. s.				m. s.			
Entry			-	99.5			-	99.4			-	99.3			-	99.4
1	4.43	25			4.37	20			4.58	13			4.57	12		
2	4.29	37			4.23	20			4.47	9			4.20	6		
3	4.24	31			4. 9	18			4.56	2			4.18	12		
1st Hour			40	99.2			55	99.3			40	99.1			40	98.9
1	4.51	11			5.13	16			4.40	3			4.31	11		
2	4.53	22			4.44	27			4.36	1			4.17	10		
3	4.10	26			4. 9	20			4.57	8			4.28	11		
2nd Hour			55	99.1			60	99.1			25	99.1			40	98.8
1	3.52	18			4.27	24			5. 7	8			5. 0	14		
2	4.43	32			4.30	20			4.28	3			4.12	9		
3	4.24	32			4.19	21			5.17	9			4.32	14		
3rd Hour			45	99.1			85	99.1			35	98.9			55	98.6

Time = recorded in minutes and seconds. B.D. = Balls dropped.
S.R. = Sweat loss in grams. R.T. = Rectal temperature °F.

Climatic Day 2. Mean Dry Bulb 84.1°F. Mean Wet Bulb 76.2°F. Effective Temp. 76.5°F.
Air Movement 100 ft/min. (Basic)

Subject	P				O				I				E			
	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.
	m.s.				m.s.				m.s.				m.s.			
Entry			-	99.4			-	99.0			-	99.4			-	98.7
1	4.46	25			4.14	16			5.17	11			4.43	10		
2	4.15	25			4.26	19			4.45	1			4.18	16		
3	4.38	27			4.24	21			4.45	6			4.43	17		
1st Hour			70	99.2			45	99.0			35	99.1			40	98.6
1	3.58	14			4.55	39			4.46	9			4.29	15		
2	4.23	36			4.20	21			4.43	10			4.11	12		
3	4.27	26			3.58	11			4.38	7			4.28	13		
2nd Hour			80	99.1			80	99.1			45	99.1			35	98.6
1	4. 9	36			3.55	18			4.41	26			4.33	19		
2	4.10	29			4.29	30			4.19	11			4.10	15		
3	4.29	41			4.11	20			4.55	16			4.26	23		
3rd Hour			60	99.1			80	99.1			38	99.0			40	98.4

Time = recorded minutes and seconds. B.D. = Balls dropped.
S.R. = Sweat loss in grams. R.T. = Rectal temperature °F.

Climatic Day 3. Mean Dry Bulb 95.0°F. Mean Wet Bulb 85.1°F. Effective Temp. 86°F.
Air movement 100 ft/min. (Basic)

	P				O				I				E			
	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.
	m. s.				m. s.				m. s.				m. s.			m. s.
Entry			-	99.5			-	99.1			-	99.6			-	99.1
1	4. 3	4			4.39	28			4.42	18			4. 2	14		
2	3.54	22			4. 8	26			4.26	21			4.27	22		
3	4.18	37			4. 3	23			4.30	9			4.10	20		
1st Hour			215	100.1			175	99.5			145	99.7			170	99.4
1	4. 8	29			4.17	28			4.47	28			4.39	20		
2	3.48	34			3.56	19			4. 6	4			4.17	6		
3	3.58	31			3.50	13			4.25	6			3.57	9		
2nd Hour			200	99.8			160	99.4			160	99.6			170	99.3
1	3.35	21			4.54	40			4.19	11			4. 2	11		
2	3.56	20			4.14	28			4.25	13			3.50	10		
3	3.56	32			4.11	26			4.18	23			4. 5	16		
3rd Hour			200	99.8			220	99.4			140	99.8			180	99.6

Time = recorded in minutes and seconds. B.D. = Balls dropped.
S.R. = Sweat loss in grams. R.T. = Rectal temperature °F.

Climatic Day 4. Mean Dry Bulb 105.1°F. Mean Wet Bulb 95.0°F. Effective Temp. 96°F.
Air movement 100 ft/min. (Basic)

Subject	P				O				I				E			
	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.
	m.s.				m.s.				m.s.				m.s.			
Entry			-	100.1			-	99.0				99.3				98.6
1	4. 1	24			3.56	19			4.16	5			4.20	16		
2	4. 8	29			4.24	32			4.32	9			4.11	18		
3	4.10	31			4.15	33			4.19	11			4. 9	17		
1st Hour			598	101.1			645	100.2			440	100.1			670	99.9
1	3.44	11			4.24	29			4.18	18			4.33	34		
2	4.23	35			3.46	24			4. 6	10			3.56	21		
3	4. 8	13			4. 3	27			4.11	16			4. 9	17		
2nd Hour			600	101.1			780	101.0			580	101.1			955	101.1
1	3.38	22			3.56	23			4. 9	13			3.47	16		
2	3.37	26			4.16	39			3.50	8			4.24	26		
3	4.53	54			3.43	23			3.54	11			3.44	16		
3rd Hour			420	102.8			665	102.0			624	101.6			785	101.9

Time = recorded in minutes and seconds. B.D. = Balls dropped.

S.R. = Sweat loss in grams. R.T. = Rectal temperature °F.

Climatic Day 5. Mean Dry Bulb 90.0°F. Mean Wet Bulb 80.0°F. Effective Temp. 81°F.
Air movement 100 ft/min. (Basic)

Subject	P				O				I				E			
	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.
	m. s.				m. s.				m. s.				m. s.			
Entry			-	99.5			-	99.0			-	99.1			-	99.0
1	3.26	7			3.43	20			4.23	9			4.18	12		
2	3.43	19			3.49	17			4. 4	7			4.30	20		
3	3.48	16			4. 4	19			3.58	13			3.49	11		
1st Hour			165	99.2			135	98.6			55	99.1			85	99.0
1	3.10	9			3.54	25			4. 2	14			4.30	28		
2	3.50	25			4.20	26			4.14	12			3.45	20		
3	3.30	17			3.56	25			4.24	18			3.55	13		
2nd Hour			170	99.2			125	98.6			105	99.4			95	98.9
1	3.24	19			3.56	30			4.17	11			3.48	16		
2	3.34	,12			3.51	25			4. 7	15			4. 0	19		
3	3.36	16			3.42	22			4.18	12			3.45	21		
3rd Hour			160	99.2			145	98.6			80	99.4			95	98.8

Time = recorded in minutes and seconds. B.D. = Balls dropped.
S.R. = Sweat loss in grams. R.T. = Rectal temperature °F.

Climatic Day 6. Mean Dry Bulb $100.1^{\circ}F$. Mean Wet Bulb $90.0^{\circ}F$. Effective Temp. $91^{\circ}F$.
Air movement 100 ft/min. (Basic)

Subject	P				O				I				E			
	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.
	m.s.				m.s.				m.s.				m.s.			
Entry			-	100.3			-	99.2			-	99.3				98.6
1	3.53	32			3.49	24			4. 5	9			4. 3	12		
2	3.55	29			3.39	21			4. 7	11			3.41	14		
3	3.55	22			3.36	19			3.57	13			4. 9	22		
1st Hour			370	100.3			280	99.4			215	99.6			195	99.2
1	3.44	26			3.59	25			4.20	10			3.46	16		
2	3.46	18			3.44	34			4.25	21			3.30	19		
3	3.32	19			3.40	20			4.17	15			3.36	18		
2nd Hour			320	100.7			300	99.8			270	100.0			300	100.0
1	3. 6	7			3.32	22			3.53	15			3.45	22		
2	3.24	24			3.31	21			4. 4	12			3.25	13		
3	3.23	21			3.56	32			3.53	11			3.43	22		
3rd Hour			290	100.7			330	99.9			240	100.1			230	100.1

Time = recorded in minutes and seconds. B.D. = Balls dropped.
S.R. = Sweat loss in grams. R.T. = Rectal temperature $^{\circ}F$.

Climatic Day 7. Mean Dry Bulb 85.1°F. Mean Wet Bulb 76.5°F. Effective Temp. 77°F.
Air movement 100 ft/min. (Basic)

Subject	P				O				I				E			
	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.
	m.s.				m.s.				m.s.				m.s.			
Entry			-	99.8			-	99.1			-	99.2			-	98.8
1	3.31	13			3.44	25			4.42	22			4.12	17		
2	3.20	15			3.45	22			4.23	17			3.45	17		
3	3.32	19			3.53	31			3.59	11			3.42	22		
1st Hour			75	99.4			70	99.0			20	99.0			35	98.8
1	3.33	18			3.56	30			4. 4	12			3.35	20		
2	3.19	14			3.41	27			3.54	11			3.22	13		
3	3.23	17			3.38	22			4. 2	18			3.35	20		
2nd Hour			65	99.2			65	99.0			35	99.2			55	98.9
1	3.15	9			3.54	31			4. 6	18			3.56	21		
2	3.17	24			3.36	26			3.42	11			3.39	24		
3	3.18	28			3.46	32			4. 7	8			3.20	10		
3rd Hour			45	99.3			85	99.0			35	99.3			50	98.9

Time = recorded in minutes and seconds. B.D. = Balls dropped.
S.R. = Sweat loss in grams. R.T. = Rectal temperature °F.

Climatic Day 8. Severe Test. (Double Run every hour)

Mean Dry Bulb 90.0 F. Mean Wet Bulb 80.1 F. Effective Temp. 81 F.
Air movement 100 ft/min. (Basic)

Subject	P				O				I				E			
	Time m.s.	D.B.	S.R.	R.T.	Time m.s.	B.D.	S.R.	R.T.	Time m.s.	D.B.	S.R.	R.T.	Time m.s.	D.B.	S.R.	R.T.
Entry			-	99.8			-	98.7			-	99.3			-	98.3
1	3.57	32			3.27	23			4.19	16			3.53	16		
2	3.26	18			3.31	25			4. 6	13			3.28	19		
3	3.39	19			3.32	25			4. 1	14			3.38	9		
4	3.27	7			3.23	22			4. 2	15			3.45	23		
5	3.11	3			3.35	21			4. 6	8			3.33	21		
6	3.36	11			3.10	11			3.52	12			3.52	23		
1st Hour			130	99.8			90	98.9			55	99.4			70	98.5
1	3.35	18			3.45	33			3.57	15			3.36	8		
2	3.52	27			3.27	26			4.15	10			3.48	18		
3	3.45	22			3.25	23			3.57	8			3.32	20		
4	3.23	14			3.42	28			4.15	12			3.25	9		
5	3.25	6			3.15	18			3.47	12			3.40	13		
6	3.31	9			3.38	23			3.51	6			3.26	10		
2nd Hour			145	99.8			120	99.0			95	99.7			105	99.1
1	3.10	14			3.22	27			3.45	10			3.44	20		
2	3.32	26			3.21	27			3.52	12			3.20	12		
3	3.45	21			3.18	20			4.13	9			3.33	15		
4	3.12	13			3.30	30			3.44	6			3.40	16		
5	3. 6	12			3.41	26			3.51	9			3.20	9		
6	3.20	19			3.12	21			3.40	10			3.28	9		
3rd Hour			105	99.5			125	99.1			85	99.8			105	99.3

Time = recorded in minutes and seconds. B.D. = Balls dropped.

S.R. = Sweat loss in grams. R.T. = Rectal temperature °F.

Climatic Day 9. Severe Test. (Double Run every hour)

Mean Dry Bulb 100.0°F. Mean Wet Bulb 90.0°F. Effective Temp. 91°F.
Air movement 100 ft/min. (Basic)

Subject	P				O				I				E			
	Time	B.D.	S.R.	R.T.	Time	D.B.	S.R.	R.T.	Time	B.D.	S.R.	R.T.	Time	B.D.	S.R.	R.T.
	m.s.				m.s.				m.s.				m.s.			
Entry			-	99.1			-	99.0			-	99.5			-	98.6
1	3.51	32			3.31	28			4.14	9			3.55	20		
2	3.25	4			3.27	25			4. 2	10			3.41	14		
3	3.40	6			3.23	25			3. 3	12			3.28	12		
4	3.26	3			3.19	16			3.47	10			3.28	5		
5	3.35	.13			2.51	8			3.43	9			3.30	5		
6	3.31	5			3. 7	14			3.59	11			3.49	10		
1st Hour			310	99.3			300	99.4			210	99.8			215	98.9
1	3. 8	7			3. 0	12			3.59	12			3.41	11		
2	3.24	13			3. 9	21			3.50	6			3.25	5		
3	3.20	.14			3.14	.17			3.52	9			3.35	9		
4	3.15	16			3.13	23			3.37	3			3.31	9		
5	3. 6	13			3. 2	18			3.40	5			3.32	10		
6	3.11	6			3.16	20			3.36	6			3.38	17		
2nd Hour			275	99.8			380	99.8			280	100.1			340	100.0
1	3. 8	1			3. 8	14			3.50	11			3.47	17		
2	3.20	13			3.18	16			3.48	9			3.12	5		
3	3. 8	12			3.32	27			3.45	11			3.22	10		
4	3. 3	10			3. 7	20			3.58	9			3.21	15		
5	3.16	20			3. 0	17			4. 3	11			3.41	17		
6	3.23	19			3.14	24			3.36	8			3.23	3		
3rd Hour			265	100.3			350	99.8			265	100.3			285	100.1

Time = recorded minutes and seconds. B.D. = Balls dropped.
S.R. = Sweat loss in grams. R.T. = Rectal temperature °F.

Consecutive Run Times of the Subject before, during and after a Prolonged stay in the heat.
(Weiner & Hutchinson, 1945)

Time in seconds. a = morning performance. p = afternoon performance.

	Cool (Before)		Hot		Cool (After)
a	950	p	803	p	661
p	823	a	764	a	645
a	815	p	756	p	610
a	869	a	725	a	638
p	794	p	(1210)+	p	624
a	764	a	736	a	596
p	740	p	714	p	631
a	732	a	728	a	618
p	750	p	698	p	651
a	714	a	721	a	637
p	726	p	682	p	655
a	678	a	705	a	614
p	692	p	613		
a	655	a	694		
p	723	p	662		
a	618	a	690		
p	656	p	655		
a	656	a	665		
p	679	p	627		
a	655	a	686		
		p	656		
		a	705		
		p	642		
		a	634		
		p	670		
		a	698		

+ = physically exhausted.

APPENDIX - Section B.

Results of Pursuitmeter Test

PRACTICE DAY 1

Handle Load = 8 lbs.

Subject	E		L		S		N	
Attempt	Error Score	Pointer Score	Error Score	Pointer Score	Error Score	Pointer Score	Error Score	Pointer Score
1	168	92	183	162	168	108	173	113
2	176	90	176	159	142	122	165	130
3	178	125	190	161	162	120	152	100
4	178	129	171	163	169	142	157	108
5	178	135	162	159	156	109	162	102
6	171	150	170	160	163	120	169	79
7	174	157	162	160	163	117	172	130
8	172	150	153	157	159	124	173	117
9	170	159	166	166	160	116	149	140
10	167	149	167	148	161	101	157	162
11	160	146	173	160	160	100	149	154
12	160	146	170	153	154	90	152	143
13	158	143	159	156	158	81	141	148
14	155	138	171	160	160	62	155	130
15	151	153	180	169	163	62	146	135
Failed Attempts	4		4		0		0	

PRACTICE DAY 2

Handle Load = 8 lbs.

Subject	E		L		S		N	
Attempt	Error Score	Pointer Score	Error Score	Pointer Score	Error Score	Pointer Score	Error Score	Pointer Score
1	144	142	145	167	152	85	135	152
2	141	151	132	170	159	70	123	169
3	143	149	137	162	165	51	121	182
4	133	154	132	170	155	75	127	152
5	147	143	125	165	152	65	121	162
6	154	127	141	173	150	79	120	170
7	138	147	142	168	148	125	129	180
8	139	155	135	172	155	107	129	160
9	142	151	130	163	158	90	129	159
10	149	144	130	169	164	96	123	158
11	146	145	151	171	159	55	122	159
12	144	146	143	172	167	100	132	148
13	142	154	150	170	172	179	126	168
14	161	157	132	172	167	126	114	124
15	160	155	159	172	166	111	136	176
Failed Attempts	0		0		0		0	

PRACTICE DAY 3

Handle Load = 16 lbs.

Subject	E		L		S		N	
Attempt	Error Score	Pointer Score	Error Score	Pointer Score	Error Score	Pointer Score	Error Score	Pointer Score
1	160	146	163	178	177	160	153	126
2	159	142	162	178	170	148	168	142
3	150	152	166	186	181	170	166	131
4	151	149	159	180	181	160	167	128
5	148	153	160	175	170	138	163	141
6	151	154	163	187	168	142	181	96
7	152	154	168	183	165	131	174	138
8	145	159	165	182	179	114	151	120
9	150	162	160	166	165	107	150	130
10	150	150	173	187	160	126	147	134
11	144	155	163	173	172	113	157	119
12	145	157	179	191	173	109	151	137
13	157	155	176	188	177	82	153	135
14	143	146	154	186	174	97	142	140
15	140	144	183	180	164	96	151	130
Failed Attempts	0		3		5		1	

PRACTICE DAY 4

Handle Load = 16 lbs.

Subject	E		L		S		N	
Attempt	Error Score	Pointer Score	Error Score	Pointer Score	Error Score	Pointer Score	Error Score	Pointer Score
1	155	162	166	186	161	142	149	150
2	151	164	156	187	167	167	146	149
3	147	163	161	194	170	170	146	160
4	153	161	166	190	172	146	145	145
5	144	162	162	179	157	110	146	156
6	153	165	182	201	158	132	151	149
7	137	168	175	196	160	120	137	170
8	138	167	181	188	167	94	151	170
9	144	164	195	188	165	125	160	164
10	150	162	172	182	164	91	140	162
11	147	163	189	183	172	117	160	147
12	141	160	179	195	174	133	152	162
13	144	161	185	185	164	123	150	158
14	150	154	195	197	169	106	145	140
15	134	158	206	196	164	94	132	161
Failed Attempts	0		8		0		0	

PRACTICE DAY 5

Handle Load = 16 lbs.

Subject	E		L		S		N	
Attempt	Error Score	Pointer Score	Error Score	Pointer Score	Error Score	Pointer Score	Error Score	Pointer Score
1	143	156	175	180	164	128	169	150
2	143	159	174	185	162	130	155	163
3	143	158	188	182	160	126	145	156
4	143	160	172	169	153	127	160	174
5	140	161	170	149	153	130	166	137
6	139	161	174	163	152	90	168	158
7	139	167	169	162	156	104	152	174
8	142	162	166	153	149	100	172	139
9	137	166	165	166	160	80	145	148
10	140	166	181	172	163	89	176	134
11	137	164	169	179	152	101	146	142
12	136	158	166	183	154	104	150	122
13	144	161	197	172	161	95	141	141
14	136	168	170	168	168	86	152	140
15	134	165	186	144	165	119	155	158
Failed Attempts	0		4		0		1	

Climatic Day 1. Mean Dry Bulb = 85.11°F. Mean Wet Bulb = 76.40°F.
Effective Temp. = 77.0°F. (Basic) Air movement 100 ft./min.

SUBJECT	E				L				S				N			
	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.
Entry			-	98.9			-	99.7			-	98.9			-	99.1
Attempt 1	139	163			168	193			161	138			153	157		
2	140	170			156	185			156	116			172	164		
3	133	165			148	175			157	102			149	159		
4	132	172			153	175			143	120			154	178		
5	136	172			150	164			152	85			153	149		
1st Hour			50	98.8			110	99.8			105	99.1			50	98.8
Attempt 6	128	168			151	170			152	84			153	131		
7	133	169			157	175			159	68			150	131		
8	128	174			158	180			153	75			148	152		
9	134	170			163	184			204	210			183	140		
10	124	160			163	190			177	154			144	180		
2nd Hour			45	98.6			95	99.8			80	98.9			80	98.7
Attempt 11	126	161			160	187			156	136			150	170		
12	130	146			167	189			167	154			151	168		
13	133	163			163	197			155	138			156	161		
14	122	155			152	182			160	152			150	175		
15	126	150			183	204			171	139			160	158		
3rd Hour			70	98.6			85	99.1			75	98.7			65	98.5
Failed Attempts	0				1				2				1			

E.S. = error score. P.S. = pointer score.
S.R. = sweat loss in grams. R.T. = rectal temperature °F.

Climatic Day 2. Mean Dry Bulb 85.29°F. Mean Wet Bulb 77.31°F. Effective Temp. 77.5°F.
Air movement 100 ft/min. (Basic)

Subject	E				L				S				N			
	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.
Entry			-	98.8			-	99.5			-	99.1			-	98.6
Attempt 1	142	164			165	181			196	213			171	150		
2	144	166			190	200			186	171			185	169		
3	137	168			186	190			164	138			175	188		
4	133	161			156	190			160	130			166	163		
5	135	167			161	195			160	122			172	176		
1st Hour			90	98.5			100	99.1			65	99.1			70	98.7
Attempt 6	121	154			140	192			143	136			152	160		
7	134	162			154	202			150	152			169	195		
8	126	163			158	196			154	139			155	179		
9	125	157			157	206			168	134			164	173		
10	125	154			159	201			157	142			173	193		
2nd Hour			75	98.3			85	98.8			90	99.2			45	98.6
Attempt 11	124	159			154	204			164	161			157	156		
12	117	157			158	189			161	162			158	174		
13	124	152			169	203			158	149			176	159		
14	124	150			162	199			169	149			166	168		
15	127	144			173	190			150	133			150	154		
3rd Hour			65	98.1			65	98.6			85	99.1			70	98.8
Failed Attempts	0				2				2				2			

E.S. = error score. P.S. = pointer score. S.R. = sweat loss in grams.
R.T. = rectal temperature °F.

Climatic Day 3. Mean Dry Bulb 95.07 °F. Mean Wet Bulb 85.01°F. Effective Temp. 86°F.
Air movement 100 ft/min. (Basic)

Subject	E				L				S				N			
	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.
Entry			-	99.3			-	99.2			-	99.5			-	98.8
Attempt 1	139	159			174	197			169	169			216	163		
2	133	162			169	193			163	157			190	198		
3	135	158			175	199			156	140			161	177		
4	125	160			168	201			161	131			158	188		
5	131	155			168	190			176	154			186	167		
1st Hour			160	99.1			220	99.4			150	99.3			160	99.4
Attempt 6	132	147			163	201			175	145			156	177		
7	127	150			168	203			158	130			158	194		
8	120	157			166	196			174	135			158	185		
9	128	150			165	196			163	127			152	185		
10	123	155			174	198			165	133			146	178		
2nd Hour			160	98.9			215	99.4			145	99.2			155	99.4
Attempt 11	126	158			178	206			172	119			157	175		
12	122	152			165	184			168	134			140	153		
13	125	153			158	187			157	141			158	173		
14	127	155			155	161			171	141			171	194		
15	130	148			179	206			164	137			154	175		
3rd Hour			150	98.8			205	99.2			160	99.1			165	99.4
Failed Attempts	0				2				1				3			

E.S. = error score. P.S. = pointer score.
S.R. = sweat loss in grams. R.T. = rectal temperature °F.

Climatic Day 4. Mean Dry Bulb 105.02°F. Mean Wet Bulb 94.96°F. Effective Temp. 96°F.
Air movement 100 ft/min. (Basic)

Subject	E				L				S				N			
	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.
Entry			-	98.2			-	99.3			-	98.7			-	98.7
Attempt 1	148	156			177	201			173	154			187	181		
2	137	154			187	191			188	180			170	187		
3	140	152			172	182			185	165			188	167		
4	141	152			174	198			182	162			190	160		
5	143	152			174	184			184	148			171	197		
1st Hour			425	99.0			975	100.0			340	99.3			615	99.9
Attempt 6	140	160			178	190			164	146			177	177		
7	144	157			175	182			171	132			176	151		
8	150	152			167	189			179	135			163	151		
9	155	159			176	187			170	146			180	145		
10	144	150			176	199			177	140			170	162		
2nd Hour			505	101.3			1095	100.9			425	100.4			755	101.0
Attempt 11	143	145			174	178			178	146			172	160		
12	141	149			178	187			192	159			170	158		
13	140	146			181	171			166	161			178	167		
14	145	155			188	187			196	156			181	165		
15	147	169			187	207			190	166			168	151		
3rd Hour			345	102.2			810	101.2			345	101.4			550	101.6
Failed Attempts	0				9				10				8			

E.S. = error score. P.S. = pointer score.
S.R. = sweat loss in grams. R.T. = rectal temperature °F.

Climatic Day 5. Mean Dry Bulb 90.13°F. Mean Wet Bulb 80.15°F. Effective Temp. 81°F. (Basic)
Air movement 100 ft/min.

Subject	E				L				S				N			
	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.
Entry			-	99.1			-	99.2			-	98.8			-	98.3
Attempt 1	137	150			170	200			176	180			151	189		
2	130	151			165	194			176	166			159	190		
3	129	150			164	185			151	168			149	182		
4	129	152			176	189			161	177			140	172		
5	125	159			157	177			159	162			141	184		
1st Hour			125	98.8			130	99.4			145	98.8			100	98.9
Attempt 6	124	148			158	180			162	157			140	181		
7	128	160			154	174			157	160			132	181		
8	124	149			162	184			166	176			134	184		
9	130	153			150	190			167	146			144	175		
10	122	148			163	195			165	149			132	194		
2nd Hour			105	98.5			165	99.4			125	98.7			125	98.5
Attempt 11	131	150			159	188			153	162			134	194		
12	123	146			159	191			177	192			135	190		
13	124	141			153	196			161	169			138	197		
14	123	150			161	198			164	171			133	190		
15	130	138			164	195			163	168			143	213		
3rd Hour			115	98.6			110	99.2			110	98.8			105	98.7
Failed Attempts	0				1				3				0			

E.S. = error score. P.S. = pointer score.
S.R. = sweat loss in grams. R.T. = rectal temperature °F.

Climatic Day 6. Mean Dry Bulb 100.06°F. Mean Wet Bulb 90.04°F. Effective Temp. 91°F. (Basic)
Air movement 100 ft/min.

Subject	E				L				S				N			
	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.
Entry			-	98.4			-	99.2			-	99.3			-	98.2
Attempt 1	142	153			179	181			205	200			178	203		
2	145	152			177	201			191	199			169	189		
3	148	155			171	182			172	185			183	175		
4	141	153			179	170			166	162			170	177		
5	143	154			174	185			181	169			169	178		
1st Hour			250	98.4			390	99.6			270	99.4			240	98.6
Attempt 6	142	151			176	195			162	154			169	177		
7	140	150			167	192			181	182			170	156		
8	140	150			180	209			191	212			150	180		
9	136	151			197	218			193	182			149	172		
10	137	150			167	204			195	209			156	189		
2nd Hour			210	98.7			360	99.7			215	99.6			255	99.0
Attempt 11	132	149			182	202			169	178			156	170		
12	139	149			185	212			177	184			154	161		
13	132	151			164	190			177	175			155	186		
14	129	154			162	202			189	201			159	153		
15	136	162			165	199			172	190			136	166		
3rd Hour			180	98.8			290	99.8			200	99.8			235	99.2
Failed Attempts	0				8				10				2			

E.S. = error score. P.S. = pointer score.
S.R. = sweat loss in grams. R.T. = rectal temperature °F.

Climatic Day 7. Mean Dry Bulb 86.10°F. Mean Wet Bulb 78.03°F. Effective Temp. 78.5°F. Air movement 100 ft./min. (Basic)

SUBJECT	E				L				S				N			
	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.	E.S.	P.S.	S.R.	R.T.
Entry			-	99.0			-	99.4			-	99.1			-	98.6
Attempt 1	123	158			165	193			183	190			145	193		
2	125	165			147	203			168	200			139	184		
3	122	169			165	203			189	194			120	185		
4	120	164			160	203			188	193			129	169		
5	112	167			163	202			182	195			118	191		
1st Hour			90	98.8			75	99.1			80	99.1			50	99.0
Attempt 6	118	159			153	213			175	195			126	176		
7	125	157			175	216			161	189			128	188		
8	117	157			175	209			170	183			130	170		
9	119	162			175	235			168	192			125	186		
10	116	157			151	213			164	191			113	179		
2nd Hour			70	98.7			65	99.1			100	98.9			70	99.2
Attempt 11	120	152			160	217			157	174			129	184		
12	115	151			163	210			162	189			126	178		
13	118	160			176	223			156	184			113	174		
14	121	154			168	202			168	189			122	184		
15	127	151			154	202			148	174			113	176		
3rd Hour			70	98.5			95	98.9			95	99.2			75	99.3
Failed Attempts	0				1				4				0			

E.S. = error score. P.S. = pointer score.
S.R. = sweat loss in grams. R.T. = rectal temperature °F.

APPENDIX - Section C.

Results of Morse Code Reception Test.

Week 1. Mean Dry Bulb 90.01°F. Effective Temp. 81°F. (Basic)

Mean Wet Bulb 80.06°F. Air movement 100 ft./min.

Subject	Ep.			Ok.			Er.			Osi.		
	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.
Entry		-	99.6		-	99.0		-	99.2		-	99.1
Message	1			7			8			10		
"	0			2			2			15		
"	3			0			2			5		
1st Hour		75	99.6		125	99.5		85	99.2		140	99.4
Message	2			6			8			4		
"	0			2			7			7		
"	1			9			2			6		
2nd Hour		165	99.4		155	99.4		100	99.1		160	99.2
Message	2			1			6			5		
"	4			11			2			11		
"	6			10			1			20		
3rd Hour		110	99.4		155	99.4		100	99.4		155	99.1
Messages Incorrect	1			5			4			8		

S.R. = sweat loss (grams). R.T. = rectal temp. °F.

Week 1. Mean Dry Bulb 90.05°F. Mean Wet Bulb 80.18°F.
Effective temp. 81°F. Air movement 100 ft./min.
(Basic)

Subject	Osg.			Okek.			Cai.			Eg.		
	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.
Entry		-	99.5		-	99.3		-	99.1		-	99.2
Message	1			4			8			2		
"	0			3			5			0		
"	0			4			0			0		
1st Hour		85	99.2		150	99.5		115	99.6		175	99.1
Message	1			3			9			0		
"	1			1			4			2		
"	3			4			7			2		
2nd Hour		95	99.1		140	99.5		134	99.3		160	98.8
Message	3			5			5			0		
"	4			0			14			0		
"	0			1			9			8		
3rd Hour		105	99.0		150	99.6		105	99.0		130	98.9
Messages Incorrect	0			1			7			1		

S.R. = sweat loss (grams). R.T. = rectal temp. °F.

Week 2. Mean Dry Bulb 105.02°F. Effective Temp. 96°F. (Basic) Mean Wet Bulb 94.98°F. Air movement 100 ft./min.

Subject	Ep.			Ok.			Er.			Osi.		
	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.
Entry		-	98.8		-	99.0		-	99.7		-	99.6
Message	5			4			4			5		
"	5			2			5			5		
"	15			10			5			12		
1st Hour		565	100.0		475	100.5		510	100.7		760	100.6
Message	1			19			5			18		
"	2			6			2			10		
"	4			7			25			9		
2nd Hour		525	101.5		675	101.4		660	101.6		870	101.3
Message	11			13			4			13		
"	21			9			13			6		
"	14			7			5			5		
3rd Hour		385	102.4		535	101.8		570	102.0		745	101.7
Messages Incorrect	6			7			6			9		

S.R. = sweat loss (grams). R.T. = rectal temp. °F.

Week 2. Mean Dry Bulb 105.06°F. Effective Temp. 96°F. (Basic) Mean Wet Bulb 95.02°F. Air movement 100 ft./min.

Subject	Osg.			Okek.			Cai.			Eg.		
	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.
Entry		-	98.4		-	99.2		-	99.0		-	99.6
Message	4			4			4			6		
"	1			5			7			4		
"	5			4			1			2		
1st Hour		490	99.5		625	100.2		585	100.6		585	100.7
Message	2			8			7			3		
"	0			1			1			4		
"	1			5			3			2		
2nd Hour		640	100.6		835	101.3		760	101.6		655	101.6
Message	1			4			11			7		
"	1			0			2			2		
"	3			2			3			3		
3rd Hour		485	101.4		640	102.0		605	102.1		510	102.0
Messages Incorrect	1			3			3			2		

S.R. = sweat loss (grams). R.T. = rectal temp. °F.

Week 2. Mean Dry Bulb 105.03°F. Mean Wet Bulb 95.06°F.
Effective Temp. 96°F. Air movement 100 ft./min.
(Basic)

Subject	Nw.			Ob.			Mb.			Iw.		
	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.
Entry		-	99.2		-	99.2		-	99.8		-	99.3
Message	4			21			11			2		
"	0			39			34			1		
"	1			41			16			0		
1st Hour		600	100.4		425	100.7		400	100.8		950	100.5
Message	2			42			18			1		
"	1			20			8			3		
"	1			37			20			2		
2nd Hour		725	101.4		310	102.1		435	101.6		750	101.3
Message	0			39			20			2		
"	0			45			13			4		
"	0			13			3			3		
3rd Hour		530	101.9		225	103.3		385	102.0		590	102.1
Messages Incorrect	0			9			8			0		

S.R. = sweat loss (grams). R.T. = rectal temp. °F.

Week 3. Mean Dry Bulb 84.6°F. Mean Wet Bulb 75.45°F.
Effective Temp. 76°F. Air movement 100 ft./min.
(Basic)

Subject	Ep.			Ok.			Er.			Osi.		
	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.
Entry		-	98.8		-	98.8		-	99.0		-	98.8
Message	2			2			1			17		
"	2			3			5			4		
"	0			3			0			0		
1st Hour		75	98.6		50	98.6		35	98.8		95	99.3
Message	3			7			2			2		
"	0			19			1			2		
"	3			31			3			8		
2nd Hour		65	98.4		50	98.8		45	98.8		95	99.5
Message	2			14			6			6		
"	6			5			8			0		
"	1			22			1			14		
3rd Hour		60	98.4		60	98.8		45	98.8		105	99.5
Messages Incorrect	1			6			3			4		

S.R. = sweat loss (grams). R.T. = rectal temp. °F.

Week 3. Mean Dry Bulb 85.07°F. Effective Temp. 76°F. (Basic) Mean Wet Bulb 75.02°F. Air movement 100 ft./min.

Subject	Osg.			Okek.			Cai.			Eg.		
	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.
Entry		-	98.9		-	99.3		-	99.0		-	99.3
Message	0			3			0			5		
"	2			1			0			1		
"	0			2			1			0		
1st Hour		35	98.7		65	99.6		80	99.1		80	99.3
Message	3			1			2			0		
"	0			0			3			0		
"	1			1			9			1		
2nd Hour		45	98.7		100	99.6		109	99.0		105	99.0
Message	2			2			11			0		
"	4			2			4			1		
"	1			1			12			0		
3rd Hour		40	98.8		85	99.2		69	98.5		95	98.7
Messages Incorrect	0			0			3			1		

S.R. = sweat loss (grams). R.T. = rectal temp. °F.

Week 3. Mean Dry Bulb 84.96°F. Mean Wet Bulb 75.18°F.
Effective Temp. 76°F. Air movement 100 ft./min.
(Basic)

Subject	Nw.			Ob.			Mb.			Iw.		
	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.
Entry		-	99.1		-	99.2		-	99.4		-	98.8
Message	0			34			12			0		
"	0			28			9			2		
"	0			7			16			0		
1st Hour		70	98.9		85	99.5		40	99.2		100	98.8
Message	2			11			4			0		
"	0			37			27			1		
"	0			48			26			0		
2nd Hour		80	99.0		80	99.4		50	99.2		110	98.7
Message	1			52			37			0		
"	1			5			3			1		
"	0			29			29			2		
3rd Hour		95	98.8		95	99.2		70	99.1		90	98.6
Messages Incorrect	0			9			7			0		

S.R. = sweat loss (grams). R.T. = rectal temp. oF.

Week 4. Mean Dry Bulb 95.16°F. Mean Wet Bulb 85.04°F.
Effective Temp. 86°F. Air movement 100 ft./min.
(Basic)

Subject	Ep.			Ok.			Er.			Osg.		
	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T
Entry		-	98.8		-	98.8		-	99.6		-	99.0
Message	0			3			0			0		
"	0			1			2			3		
"	4			1			7			1		
1st Hour		215	98.8		150	99.1		105	99.6		130	99.0
Message	2			15			4			4		
"	7			8			1			0		
"	0			12			0			0		
2nd Hour		225	98.8		185	99.2		130	99.8		155	99.0
Message	5			7			3			2		
"	0			19			1			3		
"	10			19			5			3		
3rd Hour		198	98.8		175	99.3		140	99.9		145	99.0
Messages Incorrect	3			6			2			0		

S.R. = sweat loss (grams). R.T. = rectal temp. °F.

Week 4. Mean Dry Bulb 95.06°F. Effective Temp. 86°F. (Basic)

Mean Wet Bulb 84.95°F. Air movement 100 ft./min.

Subject	Osi.			Okek.			Cai.			Eg.		
	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.
Entry		-	98.9		-	99.3		-	98.6		-	100.1
Message	21			3			7			0		
"	3			3			0			0		
"	7			4			3			0		
1st Hour		170	99.6		185	99.5		165	98.9		200	100.0
Message	4			2			22			7		
"	2			1			0			0		
"	10			0			1			0		
2nd Hour		215	99.8		215	99.8		180	98.9		200	99.5
Message	7			1			5			1		
"	8			0			13			0		
"	5			0			3			3		
3rd Hour		190	99.7		225	99.6		175	98.8		185	99.4
Messages Incorrect	6			0			4			1		

S.R. = sweat loss (grams). R.T. = rectal temp. oF.

Week 4. Mean Dry Bulb 95.02°F. Mean Wet Bulb 84.98°F.
Effective Temp. 86°F. Air movement 100 ft./min.
(Basic)

Subject	Nw.			Ob.			Mb.			Iw.		
	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.
Entry		-	99.0		-	99.2		-	99.8		-	99.0
Message	0			72			8			0		
"	1			9			0			0		
"	0			49			4			0		
1st Hour		125	99.1		175	99.6		120	99.8		255	99.1
Message	1			33			6			1		
"	1			35			5			1		
"	0			7			17			2		
2nd Hour		175	99.2		230	99.6		150	99.8		220	98.9
Message	3			11			13			2		
"	0			28			22			0		
"	0			34			24			0		
3rd Hour		145	99.0		205	99.4		155	99.6		200	98.8
Messages Incorrect	0			9			7			0		

S.R. = sweat loss (grams). R.T. = rectal temp. oF.

Week 5. Mean Dry Bulb 100.09°F. Mean Wet Bulb 90.02°F.
Effective temp. 91°F. Air movement 100 ft./min.
(Basic)

Subject	Ep.			Ok.			Er.			Osi.		
	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.
Entry		-	99.4		-	99.1		-	99.2		-	99.2
Message	2			5			0			18		
"	1			0			1			4		
"	1			3			7			10		
1st Hour		305	99.7		275	99.4		240	99.3		315	99.6
Message	0			2			2			3		
"	1			4			2			15		
"	3			14			1			7		
2nd Hour		320	99.6		300	99.8		265	99.7		320	99.6
Message	10			11			1			8		
"	7			19			7			4		
"	4			9			1			5		
3rd Hour		325	99.7		290	100.0		275	99.9		310	99.5
Messages Incorrect	2			5			2			6		

S.R. = sweat loss (grams). R.T. = rectal temp. oF.

<u>Week 5.</u> Mean Dry Bulb 100.01°F. Mean Wet Bulb 89.99°F.
Effective temp. 91°F. Air movement 100 ft./min.
(Basic)

Subject	Osg.			Okek.			Mb.			Eg.		
	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.
Entry		-	99.4		-	99.4		-	99.4		-	99.8
Message	0			0			16			2		
"	0			1			3			0		
"	0			1			10			0		
1st Hour		225	99.7		310	99.8		195	99.9		290	100.0
Message	3			1			4			1		
"	4			0			9			0		
"	10			5			12			1		
2nd Hour		280	99.8		315	99.9		265	100.2		330	100.0
Message	0			2			12			2		
"	2			9			6			1		
"	4			1			10			2		
3rd Hour		250	100.2		300	100.1		260	100.3		315	99.9
Messages Incorrect	1			2			7			0		

S.R. = sweat loss (grams). R.T. = rectal temp.°F.

Week 5. Mean Dry Bulb 100.08°F. Mean Wet Bulb 90.03°F.
Effective temp. 91°F. Air movement 100 ft./min.
(Basic)

Subject	Nw.			Ob.			Cai.			Iw.		
	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.	Errors	S.R.	R.T.
Entry		-	99.4		-	99.0		-	99.2		-	99.5
Message	1			61			2			0		
"	1			11			2			0		
"	5			50			19			1		
1st Hour		255	99.5		265	99.5		315	99.5		325	99.8
Message	2			16			24			1		
"	0			18			25			0		
"	0			51			15			1		
2nd Hour		245	99.8		270	99.8		315	99.6		300	100.0
Message	1			32			5			2		
"	1			32			5			1		
"	1			13			19			1		
3rd Hour		205	99.6		245	100.0		335	99.3		270	99.9
Messages Incorrect	1			9			7			0		

S.R. = sweat loss (grams). R.T. = rectal temp.°F.