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PSYCHO-MOTOR EFFICIENCY (AS MEASURED BY TIME FOR ACCURATE GUN-LAYING) UNDER HOT CONDITIONS

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NOTE

This paper was prepared by Dr. Douglas H. K. Lee, now Professor of Physiological Climatology at the Johns Hopkins University, while he was associated with the University of Queensland in Australia. Because of the importance of the paper to Engineering Research Institute Project No. 2167, the Engineering Research Institute of the University of Michigan undertook reproduction for limited distribution. This was done with the permission of Dr. Lee.

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FOR ACCURATE GUN-LAYING) UNDER HOT CONDITIONS

Everyone who has attempted to investigate fatigue has met the problem of measuring mental as opposed to physical deterioration. The range of tests devised for this purpose is very large - in itself a testimony to the unsatisfactory results obtained. The two main drawbacks to these tests are lack of motivation and difficulty of interpretation.

The time of onset and degree of mental fatigue developed are matters of importance in most military operations. To deal with military aspects and at the same time to minimize the drawbacks mentioned above, we endeavored to design a test which would appeal to the majority of service personnal as being something "practical", and permit of fairly direct application to military problems. The only material available when the investigation was started was that to be found in a routine teaching laboratory. Radio valves, galvanometers and electric meters were unobtainable. More specialized equipment is gradually becoming available, but at the time improvisation was the only way through. Fortunately, we possessed a fairly well equipped workshop.

The test adopted consisted essentially of measuring the speed with which a gunner laid and fired at a target suddenly appearing at an unknown spot on a landscape.

1. APPARATUS

A description has already been given (AFV 30 and 30a) of the basic apparatus under the title of "Efficiency Tester - Gun-laying Type No. 1". This essentially recorded the time taken to lay accurately upon the target, i.e., it answered the question "What time is required for accurate shooting?" Since then, the apparatus has been improved and additions made which permit an examination of the approach to the target as well, so that the complementary question can be answered, "What degree of accuracy is possible in a given time?"

For convenience, a complete description will be given here of the latest apparatus. In the section describing results, an indication will be given when the original apparatus was used.

1.1. Gun-sight Unit (Fig. 1, Diag. 1)

A "gun-sight", consisting of a stepped tube, pinhole ocular and plain glass objective with cross-wires attached, is mounted on traverse and elevation gears (from standard Mecanno parts 25a, 27b and 29) actuated by handles. A reversible eyeshield is mounted near the ocular.

Geared to the traverse mechanism is a rotor arm carrying two contacts, the inner one of which (TA) rides over a horizontal ebonite plate bearing six small contacts, and the outer one (TB) over a closely wound resistance coil (28 swg nichrome wire) mounted on the circumference of the ebonite plate and at right angles to its plane. The inner contact has a needle point, the outer a ball point, both spring loaded. The arm is mounted on the spindle by means of an insulating fibre block and retained in position by a clamping screw. The outer contact is insulated from the inner by a bakelite section.

A similar arrangement is geared to the elevation mechanism.

There are thirty-six positions in which the inner rotor arm points TA and EA will each be in contact with one of the plate contacts, and thus be able to complete a signal circuit ("pinpoint" circuit). In between these positions, the outer rotor arm points TB and EB mark off distances from these positions along the resistance coils, and thus allow their position to be recorded by the varying potentials led off ("approach" circuit).

The whole of this mechanism is mounted on a standard with a heavy base. A trigger is mounted on the standard, and incorporated in the "pinpoint" circuit. A total pressure of 2-1/2 lbs is required to establish contact. A levelling bubble is mounted on the traversing support at right angles to the axis of sight. The base is screwed to the floor in such a way that the bubble remains centered in all traverse firing positions.

Contacts are also mounted on the two main gear wheels and the two ebonite plates in such a way that a separate circuit is completed with the gun-sight is in a central (neutral) position.

1.2. Target Unit (Fig. 3)

When the gun-sight unit is built, the target unit can be made. A plywood board 6 feet square and suitably braced is set up vertically at 12 feet from the gun-sight unit and at right angles to its center line of sight. The positions of 36 targets are mapped out by "spotting".

To do this the gun-sight is first pointed at a spot approximately 9 inches away from the center of the board towards one corner. The rotor arms are then adjusted until the needle contact points are just in the centers of the small plate contacts appropriate to this position, and the clamping screws tightened. A lighted bulb is now moved about on the target board by an assistant until it is seen in the center of the sight. The position of the bulb is marked. The sight is now moved by the elevation and traverse handles until the needle contact points are centered in another pair of plate contacts, and the position on the board again determined and marked. This procedure is continued until all 36 positions have been determined. (It is essential, of course, that the initial settings of the rotor arms on the spindles remain undisturbed throughout.)

Holes of 1-inch diameter and centered on the marks are now cut in the board and a 3.5 volt torch bulb mounted centrally behind each. The board is now thoroughly painted to minimize water exchange with the atmosphere. A landscape is painted on the board itself, or on sisalkraft tacked on. 36 sisalkraft discs of 2-1/2-inch diameter, each with a central aperture of 1/2-inch diameter, are made, and the apertures covered with thin white paper. Each disc is painted to harmonize with the landscape round the hole pinned over it, so that its aperture is centered on the cross-wires when the rotor arm points are centered on the plate points, as judged by a further process of "spotting".

Fixed even illumination of medium intensity, such as that provided by two 60 watt lamps with bright tin reflectors 5 feet from the target, is required for comparative work. One-sided daylight is excluded.

1.3. Recording Unit (Fig. 2)

In the original apparatus, ink-writing magnetic signals were used. In the later type, continuous records are required of potential variations. As neither ink-writing galvanometers nor optical recording apparatus were available, we fell back upon the classical smoked paper method of recording. Magnetic signals are used to record the switching on of the target light and the successful firing of the "pin-point" circuit. The potential variations produced by the movement of the rotor arm over the resistance coils of the "approach" circuit actuate two D'arsonval type galvanometers. The recording arm of each is fitted with a Sherrington writing-point made of aluminum wire. Care has to be taken in all three planes to get the magnetic signals and the galvanometer writing points properly aligned. Strips of smoked paper 100 cm x 40 cm are used. The drum is driven by an external a.c. induction motor. This has been found to reduce error to less than 5% in a single measurement and less than 1% in the mean of 20 measurements. The paper is kept taut under the writing points by an adjustable roller. To facilitate alignment and the removal of records without marking, the counter-pulley is mounted to swing horizontally.

1.4. Control Units

The first (Control Unit I) is a panel of 36 double-circuit switches, arranged in ranks and files on the square, each corresponding to one target and controlling simultaneously the switching on of the target light and the pre-selection of the two plate contacts corresponding to that target. Also mounted on this panel is a light to indicate when the gun-sight has been returned to the neutral position.

The second (Control Unit II) consists of a pair of rotary switches for separately pre-selecting the appropriate sections of the elevation and traverse resistance coils.

1.5. Circuit (Diags. 2 and 3)

There are five basic circuits, which may be described separately.

(a) Target Circuit. One half of each double-circuit switch on Control Unit I links one pole of a 4-volt cell to the filament of a target light. The target light filaments are connected in common through a magnetic signal to the other pole of the cell.

(b) Pin-point Circuit. One pole of the same 4-volt cell is connected to the traverse rotor arm. Each traverse plate contact is connected to one side of the second half of each double-circuit switch on Control Unit I which lies in the appropriate vertical file. The other side of each switch is connected, with its fellows of the same horizontal rank, to the corresponding elevation plate contact. The elevation rotor arm is connected to the other pole of the cell through successively, the firing key, a bell, and a magnetic signal. The circuit can be completed only when the inner rotor arm contacts are in apposition with the plate contacts corresponding to the target light switched on.

(c) and (d) Approach Circuits. The elevation and traverse circuits are similar and operate from separate two-volt cells. In each case one pole of the cell is connected to the arm of the rotary switch in Control Unit II. Each stud of the rotary switch is connected to the resistance coil opposite one of the plate contacts, i.e., in a position corresponding to a target. The other pole of the cell is connected through a balancing resistance to tappings made mid-way between the previous tappings and to the ends of the coil. This pole of the cell is also connected to one of the galvanometers, which is connected in turn to the outer contact of the rotor arm. The galvanometer records the potential drop between the cell tapping and the rotor arm over that section of the coil pre-selected by the rotary switch. This is a maximum with the rotor arm in the target position, a minimum when it is opposite the cell tapping.

(e) Neutral Signal Circuit. This is a simple circuit illuminating a light on Control Unit I when the gun-sight is in a central (neutral) position.

1.6. Operation

When the gunner is in position, the controller sets the rotary switches of Control Unit II to the numbers indicated the selected target. He then lets in the clutch of the recording drum. When the smoked paper is running steadily, he throws the switch on Control Unit I, corresponding to the selected target. This lights the target lamp and the corresponding magnetic signal makes a mark on the smoked paper. The gunner, on seeing the target light go up, endeavours to lay his gun-sight accurately on the target, as quickly as possible. When he comes within radius of the target, his elevation and traverse movements are recorded by the galvanometers. When he thinks he is accurately "on target" he pulls the trigger. If successful, this will actuate the second magnetic signal and ring the bell. If unsuccessful, he re-adjusts his sight. When successful, the gunner returns his gun-sight to the central position and the controller reverses the switch on Control Unit I. The drum is then stopped.

Before commencing the day's tests and in response to any complaint by the gunner, the controller checks the accuracy of the apparatus and makes any necessary adjustments in the position of the rotor arms. A five second trace is made with the target signal before and after each sequence of targets to measure the paper speed.

The record is varnished and dried. The distance between signal marks is measured with a glass rule. The galvanometer records are examined by superimposing a transparent grid of arcs set at 2 mm intervals.

As subsequent figures will show, the basic reaction time with the improved apparatus appears to be somewhat less than with the original, but the individual variability seems to be greater.

The above explanation may make the apparatus sound complicated, but it is basically simple and should be easily set up if a workshop and suitable material are available. If better gears than Mecanno parts are available they should certainly be used. If available, an integrating device may be used in place of the magnetic signals when individual target records are not required. Ink-writing galvanometers are desirable.

2. PLAN OF EXPERIMENT

A number of targets (usually 20-25) are selected from the 36 to form a group (indicated by a letter). These are arranged in random order to form a sequence (indicated by a number). The total time taken to sight successfully on all the targets of a given sequence, divided by the number of targets, is the sequence time. This is the basic datum used throughout this report. 4-6 sequences are usually used in succession to give an hour's continuous sighting.

Information derived from an examination of the "approach" records will be dealt with in a later report.

The usual procedure is for the subject to enter the air-conditioning room after breakfast and remain there for seven hours. The second, fourth and seventh hours are spent in sighting; a standard lunch is taken in the fifth hour; during the first, third and sixth hours the subject sits or performs physical exercise as required. This exercise consists of manipulating "tank controls" against heavy weights or of lifting a heavy weight at a set rate. Free water drinking is allowed throughout. Battle dress KD is worn throughout.

The subjects are all well-trained men from the armoured units, most of them with battle experience in the humid tropics. For two or three days before investigations are commenced, they practice on the apparatus. As will be seen later, the learning process is exponential, but this preliminary practice does bring the performance well down the steep part of the curve.

Three series of experiments were performed. In Series T/9 the sighting was done from within a "tank" built up in the air-conditioning room from flat panels, which could be electrically heated to simulate a tank standing in the sun and with a hot forward gear-box. The original apparatus was used in this series. In series M/1 and M/2, the sighting was done in the open room, and the improved apparatus was used.

In general, subjects are used 4-6 days a week until the series is completed. This maintains acclimatisation and learning, while not actively promoting boredom. It does, however, prevent replacement of a subject who gets sick. All experiments were designed to use four subjects. In certain cases, minor ailments interfered. Where the number fall below three, results have been largely neglected.

The following extract from the analysis sheets of Series M/1 will indicate the way in which the basic data of sequence times are treated. All times are expressed in 1/100 secs.

Exp. M/1a.   Standard E.T. 88°F

Sequence	B1	B2	B3	B4	B1	B2	B3	B4	B1	B2	B3	B4
Subject G_{13}	421	340	396	376	627	475	360	441	448	486	466	456
Subject G_{14}	487	497	523	470	429	440	587	470	505	421	425	430
Subject G_{15}	546	634	570	472	622	690	606	477	618	529	591	492
Subject G_{16}	398	408	386	360	504	408	423	376	420	435	392	423
Within-hour Sequence Means	463	470	469	420	546	503	494	441	498	468	469	450
Within-hour Operation Means	455 ± 13.8				496 ± 24.9				471 ± 11.5			
Day Operation Mean	474 ± 9.9											

In the absence of full analyses of variance, which it has been impractical to make, the standard deviation of the mean of the appropriate sequence means has been used as the measure of variation in each case. This minimizes the effect of between-subject variation whilst retaining the effect of between-sequence variation and inter-action (see Section 3k).

Table I gives a schedule of experiments carried out in Series T/9. Although some controls against learning on the one hand and boredom on the other were provided, the length of time involved was not fully appreciated, so that several experiments (not shown in Table I) were invalidated, and had to be discarded.

In drawing up the schedule for Series M/1 (Table II) care was taken, not only to provide controls, but also to arrange the experiments with different subjects so that time factors were offset.

The arrangement of Series M/3 is similar to that of M/2 and has been given in detail in a previous report (Fatigue Laboratory Secret Report No. 2).

3. EFFECT OF REPETITION

In Table III will be seen the effect of repetition upon the reaction time. The following conclusions may be drawn:

(a) Within any one day there is frequently an improvement, especially between the second and fourth hour of the test.

(b) With repeated test days there is at first an improvement, which assumes the expected exponential form, being rapid at first and gradually falling off thereafter to a minimum.

(c) After a certain number of days, depending upon the subjects and conditions used, the reaction time commences to rise again. The process known variously as boredom or mental fatigue makes itself evident.

(d) There is a suggestion that the last effect is more prominent under hot than under temperate conditions.

(e) The variability of response tends to follow the same curve as the mean reaction times.

(These results are largely true, also, of the individual subjects as well as of the averages.)

Further interesting information is to be derived from analysis of variance carried out on the results of Experiments M/1r, M/1d, M/1f and M/1frr with the following results.

Exp.	Period	Subjects		Sequences		Discrepancy
		Mean Square	Ratio	Mean Square	Ratio	Mean Square
M/1r (Day 3)*	2nd hr	4075	0.65	6034	0.97	6226
	4th hr	18460	8.21	10841	4.82	2248
	7th hr	14658	8.24	3695	2.06	1772
M/1d (Day 6)	2nd hr	30589	19.6	570	0.36	1561
	4th hr	40291	9.74	2267	0.55	4145
	7th hr	50480	25.3	385	0.19	1992
M/1f (Day 10.5)	2nd hr	49721	54.0	1920	2.09	920
	4th hr	49730	34.6	2328	1.62	1439
	7th hr	52124	64.3	242	0.29	811
M/1frr (Day 18.25)	2nd hr	8781	4.80	1630	0.89	1829
	4th hr	10051	10.00	1677	1.59	1054
	7th hr	9124	5.50	1838	1.31	1404

Double underline indicates less than 1% probability.
Single underline less than 5%.

*Note that the first two days were practice only. The third day was the first full experimental day.

The following observations may be made:

(f) The entirely random variation (discrepancy) decreases rapidly during the course of the experiment on the third day, reaches a minimum by the tenth day, but rises again somewhat by the 18th day. (cf. (b) and (c) above).

(g) In the 2nd hour on the third day the between-sequency variation is moderately large, but is swamped by the random variation. In the fourth hour it is large, but the drop in random variation makes it probably significant. Thereafter the between-sequence variation remains low and is not significantly different from the discrepancy.

(h) In the 2nd hour in the third day the between-subject variation is small, and no greater than the random error. During the rest of the day, however, it is significant. By the tenth day, the between-subject variation is very large. By the 18th day, however, it is considerably reduced and not so highly significant. Inspection of the protocols shows that this is probably due to three of the subjects following a U-shaped, with the fourth following a very protracted learning curve. This large subject variation is the reason for using the SD of the mean of the sequence means as the estimate of variation in operation means, rather than the mean of the individual sequence times.

4. EFFECT OF HEAT ALONE

The results of those experiments which permit a comparative survey to be made of the effect of heat alone are given in Table IV. From these the following conclusions can be drawn:

(a) Reaction times at effective temperatures of 83.5 and 94°F are significantly longer than those at 65-70°F. The increase is 5-12%.

(b) Within the range of effective temperature 88-96°F when the subject is seated at rest throughout the test, the reaction time does not undergo any further increase with rise of temperature, even when physical failure is imminent.

(c) Within a similar range of effective temperatures when the subject is doing moderate physical work between tests, the reaction time does undergo a further increase under conditions which bring about physical failure, the additional increase being of the order of 10%.

(d) At an effective temperature of 84°F, a hot dry atmosphere results in a reaction time about 11% greater than a hot wet atmosphere, at least in subjects acclimatised to hot wet conditions only.

5. EFFECT OF EXERCISE IN HEAT

Table V gives the results of tests on 3 subjects with and without exercise in between the periods of gun-sight testing. "Driving" consists of simulta neously depressing the clutch pedal and pulling on the brake handle, right and left sides alternately every 7-1/2 secs. Each clutch and brake works against a weight of 40 lbs. "Lifting" involves raising 36-1/2 lbs up through 42 in. and then down

It will be seen that exercise, even to the point of physical exhaustion, has little effect upon the reaction time of trained and acclimatised subjects during the ensuing hour. (See however 4(c)).

6. EFFECT OF NOISE IN HEAT

In Table VI appear the results of experiments with noise on 3 subjects. This noise was produced in standard tank ear-phones worn by the subject, by means of an electronic noise generator and inter-communication set designed by N. E. Murray at the Acoustics Laboratory (National Health and Medical Research Council), University of Sydney (see AFV 49). Two levels of intensity were used - 100 and 120 db. In two experiments the noise was kept on continuously, but the experiment was terminated after 4 hours for safety. In the other two experiments, the subjects alternately removed and replaced the ear-phones every 5-10 minutes. No differentiation has yet been made in the last two experiments between the reaction times when the ear-phones were on and off.

The following conclusions can be drawn from Table VI:

(a) The reaction times with noise are seldom significantly greater than those of the control experiment immediately preceding the test days.

(b) The reaction times with noise are invariably much greater than those of the control experiment immediately following the test days.

(c) Reference to Table III indicates that this discrepancy is not likely to be due mainly to learning or acclimatisation. It is more probably attributable to the relief experienced upon cessation of noisy conditions. The subjects are, as it were, forced to train to a higher degree by the bad conditions created by noise and find themselves better reactors when the noise is removed.

(d) The differences in intensity and intermittency are without apparent effect.

Where a fourth subject was used, the results are confirmatory. One subject appears to be more susceptible than the others, and to be more disturbed by intermittent than continuous noise.

7. EFFECT OF LACK OF SLEEP IN HEAT

Table VII sets out the effects of lack of sleep upon the reaction times of 3 subjects. The following conclusions can be drawn:

(a) One night without sleep increases the reaction time in heat in a significant fashion. The proportional increase is of the order of 12%.

(b) One night with very short sleep following one without any does not materially alter the position.

(c) A succession of further nights with very short sleep brings about an exponentially progressive failure.

(d) As the reaction times increase with accumulated lack of sleep, the variability of the response also increases.

Where a fourth subject was used, the results are confirmatory of (a) and (b) above.

8. EFFECT OF MEALS IN HEAT

In Table VIII are set out the results obtained when meals are varied. Four subjects were used in each series. The following suggestions emerge:

(a) The taking of a heavy lunch tends to increase reaction time.

(b) The omission of breakfast is followed by an increased reaction time in the early part of the morning, but this effect is reduced or absent in the later part.

(c) The omission of lunch as well as breakfast has no further bad effect upon the reaction time.

(d) The taking of a normal lunch after the omission of breakfast does not improve the reaction time.

9. EFFECT OF RESPIRATORS

This has been dealt with in detail in a previous report. (Fatigue Laboratory Secret Report No. 2). The essential results are repeated here in Table IX. The following conclusions can be drawn:

(a) The wearing of respirators markedly increases the reaction time by 19-39%.

(b) This effect is greatest under hot conditions.

(c) The variability of response is increased by respirators under hot conditions.

(d) Mark VI anti-dim reduces the interference in temperate atmospheres by an amount which is probably significant.

(e) The light type of mask reduces the interference in the hot atmospheres by an amount which is possibly significant.

(f) The wearing of respirators makes any increase of reaction time brought about by heat much more pronounced.

10. COMPARISON OF PHYSICAL WITH PSYCHO-MOTOR REACTIONS

Table X sets out the relevant figures for two sets of experiments, from which the following conclusions may be drawn:

(a) As the effective temperature increases from 88 to 96°F the physical reactions, as indicated by the pulse rate and rectal temperature, rise markedly, while the psycho-motor reactions remain relatively constant.

(b) With progressive lack of sleep the physical reactions show a transitory rise on the second day, but return to the original levels in succeeding days, while the psycho-motor reactions show progressive deterioration.

(c) Psycho-motor deterioration and physical failure are separate phenomena which can be differentiated from each other to a surprising degree under the conditions studied.

In those experiments dealing with exercise also, there was no significant deterioration in psycho-motor reactions, when physical failure was imminent.

11. CONCLUSIONS AND PRACTICAL APPLICATIONS

The problem of "fatigue" is a confused one. Straight out muscular fatigue is fairly easily understood; so is sheer mental exhaustion. The majority of "fatigue" cases, however, fall somewhere between these two extremes and the relative mental and physical aspects are hard to differentiate. (As used here, "fatigue" may be said to be present when, without any intercurrent factor, the subject is unable to continue in his occupation without loss of efficiency.)

Because of the difficulty surrounding the basic study of intermediate types of fatigue, it is difficult to formulate prediction tables for the conditions under which fatigue will occur or the extent to which it will develop. It is frequently necessary, therefore, to make special studies of those conditions which are likely to be met.

In these experiments we have studied certain combinations of heat with other stresses, with a view to ascertaining those combinations which are particularly productive of fatigue, and of determining the extent to which "psycho-motor" as opposed to "physical" responses are affected.

11.1. Conclusions

From the results reported here the following general conclusions may be drawn for the conditions studied.

(a) In the performance of a repetitive task demanding attention, speed and precision, the learning curve pursues an exponential form. There is a rapid rate of learning in the first day or so, but this is followed by a much slower adjustment lasting several days. Under the conditions used in the experiments, an optimum speed of exact performance is obtained in 7-14 days.

(b) With such a task there is also a "boredom" factor which makes itself increasingly felt. The optimum response is succeeded by a rise in reaction time.

(c) The learning and boredom curves vary both in amplitude and time with the individual and with the conditions.

(d) Conditions which are uncomfortably hot are accompanied by 5-12% increase in reaction time.

(e) Within this range, however, the degree of heat has no further effect upon the reaction time of subjects seated at rest.

(f) Subjects undertaking moderate physical exercise between tests may show some further increase in reaction time with those high degrees of heat which threaten physical continuance.

(g) A hot dry atmosphere may induce a further 10% rise in reaction time over that in a hot humid atmosphere of the same effective temperature, at least in subjects acclimatised to the latter.

(h) Exercise, even to the point of physical exhaustion has little effect upon the reaction time of trained and acclimatised subjects, as measured in the post-exercise period.

(i) Noise does not significantly increase the reaction time of most subjects.

(j) Subjects trained to operate under the bad combination of high noise levels and sub-critical heat may show improved reactions under heat alone when the noise is discontinued.

(k) One night without sleep increases the reaction time by about 12%. A succession of further nights with very short sleep brings about an exponentially progressive failure. Under our conditions, four nights of two-hour sleep following one night without sleep led to complete failure.

(l) Meals have some effect upon reaction time. A heavy lunch tends to increase it; omission of breakfast brings about a transitory increase in the first part of the morning, but the subsequent taking or omission of lunch has little material effect.

(m) The wearing of respirators increases reaction time by 20-40%, especially under hot conditions.

(n) It is possible to induce physical failure with little or no psycho-motor deterioration. This is characteristically seen in severe degrees of uncomplicated heat and in exercise under hot conditions.

(o) Conversely, it is possible to induce marked psycho-motor deterioration with little physical reaction. This is characteristically seen with lack of sleep.

(p) In general, as reaction times increase, the variability of the reaction times increases.

11.2. Applications

In many cases these results are what we may have expected, but in the field of human endeavour, it is unwise to base practice upon expectations when measurements can be made. It is true that the results reported here have been obtained under artificial conditions, that the degree of heat used is extreme and that the number of subjects used is limited. Nevertheless, certain points seem to be sufficiently well established or coincide so well with general impressions as to warrant practical use.

The following points are of practical importance:

(a) These studies emphasize that in any repetitive task which is not purely automatic, i.e., in one which requires conscious judgement by the operative, it is important to determine the general nature of the learning and the subsequent "boredom" curves and the main factors influencing their range and duration. The time periods involved may vary from hours or days to months. It should be possible to devise simple but sufficiently adequate practical working tests to determine this in the field.

(b) It is often important to remember that the rapid initial improvement is not the end of learning.

(c) Good and bad reactors cannot be properly differentiated by a single test on apparatus and under conditions with which they are not very familiar. Repeated runs on successive days may be adequate, but even then the bad reactors may include slow learners who, given time, may become useful operators. Moreover, those who learn quickly may become bored quickly.

(d) Conditions which are uncomfortably hot are likely to result in some loss of psycho-motor efficiency, but this is not progressive.

(e) Meals taken in the course of critical work periods under hot conditions should, if possible, be light.

(f) By building up training to conditions which are more severe than expected in actual operations, a more effective performance may be achieved.

(g) Psycho-motor performances (such as gun-laying, instrument setting, etc.) may be maintained at a relatively high level under severe conditions, even though physical failure is imminent, where the stress is mainly physical (e.g., heat, exercise).

(h) On the other hand, where nervous stresses are operating (e.g., lacking sleep), physical reactions are worthless as indices of psycho-motor ability.

(i) The wearing of respirators interferes markedly with this type of performance. Improvements in mask type and anti-dim compounds have relatively small influence.

12. FURTHER WORK REQUIRED

Certain data already obtained have yet to be examined more closely. No mention has been made in this report of the elevation and traverse approach tracings made with the improved apparatus. A further report will be made at a later date.

Amongst the questions arising out of the discussion above, the following call for laboratory investigation with the present apparatus:

(a) The relation of the learning curve to heat and other experimental conditions;

(b) The ultimate shape of the boredom curve and the factors governing its development;

(c) The effect of acclimatisation to hot wet and hot dry conditions respectively upon reactions under the two conditions;

(d) The comparative effect of temperature upon the reactions produced by lack of sleep and meals;

(e) The effect of dehydration upon reactions;

(f) The effect of spaced repetitions upon the maintenance of learning without boredom.

It is desirable that parallel investigations should be made of reactions requiring long-continued alertness such as those involved in maintaining watch.

In the field, it is desirable that simple workable tests should be devised to determine the learning and boredom curves for given operational procedures requiring frequent repetition.

13. ACKNOWLEDGMENTS

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PREVIOUS REPORTS

1. Fatigue Laboratory Secret Report No. 1 - Field Investigation in the Incidence of Tropical Fatigue (Preliminary Report).

2. Fatigue Laboratory Secret Report No. 2 - Effect of Respirators (Anti-Gas) upon gun-sighting performance.

3. List of A.F.V. and P.R.C. Reports obtainable upon request by authorised persons.

TABLE I

SCHEDULE OF EXPERIMENTS IN SERIES T/9

Letter	Atmosphere	Special Conditions	Effective Temp., °F	Work	Day Order for Individual Subjects				
					G5	G6	G7	G8	Av.
c	Temp	----	70	Rest	13	4	5	5	6.75
g	Hot Wet	----	83.5	Driving	14	5	4	4	6.75
j	Hot Wet	Respirators on/off	83.5	Rest	17	8	8	8	10.25
k	Hot Dry	----	84.5	Driving	15	6	3	3	6.75
l	Hot Wet	Heated Walls	88.5	Driving	16	7	6	6	8.75
m	Hot Wet	Heated Walls Closed Back	92.5	Driving	18	9	9	9	11.25
cr	Temp	----	70	Rest	20	11	11	11	13.25
gr	Hot Wet	----	83.5	Driving	19	10	10	10	12.25
					G9	G10	G11	G12	Av.
n	Hot Wet	Heated Walls Normal Breakfast Heavy Lunch	88.5	Driving	10	10	8	8	9.00
o	Hot Wet	Heated Walls No Breakfast Normal Lunch	88.5	Driving	11	11	9	9	10.00
p	Hot Wet	Heated Walls No Breakfast No Lunch	88.5	Driving	12	12	10	10	11.00

TABLE II

SCHEDULE OF EXPERIMENTS IN SERIES M/1

Letter	Special Conditions	Effective Temp. °F	Day Order for Individual Subjects				
			G13	G14	G15	G16	Av.
a	Standard	88	4	4	8	8	6
b	Standard	90	6	6	6	6	6
c	Standard	92	8	8	4	4	6
d	Standard	94	7	7	5	5	6
e	Standard	96	5	5	7	7	6
f	Standard	Critical*	9	9	12	12	10.5
fr	Standard	Critical	14	14	--	15	14.3
frr	Standard	Critical	18	18	17	20	18.25
g	Intermit. Noise 100 db	Critical	10	11	16	18	13.75
h	Contin. Noise 100 db	Critical	11	10	15	19	13.75
i	Intermit. Noise 120 db	Critical	12	13	--	16	13.7
j	Contin. Noise 120 db	Critical	13	12	--	17	14.0
k	Normal breakfast, heavy lunch	Critical	16	16	13	13	14.5
l	No breakfast, normal lunch	Critical	15	15	14	14	14.5
m	No breakfast, no lunch	Critical	17	17	11	11	14.0
n	Lifting 15 sec. interv.	Critical	19	20	10	9	14.5
o	Lifting 7-1/2 sec interv.	Critical	20	19	9	10	14.5
p	No sleep 1 night	Critical	21	21	18	21	20.25
q_1	No sleep 1 night + 2 hrs 1 night	Critical	22	22	19	22	21.25
q_2	No sleep 1 night + 2 hrs 2 nights	Critical	--	23	20	23	22.25
q_3	No sleep 1 night + 2 hrs 3 nights	Critical	--	24	21	24	23.25
q_4	No sleep 1 night + 2 hrs 4 nights	Critical	--	25	22	25	24.25
r	Standard (Preliminary)	65	3	3	3	3	3

*Fixed (in the light of experiments a-e) at 94°F.

TABLE III

EFFECT OF REPETITION UPON GUN-LAYING REACTION TIMES

Exp.	Atmospheric Conditions	E.T. °F	Conditions between Test Hours	Avg. Day Order	Operation Means (1/100 sec)			
					2nd hr	4th hr	7th hr	Day
A - Original Apparatus (4 Subjects)								
T/9a	Temp.	70	Rest	3.75	---	---	---	542 ± 10.4
T/9b	Temp.	70	Rest	4.75	---	---	---	455 ± 3.1
T/9c	Temp.	70	Rest	6.75	458 ± 4.3	438 ± 4.2	437 ± 3.3	444 ± 4.2
T/9cr	Temp.	70	Rest	13.25	475 ± 6.1	453 ± 6.5	448 ± 4.4	459 ± 4.3
T/9g	Hot Wet	83.5	Driving	6.75	469 ± 3.9	459 ± 3.6	448 ± 2.9	459 ± 2.9
T/9gr	Hot Wet	83.5	Driving	12.25	500 ± 5.7	496 ± 8.0	---	496 ± 4.1
B - Improved Apparatus (3 Subjects)								
M/1r	Temp.	65	Rest	3.0	597 ± 27.5	504 ± 36.2	526 ± 24.3	544 ± 19.9
M/1d	Hot Wet	94	Rest	6.3	429 ± 13.2	457 ± 19.1	415 ± 4.3	434 ± 8.4
M/1f	Hot Wet	94	Rest	10.0	377 ± 14.6	361 ± 13.0	387 ± 9.1	375 ± 6.5
M/1fr	Hot Wet	94	Rest	14.3	331 ± 12.1	338 ± 8.6	342 ± 11.8	337 ± 5.0
M/1frr	Hot Wet	94	Rest	18.7	395 ± 15.7	355 ± 13.8	364 ± 10.2	371 ± 8.3

TABLE IV

EFFECT OF HEAT ALONE UPON GUN-LAYING REACTION TIMES

Exp.	Atmospheric Conditions	E.T. °F	Conditions between Test Hours	Avg. Day Order	Operation Means (1/100 sec)			
					2nd hr	4th hr	7th hr	Day
			A - Temperate/Hot Wet, at Rest (without Respirator)					
T/9c	Temp.	70	Rest No respirator	6.75	458 ± 4.3	438 ± 4.2	437 ± 3.3	444 ± 4.2
T/9j	Hot Wet Heated Tank	83.5	Rest Respirator on	10.25	471	487	465	474 ± 6.3
T/9cr	Temp.	70	Rest No Respirator	13.25	475 ± 6.1	453 ± 6.5	448 ± 4.4	459 ± 4.3
			B - Temperate/Hot Wet, at Rest (without Respirator)					
M/2a	Temp.	65	Rest S.V. Respirator on	24 + 4	379	429	390	399 ± 18.7
M/2d	Hot Wet	94	Rest S.V. Respirator on	24 + 4.3	435	459	---	447 ± 8.8
M/2b	Temp.	65	Rest L.V. Respirator on	24 + 3.7	395	441	394	410 ± 14.2
M/2e	Hot Wet	94	Rest L.V. Respirator on	24 + 3.3	422	428	475	442 ± 16.7
M/2c	Temp.	65	Rest L.VI. Respirator on	24 + 2.7	409	372	376	386 ± 11.2
M/2f	Hot Wet	94	Rest L.VI. Respirator on	24 + 3.0	---	418	---	---

TABLE IV (cont.)

Exp.	Atmospheric Conditions	E.T. °F	Conditions between Test Hours	Avg. Day Order	Operation Means (1/100 sec) 2nd hr	4th hr	7th hr	Day
				C - 5 Degrees of Hot Wet, at Rest				
M/1a	Hot Wet	88	Rest	6	455 ± 13.8	496 ± 24.9	471 ± 11.5	474 ± 9.9
M/1b	Hot Wet	90	Rest	6	467 ± 16.6	469 ± 24.7	436 ± 14.9	457 ± 10.3
M/1c	Hot Wet	92	Rest	6	475 ± 13.7	482 ± 7.8	459 ± 10.5	472 ± 6.0
M/1d	Hot Wet	94	Rest	6	468 ± 6.9	497 ± 13.6	470 ± 5.6	478 ± 6.7
M/1e	Hot Wet	96	Rest	6	473 ± 15.2	---	---	---
				D - 3 Degrees of Hot Wet, after Driving				
T/9g	Hot Wet	83.5	Driving	6.75	469 ± 3.9	459 ± 3.6	448 + 2.9	459 ± 2.9
T/91	Hot Wet Heated Tank	88.5	Driving	8.75	477 ± 5.3	455 ± 2.9	466 ± 4.9	466 ± 3.3
T/9m	Hot Wet Heated Tank Closed Back	92.5	Driving	11.25	551 ± 1.9	539 ± 6.0	---	545 ± 3.6
T/9gr	Hot Wet	83.5	Driving	12.25	500 ± 5.7	496 ± 6.8	---	496 ± 4.1
				E - Hot Wet/Hot Dry, after Driving				
T/9g	Hot Wet	83.5	Driving	6.75	469 ± 3.9	459 ± 3.6	448 ± 2.9	459 ± 2.9
T/9k	Hot Dry	84.5	Driving	6.75	522 ± 7.1	504 ± 7.9	498 ± 7.2	508 ± 4.9

TABLE V

EFFECT OF EXERCISE UPON GUN-LAYING REACTION TIMES IN HEAT

Exp.	Atmospheric Conditions	E.T. °F	Conditions between Test Hours	Avg. Day Order	Operation Means (1/100 sec)			
					2nd hr	4th hr	7th hr	Day
T/9j	Hot Wet Heated Walls	83.5	Rest S.V. Respirator on	10.25	471	487	465	474 ± 6.3
T/91	Hot Wet Heated Walls	88.5	Driving	8.75	477 ± 5.3	455 ± 2.9	466 ± 4.9	466 ± 3.3
Control*	Hot Wet	94	Rest	15.0	438 ± 18.0	---	---	---
M/1n	Hot Wet	94	Lifting 15 secs Intervals	14.5	443 ± 22.3	---	---	---
M/1o	Hot Wet	94	Lifting 7-1/2 secs Intervals	14.5	441 ± 5.3	---	---	---

*Exp. M/1frr for G13 and 14, M/1f for G15 and 16.

TABLE VI

EFFECT OF NOISE UPON GUN-LAYING REACTION TIMES IN HEAT

Exp.	Atmospheric Conditions	E.T. °F	Conditions throughout Day	Avg. Day Order	Operation Means (1/100 sec)			
					2nd hr	4th hr	7th hr	Day
1st Control*	Hot Wet	94	Rest No Noise	11.0	386 ± 13.4	365 ± 15.7	398 ± 9.4	383 ± 7.5
M/1g	Hot Wet	94	Rest Intermitt. Noise 100 db	13.0	422 ± 12.6	353 ± 3.3	374 ± 14.7	383 ± 10.5
M/1h	Hot Wet	94	Rest. Contin. Noise 100 db	13.3	392 ± 29.3	359 ± 14.6	---	376 ± 15.5
M/1i	Hot Wet	94	Rest Intermitt. Noise 120 db	13.7	378 ± 18.4	374 ± 8.6	361 ± 10.8	371 ± 6.7
M/ij	Hot Wet	94	Rest Contin. Noise 120 db	14.0	372 ± 6.9	414 ± 5.0	---	395 ± 9.2
2nd Control**	Hoe Wet	94	Rest No Noise	16.0	338 ± 10.9	329 ± 10.0	320 ± 3.8	329 ± 4.8

*Exp. M/1f for G13 and 14, M1/fr for G15 and 16.
**Exp. M/1fr for G13 and 14, M/1frr for G15 and 16.

TABLE VII

EFFECT OF LACK OF SLEEP UPON GUN-LAYING REACTION TIMES IN HEAT

Exp.	Atmospheric Conditions	E.T. °F	Conditions of Sleep	Avg. Day Order	Operation Means (1/100 sec)			
					2nd hr	4th hr	7th hr	Day
M/1frr	Hot Wet	94	Normal	18.3	433 ± 14.8	391 ± 16.6	391 ± 12.4	405 ± 9.2
M/1p	Hot Wet	94	1 Night without any	20.0	455 ± 15.7	457 ± 11.0	---	456 ± 8.2
$M/1q_1$	Hot Wet	94	1 Night without any + 1 Night with 2 hrs	21.0	484 ± 5.7	442 ± 10.1	439 ± 13.7	455 ± 8.2
$M/1q_2$	Hot Wet	94	1 Night without any + 2 Nights with 2 hrs	22.0	484 ± 5.6	---	484 ± 22.2	484 ± 9.8
$M/1q_3$	Hot Wet	94	1 Night without any + 3 Nights with 2 hrs	23.0	524 ± 43.5	535 ± 8.6	523 ± 20.9	527 ± 13.5
$M/1q_4$	Hot Wet	94	1 Night without any + 4 Nights with 2 hrs	24.0	614 ± 30.5	647 ± 10.9	---	630 ± 15.4
M/2o	Hot Wet	94	Normal for 4 Nights	26.7	409	372	376	386 ± 11.2

TABLE VIII

EFFECT OF MEALS UPON GUN-LAYING REACTION TIMES IN HEAT

Exp.	Atmospheric Conditions	E.T. °F	Meal Conditions	Avg. Day Order	Operation Means (1/100 sec)			
					2nd hr	4th hr	7th hr	Day
			A - Driving - Original Apparatus					
T/9n	Hot Wet Heated Walls	88.5	Normal Breakfast Heavy Lunch	9.0	410 ± 6.9	400 ± 5.5	422 ± 12.2	410 ± 5.4
T/9o	Hot Wet Heated Walls	88.5	No Breakfast Normal Lunch	10.0	457 ± 9.0	428 ± 8.5	411 ± 10.2	432 ± 7.1
T/9p	Hot Wet Heated Walls	88.5	No Breakfast No Lunch	11.0	428 ± 8.9	437 ± 11.6	433 ± 8.5	433 ± 5.7
			B - Rest - Improved Apparatus					
Control*	Hot Wet	94	Normal	13.0	390 ± 10.3	396 ± 5.8	393 ± 8.4	393 ± 4.0
M/1k	Hot Wet	94	Normal Breakfast Heavy Lunch	14.5	404 ± 12.5	399 ± 14.4	472 ± 23.8	425 ± 13.4
$M/1_1$	Hot Wet	94	No Breakfast Normal Lunch	14.5	425 ± 10.0	396 ± 1.2	412 ± 11.0	411 ± 5.5
M/1m	Hot Wet	94	No Breakfast No Lunch	14.0	458 ± 10.2	422 ± 14.0	395 ± 8.9	425 ± 9.7

*Exp. M/1fr for G13 and 14, M/1f for G15 and 16.

TABLE IX

EFFECT OF RESPIRATORS UPON GUN-LAYING REACTION TIMES

Exp.	Atmospheric Conditions	E.T. °F	Respirator Conditions	Avg. Day Order		Operation Means (1/100 sec)			
						2nd hr	4th hr	7th hr	Day
				4 Subjects					
T/9j	Hot Wet	83.5	Standard	10.25	Off	471	487	465	474 ± 6.3
	Heated Walls		Anti-dim V		On	554	587	567	566 ± 6.5
				3 Subjects					
M/2a	Temp.	65	Standard		Off	379	429	390	399 ± 18.7
			Anti-dim V	24 + 4	On	545	510	518	524 ± 11.7
M/2b	Temp.	65	Light	24 + 3.7	Off	395	441	394	410 ± 14.2
			Anti-dim V		On	526	575	539	547 ± 16.7
M/2c	Temp.	65	Light	24 + 2.7	Off	409	372	376	386 ± 11.2
			Anti-dim VI		On	527	473	486	495 ± 12.7
				3 Subjects					
M/2d	Hot Wet	94	Standard	24 + 4.3	Off	435	459	387*	447 ± 8.8
			Anti-dim V		On	595	649	506*	622 ± 26.0
M/2e	Hot Wet	94	Light	24 + 3.3	Off	422	428	475	442 ± 16.7
			Anti-dim V		On	571	523	628	574 ± 22.2
M/2f	Hot Wet	94	Light	24 + 3.0	Off	461**	418	374***	---
			Anti-dim VI		On	560**	562	527***	---

*Omitting G14
**Omitting G16
***Omitting G15

TABLE X

COMPARISON OF PHYSICAL WITH PSYCHO-MOTOR REACTIONS

Exp.	Item	1st hr	2nd hr	3rd hr	4th hr	6th hr	7th hr
			A - Varying Temperatures (4 Subjects)				
M/1a	Reac Time	--	455	--	496	--	471
	P.R.	88	87	80	84	89	97
	R.T.	98.3	98.7	98.7	98.8	99.0	99.0
M/1b	Reac Time	--	467	--	469	--	436
	P.R.	94	94	94	92	101	103
	R.T.	98.3	98.5	98.4	98.5	98.8	98.8
M/1e	Reac Time	--	475	--	482	--	459
	P.R.	87	94	95	98	106	115
	R.T.	98.5	98.7	99.0	99.2	99.3	99.6
M/1d	Reac Time	--	468	--	497	--	470
	P.R.	95	97	99	99	109	110
	R.T.	98.6	99.1	99.2	99.3	99.6	99.8
M/1e	Reac Time	--	473	--	--	--	--
	P.R.	102	116	--	--	--	--
	R.T.	98.9	100.5	--	--	--	--

TABLE X (cont.)

Exp.	Item	1st hr	2nd hr	3rd hr	4th hr	6th hr	7th hr
		B - Lack of Sleep (3 Subjects)					
$M/1p$	Reac Time	--	422	--	428	--	--
	P.R.	87	96	93	101	--	--
	R.T.	98.5	99.1	99.3	99.4	--	--
$M/1q_1$	Reac Time	--	436	--	406	--	419
	P.R.	98	101	104	102	109	118
	R.T.	99.1	99.5	99.6	99.9	100.0	100.1
$M/1q_2$	Reac Time	--	484	--	--	--	484
	P.R.	88	91	91	--	93	100
	R.T.	99.1	99.3	99.6	--	99.5	99.5
$M/1q_3$	Reac Time	--	524	--	535	--	523
	P.R.	90	90	91	92	94	95
	R.T.	99.2	99.3	99.4	99.3	99.3	99.3
$M/1q_4$	Reac Time	--	614	--	647	--	--
	P.R.	88	95	90	93	--	--
	R.T.	99.0	99.4	99.4	99.3	--	--

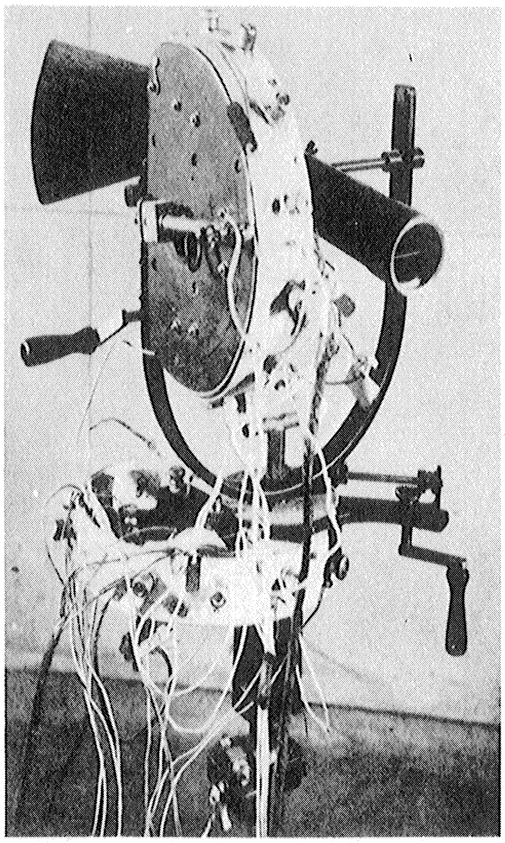


Fig. I. Gun-sight Unit.

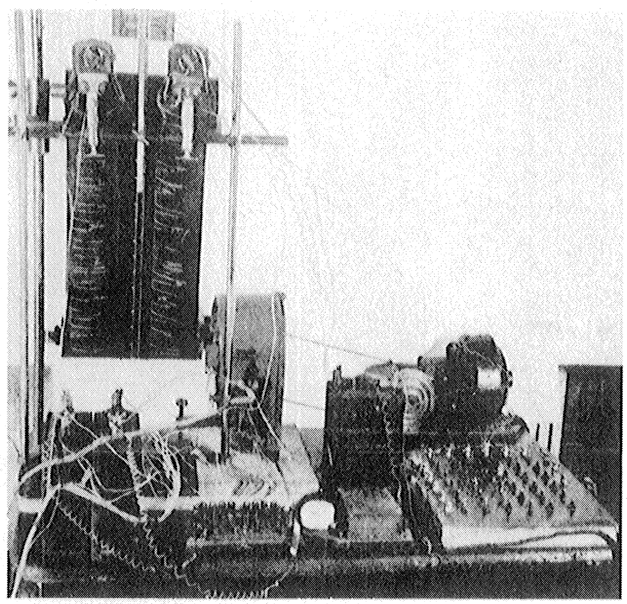


Fig. II. Recording and Control Units.

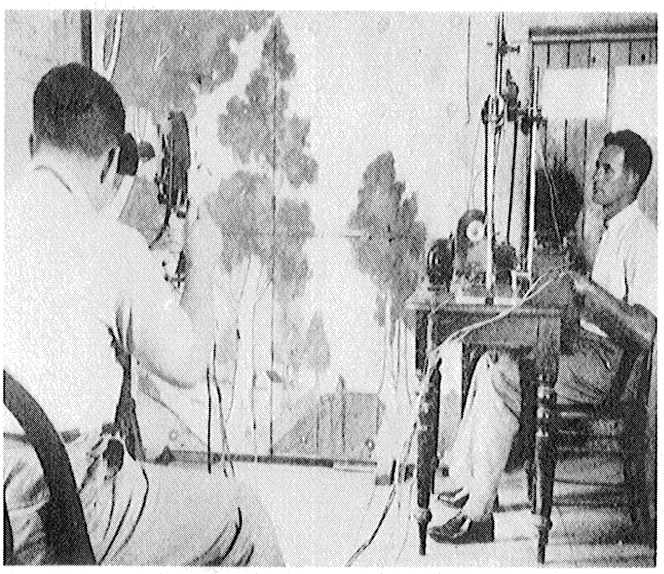
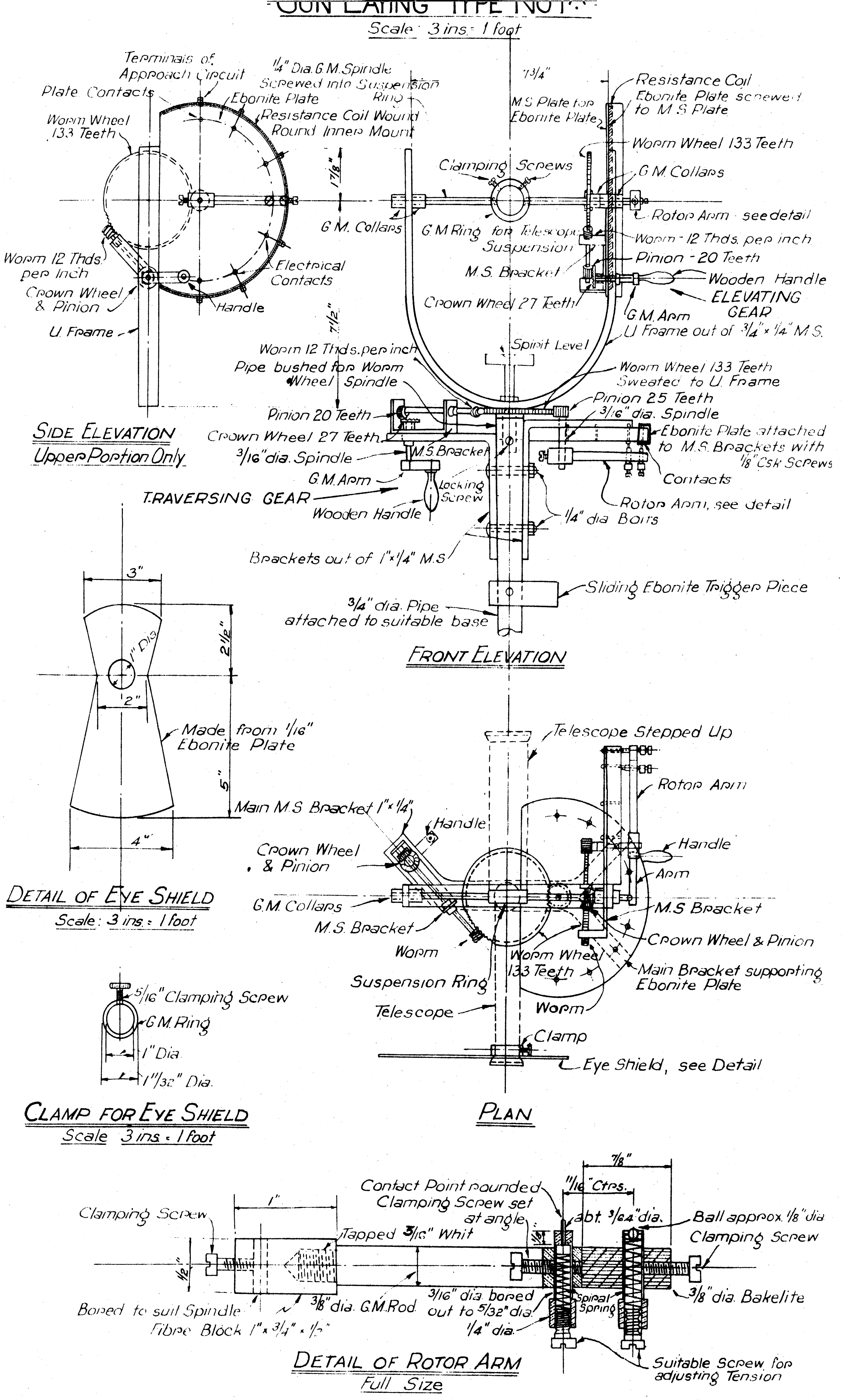
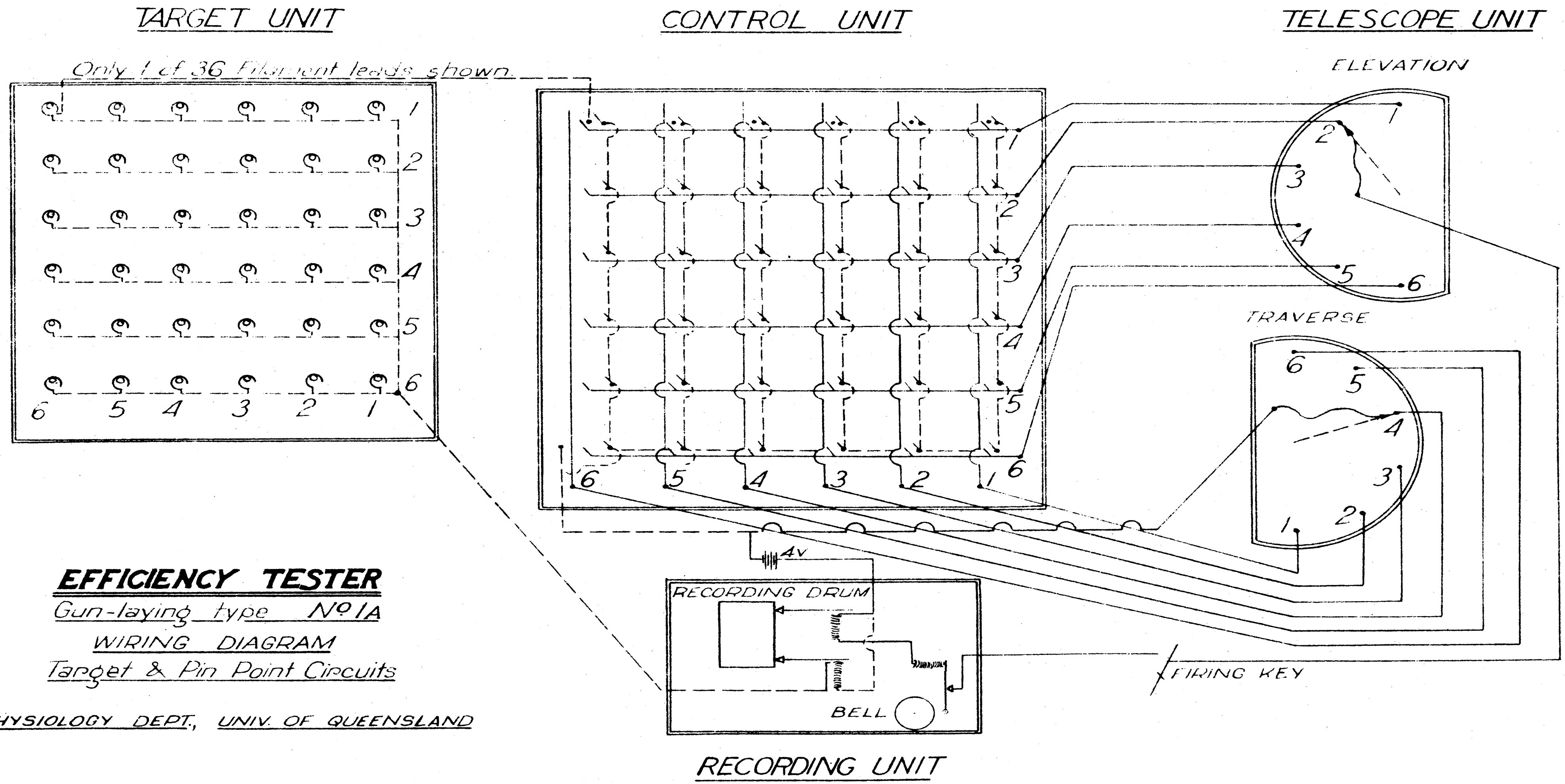


Fig. III. Efficiency Tester (Gun-laying type No. 1A) in use.



Scale: 3 ins = 1 foot
Terminals of Approach Circuit
Plate Contacts
1/4" Dia. G.M. Spindle Screwed into Suspension Ring
Ebonite Plate
Resistance Coil Wound Round Inner Mount
Worm Wheel 133 Teeth
Worm 12 Thds. per inch
Crown Wheel & Pinion
U Frame
Electrical Contacts
Handle
G.M. Collars
Side Elevation
Upper Portion Only
7 3/4"
Resistance Coil
Ebonite Plate screwed to M.S. Plate
M.S. Plate for Ebonite Plate
Worm Wheel 133 Teeth
Clamping Screws
G.M. Collars
Rotor Arm see detail
G.M. Ring for Telescope Suspension
Worm - 12 Thds. per inch
Pinion - 20 Teeth
M.S. Bracket
Wooden Handle
Elevating Gear
Crown Wheel 27 Teeth
G.M. Arm
U Frame out of 3/4" x 1/4" M.S.
Spirit Level
Worm 12 Thds. per inch
Pipe bushed for Worm Wheel Spindle
Worm Wheel 133 Teeth Sweated to U. Frame
Pinion 25 Teeth
3/16" dia. Spindle
Pinion 20 Teeth
Ebonite Plate attached to M.S. Brackets with 1/8" Csk Screws
Crown Wheel 27 Teeth
M.S. Bracket
3/16" dia. Spindle
Contacts
G.M. Arm
Locking Screw
Traversing Gear
Wooden Handle
Rotor Arm, see detail
1/4" dia Bolts
Brackets out of 1" x 1/4" M.S.
Sliding Ebonite Trigger Piece
3/4" dia. Pipe attached to suitable base
Front Elevation
3"
1" Dia
2 1/2"
2"
Made from 1/16" Ebonite Plate
5"
4"
Detail of Eye Shield
Scale: 3 ins = 1 foot
Telescope Stepped Up
Rotor Arm
Main M.S. Bracket 1" x 1/4"
Handle
Crown Wheel & Pinion
Arm
G.M. Collars
M.S. Bracket
M.S. Bracket
Worm
Worm Wheel 133 Teeth
Crown Wheel & Pinion
Main Bracket supporting Ebonite Plate
Suspension Ring
Telescope
Worm
Clamp
Eye Shield, see Detail
5/16" Clamping Screw
G.M. Ring
1" Dia
1 1/32" Dia.
Clamp for Eye Shield
Scale 3 ins = 1 foot
Plan
Contact Point rounded
Clamping Screw set at angle
11/16" Ctrs.
7/8"
abt. 3/64" dia.
Ball approx. 1/8" dia
Clamping Screw
1"
Tapped 3/16" Whit
1/2"
Bored to suit Spindle
3/8" dia. G.M. Rod
3/16" dia bored out to 5/32" dia.
Spiral Spring
1/4" dia.
3/8" dia. Bakelite
Fibre Block 1" x 3/4" x 1/2"
Suitable Screw for adjusting Tension
Detail of Rotor Arm
Full Size

Diag.1.



EFFICIENCY TESTER

Gun-laying type No. 1A

WIRING DIAGRAM

Target & Pin Point Circuits

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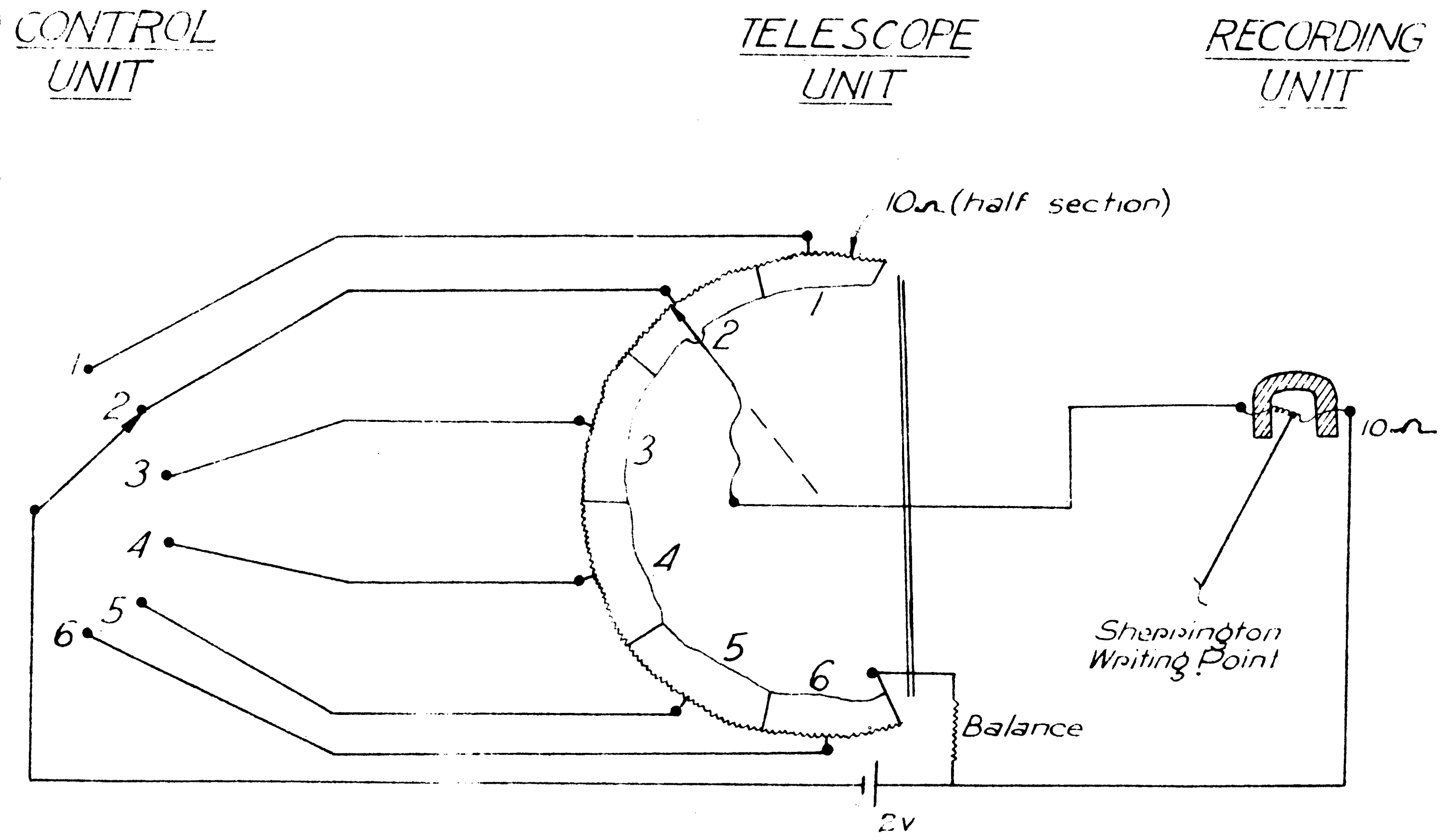
Diag.2.



EFFICIENCY TESTER

Gunlaying type No 1A

WIRING DIAGRAM

Approach Circuit

Diag.3.

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