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ARMY OPERATIONAL RESEARCH GROUP

REPORT No. 11/50.

THE DESIGN OF LOAD CARRYING EQUIPMENT FOR THE SOLDIER IN BATTLE.

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AORG

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REPORT NO. 11/50.

THE DESIGN OF LOAD CARRYING EQUIPMENT FOR THE SOLDIER IN BATTLE

Prepared by:- O.C.J. Lippold
P.F.D. Naylor

ABSTRACT

The Physiological principles concerned in load-carrying into battle are explained. Experimental procedures are outlined which may be used in the testing of equipment produced in the future and which were used to enable the deductions to be made.

The equipment which was used for load-carrying in the experiments is described and criticised and suggestions are made as to how it may be improved.

The military requirements of and for carrying-equipment in the Army are considered and it is urged that the whole problem of design of clothing, fighting order, marching order and equipment for porterage is co-ordinated before the design of any one of these proceeds further.

It is concluded that:-

(a) Carriage of loads on the hips is preferable to other methods;

(b) Less muscular effort is required to carry loads when these are close to the body and disposed in a balanced fashion.

It is recommended that:-

(a) Battle order should consist of a long, thin, narrow pack supported on the hips at the back. Pouches should be supported on the hips at the front;

(b) A small working party should consider how these recommendations can best be achieved. It should consist of an experienced Infantry Officer, representatives from S.W.V.I., and M.O.S., a Time and Motion Study expert and a Physiologist.

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Prepared by:- O.C.J. Lippold
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INTRODUCTION

1. Although modifications in the present type of web equipment have been made several times since its introduction in 1908 the design has remained basically the same. This design has a number of unsuitable features and it has become increasingly apparent, from both military and physiological considerations, that a completely new design of fighting order is necessary.

2. The pattern now in use (1937 type) has many undesirable features. From the military point of view the side, front and prone silhouettes are unnecessarily large. The basic pouches suspended on the chest make crawling difficult and lying close to the ground impossible.

3. From the physiological standpoint many faults in design are apparent. The weight of the pouches and small pack is supported by the shoulder girdle, which entails the continuous contraction of relatively weak muscles to keep the shoulders elevated. The result is early fatigue and discomfort in these muscles. Occasionally this has been followed by a drop of the clavicles with resultant compression of the brachial plexus and/or the subclavian artery which gives rise to numbness and paralysis of the arms. (Starmers F.A.R., Lancet. CCLVIII, 605. 1950). The straps over the shoulders are narrow, giving rise to high pressure on the skin; this causes considerable discomfort because the clavicles are close to the surface, with no cushion of fat or muscle intervening.

4. Work has been carried out at AORG in order to elucidate the underlying physiological principles involved in load carrying. It is hoped that the knowledge thus obtained will enable these and military requirements to be combined, producing a design satisfactory from both points of view.

PHYSIOLOGICAL PRINCIPLES

5. In the design of equipment for load carrying it is necessary to consider the normal functioning of the individual with specific reference to the tasks which he will have to perform when fighting, in order that these may be impaired to as small an extent as possible.

Load to be carried

6. The physical performance of a man is at its peak when he is unladen. Obviously this is impracticable in warfare when weapons have to be carried by each man. Any load-carrying will impair to some extent the physical performance of the soldier. Cathcart showed that when the load which a man carries exceeds 35% of his body weight, expenditure of energy becomes disproportionately large. Whether this disproportionate rise in expenditure of energy also means a disproportionate rise in rate of fatigue is not clear.

It is unimportant, because the basic fact remains, that the greater the load the greater the fatigue, and therefore the load should be made as light as possible. This is the most important single point concerning load carrying into battle.

Disposition of the load

7. In order to assess the merits of the various fundamental methods of carrying loads it is necessary to devise objective techniques which will enable a comparison to be made. Such techniques are all laboratory investigations which, from the point of view of indicating the design of efficient load carrying apparatus, are at least as important as the subjective methods employed in field trials.

8. All too little of this work has been done in the past, and most of the literature deals with metabolism experiments, the details of which were first described by Waller (Proc. Roy. Soc. B. 637:166, 1920). Significant differences in the energy expenditure for different methods of load carrying were observed by Bedale (I.F.R.B. Report No. 29, HMSO. 1924), who investigated various types of carrier used in industry. 40 lbs. was found to be the maximum economic load for most types of carrying.

9. The results obtained in these and other experiments indicate that there are four essentials in the design of any load-carrying apparatus, to ensure a minimum expenditure of energy in use. These are:-

(a) Elimination of local strain,

(b) The maintenance of normal posture,

(c) The maintenance of a normal and free gait,

(d) Chest freedom.

10. Disproportionate expenditure of energy does not necessarily mean disproportionate rate of fatigue. In the absence of evidence on this point it is reasonable to keep expenditure of energy at a minimum. Furthermore the four factors quoted above are also those which promote bodily comfort and ease of performance of military tasks. For these reasons it is therefore desirable to see how load-carrying equipment can be designed to conform with these requirements.

Elimination of local strain

11. Any method of load-carrying which entails continuous muscular contraction to counteract the effect of gravity acting upon the load must produce strain and fatigue in the groups of muscles so employed, particularly if these muscles are weak ones. This difficulty is avoided when weight is applied directly to a portion of the skeleton which can transmit the weight to the ground without the intervention of "strut muscles". There are two ways of doing this:-

(a) Carriage on top of the head.
Although this method theoretically enables loads to be carried without the use of muscles, Bedale observed that the unstable position of such a load leads to a state of increased muscular tension - particularly in the neck and shoulder region. In any case the method is obviously quite unsuitable for military operations.

(b) Carriage of weight on the hips.
The actual method of doing this will be discussed later. It was decided to investigate this method of load-carrying in order to determine whether it did, in fact, reduce the ~~ of continuous muscular contraction necessary.

Note on experimental investigation of local strain

12. When a muscle contracts, the individual fibres of which it is composed develop minute action potentials. Electrodes placed over the belly of any muscle pick up volleys of these electrical impulses throughout the duration of its contraction. During relaxation little or no electrical activity takes place. Thus it is possible by using suitable amplifying and recording apparatus to determine the presence of activity in any muscle or group of muscles.

13. A rough comparison can be made in this manner of the activity of a group of muscles when loads are carried in different ways. It will be seen from the details given in Appendix B that, in general, muscular contraction is less in the muscles of the back and shoulder girdle when the load is supported by the hips, than is the case when it is supported on the shoulders. This agrees with the conclusions arrived at from theoretical considerations.

The maintenance of normal posture

14. The normal posture of a person carrying a load may be disturbed for several reasons:-

(a) The load is too heavy;

(b) The load is not suitably attached to the body. The arms may have to be employed to steady or hold the load; or the back may have to be bent to carry it;

(c) The load is too bulky, (e.g. in order to carry a bulky suitcase the arm carrying the case must be held out at an angle from the body in order to hold the case away from the legs);

(d) The load is not properly balanced.

15. In a static system in equilibrium the Centre of Gravity lies over the base. The feet of a standing man form the base of such a system and the centre of gravity normally lies over a certain part of the feet. If a load is placed upon his back the centre of gravity is displaced backwards and his equilibrium disturbed. In order to restore the equilibrium he must bend forward so that the centre of gravity is again brought over the same part of the feet. To maintain this new posture, constant activity in certain muscles is necessary and a greater output of energy is needed than in maintaining the posture normally taken up by an unladen man.

16. Floyd, using an electro-myograph on unladen subjects, has shown that in maintenance of posture, there is least continuous activity in the muscles of the back and abdomen when the subject is in the upright stance. Slouching and bending forward increase the muscular activity considerably. Floyd did not experiment with laden subjects. But from his work it might be predicted that the muscular effort necessary to maintain posture in the laden subject would be a minimum when the load was so arranged about his body that the centre of gravity remained in the same place as in the unladen, upright body. Any displacement of the centre of gravity would increase the amount of activity necessary to maintain the standing posture.

17. Experiments were designed to test this prediction; they are described in detail in Appendix C. They showed that in standing and marching men with loads variously disposed, muscular activity concerned with maintenance of posture was at a minimum when the load was so balanced that there is no disturbance of the body's normal, static equilibrium.

Maintenance of a normal and free gait

18. Some of the factors which are concerned in the maintenance of a normal and free gait in load carrying are:-

(a) The weight of the load; no subject can walk normally if the load is excessively heavy;

(b) The posture of the carrier; an abnormal posture causes an abnormal gait;

(c) The height of the centre of gravity of the load above the ground.

19. When a man carrying a weight is walking, alterations will occur in the angle which the long axis of the body makes with the vertical. The higher the load is above the ground the greater will be the displacement of the vertical projection of the combined centre of gravity, when this angle is altered. The actions which a load carrier takes in such a case of instability are:-

(a) Preventative-by taking small steps which cause less deviation of the body from the vertical;

(b) Corrective. Once unstable equilibrium has occurred these measures are two-fold;

(i) Quickly moving the feet to lie under the centre of gravity of the load which in effect is a small staggering movement;

(ii) Bending of the body in a direction opposite to the deviation from the vertical (which entails the use of additional muscles.)

20. The closer the centres of gravity of the component parts of the load are to the centre of gravity of the body, the easier are these corrective actions, for the further away they are the greater will be the angular momentum of the load and a large angular momentum impedes necessary corrective movements.

21. The lower the centre of gravity of the load carried, the greater the angle the body can make with the vertical without loss of balance occurring. Steps of a normal length can then be taken and any unevenness in the ground, causing deviation of the body from the vertical, will not cause such a large movement of the centre of gravity of the load as to upset the gait of the load carrier. Thus, by making the load light, having it properly balanced, carried as close to the body as possible and as low as possible (but not interfering with the movement of the legs), the normal gait may be maintained.

Chest freedom

22. This may be interfered with in two ways:-

(a) Muscular tension is increased in the chest and back muscles as a result of an unstable load.
A good example of this is the carriage of loads on the head in an untrained man. The instability of such a load makes the subject hold himself very rigidly and this is a hindrance to normal respiration.

(b) Direct pressure on the chest by weights or straps also hinders normal respiration.

Thermal stress

23. The body temperature is maintained by the balance of heat production and heat loss. Exercise greatly increases heat production because only part of the energy liberated by the chemical changes in muscle is converted into mechanical work, the remainder being evolved as heat. This heat must be lost if the body temperature is to remain within normal limits.

24. Heat is lost from the body by convection, radiation and in vaporisation. Under conditions of strenuous exercise a large proportion of the total heat is dissipated through vaporisation. If during exercise the balance is to be maintained, and an excessive rise in body temperature avoided, heat production must be at a minimum and heat loss by vaporisation must be as free as possible.

25. The stimuli for the production of sweat are:-

(a) A rise in body temperature directly affecting the heat regulating centre;

(b) Through reflexes from the nerve endings concerned with temperature perception in the skin.

26. It is desirable to avoid an excessive rise in body temperature but once it has occurred and sweating has resulted, the sweat must be allowed to vaporise freely, not only to reduce body temperature again to normal but also because sweat accumulation per se is undesirable.

27. Over short periods clothing becomes saturated, in which condition it is a better conductor of heat. This is advantageous during the actual exercise. When exercise ceases, however, the damp clothing causes rapid heat loss with consequent chilling and attendant ill effects, unless a change of clothing is available. Over longer periods sodden skin predisposes to skin disease and also is more susceptible to pressure and chafing. Since areas of sweat accumulation are also areas of weight bearing, blistering and ulceration of the skin may result. It is therefore necessary to consider the factors which affect the accumulation of sweat on the skin and how they may be avoided.

28. The accumulation of sweat on the skin, after its production, occurs when the humidity of the air layer immediate to the skin is high. The humidity of this layer depends partly on general atmospheric humidity and partly upon the rate of exchange of this layer with atmospheric air. The rate of exchange of this contact layer is controlled by several factors:-

(a) In hot weather or during exercise the skin must be uncovered over as large an area as possible or, if covered, air must be allowed to circulate freely under the clothing and out again. There must be no unnecessary areas of material, especially if tight fitting, covering the skin;

(b) The air spaces under the clothing must not be divided by straps into a series of relatively air-tight compartments;

(c) Wherever possible the load should be supported away from the skin;

(d) Weight bearing areas should be small. (This clashes with the requirement of having these areas as large as possible to diminish pressure per unit area. A compromise must therefore be effected between the two. (See para. 34 below).

29. In practice it is difficult to distinguish between small differences which various clothing assemblies have upon the total volume of sweat secreted. It is therefore correspondingly more difficult to distinguish between the differences in total volume of sweat produced when wearing different load-carrying equipments.

30. In considering various types of equipment, differences in rate and distribution of sweat accumulation are more important than total sweat production. They also vary more and are therefore easier to measure.

31. Experiments on the comparison of equipment must be performed in a climatic chamber in order to standardize the temperature and humidity of the atmosphere. These experiments can be carried out using water sensitive agents on the skin or on garments next to the skin. Local accumulation of sweat is indicated by an area of colour change, the extent of which can be permanently recorded by means of a suitable photographic technique. Comparative results are given in detail in Appendix D.

Skin pressure and skin friction

32. When loads are carried for a long time the ill effects of pressure and chafing on the skin become apparent. These effects are caused by:-

(a) Steady high pressure on certain areas of skin;

(b) Variations of pressure on certain areas caused by parts of the equipment bouncing against the body;

(c) Movement of the clothing and equipment relative to the skin, causing frictional effects.

33. When any of these factors become excessive, redness, blistering, bruising and painful ulceration of the skin result. Experimental work on the relative importance of these factors in producing ill effects needs to be carried out and it is intended to do this as soon as facilities at AORG or elsewhere become available.

Steady pressure

34. Pressure per unit area of body surface is directly proportional to the total weight carried and inversely proportional to the total area over which this weight is applied. To reduce this pressure the area of supporting skin must be as large as possible. Weight bearing straps if present must be broad. In order to maintain skin pressure over the weight bearing areas at a uniformly low level, the fit of equipment to the body is important.

Bouncing of the load

35. When a man is walking at moderate pace, "bouncing" of the load is not a serious problem; when he is running, however, the frequency and amplitude of the up and down movements of the body are increased. If the load is rigidly fixed to the body, a great deal of energy is required to overcome the inertia of the load at each step. If loosely fixed, the load moves relative to the body at each step and "bouncing" occurs.

36. Different parts of the body move with different frequencies and amplitudes during normal locomotion. Steindler 1935 (Mechanics of Normal & Pathological Locomotion:- Springfield. Ill., C.C. Thomas) has shown experimentally that the shoulders move slightly less in the vertical direction than do the hips. Moreover there are relatively high frequency components in the motion of the hips not present in the shoulders, which show an altogether smoother movement. Important from the load carrying point of view is the fact that the amplitude of the vertical motion of the shoulders can be voluntarily greatly reduced (by flexing the trunk on the hips). Vertical motion of the hips cannot be so reduced, except by running

or walking with the knees bent throughout each step taken; a condition imposing severe strain. Therefore if loads have to be carried when running, bounce is more severe when hip support is used, than when straps over the shoulders are used. This is the greatest single disadvantage of the pelvic carriage method.

37. When bone immediately underlies the skin, skin compression is higher than when soft tissues intervene and exert a cushioning effect. Therefore weight bearing areas should have an adequate thickness of tissue covering the bones.

Frictional effects

38. Movements between the skin and clothing and equipment must be minimised. In practice this means that the friction between skin and clothing must be so great that movement does not occur. Thus static friction should be as great as possible and kinetic friction at a minimum.

DEVELOPMENT OF THE AORG PROTOTYPE EQUIPMENT

39. It was decided to attempt to produce a fighting order which incorporated the physiological principles which have been outlined, and the assumption has been made that the infantry soldier will have to carry the same load into battle in the future as he has been carrying hitherto. That this last proviso does in fact hold is by no means certain as will be explained later. In must be stressed that the attempt which has been made is in no way meant to be a final answer, but it suggests the lines along which future development could most profitably progress once military requirements have been more clearly defined.

The pack

40. It was decided that the weight of this should be carried by the pelvis. The choice lay between the framed ruc-sac of the Bergen type and the non-framed type. In the framed type there are several disadvantages. It is difficult to produce a frame which fits comfortably every size and shape of soldier. The load is held too far away from the back which is undesirable physiologically. Militarily, it enlarges silhouettes and restricts crawling through under-growth and confined spaces. The extra weight of the frame, if strong enough, is also to its disadvantage.

41. It was decided therefore to adopt the non-frame system. A pack was constructed of approximately equal volume to the 1937 type small pack with measurements 18" x 9" x 3". (See Figs. 1, 2 and 3.)

42. The weight of the pack is transmitted to the hips by a flexible belt and the top of the pack is kept in contact with the shoulders by broad straps which take practically no weight. The pouches are supported by the belt and carried in front and to the side thus balancing the load. Both the pack and pouches are attached to the belt by means of quick release clips so that the pack only may be detached in an emergency or the pouches may be detached and passed to another soldier. (See Figs. 6 and 7.)

43. The flat shape of the pack not only lowers the silhouette but also ensures that the centre of gravity of the pack is low down and close to the man.

44. The contents of the pack were found to be sufficient stiffening in themselves without the use of a frame. There was a slight sag in the middle which was found to be desirable as it held the pack slightly away from the back.

45. The area of canvas is kept to a minimum to prevent accumulation of perspiration but at the same time the straps transmitting weight to the body are sufficiently large to eliminate discomfort, produced by pressure.

46. Details of the pack and release clips may be seen in the photographs. (Figs. 4,5,6 and 7.)

Preliminary trials

47. Preliminary trials were undertaken by the two designers, one wearing the 1937 type webbing and the other wearing the prototype equipment. The two were exchanged on alternate days. Marching (10-15 miles) and climbing over cliffs and rough ground with full equipment were undertaken to make a comparison between the two types.

48. Photographs were taken in order to compare the silhouettes. See Figs. 8 and 9. These showed:-

(a) in the lateral prone firing position-a reduction of 3 to 4 ins;

(b) when lying as close to the ground as possible-a reduction of $2\frac{1}{2}$ ins;

(c) in the forward facing prone position-a reduction of 3 to 4 ins.

The subjective impressions gathered during the trials were as follows:-

(d) the prototype was certainly more comfortable to wear than the 1937 type equipment and produced no local strain or fatigue;

(e) the prototype was less tiring than the 1937 type;

(f) no restriction of movement was apparent;

(g) sweat accumulation was not increased in the prototype;

(h) bouncing of the pack was equal in the two when running but not excessive in either;

(i) bouncing of the pouches was more with the prototype than with the 1937 type and as these lay across bony points of the pelvis immediately underlying the skin (the anterior superior iliac spines) a certain amount of discomfort was felt there, after a time.

Suggested modifications

49. As a result of these trials the following improvements suggested themselves:-

(a) The distribution of the weight between the hips and shoulders may be altered slightly (by means of the adjustable buckles) so that the shoulders carry slightly more weight than is at present the case. This two-point suspension from the top and the bottom should reduce the bouncing of the pack when running;

(b) The belt should be more easily adjustable in girth;

(c) If the belt fastenings are made slightly narrower than the belt itself, slide fastenings may be used to attach the pouches to the belt and these may be slipped off the belt when it is unfastened. In addition, if the belt is made slightly broader this combination should ensure greater stability of the pouches when the user is running;

(d) Instead of the large basic pouches at present used, pouches of about half the size may be attached to the belt in front or at the sides according to whether the user is walking or crawling. Pockets in the clothing may be used for Bren-Gun Magazines which are of an awkward size and shape and thereby, at the moment, prevent any reduction in the size of basic pouches.

MILITARY CONSIDERATIONS

50. When the military requirements of fighting order came under consideration it was soon realised that the investigation would have to be extended to include not only fighting order but also clothing and the necessity for and the design of marching order and equipment for porterage. To consider one small facet of the whole problem would lead to a great wastage of research in design and development and to a wastage of material when the equipment came into production and use. Overlaps and gaps in the field of utility of the different equipments so produced would be numerous.

51. Furthermore, unless clothing, fighting order, marching order and equipment for porterage are all developed together, some particular principle which has been developed in one may be negated when this is used in conjunction with another. For example, if the clothing is designed to be used without a belt and the load carrying equipment incorporates a belt as an essential part of its design, the two are incompatible. On the positive side, deficiencies in one item may be made good by suitable provision in another and the two made to interlock in design. For example, lack of a certain size and shape of pouch in the fighting order may be compensated for by the provision of suitable pockets in the clothing.

52. The whole problem is made even more difficult at the moment, by the state of flux which exists in the field of clothing and by the change which will probably take place in the type and design of weapons and mode of transport of men.

53. These factors render definitive design of fighting order useless at the moment. The whole problem will have to be co-ordinated and decisions made at a high level as to exactly what is required.

54. Several designs for fighting order have been made recently which show promising ideas. Also many more suggestions have been made for further designs. Until such time as the whole problem has been co-ordinated, designs and ideas will continue to be produced in great numbers, each one differing from the others to a greater or lesser degree. The number and variability of such designs is in itself a measure of how indistinct and vague is the final goal. It is felt that the most economical way to attack the problem is to form a team consisting of an experienced Army Officer, a representative from the Ministry of Supply, a Time and Motion Study expert, the G.S. branch concerned and a Physiologist.

55. Appendix A is devoted to a discussion on ideas of the military requirements which have been proposed from the user point of view. The lack of agreement concerning military requirements is shown in the discussion which represents the opinions of Army Officers concerned in Operational Research or the development of fighting order, each one having had considerable user experience.

CONCLUSIONS

56. As a result of the experimental work described and the theoretical discussions of the physiological principles involved in load carrying, certain conclusions are reached:-

(a) Carriage of loads on the hips is preferable to other methods;

(b) Less muscular effort is required to carry loads when these are close to the body and disposed in a balanced fashion.

RECOMMENDATIONS

57. It is strongly recommended that future designs of battle order have the following features incorporated in them:-

(a) The small pack to be supported on the hips and to be long, thin and narrow in shape;

(b) The pouches to be carried by the hips. The weight of the pouches should balance the weight of the pack;

(c) A small working party should coordinate all the load carrying problems in the Army and should consider how these recommendations can best be achieved. It should consist of an experienced Infantry Officer, a representative from S.W.V.1. and the Ministry of Supply, a Time and Motion Study expert and a Physiologist.

ACKNOWLEDGEMENTS

58. We wish to thank all who have taken part in the work and in the preparation of this report especially Mr. E.E.E. Treadwell, for the design and manufacture of the quick release mechanism and clips.

Superintendent, A.O.R.G.

SEPTEMBER 1950

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Appendix A

Carrying-Equipment for the Infantry Soldier, an Opinion Survey.

1. The following paragraphs represent differing opinions concerning Military requirements of and/or carrying-equipment and show how they conflict. Each is the opinion of an experienced officer.

(a) Requirements of fighting order.

Opinion (i) The amount of ammunition and fighting implements which the soldier will have to carry will probably increase in the future, and therefore the infantryman will not be expected to carry anything but these into battle.

Opinion (ii) There will be no great changes in the equipment which the infantry soldier will be expected to carry into battle in the future and the weight and volume will remain substantially the same. (i.e. ammunition and fighting implements plus water and a small amount of food and clothes.)

Opinion (iii) In addition to ammunition and fighting implements quite often the infantry soldier will be expected to carry substantially more than is at present the case. For example, when on patrol he may have to carry food, clothing and bedding for several days.

(b) Method of carrying fighting order.

Opinion (i) Everything should be carried in multiple pockets, either in the normal fighting garments, or a special item of clothing should be issued which has such pockets.

Opinion (ii) Ammunition should be carried in pouches, preferably easily detachable, and the rest of the equipment should be carried in pockets.

Opinion (iii) The chest is the only accessible position for pouches.

Opinion (iv) Pouches may equally well be placed at the back over the buttocks.

Opinion (v) The ammunition should be carried in pockets or pouches and the remainder in some type of small pack.

(c) Capacity of fighting order

The size of the pack is also open to dispute. Opinions range from the present type small pack to a larger pack with a stiffened back and finally to the mmupack carrier which is required on patrols to carry food, clothing and bedding. There is no agreement on the position in which such a pack should be carried. Some maintain that from the point of view of comfort, any pack must always be carried high up on the shoulders. Others maintain that the pack must be supported by the pelvis. Different degrees of importance are attached to the question of silhouette some maintaining that it is extremely important and others that it does not matter.

(d) Marching Order

Opinion (i) As ammunition and fighting implements increase in quantity and also as mechanisation improves, the infantry soldier will be expected to carry bedding and extra clothes less often and therefore equipment for marching order will be needed less.

Opinion (ii) Marching order will frequently be needed and provision for this should be a general issue.

Opinion (iii) Extra clothing and bedding should be placed in an extra pack, when it has to be carried, and attached to the fighting order. Provision is made so that this may be dropped quickly.

Opinion (iv) The extra clothing and bedding should be placed in a larger pack and to this should be added the contents of the small pack of fighting order. The small pack may be rolled up and also placed inside the larger pack. This arrangement renders the change to fighting order slower. But, if the ammunition is carried in separate pouches, it is argued that the large pack may be dropped instantly and the soldier can be ready to fight. In this case he is without the contents of his small pack which some people consider essential for fighting order.

(e) Equipment for porterage

Opinion (i) Equipment for porterage will rarely be needed and should be issued when required.

Opinion (ii) This will be needed fairly frequently. If man-pack carriers, which are considered to be well designed for load carrying, are made a general issue they will cover the need for carrying marching order and will be available for porterage and no extra equipment will therefore be needed. It is argued that this would produce a considerable economy in the total load-carrying equipment issued.

Appendix B

Electromyographic investigation of load carriage on the hips and on the shoulders

1. When a muscle contracts, small potentials occur in the individual fibres of which it is composed. These can be recorded using suitable apparatus, to give a rough idea of the state of contraction of the muscle. This method suffers from severe limitations in its application for several reasons.

2. Firstly, only those muscles directly underlying the pick-up electrodes can be investigated. Although some indication of the activity of the surface musculature can be obtained, it by no means follows that the state of the deep muscles can be deduced from these results.

3. Secondly, the electromyographic method differentiates only between contraction and relaxation of muscle. It does not give any reliable measure of the degree of contraction of a muscle. Not only is there stray pick-up from neighbouring muscle groups, but when muscles contract, their relative positions beneath the skin change. It follows from this that any system of multi-channel recording of muscle action potentials, using numbers of skin electrodes in order to **differentiate finely** between the degree of contraction of various muscles, is bound to produce extremely misleading results.

4. There is no doubt, however, that in spite of these difficulties the electromyographic method has a limited application to load carrying problems in that it is able to give a rough confirmation of the expected behaviour of certain large muscle groups. At AORG experimental work has been carried out in an attempt to differentiate between the muscular effort involved in hip and shoulder carriage.

5. The conclusion has been reached that the electromyographic method has no place in routine laboratory tests on specific carrying equipments especially when differences between them is small, although it is of use in the comparison of fundamentally different ways of load carriage.

Methods:-

6. Action potentials are led from the muscles by skin surface electrodes, consisting of brass cups ½ inch dia. and ½ inch deep, connected via ⅛ inch ext. dia. pressure tubing to a Bunsen vacuum pump Fig. 11. The cups are electrically connected via earthed balanced twin, low impedance cable to a push-pull amplifier. (Fig. 10).

7. The input, balanced with respect to earth, is fed to a push-pull buffer stage followed by a Tönnies compressor, which gives good discrimination between signal and interference. Two further stages in cascade, drive a cathode ray oscilloscope, the vertical deflection of which is photographed upon a continuously moving strip of bromide paper. The overall gain is such that when using electrodes over the extensor indicis longus, elevation of the forefinger results in a vertical deflection of the spot by about 4 cm. The apparatus is so arranged that the subject is able to walk and run a distance of 20 yards in the open, while records are being taken.

8. The electrodes are attached to the subject as follows (Fig. 12).

(a) Trapezius

(b) Cervical part of sacrospinalis

(c) Thoracic sacrospinalis

(d) Lumbar sacrospinalis

(e) Over abdominal muscles (rectus, int. and ext. oblique)

9. In all cases the subject stands at ease, attention, marches and halts, firstly wearing equipment carrying 45 lbs over the shoulders (1937 pattern web equipment), secondly carrying 45 lbs on the pelvis (AORG prototype) and thirdly unladen. Each experiment is carried out with electrodes untouched from beginning to end. Four subjects took part in 52 experiments.

Results

10. When the electrodes are placed on the back as in cases (a), (b), (c) and (d) above, very considerable difference in activity of the underlying muscles is observed. (Fig.13). Weight carried on the shoulder girdle causes a continuous contraction of Trapezius and the sacrospinalis. This is the case in all experiments.

11. In most, but not all, experiments there is lack of activity in these muscle groups when weight is carried on the hips. Records taken from the abdominal musculature give equivocal results. A very few records taken from other muscles (limbs and back) fail to reveal any significant difference in activity.

Discussion

12. The fact that there is considerable activity of the trapezius and of underlying muscles both when standing still and walking with the 1937 type indicates that these muscles are being used to keep the shoulder girdle elevated. When the weight is transmitted directly to the pelvis it is seen that these muscles are no longer in continuous use.

13. The increased activity of the sacrospinalis which occurs with the 1937 type equipment when walking, indicates that the high position of the Centre of Gravity in this case leads to a condition of increased instability compared with a method of load carriage in which the Centre of Gravity is lower down. This increased activity of the sacrospinalis represents the force necessary to restore the body to the vertical after its displacement during a step.

14. While it cannot be concluded from these results that hip carriage is invariably preferable to shoulder carriage, other factors being equal, it is reasonable to suppose that a method of load carrying involving less muscular effort to support the load is the more efficient.

Appendix C

Experimental investigation of load "balance"

1. Using the same technique as described in Appendix B the effects on the activity of major muscle groups can be investigated when loads are carried so that they are "balanced" or "unbalanced". A "balanced" load is so disposed that the centre of gravity of the component parts of the load coincides with that of the body. Loads amy be unbalanced laterally or anteroposteriorly.

Methods

2. Separate weights of 33 lbs each are hung on the shoulders and hips in different ways. The activity of the sacrospinalis and other superficial muscles is investigated as before, using electrode positions (a), (b), (c) and (d).

Results

3. It will be seen from the tracings produced in Fig. 14, that the activity in all cases tends to be much increased when the load is carried in an unbalanced manner.

Discussion

4. The fact that there is considerable activity of the back muscles when carrying a weight unbalanced, indicates that dorsal displacement of the combined centre of gravity is compensated by a continuous contraction of these muscles in order to fix the spine and hip joints in a position of semi-flexion.

5. When the weight is evenly distributed, as in the second series of experiments, little alteration in the vertical projection of the combined centre of gravity takes place, posture is normal, and there is little or no activity in the back muscles.

Appendix D

Experiments on local sweating

1. The total volume of sweat secreted by the body in a given time depends mainly on its expenditure of energy during the period and the "effective temperature" of the enviroment. The effect on expenditure of energy in carrying a particular load in different ways is relatively small, so that any resulting change in total sweat rate will be negligible over short periods.

2. Local accumulation of sweat, due to failure of its evaporation, is a major cause of discomfort during exercise. The design of load-carrying apparatus profoundly influences the extent of sweat accumulation when it is worn.

3. To demonstrate the degree of impairment of sweat evaporation due to any type of equipment, the areas of the body on which the accumulation of sweat occurs, can be demarcated.

Methods

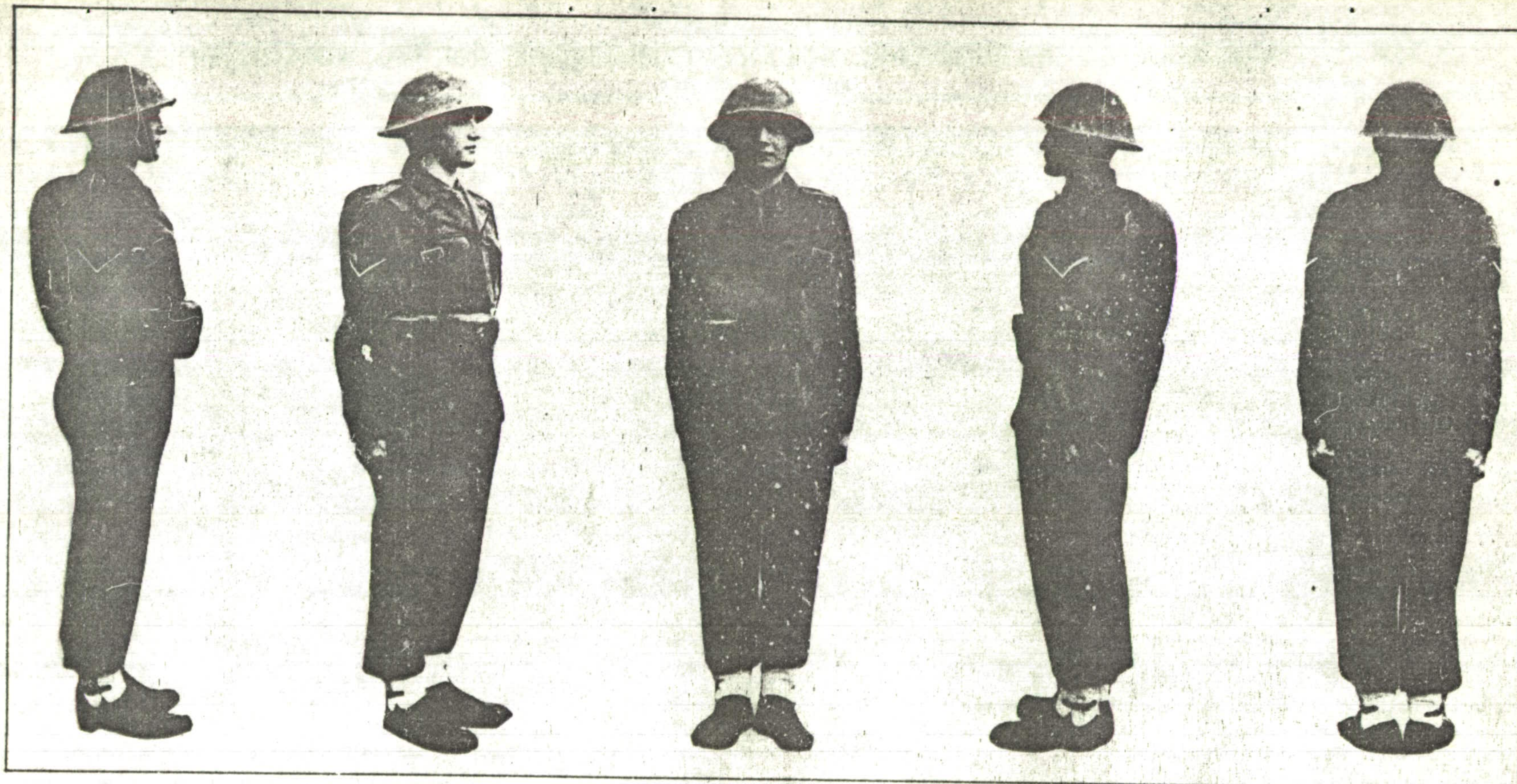
4. White "Aertex" vests (largest size to allow for shrinkage) are dyed evenly in a saturated solution of cobalt chloride. After drying in a forced ventilation heating cabinet, a vest is donned by the experimental subject. The equipment investigated is worn over the vest.

5. After a standard period of exercise in the hot chamber, the vest is photographed, front and back. Areas of sweat accumulation appear bright red. Areas where evaporation proceeds normally remain blue.

6. Photography is rendered difficult by the colours being very unsaturated (owing to the use of the white vest). Use of a minus blue filter of appropriate type together with panchromatic film gives the best results. Adequate contrast can however be obtained by using orthochromatic film and a blue filter.

Results

7. Fig.15 shows the comparison between 1937 type webbing and the AORG prototype. It can be seen that the areas of weight bearing show sweat accumulation in both types, but whereas under the pack and the numerous chest straps in the 1937 type are massive accumulations, the AORG prototype gives rise to very few additional areas of sweat accumulation.



BATTLE ORDER Mk.III SHOWING THE ALTERNATIVE OF TWO SMALL POUCHES REPLACING ONE LARGE POUCHE ON THE RIGHT. THE TWO SMALL POUCHES ON THE LEFT HAVE BEEN OMITTED TO SHOW THE POUCH FASTENINGS ON THE BELT.

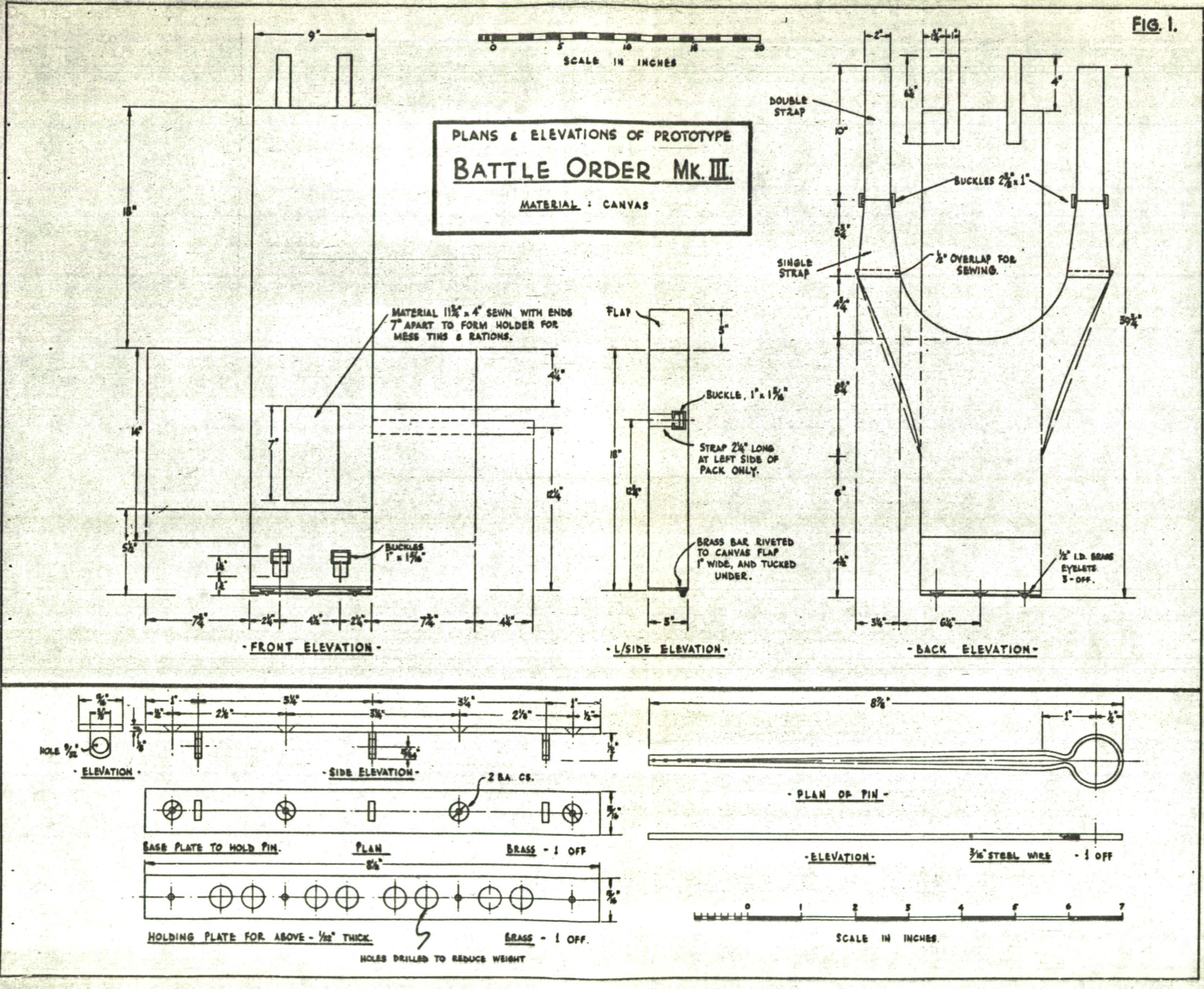
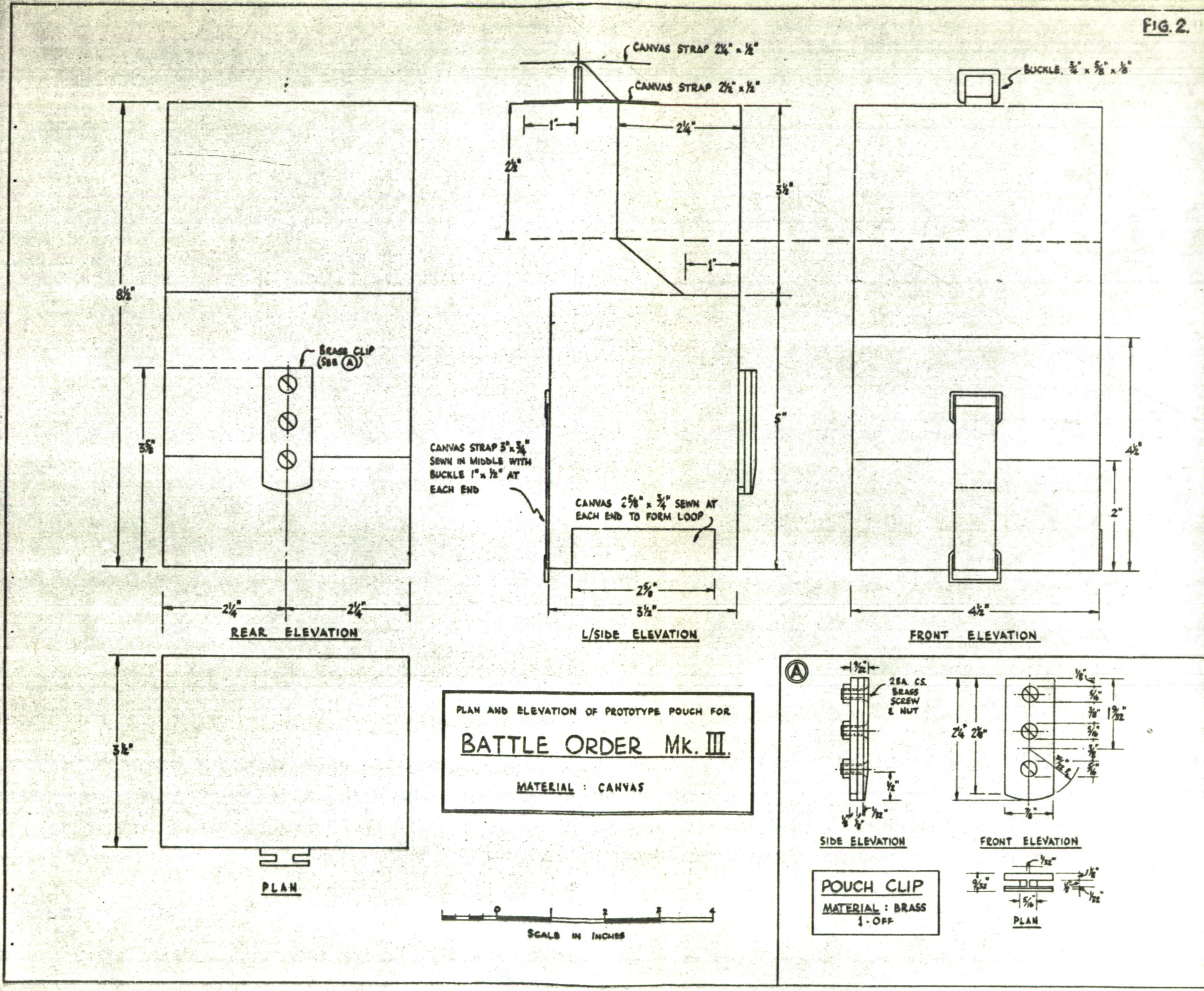


FIG. 1.
PLANS & ELEVATIONS OF PROTOTYPE
BATTLE ORDER MK. III.
MATERIAL : CANVAS
SCALE IN INCHES
MATERIAL 11¾" x 4" SEWN WITH ENDS 7" APART TO FORM HOLDER FOR MESS TINS & RATIONS.
BUCKLES 1" x 1⁵⁄₁₆"
- FRONT ELEVATION -
FLAP
BUCKLE, 1" x 1⁵⁄₁₆"
STRAP 2¼" LONG AT LEFT SIDE OF PACK ONLY.
BRASS BAR RIVETED TO CANVAS FLAP 1" WIDE, AND TUCKED UNDER.
- L/SIDE ELEVATION -
DOUBLE STRAP
BUCKLES 2⅜" x 1"
SINGLE STRAP
½" OVERLAP FOR SEWING.
½" I.D. BRASS EYELETS 3 - OFF.
- BACK ELEVATION -
HOLE ⁹⁄₃₂"
- ELEVATION -
- SIDE ELEVATION -
2 B.A. CS.
BASE PLATE TO HOLD PIN.
PLAN
BRASS - 1 OFF
HOLDING PLATE FOR ABOVE - ¹⁄₃₂" THICK.
BRASS - 1 OFF.
HOLES DRILLED TO REDUCE WEIGHT
- PLAN OF PIN -
- ELEVATION -
³⁄₁₆" STEEL WIRE - 1 OFF
SCALE IN INCHES.

FIG. 2.


CANVAS STRAP 2¼" x ½"
CANVAS STRAP 2½" x ½"
BUCKLE, ¾" x ⅝" x ⅛"
BRASS CLIP (SEE Ⓐ)
CANVAS STRAP 3" x ¾" SEWN IN MIDDLE WITH BUCKLE 1" x ½" AT EACH END
CANVAS 2⅝" x ¾" SEWN AT EACH END TO FORM LOOP
REAR ELEVATION
L/SIDE ELEVATION
FRONT ELEVATION
PLAN
PLAN AND ELEVATION OF PROTOTYPE POUCH FOR
BATTLE ORDER Mk. III.
MATERIAL : CANVAS
SCALE IN INCHES
Ⓐ
2BA. CS. BRASS SCREW & NUT
SIDE ELEVATION
FRONT ELEVATION
PLAN
POUCH CLIP
MATERIAL : BRASS
1-OFF

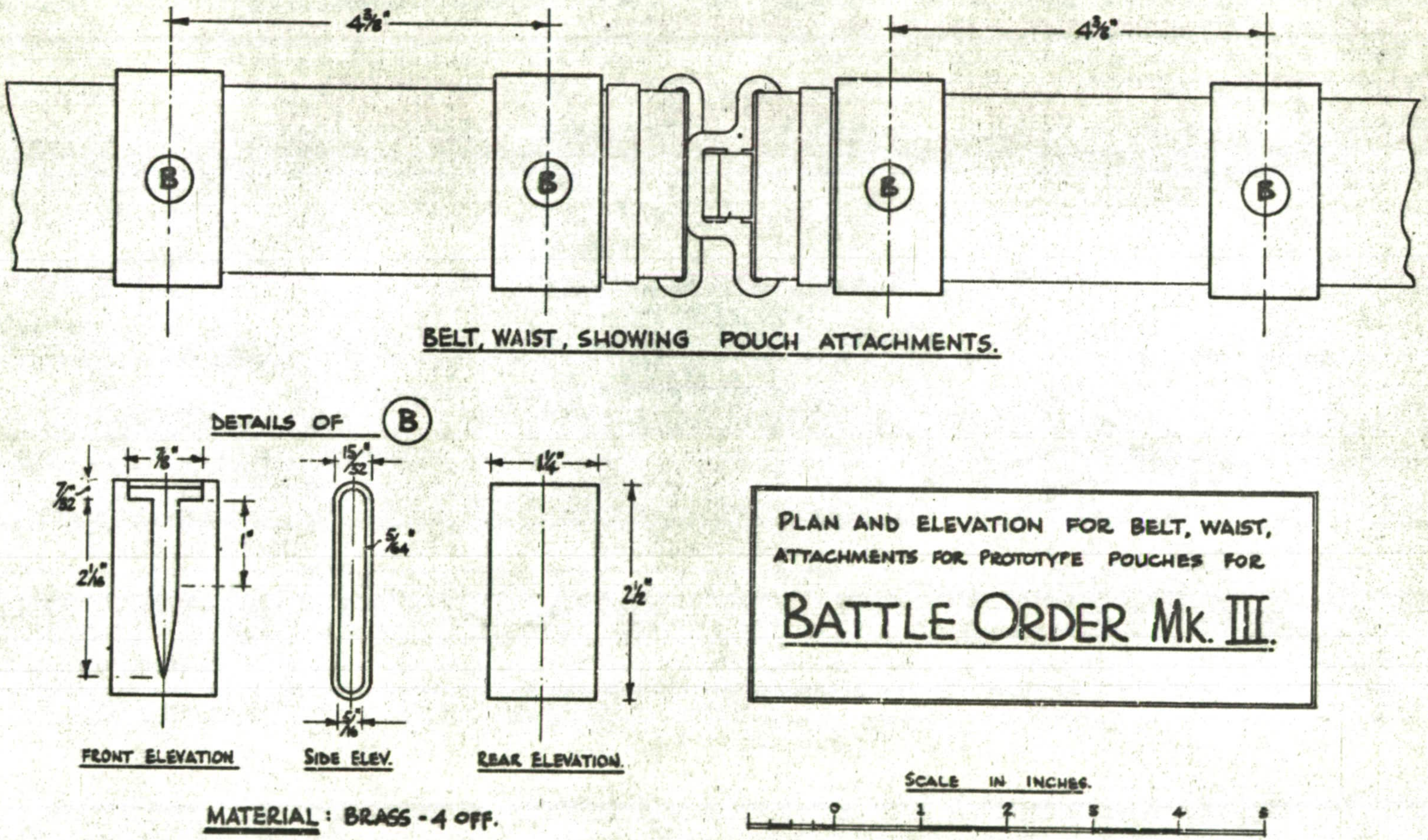
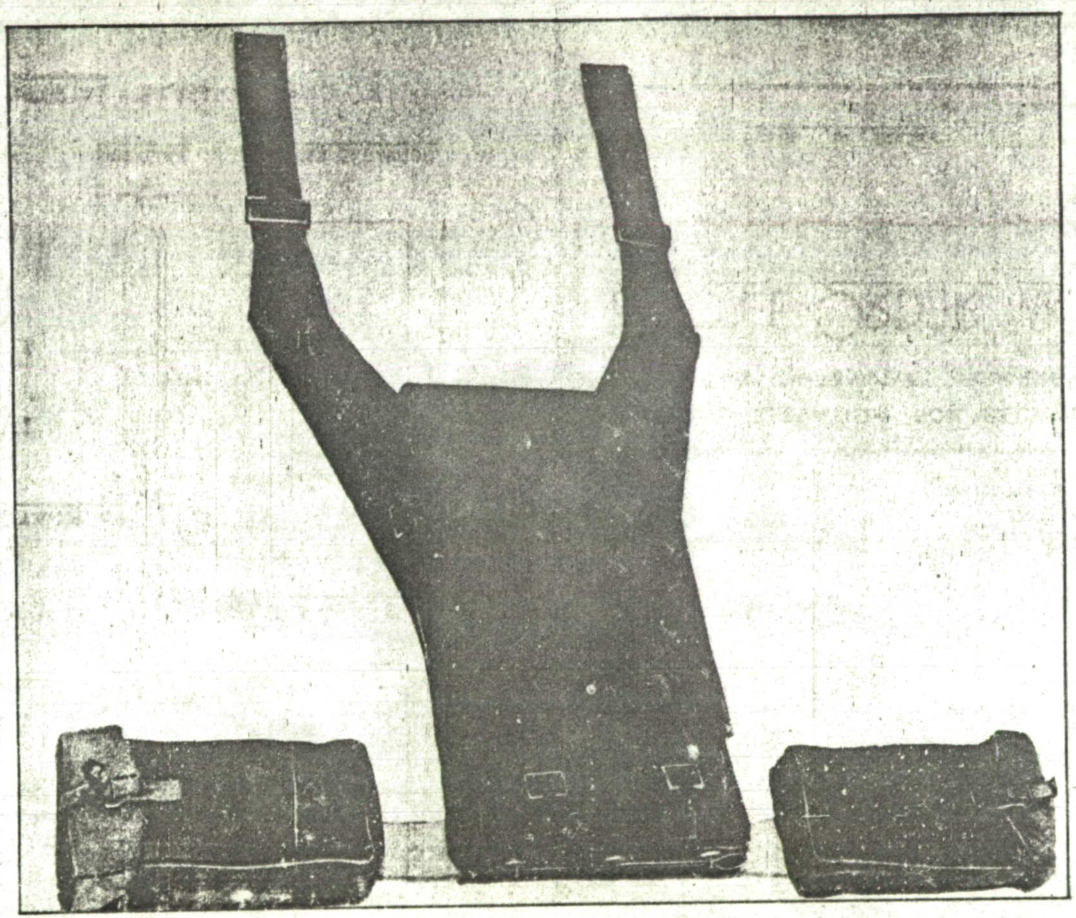

4⅜"
4⅜"
B
BELT, WAIST, SHOWING POUCH ATTACHMENTS.
DETAILS OF B
⅞"
7/32"
2 1/16"
1"
15/32"
5/64"
5/16"
1¼"
2½"
FRONT ELEVATION
SIDE ELEV.
REAR ELEVATION.
MATERIAL: BRASS - 4 OFF.
PLAN AND ELEVATION FOR BELT, WAIST, ATTACHMENTS FOR PROTOTYPE POUCHES FOR
BATTLE ORDER MK. III.
SCALE IN INCHES.
0
1
2
3
4
5

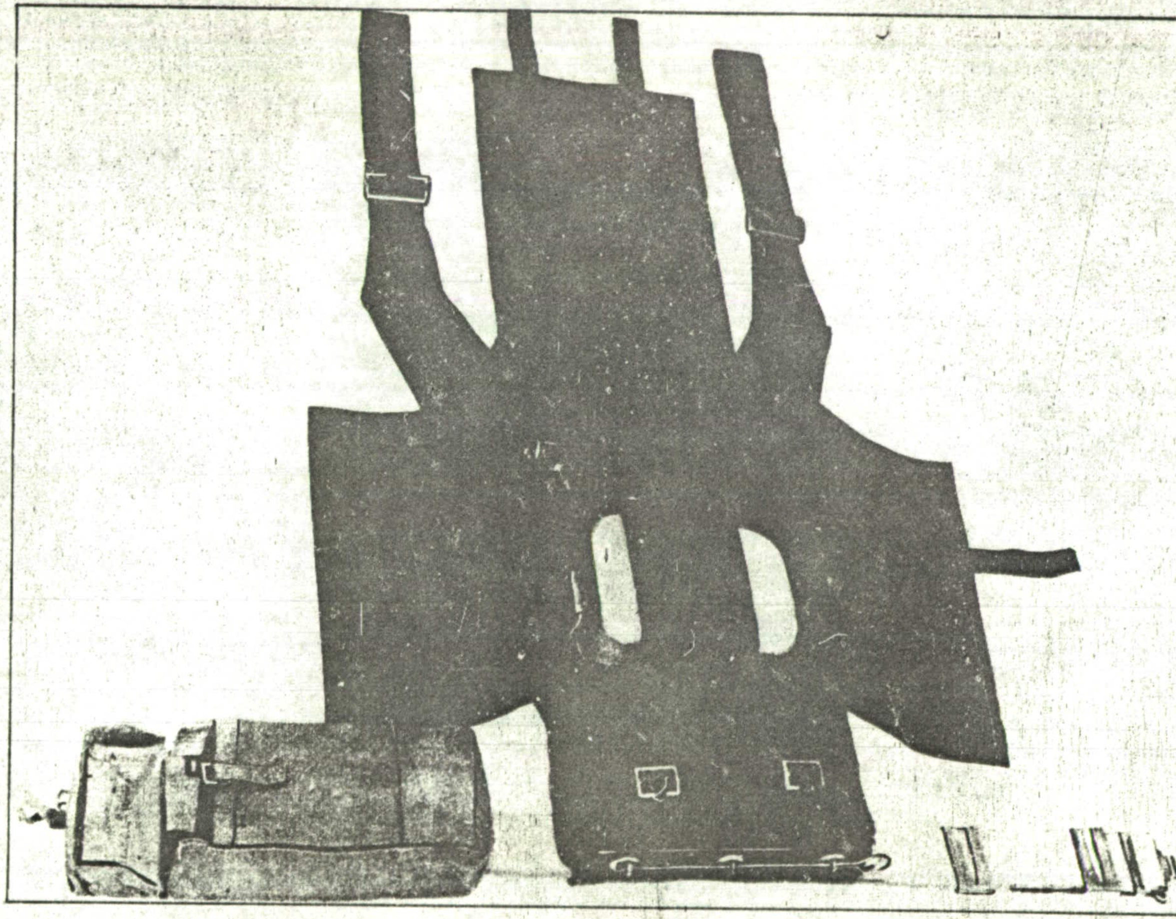
FIG. 3.

FIG. 4.



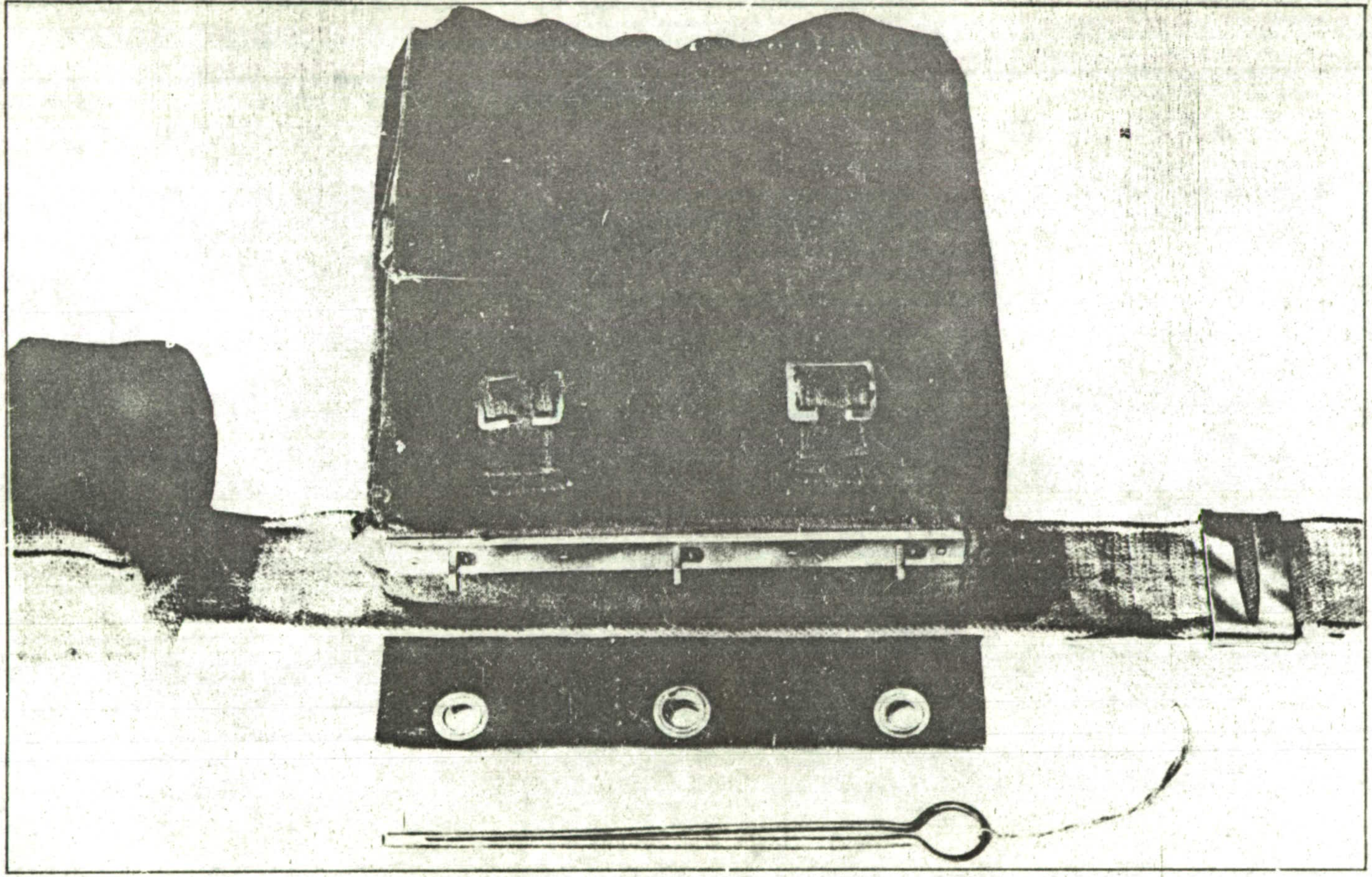
BATTLE ORDER MK.III. FITTED WITH TWO LARGE POUCHES. REAR THREE-QUARTER UNDERSIDE VIEW.

FIG. 5.



BATTLE ORDER MK.III WITH THE PACK OPEN AND ONE POUCH REMOVED.

FIG. 6.



QUICK RELEASE MECHANISM ON THE PACK. THE EYELETS FIT OVER THE BRASS SPIGOTS AND ARE KEPT IN PLACE BY A STEEL PIN.

FIG. 7.

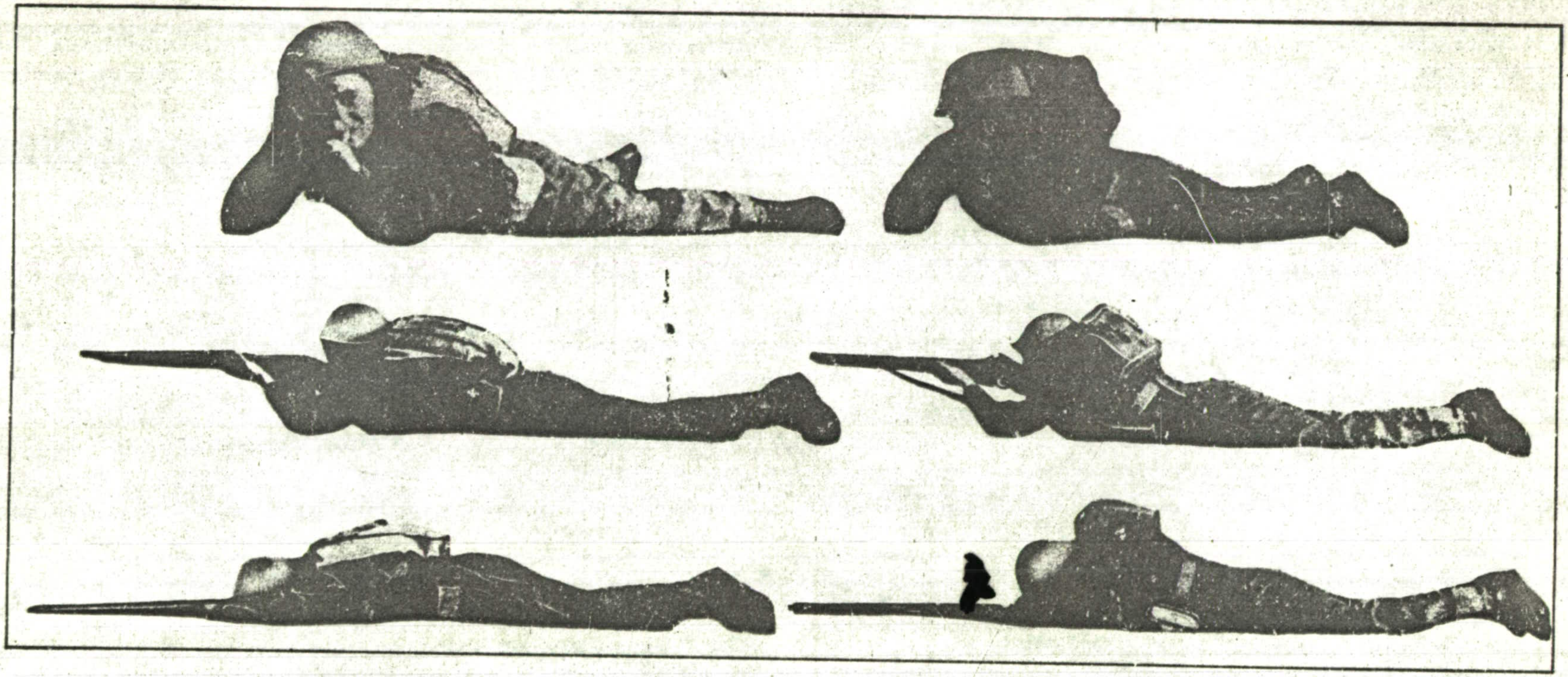
QUICK RELEASE FASTENINGS ON THE POUCHES.

ONE SLIDER IS SHOWN HALFWAY ENGAGED. THE OTHER SHOWS THE SLOT INTO WHICH SLIDES THE BRASS FITTING ON THE POUCH.

FIG. 8.

SILHOUETTES COMPARING THE 1937 TYPE EQUIPMENT WITH THE MK.III BATTLE ORDER.

FIG. 9.



SILHOUETTES COMPARING THE 1937 TYPE EQUIPMENT WITH THE MK. III BATTLE ORDER.

FIG. 10.

AMPLIFIER CIRCUIT.

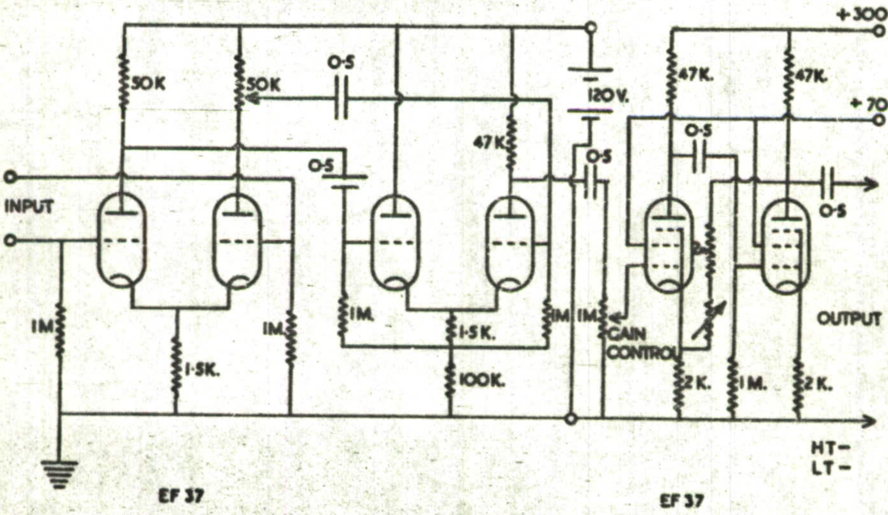


FIG. 11.

ELECTRODE ASSEMBLY.

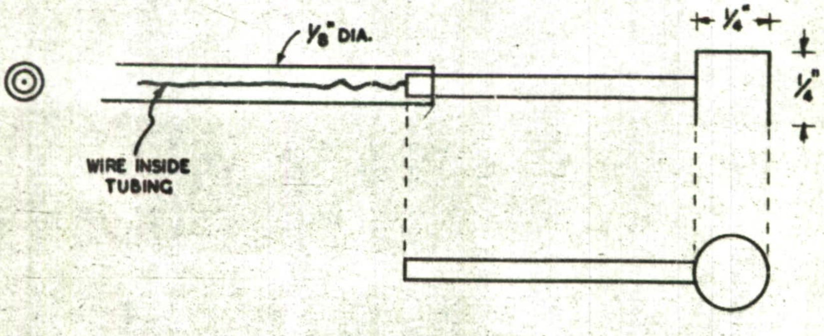
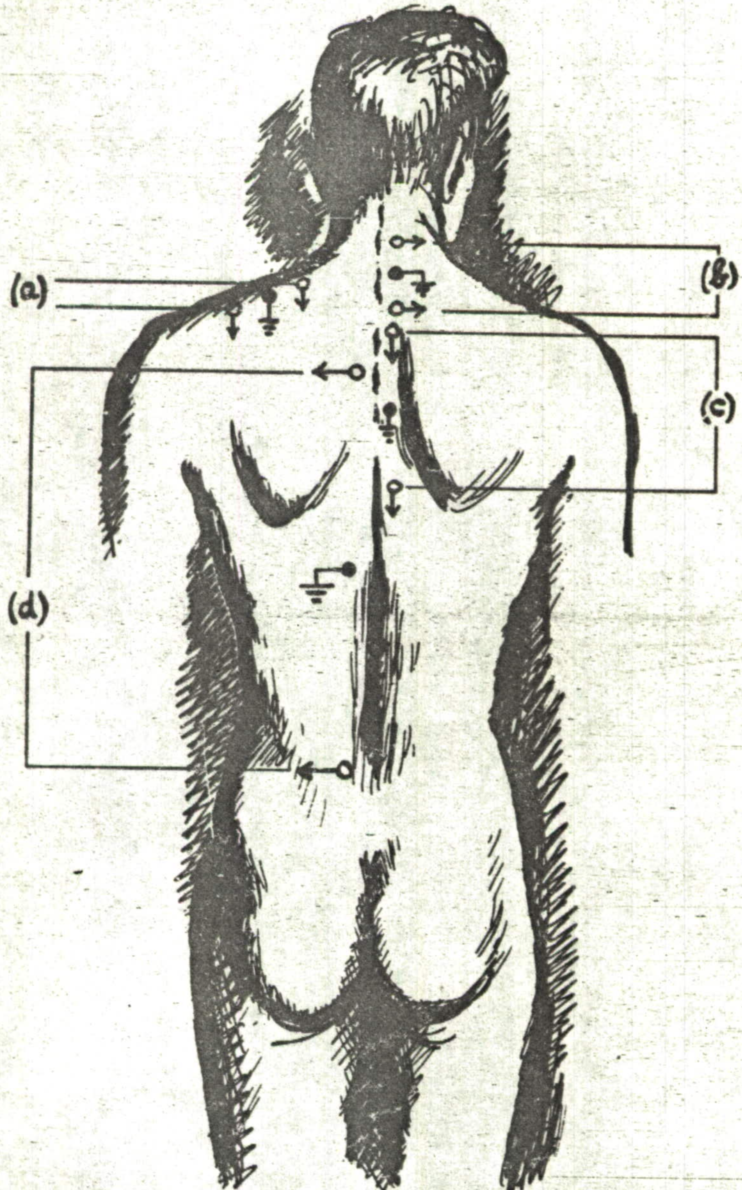
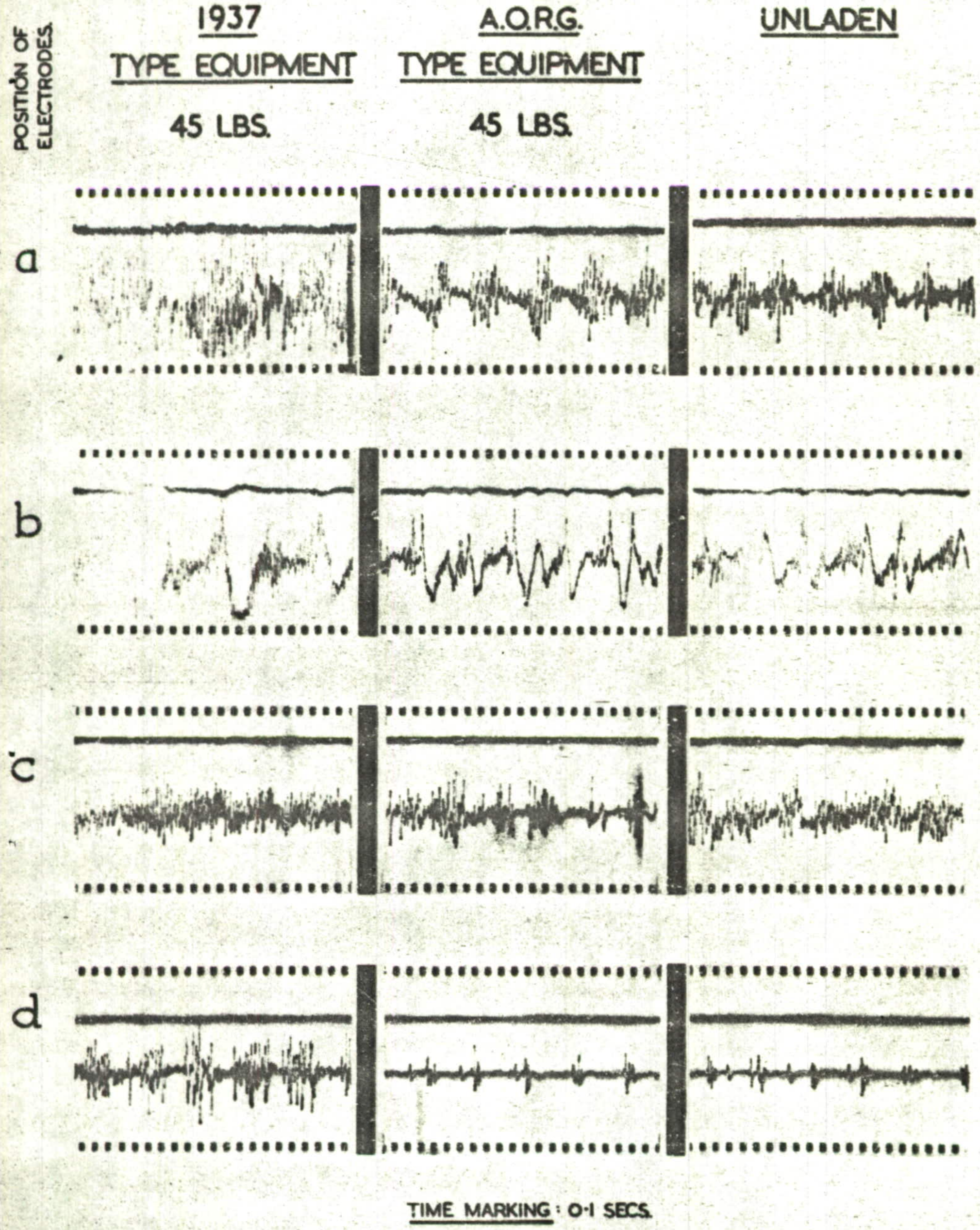


FIG. 12.



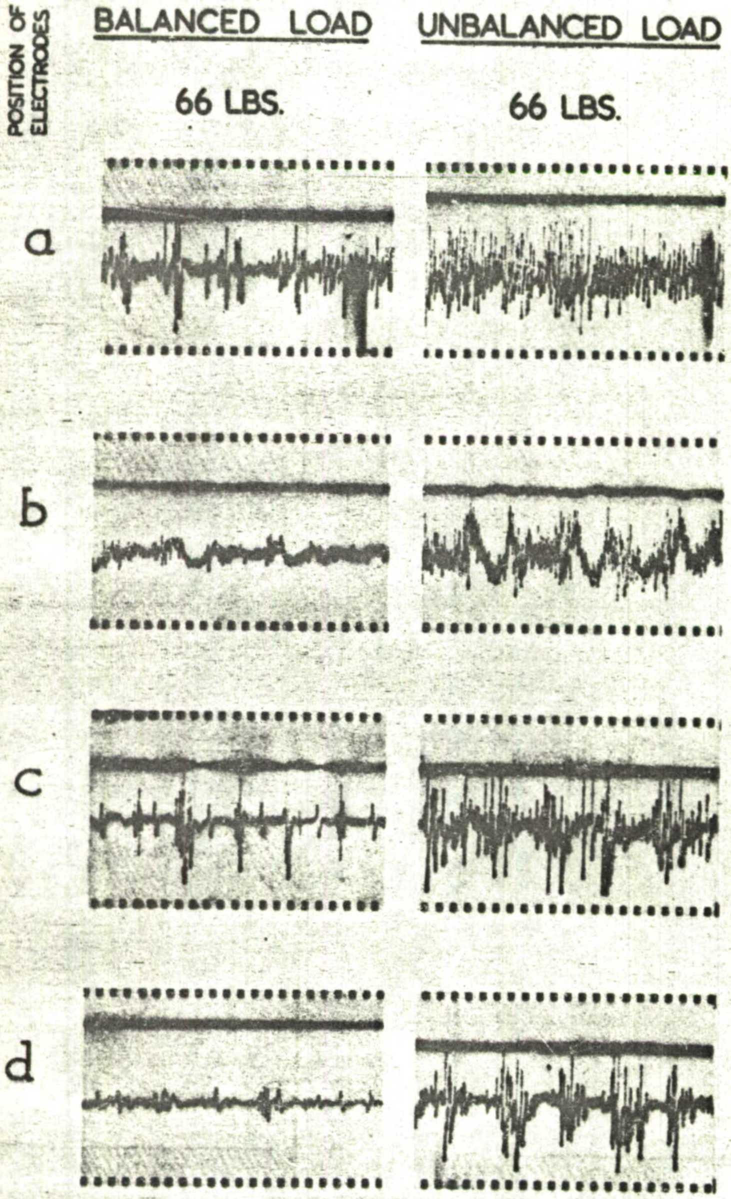
ARRANGEMENT OF ELECTRODES.

FIG. 13.



ELECTROMYOGRAPHIC RECORDINGS.

FIG. 14.



TIME MARKING: 0·1 SECS.

ELECTROMYOGRAPHIC RECORDINGS.

FIG. 15a.

1937 TYPE EQUIPMENT.

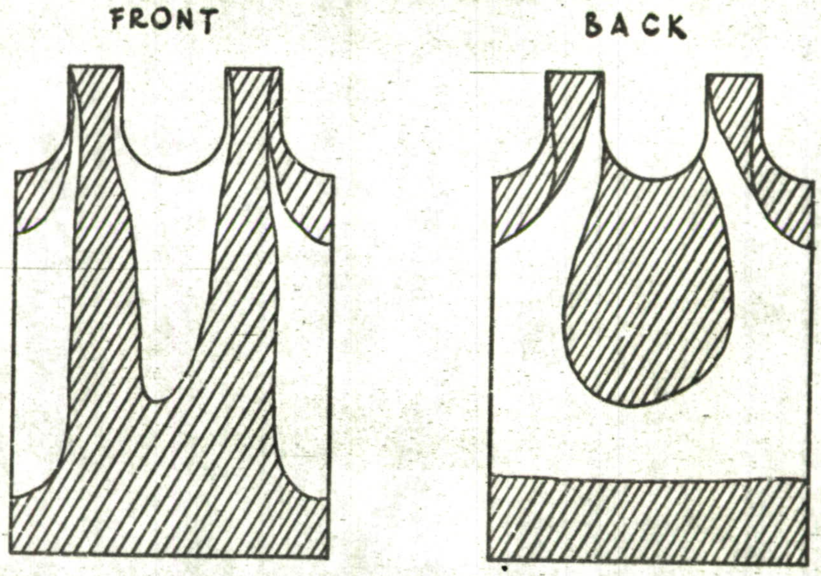
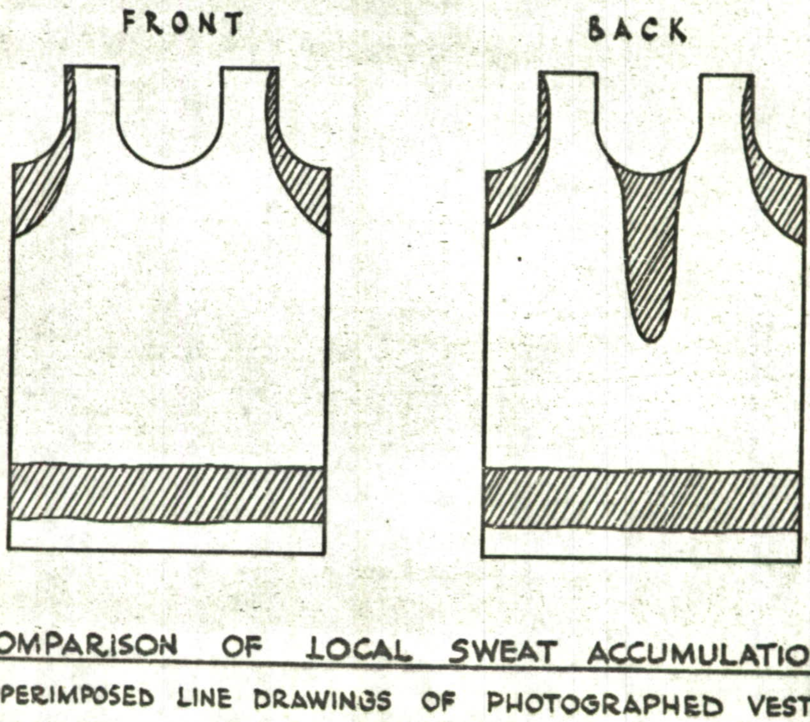


FIG. 15b.

A.O.R.G. PROTOTYPE.



COMPARISON OF LOCAL SWEAT ACCUMULATION.

SUPERIMPOSED LINE DRAWINGS OF PHOTOGRAPHED VESTS.

(5 EXPERIMENTS)

21598/4/50

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ORO	~~3~~
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