ARMY HYGIENE ADVISORY COMMITTEE REPORT No. 2.

An Investigation on the Motion Study of Digging and the Energy Expenditure Involved, with the Object of Increasing Efficiency of Output and Economizing Energy.

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SECTION IV.

PRACTICAL AND SCIENTIFIC TESTS OF THE PROPOSED NEW METHODS.

Tests of the proposed new methods were carried out on the following lines:

1. An initial practical test to prove the feasibility of these methods being taught in a drill.
2. By the determination of energy expenditure on work performed under the present and proposed new methods to arrive at a definite conclusion as to the increase or decrease in energy, cost and output.
3. By cyclegraph records of the present and proposed new methods to show a comparison of their respective motion paths.
4. By slow motion photographs of the present and proposed new methods to show their respective actions.
5. By a final practical test on two equal squads of untrained recruits to prove the increased efficiency (if any) of the proposed new drill.

1. The initial practical test proved that the methods suggested were feasible in every way and though trained subjects did not show any improvement in shovelling on the new method, the fact had been realized that men trained in one particular method of shovelling would require more than a few demonstrations on the improved method to change their natural mode at once, and that the untrained subjects would show the relative values of the two methods to a much greater extent and with less teaching. This was proved by comparing the figures of the two unskilled subjects "H" and "I."

2. Energy expenditure. Tests on the energy costs of picking, shovelling and combined work were first made on various subjects to give a rough idea of what the actual cost of digging was.

The figures showed that digging (pick and shovel work) from the point of view of energy expenditure is relatively costly and therefore frequent.
rest pauses are a necessity. Its cost may be compared to that of slow double marching carrying a total weight (clothing and equipment) of about ten kilos.

Picking, itself, is less expensive than shovelling, and these two types of work are so different in action that the one affords relief to the other and forms a distinctive rest to the different muscles used. The change over from one tool to the other (about five seconds on the average) is also a rest. In a long combined spell, therefore, the average hourly cost would fall below the figures actually obtained.

(A) COMPARISON OF THE RELATIVE ENERGY COSTS AND OUTPUTS OF THE PRESENT AND PROPOSED NEW METHODS OF SHOVELLING.

Condition of soil, tools, base, height and length of throw, rate and general conditions were standardized for these experiments, and unskilled subjects were chosen as being likely to give better relative results with the two methods.

The methods were performed alternately throughout the test series so that the factor of "freshness" would be eliminated. The subject "warmed up" to the work for a period of ten to fifteen minutes prior to the expired air being collected.

The actions and style of the present method were those taught and used at present in the S.M.E. Chatham.

Those of the proposed method were as described in Section 3 of this report.

Results.—The results obtained were very satisfactory in every way. Not only was the average output increased by nearly six per cent, but the average energy cost showed an actual decrease of over ten per cent; thus making for a total increased efficiency of sixteen per cent.

We are convinced that this great saving in energy with increased output is a result of combining the muscle actions of the trunk, legs and arms in the final throw, as against their separate action in the present method.

(B) COMPARISON OF THE RELATIVE ENERGY COSTS AND OUTPUTS OF THE PRESENT AND PROPOSED NEW METHODS OF PICKING.

Conditions of experiment were, as before, standardized; the actual output was measured by the amount of loose earth picked down from a definite working face to the trench base.

The originally devised new method when put to the test resulted in the large increase in output of twenty-nine per cent, but had a correspondingly large increase in energy cost of eighteen per cent, which we considered too expensive and so discontinued it.

Thus originally the pick-head was carried straight up to the per-
pendicular in the upward swing and the arms were not flexed to any degree. The cost of this was high.

It was now decided to allow the forward arm to bend to a right angle at the elbow at the top of the swing while still preventing the pick-head from falling behind the shoulder.

The actions and style of the present method were those taught and used at present in the S.M.E. Chatham.

Results.—The results obtained showed an average output increase of 9·5 per cent with a slight increase in average energy cost of 1·7 per cent, totalling up to an increased efficiency of nearly 8 per cent. These figures, though not as favourable as those obtained on shovelling, show nevertheless a distinct improvement over the present method.

In a combined spell of picking and shovelling therefore the proposed methods would result in an increased efficiency of nearly 24 per cent.

(3) Cyclegraph Study of the Present and Proposed New Methods.—To find out if the new drill drawn up and taught produced movements whose motion paths corresponded to those which we considered the most favourable in our preliminary study, cyclegraph records were made of a trained subject performing the picking and shovelling cycles in both the present and proposed methods.

Prints of the actual photographs taken are shown in fig. 8, and an explanatory table of these photographs on p. 103.

The results showed that the new drill was based on the correct lines and that the drill of the present method of shovelling accentuated if anything the rise in the path of the backward swing of the shovel prior to the throw (described in detail in the previous cyclegraph section).

The picking records of the new method showed the limited upward swing and the continuation of the raking stroke with the last movement of the break.

(4) Slow Motion Study.—Cinematographic records were taken of both the present and proposed new styles, and selected photographs at different points of the cycle are attached.

These show very clearly the differences in action between the two methods and will help to demonstrate efficient and inefficient movements.

(5) The Final Practical Test.—To test the efficiency of the drill on large numbers of men, and to prove its likelihood of increasing output and economizing energy, two equal squads of untrained raw recruits were chosen; conditions of height, weight, age, previous service and experience in digging being taken into account, and the two squads balanced as equally as possible as regards all these factors. Each squad to start with numbered twenty recruits. Three N.C.O.s instructed in the present system of digging drill were put in charge of one squad, an equal number of N.C.O.s instructed in the new type of drill were put in charge of the other squad.
PICKING AND SHOVELLING.

Present Method.

1. Pick-head and forward hand.

Proosed Method.

1a. T-piece and forward hand and high throw over arrow.

2. T-piece and forward hand—long throw over arrow.

FIG. 8.
EXPLANATORY TABLE OF CYC~EGRAP~ RECORDS IN FIG. 8

PRESENT METHOD.

Picking.—(1) Motion paths of pick head (continuous line) and forward hand (dotted line). Shows dropping of the pick head behind the shoulder path DE with the consequent after-raising to the perpendicular; the movement of the forward hand sliding down the helve until it meets the back hand—the absence of a raking stroke.

Shovelling.—(2) Motion paths of right hand (on T-piece) (dotted line) and left hand (on helve) (continuous line). Shows rise of path DE caused by the straightening of the knees and body causing the final throw (path EF) to be made by the arms alone.

(3) Paths as in (3). Shows action very similar to above (long throw).

PRESENT METHOD: ' 

Picking. Shovelling.

--- = Pick head. --- = Forward hand.
--- = Forward hand. --- = T-piece.

PROPOSED METHOD:

Picking. Shovelling.

--- = Pick head. --- = Forward hand.
--- = Forward hand. --- = T-piece.

KEY.

Picking. Shovelling
A—B = Downward stroke.
B—C = Raising small end of helve to break the earth.
C—D = Raking back the broken earth.
D—E = Raising head of pick upwards over shoulder for next stroke.

A—B = Backward swing.
B—C = Forward thrust.
C—D = Depression of T-piece.
D—E = Backward swing prior to cast.
E—F = Cast.

PROPOSED METHOD.

Picking.—(1a) Motion paths as above. Shows upward swing limited to the perpendicular; the break path BC followed by the raking down of the broken earth to the feet path CD; the limitation of the sliding down the helve movement of the forward hand.

Shovelling.—(2a) Motion paths as above. Shows the low path of action DE, followed by the final throw path EF which is a combined knees, trunk and arms movement. (3a) Motion paths as above. Shows action similar to (2) long throw.
Training was continued over a period of eight days, with three working hours in each day, totalling twenty-four hours.

Tests were carried out on the ninth and tenth days of the period, the first test being a definite task and the second a four-hour spell.

In these tests, which were intended to show the actual increase or decrease in output or time taken to complete the task, we decided to work the squad instructed in the present type of drill, resting at their own times (which is the present method), and to work the squad on the new drill on our rest-pause system (8 minutes work and 2 minutes rest with an extra 3 minutes at the end of each hour's work).

This original idea was somewhat changed at the suggestion of the O.C. Training Battalion R.E., whose recruits were being used in the test.

In order to make a comparison between the two drills alone, unaffected by rest pauses, both squads were worked to the eight-minute and two-minute type of rest-pause in the task work. Also an additional squad of partially trained recruits, but untrained in pick and shovel drill, was selected to complete the comparative series, and worked in its own time and rests.

In the four-hour spell we worked the squad on the new method according to the rest-pause system. Both other squads worked in their own time.

Results were gauged in the task work by the time taken to complete each separate task and then averaged up as shown in the table of results. After-condition was noted.

In the four-hour spell, results were gauged by a careful measurement of output. After-condition was again noted.

Results.—(A) Task Work.—438 cubic feet solid excavated. Measure of task: 3 feet deep by 4 feet 6 inches long by average breadth 3 feet 3 inches (R.E. pick and shovel).

(1) Squad “A”: On the new method (fifteen men).
   (i) Average time taken: 3 hours, 12 2/3 minutes.
   (ii) Condition afterwards: 14/15 good.
   (iii) Average type of soil: Clay, loam and large flints.

(2) Squad “B”: On present method (sixteen men).
   (i) Average time taken: 3 hours, 34 1/2 minutes.
   (ii) Condition afterwards: 12/16 good.
   (iii) Average type of soil: Clay, loam and large flints.

(3) Squad “C”: Untrained in drill (fifteen men).
   (i) Average time taken: 4 hours, 16 1/3 minutes.
   (ii) Condition afterwards: 10/15 good.
   (iii) Average type of soil: Top nine inches loam, below clay and large flints.
(B) Four-hour Spell.—Type of work: Excavating from three feet downwards.

Squad "A": On new method (eleven men):
(i) Average output: 38·1 cubic feet.
(ii) After condition: Good, 11/11.
(iii) Soil: Clay and large flints. One man struck friable chalk at six feet deep.

Squad "B": On present method (twelve men).
(i) Average output: 31·35 cubic feet.
(ii) After condition: Good, 12/12.
(iii) Soil: Clay and flints. Five men struck friable chalk and flints at five feet six inches.

Squad "C": Untrained in drill (eleven men).
(i) Average output: 26 cubic feet.
(ii) After condition: Good, 11/11.
(iii) Soil: Clay and flints; friable chalk and flints at five feet.

These results give the following percentages:

1) Task Work.
Taking the untrained squad as a basis.
Trained in present drill: 16·4 per cent decrease in time.
Trained in proposed method: 24·7 per cent decrease in time.
Taking "Trained in present drill" squad as a basis.
Proposed drill results in a 10·1 per cent decrease of time.
After-condition was best in the proposed method, next best in the present method, and worst in the untrained.
Soil was equal for the two trained squads and easier for the untrained squad.

2) Four-hour Spell.
Taking the untrained squad as a basis.
Trained in present drill: 20·6 per cent increase in output.
Trained in proposed drill: 46·6 per cent increase in output.
Taking the trained in present drill squad as a basis.
Proposed drill results in a 21·5 per cent increase in output.
After-condition showed no appreciable difference in the three squads.
Soil was easiest for the untrained squad, more difficult for the "present drill" squad, and still worse for the "proposed drill" squad.

Conclusions.
The results given above tend to prove that the new drill recommended for picking and shovelling produces a marked increase in output and a saving in energy. As this is the only test of its type that has been carried
out, the results may not be sufficiently accurate to warrant definite conclusions, but they undoubtedly point to a great increase in efficiency.

A long series of tests, to level up the factors of soil, physique, capabilities of instructors, previous experience and other minor elements which affect results, would alone show true figures.

SECTION V.

REST-PAUSE EXPERIMENTS.

Owing to the necessarily lengthy nature of these experiments, work under this section was started on two subjects only, and two men were selected who would be most likely to give average consistent results.

The method adopted was as follows: Each subject was given four hours' work to do and his rest intervals were carefully controlled by means of a stop-watch. The work consisted of digging a trench three feet wide by four feet deep, and the excavated earth was thrown up on to wooden bankers placed alongside the trench, where it was carefully measured in boxes and the time taken to fill each box was noted. In this way a record was obtained of the subject's output per minute as the time progressed. This method, however, had the disadvantage of not always including an equal number of pick spells and shovel spells in the time period for each box, and thus showed a very uneven estimate of output per minute over short periods. The output during the definite working periods was then noted, in lieu, and gave a much more even result.

Owing to sickness of one of the subjects it became necessary to start another subject working in his place so as to avoid the possibly unsteadying effect on the other subject of working alone. On the return of the subject who went sick his series was completed as was also the series of the new subject. Thus in some cases results have been duplicated.

In preparing the averages for comparison the average of all three subjects' averages has been taken and not the direct average of all experiments in each type of rest pause.

The rest intervals investigated were as follows:—


2. 12 minutes work, 3 minutes rest + 2 minutes extra rest at end of each hour. (14 minutes per hour.)

3. 8 minutes work, 2 minutes rest + 3 minutes extra rest at end of each hour. (15 minutes per hour.)

4. 7 minutes work, 3 minutes rest. All through whole period. (18 minutes per hour.)

5. Two complete pick and shovel spells and 2 minutes rest + 5 minutes rest at end of each hour. (Approx. 15 minutes per hour.)

6. 5 minutes work and 1 minute rest + 6 minutes extra rest at end of each hour (15 minutes per hour). A basis was obtained first by finding out the
frequency and length of each subject's rest intervals when working "at his own time"—called by us "voluntary rests."

The first organized rest pause investigated was the 12 minutes work 3 minutes rest as suggested in S.M.E. Fortification Circular No. 61 on Digging. It became apparent early on in this experiment that this relatively long working spell with so little rest tended to produce exhaustion very quickly, and forced the worker to take longer changing over from pick to shovel and vice versa, and also to depart from the optimum rates in the use of his tools. In view of this an extra two minutes rest were added at the end of each hour. In the last hour's work the final rest pause was brought forward and joined with the previous rest pause so as to avoid ending the period with rest.

The long-pause at the end of each hour was generally liked by the subjects and was adopted throughout the experimental series except in the 7 minutes work, 3 minutes rest type. The bringing forward of the final rest was considered good, but was better dealt with by distributing it throughout the final hour, as in types 8 minutes to 2 minutes and 5 minutes to 1 minute.

In each case the worker's own opinion was asked and has been recorded. Further a rough estimate of his condition after work was made.

The weather conditions during these experiments were most uncertain, and on several occasions experiments had to be discontinued owing to rain and the results discarded. On some days the soil was much damper than on others and materially affected output.

Another element which affected the results was the psychological factor, which was ever present to some degree. For instance, subject "D," under the impression that he was going to do the last of his series (experiment 5), worked throughout with the definite intention of "showing what he could do." The result was an average output of 907 pounds per minute, which shows what a tremendous effect the psychological factor may have on the capacity for work.

In every case the actual results have been tabulated and plotted, but an attempt to allow for psychic and other factors has been made. The only satisfactory way of overcoming such difficulties is to carry out a large number of experiments on a large number of subjects and take a general average. This has not been possible in the present work, which only gives a strong indication of the optimum, and not a definite and unchallengeable result.

It is interesting to note in the voluntary rest-pause experiment the two results obtained from subject "D." The first of these was obtained at the commencement of the series, and the second towards the end. In the second the subject had evidently been influenced by the organized rest-pause experiments carried out on him. His rest pauses were more evenly distributed, particularly as regards the amount of rest taken during each hour; and his hourly output was more even. A slight increase in output
is noticeable, though not marked. It was originally intended to apply the same test to the other subjects, but the disbandment of this section made this impossible.

Results.—From a study of the average of all the experiments undertaken the following points will be noted:

1 Voluntary rests. The average hourly rest was seventeen minutes three seconds, and the average output was 58.95 pounds per minute. General after-condition was medium. Subjects' opinion: Generally liked (as would be expected).

2 Twelve minutes work and three minutes rest. This gives an average hourly rest of fourteen minutes. Average output was 58.10 pounds per minute. General after-condition was poor. Subjects' opinion: Working spell too long. Disliked.

3 Eight minutes work and two minutes rest. This gives an average hourly rest of fifteen minutes. Average output was 65.57 pounds per minute. General after-condition was good. Subjects' opinion: General opinion was that the rest was sufficient. Liked.

4 Seven minutes work and three minutes rest. This gives an average hourly rest of seventeen minutes fifteen seconds. Average output was 63.42 pounds per minute. General after-condition was very good. Subjects' opinion: Generally liked, but the longer rest at the end of each hour was missed.

5 Two complete pick and shovel spells—two minutes rest. This approximated to an average rest of sixteen minutes twelve seconds. Average output was 61.0 pounds per minute. General after-condition good. Subjects' opinion: Generally liked.

6 Five minutes work and one minute rest. This gives an average hourly rest of fifteen minutes. Average output was 69.05. General after condition good. Subjects' opinion: Disliked. Both work spell and rest considered too short.

Taking the voluntary rest-pause experiment as a standard, the percentage increase and decrease in time and output is as follows for the organized rest-pause series:

<table>
<thead>
<tr>
<th>Spell</th>
<th>Time</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 minutes and 1 min</td>
<td>12 per cent decrease</td>
<td>17 per cent increase</td>
</tr>
<tr>
<td>8 min, 2 min</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>7 min, 3 min</td>
<td>1 increase</td>
<td>8</td>
</tr>
<tr>
<td>Two P. and S. spells</td>
<td>5 decrease</td>
<td>3</td>
</tr>
<tr>
<td>+ 2 min rest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 minutes and 3 min</td>
<td>1 decrease</td>
<td></td>
</tr>
</tbody>
</table>

Conclusions.

(1) Although the five-minute and one-minute spell shows the best results as regards output and total rest, the subjects' opinion and the fact that it would be difficult to control, rule it out for practical purposes.
(2) The eight-minute and two-minute and the seven-minute and three-minute spells are good for all practical purposes, the division of the time on a ten-minute basis facilitating the control of the working squad.

(3) The two-pick and shovel spells could not be controlled in a squad, but would in all probability be the best type for an individual organizing his own rests.

(4) The twelve-minute and three-minute spell is not good, both from results and subjects' opinion.

(5) Generally these results indicate that the onset of fatigue is checked by the introduction of suitable rest pauses. The pauses allow the waste products of muscular work to be got rid of by the system and thus prevent the local paralysing effect of these products on the end plates, and they combine with this a tonic effect on the central nervous system.

SECTION VI.
EXPERIMENTS ON NEW DESIGNS OF TOOLS.

(1) PICKS.

Varying weights of pick-heads were tested by the various subjects and the conclusion was reached that a head of about six pounds weight would produce the best results on all types of soil and be suitable for the average physique of the soldier.

The 8-pound head is too heavy and the 4½-pound head a little under weight.

(2) SHOVELS.

We came to the conclusion early on in our investigations that the present G.S. shovel is too small and too light for average shovelling and is not economic from the point of view of energy expended.

The R.E. shovel produced good results with trained men, but was not quite fitted for average trench work, being a little too broad in the pan and not being adapted for actual digging, i.e., has no tread.

Accordingly various designs of shovel pan were made and constructed on the general principle of combining the average weight of shovel load of the R.E. tool with the digging powers of the G.S. tool.

Unfortunately facilities for construction were not available to furnish us with shovels made to the exact weight detailed, so that though we had the exact sizes desired the weights were in all cases over specification and affected the optimum rate to a slight extent.

The average shovel load however gave interesting results.

Results.—From a consideration of the results obtained on the various designs of shovel tested we are of opinion that for the average man and in all types of soil a design on the following measurements will approach nearer the optimum than any other. (See fig. 11.)

Description.—Pan well scooped, 1½ inches at deepest point in pan.
Pan, frog and straps forged from solid. Top edges of pan turned over to form treads.

Pan 13 inches × 9½ inches. Treads ¾ inch × 3 inches. Set of straps and helve as in R.E. shovel. Length 3 feet 5 inches over all. Weight 5 pounds.

Fig. 11.

ADVANTAGES.

1. This shovel will take a slightly larger average shovel load on account of the shape of the pan and the fact of the treads preventing earth falling away during the upward throw.

2. The pan being narrower than the R.E. type, will be more suitable for shovelling in a confined space and in heavier soils.

3. Owing to its shape and design it can be used for actual digging.

4. There is no increase in weight over the R.E. shovel.

5. Combining the qualities and uses of both the R.E. and G.S. shovels it will suffice as a universal type for all services, and will thus do away with the present two types.

SECTION VII.

GENERAL CONCLUSIONS.

1. We are of opinion that the drill we have formulated for picking and shovelling will, if properly instructed, increase average efficiency in digging by about twenty per cent, by an increase in output and a saving in energy cost.

2. This twenty per cent increase in efficiency will be obtained over the results of the present drill, and another twenty per cent may be claimed over the results of the untrained man.

3. It has been proved that this drill can be easily picked up by the average man and will not require more than a few days training.

4. During a long task or spell we advise a systematized form of rest pauses to be taken. Probably a seven minutes working spell and a three minutes rest period or an eight-minute work and a two-minute rest approach nearest the optimum. These organized rest pauses are easy to control by an N.C.O.

During these working spells the use of the tools should be continued at
the optimum rates of 17-19 throws per minute for the shovel, and 25-30
strokes per minute for the pick.

(5) Various important directions for picking and shovelling have been
laid down in Section III, and compliance with them is essential if efficiency
is to be aimed at.

(6) We consider a three-four hour spell with the definite rest pauses as
advised, an optimum period of work. The subjects will turn out a good
output and will be in good general condition afterwards. An average hourly
output on this spell will be from twenty-five to thirty cubic feet per hour,
in a medium type of soil, and under conditions as laid down in Appendix

(7) We consider that for the average man and in different types of soil,
the best size, shape, and weight of pick and shovel would be as described
in Section V of this report.

(8) Finally, we are of opinion that these conclusions should be
thoroughly tested on large bodies of men to prove their general efficiency.

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