A STUDY OF THE TIME RELATIONSHIPS BETWEEN THOUGHT-CONTROLLED AND AUTOMATIC MANUAL MOVEMENTS

Thesis for the Degree of M. S.

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This is to certify that the

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A THESIS

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ABSTRACT

This thesis reports the experiment methods and results concerned with the following investigations conducted in the Industrial Engineering Laboratory at Michigan State University by the writer, served by sixteen experimental subjects:

1. A study of the determination of the relationship between human simple reaction time and simple manual movement time.

2. A study of the determination of the time relationships between inspection time and posting time.

From the experiment results, the following conclusions are suggested for situations typified by the experimental conditions:

1. Measurement of the simple reaction time to a simple audible signal of job applicants in industry may be used to predict, with certain qualifications, their maximum working speeds.

2. Since it was found that there were significant differences in the changes of working speed, comparing thought-controlled inspection time with the less thought-controlled posting time, as the experimental subjects went from their natural to their maximum speeds, it suggests that the synthetic rating technique (applying ratings assigned to easily rated automatic manual duties to thought-controlled duties) would not be sound when used in behalf of simple

inspection jobs as typified in the experiments.

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CHAPTER I

INTRODUCTION

Time standards are one of the most important fundamental units of information in the field of scientific management. They are useful to virtually all manufacturing enterprises, fundamentally for the following functions:

1. Design of product.
2. Design of production facilities and methods.
3. Determination of operation standards required to control production and evaluate productive efficiency.
4. Planning and scheduling of production.

Because of the many important uses of time standards, it is necessary that they be carefully and properly established. To set a time standard for a given operation, the estimated normal work time and the estimated operator personal, fatigue and delay requirements are added together. Normal work time is usually measured through direct stop watch time study. It is obtained by multiplying the working time observed by the time study man by the estimated "rating" at which the operator works. If the time study man feels that the operator works at an efficiency which is twenty per cent faster than normal during his timing, then the operator is rated at one-hundred and twenty per cent. Thus, the estimated normal time for the operation is the observed working time multiplied by one-hundred and twenty per cent.

Since the process of rating is generally the least accurate determinant in the setting of time standards, the time study man's ratings (judgements) have been the object of controversy. It is intended that this thesis will contribute toward the betterment of the science of setting time standards.

This thesis treats the question: Do operators perform thought-controlled acts (acts requiring decisioning during their performance) and automatically decisioned acts (henceforth to be called "automatic acts") at predictable efficiency (rating) ratios? If they do, then time study men can rate thought-controlled acts with virtually the same degree of reliability with which they rate the presently more easily rated automatic acts (predominantly rhythmic manual work).

If it is found that thought-controlled acts are performed at approximately the same ratings as automatic acts, such acts can, under certain conditions, be reliably rated by assigning to these acts ratings applied to the automatic acts in the work cycle in which they are included. This procedure is conventionally called "synthetic rating". If, however, it is found that thought-controlled acts are performed at higher or lower ratings than automatic acts, such acts can be rated by applying the ratings exhibited in behalf of automatic acts, factored by the known degree of difference of performance of thought-controlled and automatic acts.

Since thought-controlled acts are characterized by numerous decisions requiring, more fundamentally, reactions to various stimuli, the question "do operators generally perform thought-controlled acts at the same ratings they perform accompanying automatic acts?" would seem to warrant determining the degree of correlation between reaction time and automatic movement time. If a high positive correlation is found between reaction time and simple manual movement time accomplished at maximum motivation level, such findings would seemingly suggest that qualified, trained operators performing work at a consistent maximum motivation level perform both thought-controlled acts and automatic acts at approximately the same rating. Of course, different operators would have different maximum rating (efficiency) potentials due to natural individual differences. Thus, through the application of the synthetic rating technique, the time study man could indirectly (synthetically) rate thought-controlled work performed at maximum motivation level with virtually the same degree of proficiency he could directly rate the automatic movements performed at maximum motivation level.

In practice, operators seldom perform at maximum motivation level. Thus, assuming the aforementioned high positive correlation exists between reaction time and simple manual movement time accomplished at maximum motivation level, the following question should be answered in determining the validity of the synthetic rating technique applied under these practical conditions. As one slows down from maximum motivation level to his natural motivation level, is there any significant change in the ratio of times spent in behalf of thought-controlled acts and accompanying automatic acts at these two motivation levels? If there is no significant change in these ratios, and if a reasonably high positive correlation has been found between reaction time and automatic act time at maximum motivation level as discussed above, it would seem possible to validly conclude, for the conditions under study, that persons working at their natural motivation levels perform their thought-controlled and automatic acts at approximately the same ratings, thus calling for the application of the synthetic rating method in behalf of the thought-controlled acts. On the other hand, if there is a significant change in the ratios and if a reasonably high positive correlation has been found between reaction time and automatic act time at maximum motivation level as discussed above, it would seem possible to validly conclude, for the experimental conditions under study, that persons working at their natural motivation levels perform their thought-controlled acts at ratings a certain degree faster or slower than the ratings at which automatic movements are performed.

CHAPTER II

OBJECTIVES

The objectives of this thesis are as follows:

1. To determine the degree of correlation between human reaction time to an audible signal and human movement time when experimental subjects work at maximum motivation level (Experiment A).

2. To determine the time relationships between thought-controlled and automatic manual movements of experimental subjects working at natural motivation levels and then working at respective maximum motivation levels (Experiment B).

3. To draw conclusions from the results of Experiments A and B related to the problem of time study rating the performance of thought-controlled acts.

CHAPTER III

LITERATURE SURVEY

One of the first psychologic phenomena to be investigated was reaction time (1). Reaction time is defined as a measure of the amount of elapsed time between the onset of a stimulus and the required response (2). In the writer's search for related studies, he found reaction time commonly used as a factor in work measurements and in mental abilities.

Ross A. McFarland. In an article by Ross A. McFarland "The Role of Speed in Mental Ability" (3), several studies on the role of speed in mental ability were cited. He wrote of the discussion by Binet and Henri in an article on "Individual Psychology" on the question of the inter-relationships of different mental functions in which they stated that persons who are slow in ordinary reactions, such as walking or writing, are probably slow in ordinary reaction experiments. This statement was later qualified by Binet by saying that this is only a probable conclusion. McFarland wrote on certain investigations in which speed or reaction was either related or not related to the higher mental process or some factor in mental ability. In all these studies, total evidence, although somewhat contradictory in nature, tends to favor the existence of a positive relationship between rate and mental ability. However, McFarland suggests that research confined to laboratory technique is necessary in order to clear the issue and to establish the negative or positive significance of that important problem.

F.M. Henry. In the article "Independence of Reaction Time and Movement Time" by F.M. Henry (4), no correlation between reaction time and movement time was found in a ball snatch and treadle press task. This study involved discrete movements which ended in the snatching (grasping) of a suspended ball and depressing a treadle. The hand reached forward and upward twelve inches to snatch a suspended ball and moved it one-eighth of an inch to end the movement. In the writer's opinion, the act "snatching" involved a certain degree of adjustment and may have lead to a sizeable deceleration of movements for the less skilled experimental subjects. Furthermore, no mention was made of the degree of motivation of the experimental subject while performing the experiment. Therefore, in the writer's opinion, had Henry experimented on a simpler manual movement and performed at maximum motivation level, it is quite possible he could have arrived at a different conclusion.

J. H. Westerlund, W. W. Tuttle. In a study of "The Relationship Between Running Events in Track and Reaction Time" made by J. H. Westerlund and W. W. Tuttle (5), a high correlation of +0.86 was found between reaction time and speed in sprinting for several athletes trained in track running.

In this investigation, it is the writer's opinion that one cannot draw the conclusion that measurement of reaction time can be used to predict speed of movement made in behalf of industrial operations, although the high positive correlation does suggest such a conclusion. As such, it was therefore deemed beneficial by the writer to explore a possible aspect to the problem by experimenting with a simple manual movement typifying industrial bench work operations and then, from the results thereof and subject to the conditions of the experiment, suggest conclusions pertaining to the relationship of reaction time and speed of simple manual movement.

The literature survey was conducted farther to include the process of rating the thought-controlled acts or those acts requiring concious decisioning during their performance. In more conventional terminology, the problem was to investigate from other research reports, the validity of "synthetic rating" and its application to this area of rating thought-controlled portions of work.

Synthetic rating has been discussed by authors such as M. E. Mundel (6) and B. W. Niebel (7) but not one of them has presented evidence of evaluation of its soundness.

R. L. Morrow (8), in his book "Time Study and Motion

Economy", has proposed the basic assumptions that within limits, all manually controlled elements of a time study are affected equally by variations in operator pace, exertion, attitude, skill, etc. P. W. Schwab (9), claims to have investigated the truth of this statement, and concludes that the basic assumptions proposed by Morrow were not even remotely tenable and that the residual error with such a procedure had limits too wide for acceptance.

L. G. Ritzema (10), in his thesis "An Investigation of the Validity of Synthetic Rating" investigated the validity of synthetic rating under certain conditions by determining whether there is any significant difference in the change of rating in performance of skilled elements as compared with unskilled elements as operator motivation level increases from low to high. The conclusions he suggested were:

1. The experimental results obtained indicate that there is no significant difference in the change of rating in performance of skilled elements as compared with unskilled elements as operator motivation levels increase from low to high.

2. These findings therefore suggest that unskilled elements are performed at about the same speed rating as skilled elements, when these elements are performed by qualified, well-trained and well-motivated operators.

3. The experimental results obtained, therefore, tend to support the validity of synthetic rating as an improve means of establishing better time standards.

In the writer's opinion, Ritzema did not conduct his experiments in a manner of refinement sufficient to warrant final sound conclusions pertaining to the validity of the synthetic technique. For example, there does not seem to be a significant difference in complexity of the "skilled" elements as compared with the "un-skilled" elements of the two operations involved in his experiments. Also, the timings of the elements of the two operations involved in his experiments were performed manually by the experiment director, who tapped the timing switch at his observed endings of the elements of work comprising the cycle. This procedure may have subjected his obtained time values to various inaccuracies accountable to the human error of judgement. The director who tapped the timing switch at his observed endings of the elements could have very easily incorrectly judged the endings of said elements in some instances.

CHAPTER IV

THE EXPERIMENTS (GENERAL)

Work-Place and Surroundings. The experiments of this thesis were performed in the Industrial Engineering Laboratory of Michigan State University. The room was approximately 18 feet wide and 25 feet long. It was well illuminated and ventilated. The work-place consisted of a work table approximately 2 1/3 feet wide, 5 feet long and 3 feet high. A work stool which was adjustable to allow the forearm of the experimental subject to be parallel to the top of the table, was provided. For Experiment A, (see Figure 1), a micro-switch, henceforth to be called "manual posting switch", was fixed in front of the experimental subject and a few inches from the edge of the work table. This was the switch used to perform the reaction test. A two-inch diameter thin metal marker was also positioned and fixed fifteen inches beyond the manual posting switch. This, in conjunction with the manual posting switch, was used to perform the fifteen-inch push-pull arm movement, henceforth to be called the "push-pull movement". For Experiment B, (see Figure 2), the manual posting switch was fixed in front of the experimental subject at a point approximately fifteen inches away. An inspector's sheet, 4 inches by 8 inches which was used to record data, was fixed close to the manual posting switch. A cross-marked piece of paper fixed at a point slightly

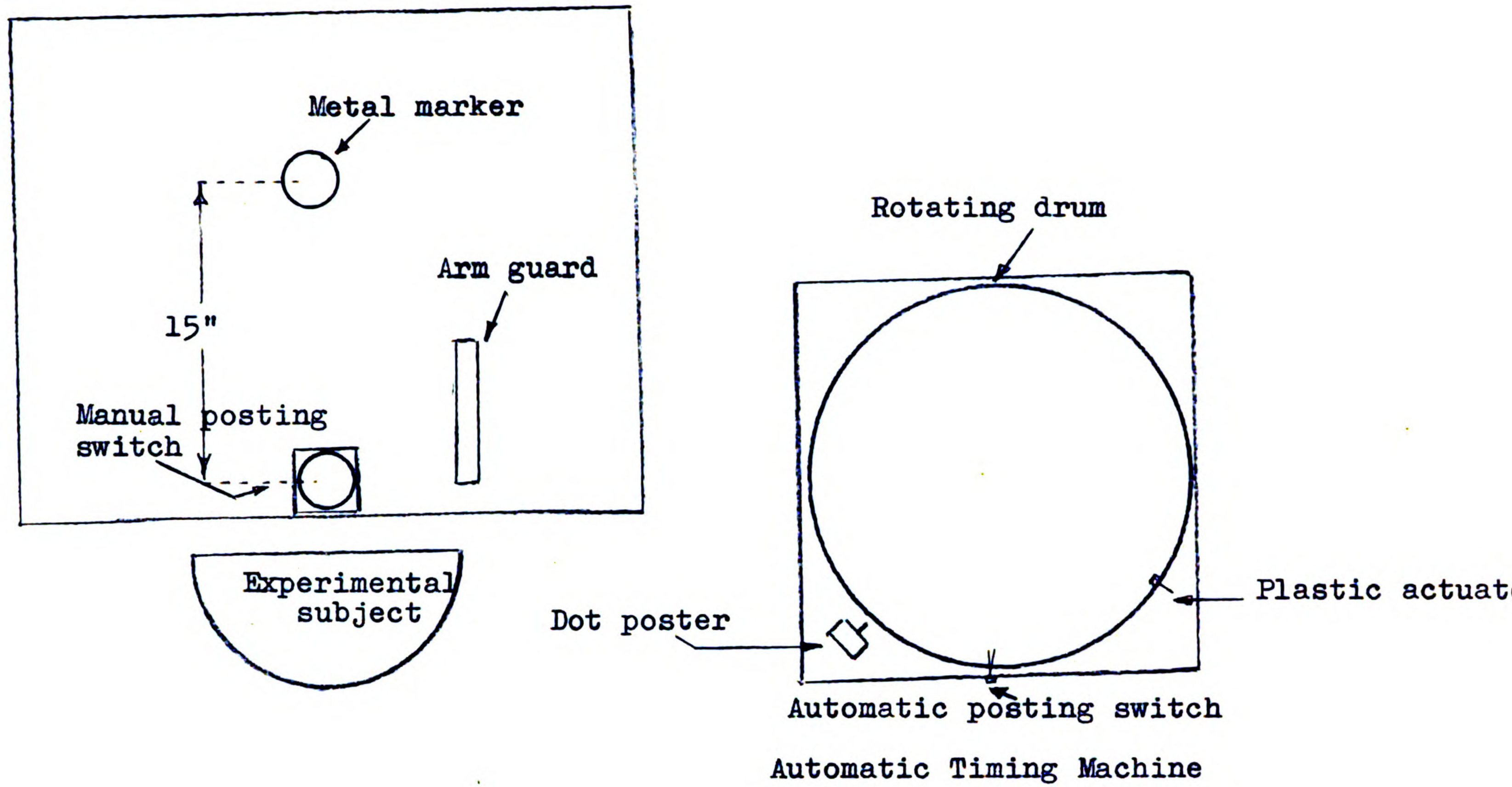

Figure 1. Work-Place Layout for Experiment A

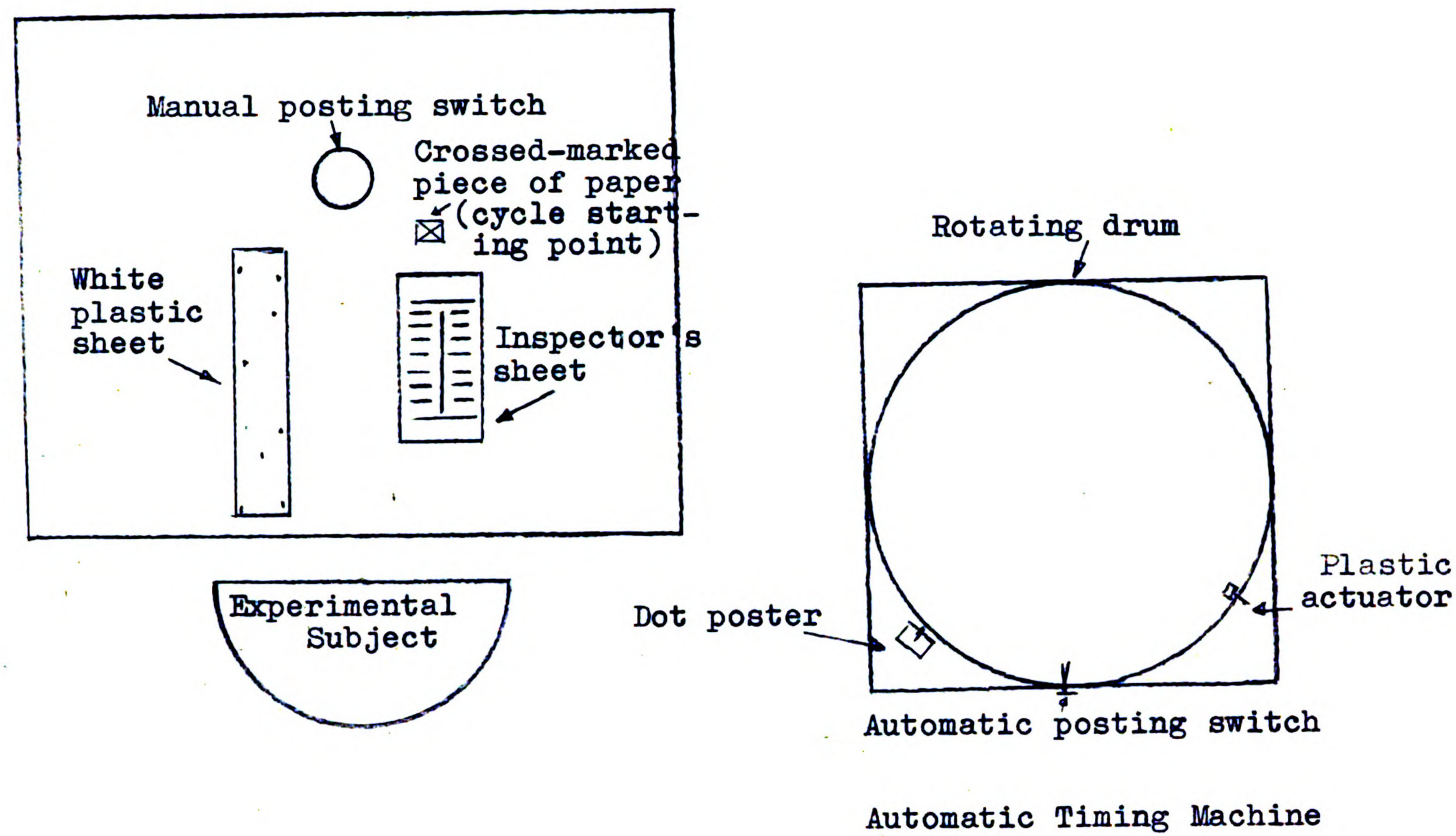

Figure 2. Work-Place Layout for Experiment B

above the inspector's sheet, served to mark the position of the point of a pencil (used in the experiment), prior to the start of the cycle. This piece of paper also served to mark the spot to which the experimental subject focused his eyes prior to the beginning of the cycle. A 2 3/5 inch by 15 2/5 inch white plastic plate marked with indented pencil dots (defects), was positioned a little to one side of the experimental subject opposite the inspector's sheet. There were ten such white plastic plates with different number of defects well scattered, one plate being used for each cycle in a manner to be described later. There were two white plastic plates with eight defects, two with seven defects, three with six defects, two with five defects and one with three defects. The experimenter could determine from tags taped on the under-sides of the white plastic plates, the number of defects on each.

<u>The Timing Machine</u>. The timing machine (see Figure 2a) used was developed by Dr. Dale Jones in the Industrial Engineering Laboratory of Michigan State University in connection with the Fair Day's Work Research Program. The timing machine which stands 3 feet, is 3 feet square and consists of a stationary body which supports a rotating drum 100 inches in circumference. The rotating drum is directly coupled to a 10 r.p.m. synchronous motor. Paper tape, a little less than the height of the rotating drum, is wound around

Figure 2a. Picture of Automatic Timing Machine

its periphery once and then held in place with scotch tape. A stylus, henceforth to be called the "dot poster", is connected to a small relay in such a manner that whenever the relay is energized, the dot poster hits against the side of the rotating drum once, after which the relay is open-circuited. Postings in the form of either black or red dots are made by the dot poster, according to the position of the red-black carbon paper combination located between the paper tape and the dot poster. The red-black carbon paper combination is attached to a lever device held in place and is manually shifted horizontally and alternately by the experimenter, in conjunction with the manual vertical indexing of the dot poster, also done by the experimenter. This shifting of the carbon paper combination to the alternate color in conjunction with the vertical indexing of the dot poster is necessary after each cycle of the experiments in order to later identify the postings for each cycle, and to facilitate their location preparatory to their measurements. Since the drum rotates continuously at 10 r.p.m. and the circumference of the drum is 100 inches, each linear inch of tape represents 1/1000 of a minute. When necessary, with proper vertical indexing, as many as forty separate sets of postings may be obtained on a single tape. The standard deviation of postings produced by the timing machine is approximately 0.00001 minute, as established by careful testing.

<u>The Experimental Subjects</u>. Sixteen college students, all males aged twenty to twenty-eight years, were chosen as experimental subjects. None possessed sight, hearing or any obvious physical defects. Thirteen of the subjects were right-handed and three were left-handed. Each experimental subject used his favored hand in performing the experiments.

<u>Standardization and Administration of Experiments</u>. The experiments entailed standardized instructions and administration, and an environment free from distractions. The experiments were performed for several days from 8 AM to 11 AM and from 1 PM to 4 PM. The experimental subjects appeared to be very cooperative, and had practice aimed to produce reliable and consistent results. The experimental subjects were instructed as a group in the proper conduct of the experiments and later individually during each individual performance. The experimenter administered the experiments carefully to keep all known motion time determinants such as equipment, motion patterns, positions of subjects and objects, light, ventilation and heat as near constant as possible throughout all of the experiments of any given type.

CHAPTER V

EXPERIMENT A.-DETERMINATION OF THE RELATIONSHIP BETWEEN HUMAN SIMPLE REACTION TIME AND SIMPLE MANUAL MOVEMENT TIME

Introduction. A reasonably high degree of correlation between simple reaction time and simple manual movement time resulting at maximum motivation level would suggest that persons perform thought-controlled acts and automatic acts at approximately the same respective ratings at maximum motivation level. As previously mentioned, the results from such a test would aid in the determination of the validity of the synthetic rating technique as applied in the area of time study rating thought-controlled acts. Also, measurement of the simple reaction time of job applicants in industry may be used to predict, with certain qualifications, their maximum working speeds. This information would be useful to management in the selection and placement of new employees.

Production of the Sound Stimulus. The sound stimulus, henceforth to be called the "signal", was produced by the loud sound heard by the experimental subject when the dot poster of the posting mechanism of the timing machine tapped the rotating drum. In this instance the dot poster was energized as a plastic actuator, fixed close to the periphery of the rotating drum hit and swept past a catwhisker contact switch, henceforth to be called the "automatic posting switch", fixed on the body of the timing machine.

The Manual Posting Switch. The smallest available micro-switch was embedded into a wooden block and fixed beneath a two-inch diameter piece of thin metal which was hinged on the wooden block and the latter in turn was nailed to the table surface. This set-up served as the terminal contact of the manual posting switch. A slight finger pressure on the metal was enough to actuate the manual posting switch which in turn energized the relay of the posting mechanism to cause the dot poster to hit against the rotating drum of the timing machine.

The Practice Test. After orientation and demonstration, the experimental subject was required to perform the experiment for a practice period. This was done to completely familiarize the subject with the proper conduct of the experiment, and equally important, for his adjustments to the feel of the equipment. Another reason for this practice test was to note the effects of uncontrollable distractions. As J. E. Evans phrased it, "Practice lessens the influence of distraction, but never wholly overcomes it", (11).

The Actual Test. The experimental subject sat on the work stool which was adjusted to allow his forearm to be parallel to the top of the work table. The subject relaxed and sat comfortably in his natural position. The experiment motion pattern, now to be described, is illustrated in Figure 3. The experimental subject curled the fingers of his favored hand slightly and placed them lightly on top of the manual posting switch. The other hand rested on his lap. As soon as the experimental subject heard the signal, he depressed the manual posting switch at his maximum motivation level using finger and wrist movements. This completed the postings for the first cycle of the reaction test. The experimental subject then waited for a few seconds while the experimenter indexed vertically the dot poster of the timing machine, and shifted the red-black carbon combination to the alternate color, preparatory to the push-pull movement test.

After each reaction timing the push-pull movement was timed. The experimental subject rested his hand close to the manual posting switch and focussed his eyes at the center of the previously mentioned two-inch diameter metal marker which was located fifteen inches in front of the manual posting switch. He was then ready to perform the push-pull movement test at maximum motivation level. As soon as the experimental subject heard the signal, he reached his fingers to the manual posting switch, depressed it, and then without hesitation reached (pushed) in almost a straight line toward the center of the metal marker

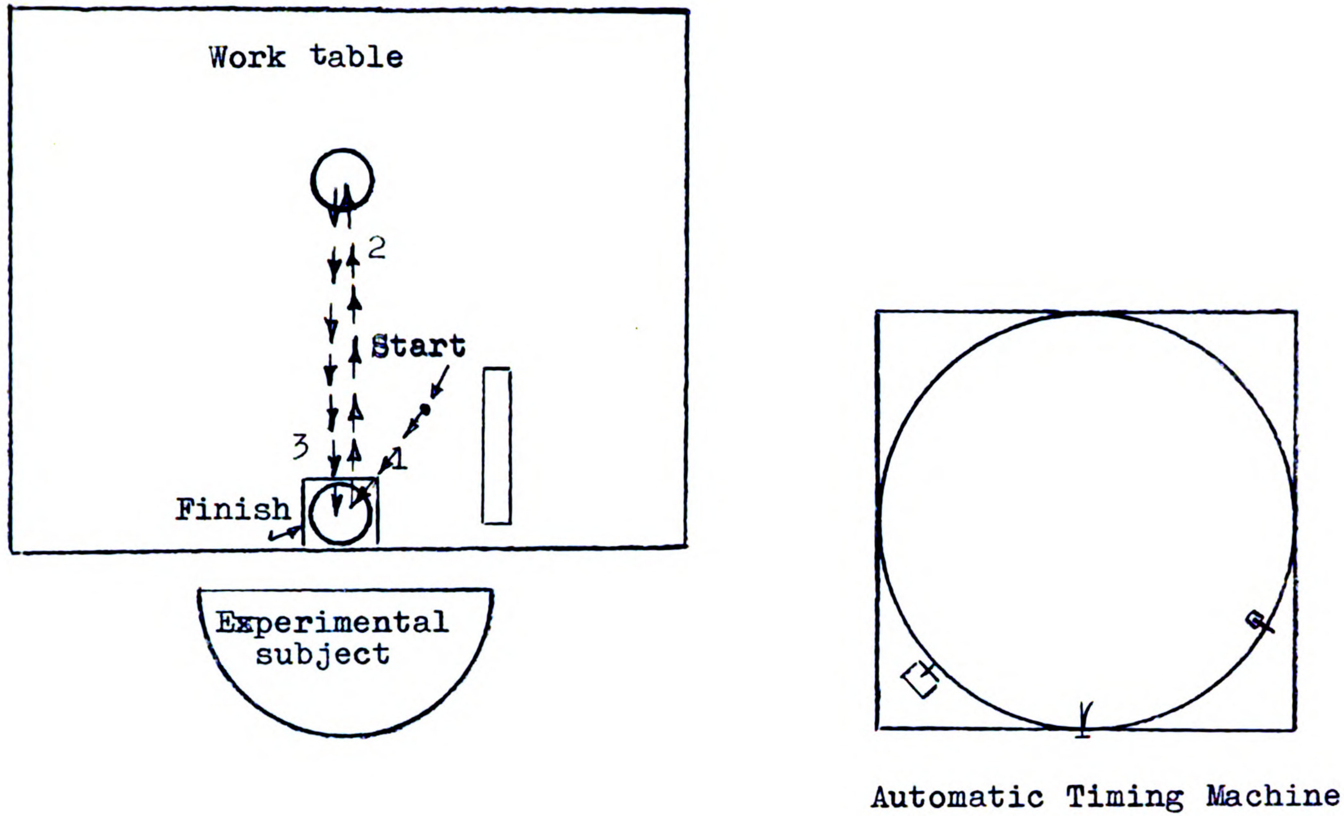

Figure 3. Push-Pull Movement Motion Pattern for Experiment A

using arm movement, touched the metal marker with his extended fingers, then reached (pulled) back in almost a straight line and depressed the manual posting switch again. Sideward arm movement was prevented by fixing vertically on the table surface a piece of metal, in such a manner as to serve as an arm guard to limit arm movement to the desired forward and reverse directions only. The cycle was completed for the push-pull movement, upon the last depression of the manual posting switch just described.

Fifteen performances of both the reaction and the push-pull movements were timed for each experimental subject, taking care to properly index vertically the dot poster and to shift the carbon paper to the alternate color after each cycle.

<u>Results</u>.

(a) <u>Evaluation of Postings</u>. The content of the timing tape for Experiment A, now to be described, is illustrated in Figure 4. Black dots represented the postings for the reaction timings, and red dots represented the postings for the push-pull movement performances. These postings were properly marked and identified with numbers. The first pair of black dots starting from the bottom of the paper tape represented postings for the performance of the reaction timing. The first of each pair of dots denoted

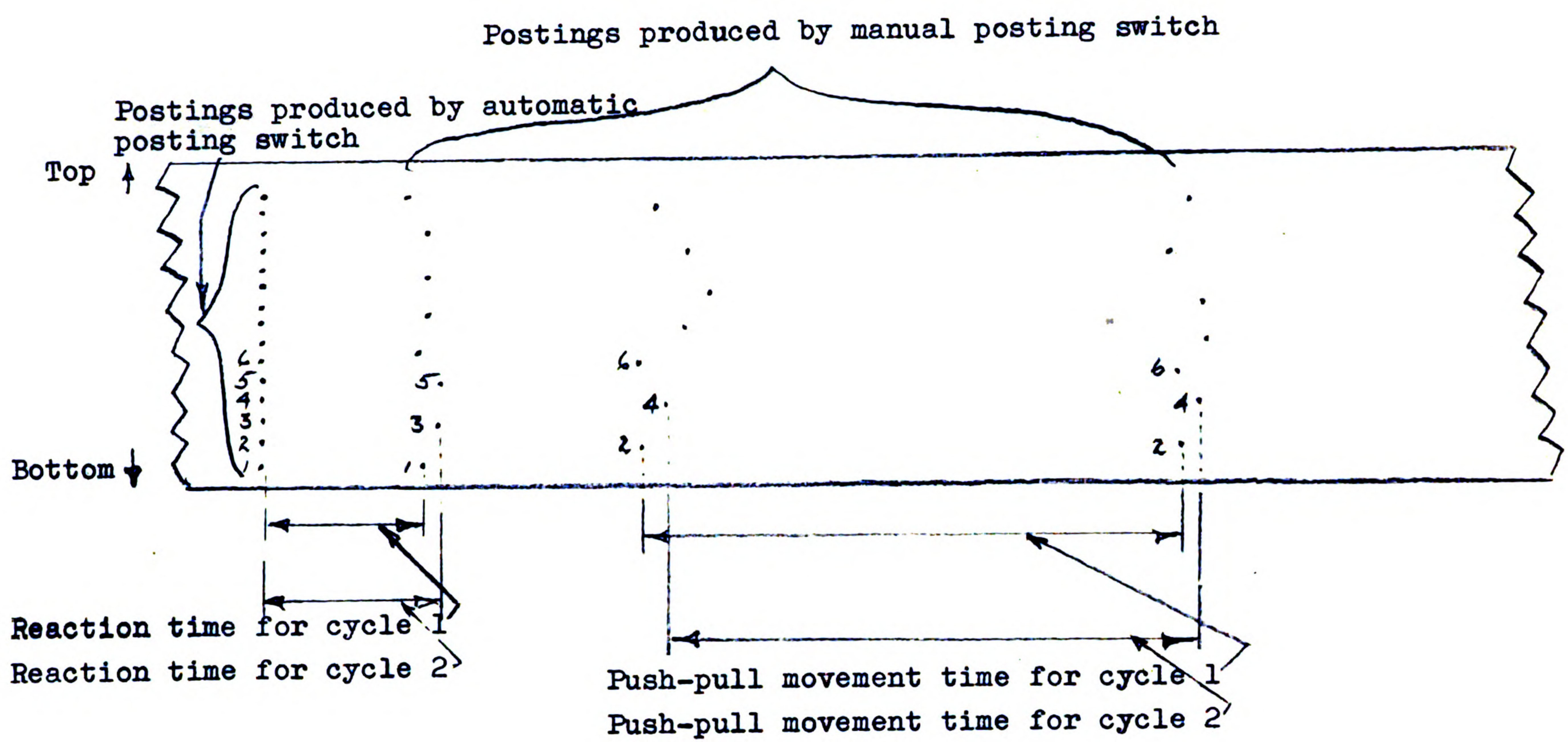

Figure 4. Diagram of Timer Tape for Experiment A

the automatic posting accomplished simultaneously with the automatic signal and the second dot represented the posting resulting when the experimental subject tapped the manual posting switch. This pair of dots was marked with the first odd number. On the paper tape, one step vertically upward from this first pair of black dots was a set of three red dots representing postings for the push-pull movement test. The first of this set of three dots denoted the automatic posting accomplished simultaneously with the automatic signal and the second of the set of three dots represented the posting resulting when the experimental subject tapped the manual posting switch at the beginning of the "push" motion. The third of this set of three dots represented the posting resulting when the experimental subject tapped the manual posting switch at the end of the "pull" movement. This set of three red dots was marked with the first even number. Time values were obtained by measuring the distances between dots, using scales and dividers. In the case of the even-numbered postings consisting of three red dots representing postings of the push-pull movement performances, only the last two red dots were used, the first red dot having been made when the automatic switch was energized by the aforementioned plastic actuator attached to the timer drum, thereby providing the audible signal which served only as the cue for the experimental subject to start the cycle for the push-pull movement. Thus, only the distance between the last two red dots, which in this case were assigned the first even number, was measured to obtain the time value for the push-pull movement. A pair of the reaction time values and the respective push-pull movement time values constituted one cycle. The last ten seemingly representative cycles of each experimental subject were recorded on a tally sheet for evaluation.

(b) Evaluation of Raw Data. The last ten pairs of time values for the seemingly representative reaction timings and the respective push-pull movement performances were averaged separately for each experimental subject and are presented in Table 1, along with their respective standard error (σ_m) values. Each experimental subject's average reaction time was paired with his respective average push-pull movement time resulting in sixteen paired scores for the sixteen experimental subjects. These paired scores were tested for significance of relationships by the use of the product-moment method. A correlation coefficient of +0.68 was obtained. From the correlation coefficient table, a positive correlation coefficient of 0.623 is required for significance at one per cent level of confidence, for the conditions of this experiment. It is noteworthy that the average standard error of the mean as

Table 1. Average Time to React to Audible Signal and Average Time to Perform Push-Pull Movement at Maximum Motivation Level. Note: Time values as shown in table x 10^{-5} gives time values in decimal minutes.

Subject	Time to React to Audible Signal	Standard Error of Mean (React)	Time to Perform Push-Pull Movement	Standard Error of Mean (Push-Pull)
A	300	12.65	726	9.19
B	331	10.76	744	26.70
C	316	23.09	749	26.80
D	270	6.16	642	11.33
E	308	18.40	587	7.18
F	302	23.10	636	15.40
G	346	23.60	615	8.58
H	265	9.36	620	5.92
I	310	15.50	615	11.85
J	288	8.93	532	10.20
K	406	35.30	838	15.90
L	254	12.40	549	10.60
M	315	8.22	590	7.99
N	299	11.10	598	11.50
O	243	9.92	573	14.46
P	285	12.98	603	7.39

Average Error of Mean as a % of Average Mean.........4.99% (for react) .... 2.16% (for push-pull)

Table 1a. Calculation of Correlation Coefficient (r) Between Reaction and Push-Pull Movement Times at Maximum Motivation Level (Experiment A)

Measure	Value
Total of Reaction Time (ΣX)	4,838.00
* Mean of Reaction Time ($\bar{X}$)	302.37
Total of Push-Pull Movement Time (ΣY)	10,217.00
* Mean of Push-Pull Movement Time ($\bar{Y}$)	638.56
Total of Product Difference ($\Sigma d_x d_y$)	35,196.84
where: $d_x = \bar{x} - x_{1,2,..,16}$	
$d_y = \bar{y} - y_{1,2,..,16}$	
Total of the Square of the Deviation of Reaction Time from its Mean (Σd_x^2)	22,731.77
Total of the Square of the Deviation of Push-Pull Movement Time from its Mean (Σd_y^2)	103,809.88
Standard Deviation of Reaction Time (σ_x)	38.90
where: $\sigma x = \sqrt{\Sigma d^2 x / n-1}$	
Standard Deviation of Push-Pull Movement Time (σ_y)	83.09
where: $\sigma y = \sqrt{\Sigma d_y^2 / n-1}$	
Correlation Coefficient (r)	.68
where: $r = \Sigma d_x d_y / n(\sigma_x)(\sigma_y)$	

* Time values as shown x 10^{-5} equals value in decimal minutes.

a per cent of the average mean of the simple reaction act of this experiment was 4.99%, whereas that of the simple push-pull movement was 2.16%. In evaluating this finding the reader should keep in mind the fact that virtually no mental activity was performed in behalf of the simple push-pull movement since timing of the movement began <u>after</u> the experimental subject had reacted and touched the switch denoting the beginning of the movement.

The writer also considered the possibility of the experimental subject's arm's length as a probable significant time determinant in the experiments by correlating arm lengths of the sixteen experimental subjects with their respective push-pull movement times performed above. In this respect, only a small correlation coefficient of +.11 was found, which suggests remote significance of relationship between the two variables mentioned.

<u>Conclusion</u>. The conclusion suggested, for the conditions of this experiment, is that there exists a high positive correlation between the time for human beings to react to simple, clear audible signals and the time to perform simple manual movements at maximum motivation level.

CHAPTER VI

EXPERIMENT B-DETERMINATION OF THE TIME RELATIONSHIPS BETWEEN INSPECTION TIME AND POSTING TIME

Introduction. If a reasonably close positive correlation exists between inspection (thought-controlled) and posting (automatically decisioned) times of a given task, time study men will be able to rate more accurately the thought-controlled manual movement portions of jobs via the synthetic rating technique. The experiment described below was first intended to be done at the experimental subject's natural motivation level and then intended to be repeated at his respective maximum motivation level.

The Practice Test. The experimental subject was given orientation, demonstration and practice prior to the start of the experiment by the writer. The reasons for these are discussed above in Experiment A.

The Actual Test. Figure 5 illustrates the motion pattern of this experiment. The experimental subject sat on the work stool which was adjusted to allow the forearm to be parallel to the top of the work table. The experimental subject relaxed and sat comfortably in his natural position. He held a new and sharp pencil in his favored hand, the point of which was made to concide with the cross-marked piece of paper fixed slightly above the inspector's sheet. At this same instant the experimental subject focused his eyes on the aforementioned cross-marked piece of paper.

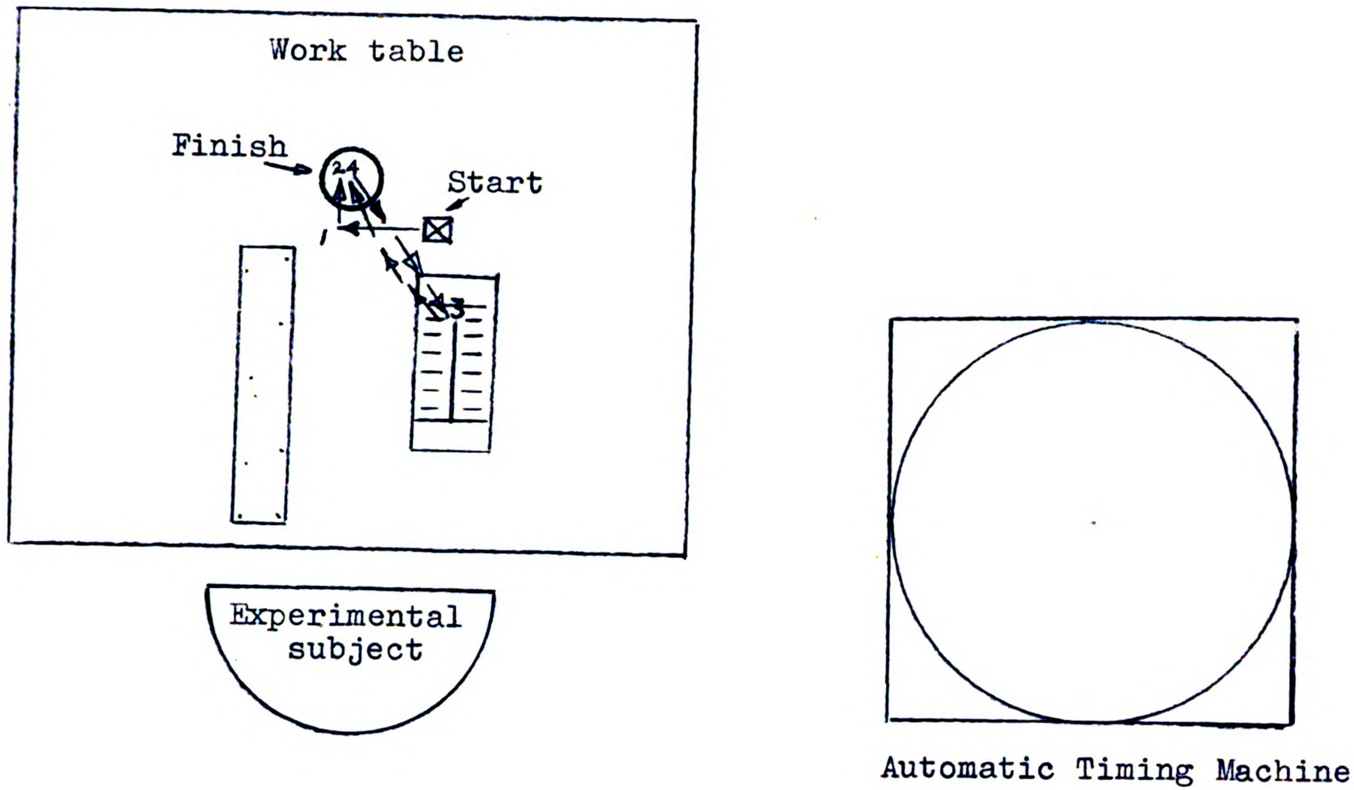

Figure 5. Motion Pattern for Experiment B

As soon as he heard the signal, the experimental subject reached and placed his hand close to the bottom of the manual posting switch while his eyes travelled to the bottom of the white plastic plate, after which he visually counted the number of dots on it, being careful to cover the entire surface area as he searched from the bottom to the top of the white plastic plate. During his visual counting, the vertical distance from the eyes of the experimental subject to the white plastic plate was estimated at approximately eight inches. Upon completion of his inspection, he moved his pencil and with its point depressed the manual posting switch. Then he moved his pencil to the inspector's sheet and wrote down the number of pencil dots he visually counted, on the first designated line. Then he moved his pencil back to the manual posting switch and once more depressed it with the point of his pencil, after which, he moved his pencil to return it to the starting position. This completed one cycle of the test. Each of the above-described phases of the cycle were consistently performed without hesitation in a rhythmic manner. The experiment consisted of ten cycles, each cycle entailing a different white plastic plate to vary the number of defects for the experimental subject to count. This insured that the subject would actually search, find and count the defects of each of the ten white plastic plates inspected. As previously mentioned, this experiment was first performed with the intention of using the experimental subject's natural motivation level for all movements. As will be shown later, the experiment results indicated that, in a few instances, experimental subjects performed the intended natural motivation performances at motivations faster than their naturals. After completing ten cycles, the same experiment was repeated with the intention of using the experimental subject's maximum motivation level. This was done with prior practice runs and with the use of practice plastic plates. Both experiments were tested for accuracy so that any cycle with erroneous counting and/or recording of the number of observed defects by the experimental subject was cancelled and re-run. All re-runs were done after completion of the original sequence of ten cycles for the ten white plastic plates. Actually then, each of the sixteen experimental subjects performed ten seemingly representative cycles at his natural motivation level and ten seemingly representative cycles at his maximum motivation level.

Results.

(a) Evaluation of Postings. The content of the timing tape for Experiment B, now to be described, is illustrated in Figure 6. Postings were properly marked and identified with numbers. The first odd number was

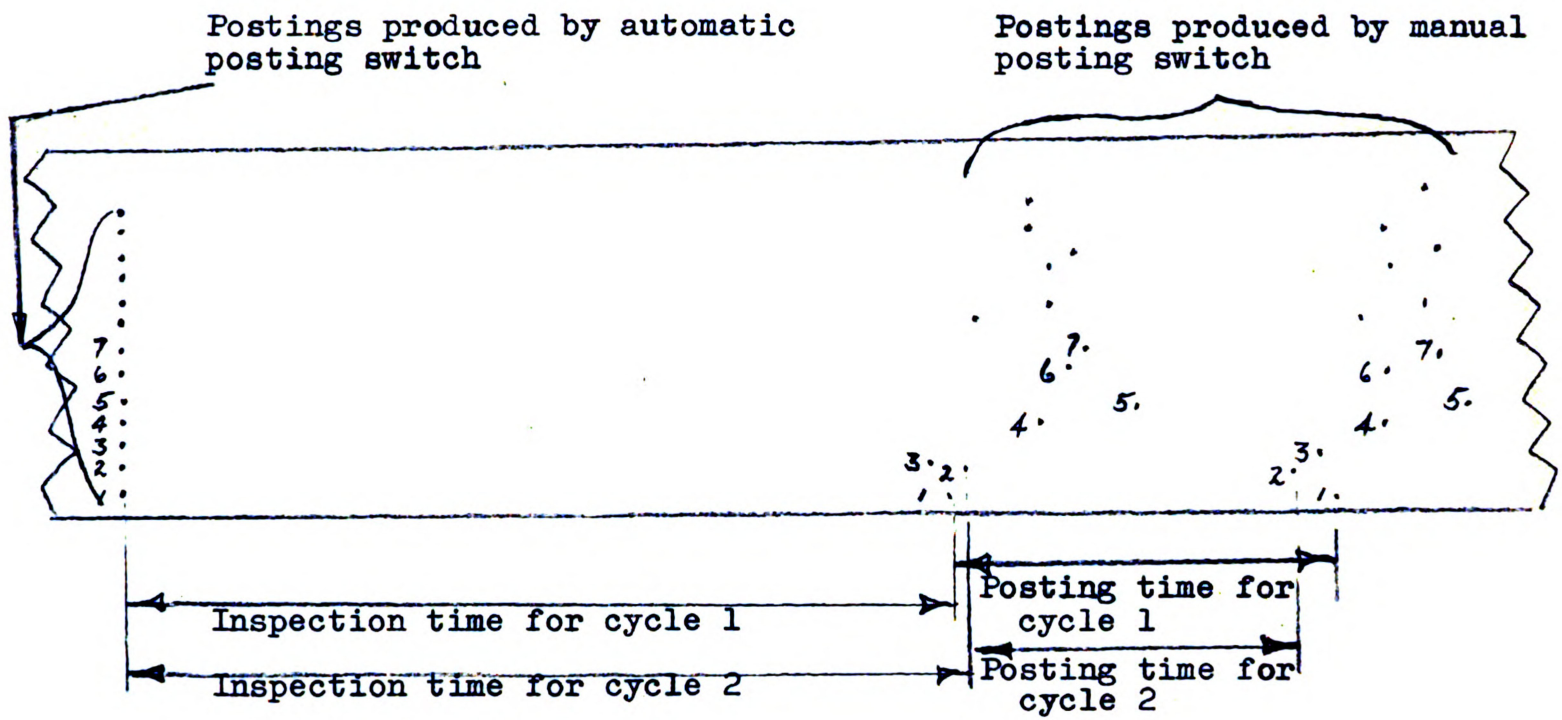

Figure 6. Diagram of Timer Tape for Experiment B

assigned to the first set of postings starting from the bottom of the paper tape. The first set of postings made up the first cycle. Each cycle constituted the times for inspection and posting. There were three postings in the set for each cycle. On each cycle, the distance from the first posting to the second posting of a set was measured by the use of scales and dividers, and was converted into time value, knowing that each inch of horizontal distance on the paper tape represented one-thousandth of a minute. The time value obtained represented the inspection (thought-controlled act) time for that particular cycle. The distance from the second posting to the third posting of the same cycle was likewise measured and converted into time value. This resulting time value represented the posting (automatic act) time for that particular cycle. The last ten seemingly representative cycles for the whole performance of each subject were recorded on a tally sheet for evaluation.

(b) Evaluation of Raw Data.

(1) Correlation Coefficient at Natural Motivation Level. The last ten seemingly representative pairs of time values for the inspection and posting jobs were averaged separately for each of the sixteen experimental subjects, and are presented in Table 2. An average inspection time value and an average posting time value were obtained for each

Table 2. Average Inspection and Respective Posting Times at Natural and Maximum Motivation Levels. Note: Time values as shown in table x 10^{-4} gives time values in decimal minutes.

Subject	At Natural Inspection	At Natural Posting	At Maximum Inspection	At Maximum Posting
A	675	375	456	316
B	667	440	496	266
C	567	373	449	254
D	401	287	387	247
E	573	324	377	238
F	592	312	384	281
G	806	381	523	279
H	691	306	515	228
I	663	284	248	243
J	448	240	354	201
K	792	414	589	288
L	471	296	454	224
M	598	372	450	280
N	570	327	492	221
O	506	322	442	233
P	533	309	396	246

experimental subject. For each experimental subject, the average inspection time was paired with his average posting time. The sixteen paired scores were tested for significance of relationships by the use of the product-moment method. A correlation coefficient of +0.63 was obtained. For the conditions of this experiment, the correlation coefficient table states that a coefficient of +0.623 is required for significance at one per cent level of confidence.

(2) Correlation Coefficient at Maximum Motivation Level. The above-described procedure was followed at maximum motivation level to arrive at sixteen paired scores which were again tested for significance of relationship by the use of the product-moment method. The results obtained give a correlation coefficient of +0.30 and are shown along with those obtained at natural motivation level in Table 3. From the correlation coefficient table, for the conditions of this experiment, a correlation coefficient of +0.497 is required for significance at five per cent level of confidence.

(c) Relationships Between Experimental Subjects' Natural and Maximum Motivation Levels. First the experimental subject was instructed to work at what he considered his natural motivation level. Later, the experimental subject was asked to work at what he considered his maximum motivation level. In reference to Table 3a, it can

Table 3. Calculation of Correlation Coefficient (r) Between Inspection and Posting Times at Natural and Maximum Motivation Levels (Experiment B)

Measure	Natural	Maximum
Total of Posting Time (ΣX)	5,362.00	4,045.00
* Mean of Posting Time ($\bar{X}$)	335.00	252.00
* Total of Inspection Time (ΣY)	9,553.00	7,012.00
Mean of Inspection Time ($\bar{Y}$)	597.00	438.00
Total of Product Difference ($\Sigma d_x d_y$)	60,094.00	11,796.00
where: $d_x = \bar{X} - X_{1,2,\ldots 16}$ $d_y = \bar{Y} - Y_{1,2,\ldots 16}$		
Total of the Square of the Deviation of Posting Time from its Mean (Σd_x^2)	41,811.00	13,567.00
Total of the Square of the Deviation of Inspection Time from its Mean (Σd_y^2)	196,082.00	97,254.00
Standard Deviation of Posting Time (σ_x) where: $\sigma_x = \sqrt{\Sigma d_x^2 / n-1}$	52.00	30.60
Standard Deviation of Inspection Time (σ_y) where: $\sigma_y = \sqrt{\Sigma d_y^2 / n-1}$	114.00	80.40
Correlation Coefficient (r) where: $r = \Sigma d_x d_y / n(\sigma_x)(\sigma_y)$	.63	.30

* Time values as shown x 10^{-4} equals value in decimal minutes.

Table 3a. Determination of Significance of Difference Between Average Performance Times Comparing Natural Motivation Level Times (n) and Maximum Motivation Level Times (m). Note: (σ_{n-m}) values presented below represent the standard error of the difference of the mean (n-m) obtained for inspection and posting.

Subj.	Inspection (n-m)	Inspection (σ_{n-m})	Was Speed-up Significant?*	Posting (n-m)	Posting (σ_{n-m})	Was Speed-up Significant?*
A	171	35.1	yes	59	58.0	no
B	209	17.7	yes	174	22.6	yes
C	17	21.5	no	119	23.7	yes
D	118	42.0	no	40	10.8	yes
E	176	19.8	yes	86	21.9	yes
F	137	27.8	yes	31	19.2	no
G	14	21.9	no	102	51.0	no
H	415	24.1	yes	78	11.8	yes
I	64	37.4	no	41	15.0	no
J	203	44.1	yes	39	11.6	yes
K	94	21.5	yes	126	11.1	yes
L	78	17.7	yes	74	10.0	yes
M	283	43.8	yes	92	14.2	yes
N	196	23.4	yes	106	15.8	yes
O	148	21.4	yes	89	19.3	yes
P	219	32.4	yes	63	8.9	yes

* For example, in the case of subject A, $171 > 3(35.1)$; for subject C, $17 < 3(21.5)$

be seen that, in the case of four of the experimental subjects, there was no significant increase in working speed as they went from what they considered their natural to what they considered their maximum motivation levels of inspection. It is also to be noted that two of these subjects and two others also showed no significant increase in posting speed in going from what they considered their natural to what they considered their maximum motivation levels. A possible explanation to this happening is that the experimental subjects in question may have by nature faster or slower natural speeds and faster or slower maximum speeds as the case may be, compared with the rest of the experimental subjects. As such, the results of the experimental subjects in question were not discarded as atypical but were included in calculating the correlation coefficients because there is no proof that their natural motivation levels are significantly different from their respective maximum motivation levels.

(d) Ratios of Thought-Controlled Time to Thought-Controlled plus Automatic Times (R). The experimental subjects' ratios of inspection time (thought-controlled time) to inspection plus posting (automatic) times at both natural and maximum motivation levels were obtained. These ratios are presented in Table 4.

(e) Significance of Difference of Average Ratio

Table 4. Experimental Subjects' Ratios of Inspection Time (Thought-Controlled Time) to Inspection plus Posting (Automatic) Times at Both Natural (R_n) and Maximum (R_m) Motivation Levels.

Subject	Natural (R_n)	Maximum (R_m)
A	.64	.59
B	.60	.65
C	.60	.64
D	.58	.61
E	.64	.61
F	.65	.58
G	.68	.65
H	.69	.69
I	.70	.51
J	.65	.64
K	.66	.67
L	.61	.67
M	.62	.62
N	.64	.69
O	.61	.65
P	.63	.62

Mean (R_n) ...... 0.637 Mean (R_m)..0.631

Standard Error of the Mean (σ_n)... 0.008 Standard Error of the Mean (σ_m)...0.0001

Standard Deviation of R_n.............. 0.03 Standard Deviation of R_m...............0.04

No significant difference between means as established by t-test at .2 probability level.

at Natural Motivation Level (R_n) and Average Ratio at Maximum Motivation Level (R_m). It is to be noted in Table 4, that R_n is .637 and R_m is .631. The standard deviation of R_n is .03 and the standard deviation of R_m is .04. Thus, according to the t-test, there is no significant difference between R_n and R_m at .2 probability level.

(f) Relationship Between Reaction and Posting Times at Maximum Motivation Level. Reaction time (from Experiment A) was correlated with posting time at maximum motivation level. The result yielded a correlation coefficient of +.55. For the conditions of this experiments, the correlation coefficient table gives a value of +.497 for significance at five per cent level of confidence.

(g) Relationship Between Reaction and Inspection Times at Maximum Motivation Level. Reaction time (from Experiment A) was correlated with inspection time at maximum motivation level which resulted in a correlation coefficient of +.36. For the conditions of this experiment, a correlation coefficient of +.497 is required for significance at five per cent level of confidence, as obtained from the correlation coefficient table.

Conclusions. Subject to the conditions of this experiment, it can be concluded that there exists a reasonably close correlation between the times of inspection (thought-Controlled) and accompanying posting (automatic) acts performed at natural motivation level. There was a reduction in the correlation between the times of inspection and accompanying posting acts performed at maximum motivation level. Subject to the conditions of this experiment, it can be farther concluded that there is no significant difference in the ratios of thought-controlled act time to total cycle time, comparing ratios established at natural and at maximum motivation levels.

In relating Experiment B with Experiment A, it can be concluded that there exists a reasonably close correlation between reaction and posting times at maximum motivation level, subject to the conditions of the experiments. Also, there is a reduction in correlation between reaction and inspection times at maximum motivation level, subject to the conditions of the experiments.

CHAPTER VII

SUMMARY AND GENERAL CONCLUSIONS

The experimental conditions which seem relevant to drawing general conclusions from the experimental results are summarized as follows:

1. The experiments were conducted in a laboratory, under observation and counsel of the writer and under carefully controlled operational and external conditions.

2. The experimental subjects were male university students aged twenty to twenty-eight years, who were quite cooperative.

3. The experimental operations were quite simple.

4. The assigned "learning periods" of the experimental subjects seemed to be of sufficient length to permit mastery of the operation methods but not necessarily long enough to insure complete rhythm and absence of hesitation in the operation performances.

5. The timing of the experimental subjects was accomplished automatically, with very high accuracy and precision.

The aforementioned experimental results, summarized in a form facilitating comparison, analysis and general conclusions, are as follows:

1. Maximum motivation level reaction time versus push-pull movement time coefficient of correlation =+.68.

2. Natural motivation level inspection time versus respective posting time coefficient of correlation = +.63.

3. Maximum motivation level of inspection time versus respective posting time coefficient of correlation = +.30.

4. Maximum motivation level reaction time versus maximum motivation level posting time coefficient of correlation = +.55.

5. Maximum motivation level reaction time versus maximum motivation level inspection time coefficient of correlation = +.36.

6. Natural motivation level average ratio of inspection time to inspection plus respective posting time = .637.

7. Maximum motivation level average ratio of inspection time to inspection plus respective posting time = .631.

8. No significant difference between (6) and (7).

In the light of the above-summarized experimental conditions and results, the following general conclusions, with interpretative statements, seem to be in order:

1. In view of the existence of a high positive correlation coefficient at maximum motivation level between (a) simple reaction time to a simple audible signal and simple push-pull movement time, and (b) simple reaction

time to a simple audible signal and posting time, then measurement of the simple reaction time of job applicants in industry may be used to predict, with certain qualifications, their maximum working speeds. This information would be useful to management in the selection and placement of new employees.

2. From the results of Experiment B, it was computed that there were significant differences in the changes of working speed (rating), comparing thought-controlled inspection time with the more thoughtless posting time, as the sixteen experimental subjects went from their natural to their maximum speeds. This strongly suggests either or both of the following:

a. The experimental subjects were not performing the inspection and posting tasks at approximately the same respective ratings when working at the instructed natural motivation level.

b. The experimental subjects were not performing the inspection and posting tasks at approximately the same respective ratings when working at the instructed maximum motivation level.

Thus, this finding suggests that the synthetic rating technique (applying ratings assigned to easily rated automatic manual duties to thought-controlled duties) would not be sound when used in behalf of simple inspection jobs as typified by Experiment B.

It would have been possible to improve the correlation coefficient of the experiment involving posting versus inspection times at maximum motivation level, (see Figure 9., Appendix), by discarding the seemingly atypical high point and the seemingly atypical low point respectively above and below the line of best fit. Likewise, the correlation coefficients for the other experiments could have been slightly affected by discarding seemingly atypical values. Instead, the seemingly atypical values were retained in the computation of correlation coefficients because, in the writer's opinion, one would also find a certain percentage of atypical industrial workers. Thus, to select only the good values and to discard the bad ones in the computation may render the sample values unrepresentative of the true population values.

APPENDIX

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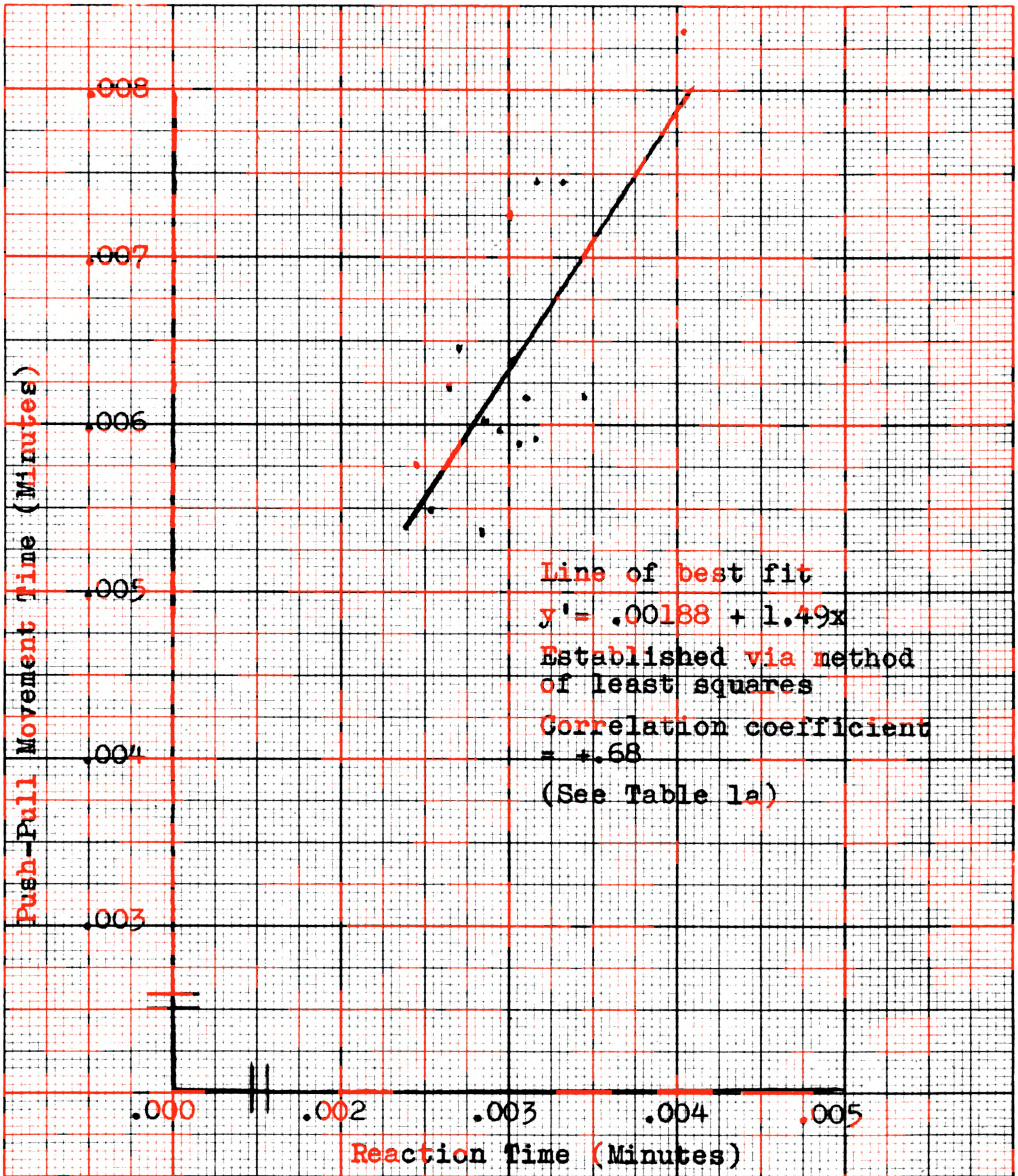

Figure 7. Graph of Reaction Time vs Push-Pull Movement Time at Maximum Motivation Level