THE EFFECTS OF HAND-WRIST AND BODY ORIENTATION ON THE FORCE REQUIREMENTS TO PERFORM A PUSH-PULL TASK

by

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INTRODUCTION

Human engineers, motion study engineers, and work analysts use standard data systems to specify time values for "reach" and "move" elements in motor tasks. This method is acceptable with certain limitations. The time values used account for only the distance and weight moved in the task and not for the directions of the moves. According to Dempster and Gaughran (1956), push-pull movements (such as opening and closing file drawers) are performed by muscles contracting and relaxing to move the body member. Muscular interactions can cause an increase or decrease in the force needed to perform a task.

The purpose of this thesis was to determine the significance the orientation of the wrist and hand and height of task in relation to an operator had on the force required to perform a push-pull task. The task was performed at five hand-wrist orientations and five working heights.

The secondary purpose of this thesis was to use a force platform as a way to measure individual differences among the selected subjects. The push-pull task was performed on the platform and the resulting data were statistically analyzed.

LITERATURE REVIEW

According to Dreyfuss (1959), the location of a specific control (dials, meters, etc.) in the work area should be positioned relative to the person doing the motor activity. He analyzed and catalogued body orientations and body movements for various motor tasks and designated optimum working areas for the tasks.

It was noted in an unpublished Master's of Science thesis by Dunnington (1960), and again in an article by Barany (1963), that anthropometric measurements of individuals do not affect the ability of individuals to perform specific motor tasks. However, the position of an operator in relation to his work is thought to be important. Hudson (1962), although slightly contradictory to Barany (1961), indicated that although there are accepted average values for placement of tools, knobs, handles, cranks, etc., there is also a great need for an analysis of the specific work place design for specific individuals. Dunnington (1960), urged the use of adjustable work stations (i.e., designed for the specific individual) which he indicated minimized forces exerted.

Work energy requirements have been measured by many different and elaborate methods all of which have their own particular advantages. Greene et al. (1958) have done research on the various apparatuses which available. Most of the equipment is costly and requires extensive training on the part of the experimenter and also in many cases requires the subject to be attached to the instrument in some way. For instance, in a gasometer investigation by Greene and Morris (1958), exhausted air from an individual was collected and its contents analyzed. The gasometer was attached to the person like a gas mask. From the CO_2 content of the exhausted air, a relationship was established as to the amount of work the person had done. This method of course had a physical as well as a phychological effect on the worker's performance.

Nichols and Amrine (1959) measured energy expenditure by using the heart rate as a criterion. The principles of motion economy were applied to the results of their research. In other words, a faster heart rate was associated with more effort or energy by the subject. According to an article by Fahnestock et al. (1963), the heart beat method of determining the amount of energy required for the task, is not a true indication of the work done to perform the task since this method assumes a linear relationship between energy and heart beat rate. The article also pointed out that the heart rate reaches a plateau and does not increase as the person works harder.

Greene et al. (1959) said that the force platform can be used to measure energy faster and easier than the more elaborate types of testing equipment mentioned and with comparable accuracy. Hicks (1955) pointed out how the use of a force platform determined that the force used by a stenographer in the simple task of filing office material was twice that of a housewife ironing a shirt. A housewife ironing a shirt used twice as much energy as her husband painting the ceiling of a room. His article also pointed out that the casual observer does not have the objective ability to predict the forces involved in simple motor activities, but that a more refined method of analysis is necessary to accurately describe the activities.

Personnel selection may be aided by a force trace analysis which is characteristic of the force platform. Barany (1961) suggests that the optimum motion pattern can be obtained through the use of such an apparatus by using the trace characteristic as the criterion. If, for example, the motor activity were determined to be best performed when a minimum area under the vertical, lateral, and frontal curves resulted, then a standard area could be established as an acceptable value for a particular activity. If it could be assumed that a person with an initially desirable area could learn the specific task more simply than an individual not demonstrating the desired initial force trace pattern, then this could be used for personnel selection. Thus an individual could be selected for a specific task by his force trace.

Beauchamp (1962) suggests a need for industry to establish some method of rating a job according to skill or performance requirements. He suggested using the force trace selection method, which would facilitate calculating man power requirements for specific jobs. His study suggests that a method of quantitatively determining skill requirements for a particular job would be helpful in personnel selection.

Barany (1961) determined that individuals could control their force output for a given motor task. In his experiment, thirty different individuals worked at their own pace and by their own method. His instructions were do the task as smoothly and as effortlessly as possible. In other words, he wanted the subjects to control their force patterns.

Barany (1961) indicated that subjects can vary their force patterns, and that it might be assumed that from pre-established force trace criteria, performance on motor tasks can be adjusted to meet a standard pattern. If the above assumptions are correct, then natural ability for certain motor tasks could be detected by the force trace pattern of the worker.

STATEMENT OF THE PROBLEM

Markstrom (1962) indicated that the direction of movement of a "reach" had a definite bearing on the amount of force exerted to perform the reach. Wu (1965) indicated that a person exerted a greater force towards the body than was exerted away from the body when moving small weights. By using various muscles to orient a body member to perform a task, the reaction force to the muscular involvement was detected as an increase or decrease in force required to perform the task.

The purpose of this thesis was to investigate the amount of force exerted in three perpendicular planes (vertical, lateral, and frontal) while doing a push-pull task when the hand and wrist were in five working angles and the task was positioned vertically in five working heights relative to the subject.

The force which was measured while each subject performed the task is believed to be a resultant of a force required to orient the body member involved to perform the task and a force required to do the task itself.

Co-ordinative ability (ability to control muscular interactions so as to perform the motor task with a reasonable amount of dexterity) was considered as the variable while the task force itself was considered constant. In other words, the force required to perform the task will be constant, but the subject's method of performance will vary. By measuring individual differences of the selected subjects, in their performance of the task, predictions were made as to specific handle orientations at specific working heights for these subjects.

Simple push-pull movements basically use five muscles (Ansen, 1963): deltoid (arm raising), triceps (forearm extension), biceps (forearm flexion), pronator (turns hand palm downward), and supinator (turns hand palm upward).

The deltoid or shoulder muscle is used to raise the arm into the reaching motion. It also holds the arm in the working position while the push and pull movements are performed. The deltoid is slightly contracted during the entire push-pull cycle.

The contraction of the biceps results in a pulling motion while the contraction of the triceps is used for pushing. When the arm is fully extended, the triceps reaches its maximum contraction while the biceps reaches its maximum contraction when the arm is fully flexed. Thus somewhere between maximum extension and maximum flexion is a point where both the biceps and triceps are partially relaxed.

The two muscles located just above the elbow joint running diagonally across the long axis of the forearm provide the power to rotate the forearm and hand. The contraction of the pronator muscle turns the right hand counterclockwise and the left hand clockwise. The opposite rotation of the forearm and hand is accomplished by the contraction of the supinator. A relaxed position for both the pronator and supinator results when the right hand is slightly turned palm downward at an angle of about 45 degrees counterclockwise from the vertical.

Therefore, the push-pull task could be described as the action of the deltoid muscle raising the arm into position with the contraction and relaxing of the biceps and triceps performing the push-pull motion while the pronator and supinator orient the hand to the desired position. Thus the interaction of these five muscles result in the accomplishment of the task. The reaction force to the action of these muscles was measured directly by the force platform and was converted by the introduction of a constant into force needed to perfom the task. The muscles used to position the body, other than the body member directly doing the task, was disregarded.

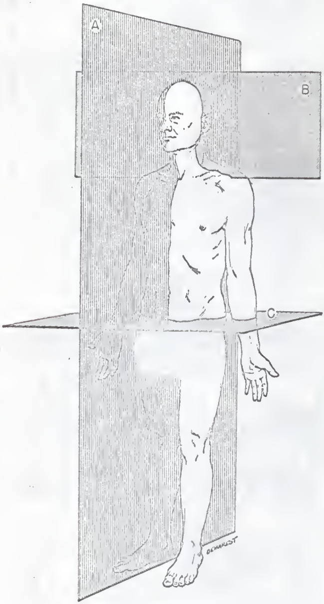
The analysis was made in three independent planes using a force platform to measure the forces. Plate I shows the three planes in which the analysis was performed: Plane A-vertical movements, Plane B-lateral movements, and Plane C-frontal movements.

The data obtained from the force platform were used to test the following hypotheses:

DESCRIPTION OF PLATE I

Drawing shows the three independent working planes used to analyze the force required to perform a push-pull task.

PLATE 1



I Working heights affect the force patterns of the selected subjects when they performed the push-pull task.

II The orientation of the handle can cause an increase or decrease in force required to do the push-pull task.

III There is a best handle orientation for a given working height which will be indicated by a statistically significant force value.

IV The force required to perform a push-pull task in a given plane will be relatively constant in the plane in which the task is performed for the selected subjects.

V The extraneous force required to perform the push-pull task will be detected in one or both of the planes not considered as primary planes of action.

DESIGN OF EXPERIMENT

Task

The force exerted when the hand-wrist and body were positioned to perform a push-pull task was studied.

The task was performed by each subject at five working heights (eye, chest, waist, hip, knee) relative to each individual subject, and five handle orientations. (See Subject-Task Positioning Specification, Table I in Appendix 2 for coding used.)

A push-pull simulator (Plate II) was specially constructed for the task which could be adjusted easily into five handle orientations and five working heights.

A push-pull cycle consisted of pushing and pulling the handle of the simulator against spring stops on the simulator which limited the length of movement to six inches. The cycle time was maintained constant to thirty cycles per minute by a music metronome. Each cycle started and ended at full arm extension i. e., handle at end of push portion of cycle. Thus a cycle consisted of pulling the handle to the spring stop and pushing it back to the starting position.

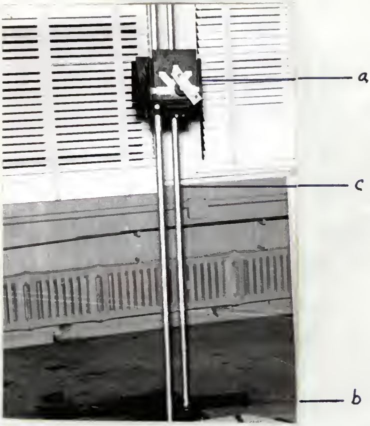
Vertical heights were measured on each subject individually to assure that the task was performed in the same body region for each height. Placement of the task relative to assigned body regions for each subject was necessary due to the sensitivity of the force platform. For example, in a previous demonstration by

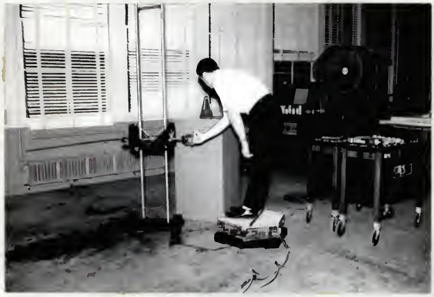
DESCRIPTION OF PLATE II

Top photograph shows the complete push-pull simulator (a), base (b), and vertical supporting pipes (c).

Bottom photograph demonstrates how the simulator can be adjusted to a specific subject-height-orientation relationship.

PLATE II





the author, a tall subject seemed to pull upward as well as outward while performing a pushing and pulling movement when the simulator was placed in a low position.

The handle orientation was positioned to align with numbers placed on the face of the simulator which corresponded to the code values. (Plate III) Each subject stood erect at each height except for the knee position. Here the subject was instructed to place his left hand on his left knee and bend at the waist while performing the task.

The location of the handle in the lateral plane (right-left) was in line with the subject's right shoulder. Only right handed subjects were used in this experiment. Vertical positioning of the handle with respect to eye, chest, waist, hip, and knee heights was determined by careful inspection by the experimentor. Each subject was placed on the platform so his shoulders were parallel to the lateral plane and the natural forward reach of his arm was parallel to the frontal plane. As a result of the above arrangements, the push-pull motion was performed in the same body area for each subject. Plate IV shows a complete layout of equipment.

Apparatus and Measuring Techniques

The force sensing device used was a force platform which is capable of detecting forces as small as a heart beat in three independent perpendicular planes. The force platform used was a

DESCRIPTION OF PLATE III

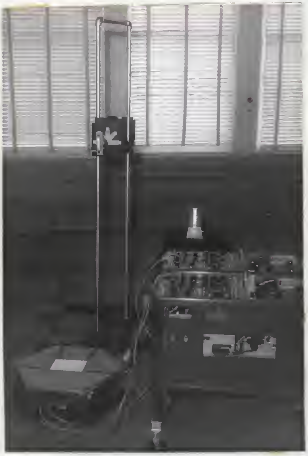
Photograph showing a close up of the face of the push-pull simulator. The numbers correspond to handle orientation positions.

PLATE III

DESCRIPTION OF PLATE IV

Photograph shows the complete layout of apparatus used to measure the force requirements for a push-pull task.

PLATE IV



slight modification of the platform designed by Barany (1961). The basic design used cantilever beams for table movement restraints which assured linearity between movement of the working surface and the force required to cause the movement. Slight platform movements were detected by the three Linear Variable Differential Transformers (LVDT's). The exact arrangement of the LVDT's can be noted in Barany's (1961) original specifications.

The movement was restricted so that forces were resolved into three planes: vertical, lateral, and frontal. The independence of the planes was accomplished physically by using point contacts at the support locations. A mathematical verification of the independence of the planes was given by Greene et al. (1959).

The effect of different actions measured by the force platform on the vertical plane can be visualized more clearly by referring to Plate V.

When the subject stood motionless as shown on Plate V (top figure) his weight (W) passes through his center of gravity (G) and through a pivot point (C) and was detected by the platform as a force (F). Assuming no swaying movement backward and forward, F will equal W.

If the subject moves forward or backward his center of gravity shifts slightly as shown on Plate V (middle figure). The subject now "bears down" on his toes with force F'. Because the sum of forces in the vertical direction must be zero, the

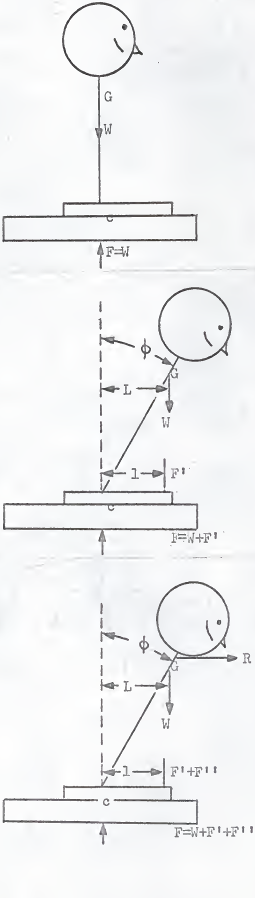
DESCRIPTION OF PLATE V

Top figure shows the force detected by the force platform in the vertical plane when the subject stands erect and motionless.

Middle figure shows the force detected in the vertical plane when the subject moves forward and backward slightly.

Bottom figure shows the force detected in the vertical plane when the subject moves forward and backward slightly when doing a push-pull task.

PLATE V



recorded reaction force was F=W + F'.

Another vertical force was introduced when a horizontal force was exerted by the subject shown on Plate V (bottom figure). The subject reacts to this force with force F'' through the same point as force F' is exerted. Since the sum of the forces in the vertical direction must be zero, the recorded reaction force was F=W+F'+F''.

According to the theory just presented, the vertical force trace appeared at some inital level. The vertical force level shifted if the subject leaned forward or backward and the force level shifted again if he pulled horizontally. A moment couple would also occur if the control was placed to the left or right of the subject.

Each of three LVDT's of the force platform consist of a primary coil input winding and a secondary output winding. Excitation voltage for the primary was four volts at 2500 cps. A core .940 inches in length and .150 inches in diameter was held in the center of the LVDT by copper springs which also held the core solidly against a facing plate for each axis.

When the platform table moved slightly, this also moved the core in the coil. The core movement produced a slight change in output voltage. This change was amplified through a Sanborn Amplifier and recorded on a heat sensitive paper.

The variable output voltage was recorded as a force-time area for each of the three axes. The area was measured by a planimeter, and was proportional to the force required to perform the motor task in each of the three planes. Thus the data was handled as an average force per time interval when a constant was applied to the areas. An example of the force trace for the three planes is shown on Plate VIII.

The constant applied to the area was calculated from the paper speed of the recorder, the resulting pen deflection in each plane when loaded with a constant force and the time to perform the task. Table 2 shows the conversion constants used.

The simulator was constructed of wood and used two identical springs to control the push and pull elements of the task. Plate VI. A 3/4" steel pipe 14" long was inserted in the wooden box construction of the simulator to control the plane of movement of the task. A 1/4" slot 9" long was cut in the pipe which allowed a guide attached to the 1/2" rod inserted in the pipe to be connected to the springs. On one end of the 1/2" rod was mounted a cushion spring and the push-pull handle. On the other end was a cushion spring and rubber washer which was held to the rod by a nut.

The five handle positions were marked on the front of the simulator which was supported between two 1" pipes. Thus the five handle orientations and five working heights were easily adjustable to the specific position.

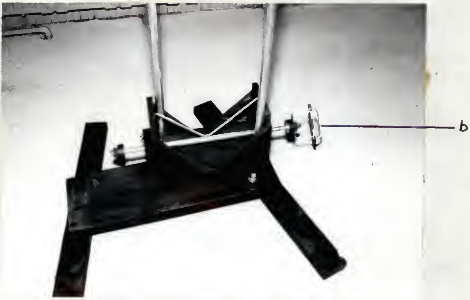
Two identical Sanborn 2-channel amplifier recorder units were

DESCRIPTION OF PLATE VI

Top photograph shows the two identical springs (a) used to control the force required to push and pull the simulator handle.

Bottom photograph shows the rod, pipe, and rubber stop assembly which controlled the simulator handle (b).

PLATE VI



used to record the data. The resistance and capacitance of the entire system were balanced for a null needle setting (0) for each axes. The gain controls were not calibrated but were set for each channel to maximum deflection which was determined by the null (0) setting of the recording pens.

A music metronome set for sixty beats per minute provided the cadence for the task.

Subjects

Ten right handed subjects (three female and seven male) were used to perform the task. The male subjects were junior and senior engineering students from Kansas State University and the females were college student wives. None of the subjects were physically handicapped or considered abnormal in any way. The subjects were paid $1.00/hour for the one and half hours of the task.

Statistical Design

The data for this investigation was coded and analyzed on an IBM 1410 computer with a three factor factorial classification Model I, randomized block design analysis of variance (ANOVA). The following is the mathematical model and description of the terms:

$$Y=\mu+S_i+O_j+H_k+R_l+(SO)_{ij}+(OH)_{jk}+(SH)_{ik}+(SOH)_{ijk}+\varepsilon_{ijkl}$$

$i = \ldots 10$
$j = \ldots 5$
$k = 1 \ldots 5$
$l = \ldots 1, 2$

μ = average effect in the absence of any treatment or block effects.

S_i = additive effect attributable to the i^{th} subject.

O_j = additive effect attributable to the j^{th} orientation.

H_k = additive effect attributable to the k^{th} height.

R_l = additive effect attributable to the l^{th} replication.

$(SO)_{ij}$ = additive effect attributable to the combination of subject i performing at orientation j.

$(OH)_{jk}$ = additive effect attributable to the combination of orientation j and height k.

$(SH)_{ik}$ = additive effect attributable to the combination of subject i performing at height k.

$(SOH)_{ijk}$ = additive effect attributable to subject i performing with orientation j at height k.

ε_{ijkl} = random additive effect assumed to be normally distributed with mean 0 and constant variance σ^2.

Model I implies fixed treatment effects.

The following assumptions were made before using the ANOVA method of data interpertation:

(1) The treatments were a fixed source of variation i.e., the handle orientations, working heights, and subjects were selected for this investigation.

(2) Treatment effects were assumed additive and independent of each other i.e., the force required to perform at a specific height was not related to the handle orientation used.

(3) The error term was considered an additive effect normally distributed with a mean 0 and constant variance σ^2.

Least Significant Difference (LSD) tests were used to determine the significance of differences between means of treatments (Subjects, Heights, Orientations). All LSD values were calculated using an α risk of .05 ($p<.05$).

The order of the task presentation was randomized for working heights and handle orientations. This was done by inscribing specific heights and orientations on blocks of wood and drawing a different block for each trial for each subject.

A sample Subject Data Sheet can be seen in Appendix II. The data was coded from the data sheets for: subjects, trials, (1 and 2), axes (lateral, vertical, frontal), working heights, and handle orientations. Thus it was possible to compute all possible interactions.

The data for all axes were converted to average pounds of force for the cycle time of four seconds by dividing the area reading from the original force-time curves by the corresponding constant. (Table 2)

Four three way ANOVA's were calculated, one for each axis and one for the total force of all three axes. Theoretically the forces should be added vectorially but this was not possible because the absolute direction of force application was not readily interpertable from the force-time curves so the forces were just added. This inconsistancy was not thought to invalidate the results.

Experimental Procedure

Each subject stood with his heels six inches apart and toes aligned with two lines marked on the force platform to help the subject maintain body balance during the task (See Plate VIII). A constant standing position for each subject on the platform insured that the vertical force due to the subject's weight ran through the center of rotation "G" of the platform.

Each subject performed the push-pull cycle three times for each of the five working heights and the five handle orientations. The experiment was replicated so for each subject there were fifty observations for each of the three planes of motion (vertical, frontal, and lateral).

Each subject was given time to practice co-ordinating his movements with the metronome before the measured cycle. During this period, proper synchronization of the simulator movement and timing device could be achieved. In addition, the practice trials could be used to make minor adjustments on the recorder.

Thus a typical cycle was performed as follows: each task (height-handle orientation) started from a "neutral" position. Neutral for each subject was defined as standing in a relaxed position on the platform with the arms hanging naturally at the sides. The recorder was turned on for a short time (one or two seconds) and then off. This established a reference line marked 0 on Plate VII.

With the recorder turned off, the subject was told to go to "startin " position. In the starting position the subject grasped the handle of the simulator but did not move its position. Again the recorder was turned on and off for a short interval. This established the 0_s reference line.

With the recorder turned off, the subject was told to "start" the push-pull cycle. As soon as the cycle speed had been synchronized with the metronome, the recorder was turned on and the area between T_1 and T_2 was recorded.

At the end of three complete cycles (pull to stop and return to stop three times), the recorder was turned off. The subject was told to stop but remain in the task position. The recorder was again turned on and off for a short interval. This established the 0_e reference line.

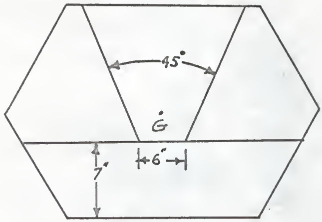
A line from the intersection of 0 and T_1 to 0' and T_2 defines the force-time area needed to perform the task while the body was orientated in the task position. This area, however, does not include the force needed to get to the task position but only the force exerted while performing in the task position

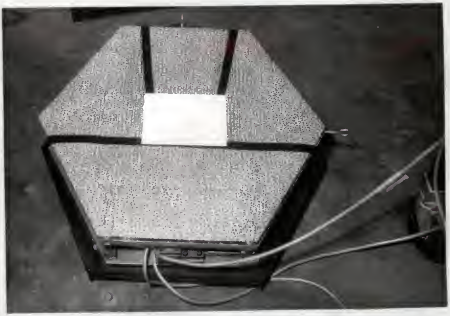
DESCRIPTION OF PLATE VII

Top drawing shows the line specifications for placing of subjects to the prescribed position on the force platform with "G" indicating the platform's center of rotation.

Bottom photograph shows top of force platform showing standing position used by each subject.

PLATE VII



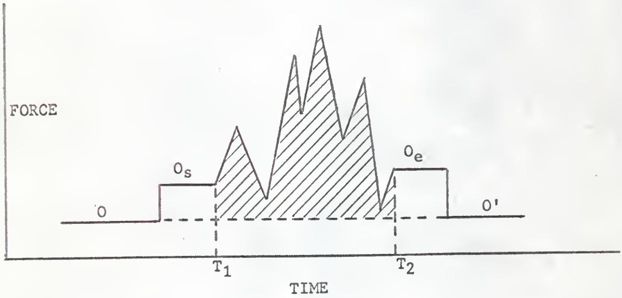


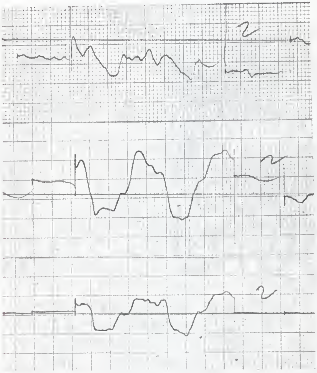
DESCRIPTION OF PLATE VIII

Top diagram shows reference lines which were established for each cycle of the push-pull task. The area shaded indicates the area used for calculations.

Bottom traces are actual force-time curves used as data for the push-pull task.

PLATE VIII





FORCE-TIME AREA

At the end of the first set of tasks, the subjects were given a rest period of approximately ten minutes. During the rest period, the task was discussed and the subjects were asked to think about which handle orientation he preferred at each of the working heights.

RESULTS

It was the purpose of this investigation to measure the variability of ten selected subjects while performing a push-pull task in three independent perpendicular planes. A general breakdown of the force patterns according to the main effects will aid to a better understanding of the results.

Tables 3,4,5, and 6 in Appendix I show the ANOVA calculations for the lateral, frontal, vertical, and sum of the three planes for the push-pull investigation. Due to the statistical design chosen for this investigation, the following results may be applied only to the ten selected subjects used in this investigation.

The effect the subjects had on the push-pull task was significant ($p<.01$) in the lateral, frontal, and vertical planes as well as the sum of the planes. Since subjects were considered a fixed rather than a random factor, these results may not be extended to other subjects. Subjects differed by their body position and specific movement used to accomplish the task. This was directly evident from the ANOVA tables and was also observed directly on the force-time areas.

Handle orientation effect was significant only in the lateral plane ($p<.05$). In the ordered array of orientation means shown in Fig. 1, the 180 degree orientation and 135 degree orientation required the most force while the 90 degree orientation and 45 degree orientation required the least force. The 0 degree orientation was observed to be approximately the average of the means (.2782).

Angle	180	135	0	45	90
Average Force	.2996	.2994	.2775	.2593	.2555

LSD=.0344

Fig. 1. Ordered array of forces for handle orientations in the lateral plane.

The plane of motion (frontal) for handle orientation was non-significant as was predicted in Hypothesis 4. A best handle orientation for each specific working height was not demonstrated (rejection on Hypothesis 3), but the 90 degree orientation did require the least force while an orientation of 180 degrees required the most force.

The three handle orientations most preferred (0,45, and 90 degrees) were also the orientations which required the least force. The least preferred orientations (135 and 180 degrees) required the most force. The summaries are in Tables 12 and 13.

The height of the simulator was significant in all individual planes as well as the sum of the three.

An LSD comparison was made for each plane and for the sum of the three planes using an α risk of .05. The dotted lines on the graphs indicate which mean values were significantly different. The vertical plane appeared to be most affected by the task movements while the frontal (primary plane of motion) and lateral planes were relatively unaffected by the task. The results for the three planes are given in the ordered array of force for each height in Fig. 2 and Graph 3 in Appendix III.

Height	Hip	Knee	Eye	Waist	Chest
Force	2.35	2.19	2.15	1.73	1.64

LSD=.22

Fig. 2. Ordered array of forces for heights of the three planes.

For the sum of the three planes, the hip height required the most force followed by the knee,eye, waist, and chest heights. Most of the force to perform the task, as observed from Graph 3, was detected in the vertical plane. According to the data, the best height was the chest and the height which required the most force was the hip.

DISCUSSION

Because the experiment considered subjects as a constant source of variance, the results previously given can be theoretically applied only to the ten subjects used. The selected subjects were not a random sample of any one population but it was believed intuitively that the subjects did represent the population in general. Therefore, the following discussion will apply to the ten selected subjects and also some possible conclusions can be drawn to the population in general.

Subject Effect

Subject effect was highly significant ($p<.01$). Although subject effects were not one of the hypotheses of this investigation, it was expected that a specific subject's performance would vary from other subjects when doing the task i.e., subjects don't perform push-pull tasks alike.

As indicated in the results, the forces exerted while doing the push-pull task in the vertical, frontal, lateral, and sum of the three planes were significantly different. Positioning the body to each of the five heights does require differing muscular complexity to finally arrive in the prescribed position. Each subject had his own unique way of orientating his body to perform the task. It was observed that the force-time areas were effected differently by each subject when in the "task position".

The effect appeared on the force-time curves when the zero points mentioned previously (Plate VIII) were established. For example, refering to Plate VIII, the measured distance (ordinate) from 0 to 0_s varied for each subject on all three planes when the hip position was used. Thus the resulting force-time relationship/subject varied.

Orientation Effect

Handle orientations were significant ony in the lateral plane. Logically the lateral plane will be affected when the hand and forearm are twisted about the long axis of the arm. From mechanics the force from twisting will result in a force perpendicular to the axis of rotation.

The non-significance of the plane of motion (frontal) as to handle orientation was predicated in Hypothesis 4. This result is logical for theoretically the force of the task did not change for each subject.

Although no general statement can be made as to handle orientation for a specific height, tables similar to Tables 7-11 could be used on an individual selection basis if force measurements were made for all orientations for a specific subject. For example, Subject 1 performed the push-pull task at height 1 with no appreciable difference in force for all of the handle orientations except orientation 4. There it can be said (assuming the subject had previously established a set pattern of performance) that he would require more force to do the task 95 times in 100 using orientation 4 as compared to the force required for the task at eye height with any of the other four orientations. Subject 2 performs the task equally well using any of the five orientations but Subject 7 would apparently find handle orientation 3 most comfortable. As indicated in Table 7, most of the subjects performed the task equally well using four of the five orientations with 5 of the subjects showing no statistical difference among any of the orientations. A similar analysis could be made from the remaining tables at each height. Thus if only one individual were to use a device, it could be designed just for him so as to minimize the work required of him.

Height Effect

The vertical height of the push-pull simulator was significant in the lateral ($p<.05$), vertical ($p<.01$), frontal ($p<.05$), and sum of the three planes ($p<.01$). As mentioned previously, subjects seem to perform a simple motor task with excessive force when the proper positioning of the task was not maintained. These results show that the height of the task is important to the performance efficiency of the task. As indicated on Graph 3, the chest height required the least force while the hip height required the most force. In the task position for the hip height, the subject was slightly stooped when reaching for the handle. For the knee height the subject had his left hand on his left knee. The resting position for the knee height was thought to explain why the hip height required more force than the knee height.

Replication Effect

Subject replication effect was non-significant i.e., the subjects performed the push-pull task with the same force pattern for each of the three planes and sum of three planes in Trial 1 and Trial 2. This resulted partially from an instruction given to each subject asking him to perform the task in a relaxed position and as effortlessly as possible.

Subject-Height Effect

It was stated earlier in this investigation that extraneous forces (appearing in the lateral and vertical planes) which characterized individualism among subjects would be recorded as a decrease or increase in force in a plane other than the plane of action (frontal). Subject x height interaction was significant ($p < .01$) for the lateral and vertical as well as the sum of the planes indicating that subjects did not consistently change their forces as the height was varied. Thus although a best height can be calculated on an average basis, it can not be calculated for an individual unless he is measured at each height.

In the vertical plane (Graph 2), hip height required the most force to perform the task for five of the ten subjects. Also, in the vertical plane, hip height showed the greatest force recorded. It was observed during the experiment that the subjects seemed to sway backward and forward when performing the task. This accounts for the large amount of force being recorded in the vertical plane.

The subject x height interaction in the lateral plane, plotted on Graph 1, does not appear so erratic as the vertical plane interaction in Graph 2. This is not surprising since the lateral effect was only significant at $p<.05$ while the vertical effect was significant at $p<.01$.

Other Effects

The investigation failed to show any significant effects due to subject x orientation or orientation x heights in any of the three planes. Subject x height x orientation was significant ($p<.05$) only in the frontal plane. This third order interaction could be the result of the non-significance shown for the subject x height interaction in the frontal plane. As mentioned previously, only the frontal plane failed to show significance for subject x height interaction.

Between Trial 1 and Trial 2, the subjects were asked to think about which handle orientation he preferred at each of the five

Working heights. Handle orientations of 0, 45, and 90 degrees (28%, 36%, and 22% respectively) were most preferred. These preferences apply to right handed subjects only. These three orientations also required the least force in the lateral plane to perform the task. Orientations 135 and 180 degrees were least preferred and required the most force to perform the task in the lateral plane.

SUMMARY

The results indicated that the subjects differed in their performance of a simple motor task. Height of the task is a significant factor while handle orientation in general is not. The differences are not in performing the task itself but in the way the subject aligns his body in the working position.

There seems to be an inverse relationship between preference for a body position and the amount of muscular complexity involved in performing the task. For example, muscular complexity increases as the working height falls below waist height. According to this investigation, the two heights below the waist (hip and knee) required more force than the waist and chest heights to perform the task while reaching up to eye level also required an excess force.

Thus the results of the investigation would be: place the push-pull task at each person's chest height with the handle position vertical.

This research did reveal that much more interesting work remains for the engineer interested in designing specifically to meet individual needs. With data made possible by such a measuring apparatus as the force platform, it is felt that personal consideration to the worker is more feasible.

ACKNOWLEDGEMENTS

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APPENDIX I

TABLE I

SUBJECT-TASK POSITIONING SPECIFICATIONS

WORKING HEIGHTS	DESCRIPTION
1	Handle at eye level
2	Handle at chest level
3	Handle at waist level
4	Handle at hip level (approximately 9" below waist)
5	Handle at knee level

HANDLE ORIENTATIONS		DESCRIPTION
1	—	* Handle rotated 0 degrees from horizontal
2	\	Handle rotated 45 degrees clockwise from horizontal
3	|	Handle rotated 90 degrees clockwise from horizontal
4	/	Handle rotated 135 degrees clockwise from horizontal
5	—	**Handle rotated 180 degrees clockwise from horizontal

* Orientation 1 palm down

** Orientation 5 palm up

TABLE 2

AREA CONVERSION CONSTANTS
FOR PEN DEFLECTION USING
A TWO POUND WEIGHT FOR
A FOUR SECOND SEQUENCE

PEN DEFLECTION (mm)	CONSTANT
1	0.129
2	0.528
4	0.576
6	0.774
8	1.032
9	1.161
10	1.290

TABLE 3

LATERAL PLANE

ANALYSIS OF VARIANCE

VARIATION	D/F	MEAN SQUARE	F
Subjects (S)	9	.489	32.60**
Orientation (O)	4	.046	3.02*
Height (H)	4	.038	2.50*
Replications (R)	1	.038	2.50*
OxS	36	.016	1.05
OxH	16	.013	.85
SxH	36	.059	3.86**
OxHxS	144	.033	.86
Error	249	.015	
Total	499		

* $p<.05$

** $p<.01$

TABLE 4

FRONTAL PLANE

ANALYSIS OF VARIANCE

VARIATION	D/F	MEAN SQUARE	F
Subjects (S)	9	3.207	100.25**
Orientations (O)	4	.046	1.43
Heights (H)	4	.098	3.09*
Replications (R)	1	.106	3.33
OxS	36	.032	1.00
OxH	16	.033	1.03
SxH	36	.039	1.21
OxHxS	144	.044	1.41*
Error	249	.031	
Total	499		

* $p < .05$

** $p < .01$

TABLE 5

VERTICAL PLANE

ANALYSIS OF VARIANCE

VARIATION	D/F	MEAN SQUARE	F
Subjects (S)	9	15.732	41.47**
Orientations(O)	4	.597	1.57
Heights (H)	4	6.573	17.32**
Replications (R)	1	.028	.07
OxS	36	.309	.81
OxH	16	.373	.91
SxH	36	2.286	6.02**
OxHxS	144	.305	.81
Error	249	.379	
Total	499		

* $p < .05$

** $p < .01$

TABLE 6

SUM OF THREE PLANES

ANALYSIS OF VARIANCE

VARIATION	D/F	MEAN SQUARE	F
Subjects (S)	9	19.727	37.05**
Orientations (O)	4	.837	1.57
Heights (H)	4	8.102	15.22**
Replications (R)	1	.100	.19
OxS	36	.419	.78
OxH	16	.568	1.07
SxH	36	2.750	5.17**
OxHxS	144	.428	.81
Error	249	.532	
Total	499		

* $p<.05$

** $p<.01$

TABLE 7

FRONTAL PLANE
FORCES FOR EYE HEIGHT

ORIENTATION

SUBJECT	0°	45°	90°	135°	180°
1	.560	.560	.560	1.045	.660
2	.390	.370	.410	.410	.430
3	.485	.720	.525	.485	.895
4	.465	.465	.485	.505	.605
5	.760	.800	1.485	.600	.740
6	.505	.540	.425	.620	.425
7	1.125	1.050	.425	1.550	1.585
8	.600	.680	.680	.600	.585
9	.370	.370	.430	.465	.455
10	1.055	1.210	.960	.860	1.310

* $p<.05$

LSD=.350

TABLE 8

FRONTAL PLANE
FORCES FOR CHEST HEIGHT

	ORIENTATIONS				
SUBJECT	0°	45°	90°	135°	180°
1	.560	.600	.620	.580	.580
2	.465	.430	.405	.295	.350
3	.445	.430	.445	.445	.585
4	.370	.450	.470	.465	.470
5	.625	.910	.815	.700	.740
6	.505	.505	.350	.425	.515
7	1.125	.740	.545	1.005	1.165
8	.505	.620	.580	.680	.640
9	.365	.465	.350	.470	.365
10	.980	1.325	1.035	1.350	1.175

* $p<.05$

LSD=.350

TABLE 9

FRONTAL PLANE
FORCES FOR WAIST HEIGHT

	ORIENTATIONS				
SUBJECT	0^{o}	45^{o}	90^{o}	135^{o}	180^{o}
1	.580	.540	.580	.505	.520
2	.410	.470	.370	.350	.430
3	.870	.390	.410	.585	.430
4	.450	.390	.450	.430	.505
5	.780	.680	.950	.660	.700
6	.595	.425	.620	.515	.390
7	.890	1.005	1.125	.970	.965
8	.484	.600	.485	.505	.580
9	.445	.390	.485	.370	.385
10	.815	1.020	.935	.895	1.175

* $p<.05$

LSD=.350

TABLE 10

FRONTAL PLANE
FORCES FOR HIP HEIGHT

ORIENTATIONS

SUBJECT	0^{o}	45^{o}	90^{o}	135^{o}	180^{o}
1	.560	.580	.580	.540	.580
2	.465	.350	.465	.450	.520
3	.445	.410	.505	.505	.330
4	.450	.370	.430	.605	.505
5	.660	.815	.640	.760	1.080
6	.390	.775	.465	.350	.505
7	1.205	1.165	1.315	1.010	1.045
8	.720	.680	.580	.835	.545
9	.390	.410	.465	.350	.425
10	1.695	.875	1.195	.995	1.240

* $p<.05$

LSD=.350

TABLE 11

FRONTAL PLANE
FORCES FOR KNEE HEIGHT

ORIENTATION

SUBJECT	0°	45°	90°	135°	180°
1	.620	.600	.560	.520	.565
2	.485	.540	.465	.410	.470
3	.540	.465	.445	.580	.390
4	.525	.430	.410	.505	.470
5	.330	.780	.720	.465	.560
6	.350	.630	.385	.580	.750
7	1.045	1.390	1.280	1.010	.970
8	.585	.505	.640	.545	.760
9	.425	.450	.410	.505	.370
10	1.130	.900	1.030	1.250	1.170

* $p<.05$

LSD=.350

TABLE 12

SUBJECT-HANDLE PREFERENCE FOR SPECIFIC HEIGHTS

HEIGHT OF HANDLE

SUBJECT	EYE	CHEST	WAIST	HIP	KNEE
1	90°	45°	135°	0°	135°
2	0°	45°	90°	45°	0°
3	45°	0°	135°	45°	45°
4	45°	45°	0°	45°	0°
5	90°	45°	90°	0°	0°
6	180°	45°	0°	180°	0°
7	45°	45°	90°	45°	90°
8	45°	45°	0°	90°	90°
9	0°	0°	180°	90°	90°
10	45°	90°	45°	0	180°

TABLE 13

ORIENTATION PREFERENCE
SUMMATION

		ORIENTATION			
HEIGHT	0^{o}	45^{o}	90^{o}	135^{o}	180^{o}
EYE	2	5	2	0	1
CHEST	2	7	1	0	0
WAIST	3	1	3	2	1
HIP	3	4	2	0	1
KNEE	4	1	3	1	1
TOTAL VALUES	14	18	11	3	4
PERCENTAGE	28%	36%	22%	6%	8%

APPENDIX II

SUBJECT DATA SHEET

SUBJECT 1 (Male)

POS.	LATERAL 1	LATERAL 2	FRONTAL 1	FRONTAL 2	VERTICAL 1	VERTICAL 2	TOTAL 1	TOTAL 2
1-1	.31	.27	.54	.58	.70	.82	1.55	1.67
1-2	.32	.39	.58	.58	1.20	.35	2.10	1.28
1-3	.31	.22	.54	.54	1.16	.39	2.01	1.14
1-4	.31	.21	.54	.58	1.55	.39	2.40	1.18
1-5	.58	.31	.55	.54	3.29	.35	5.42	1.20
2-1	.27	.25	.54	.58	2.33	.39	3.14	1.22
2-2	.33	.35	.62	.58	1.12	.19	2.07	1.12
2-3	.16	.31	.50	.50	1.16	1.05	1.82	1.86
2-4	.47	.39	.70	.54	1.16	2.29	2.33	3.22
2-5	.39	.47	.62	.54	1.16	.47	2.17	1.48
3-1	.27	.31	.58	.58	.82	1.75	1.67	2.64
3-2	.22	.26	.54	.54	.78	.43	1.54	1.32
3-3	.32	.19	.58	.58	1.16	.19	2.06	.16
3-4	.42	.26	.58	.43	.78	1.16	1.78	1.85
3-5	.31	.27	.50	.54	.58	.50	1.39	1.31
4-1	.27	.27	.50	.62	1.55	1.67	2.32	2.56
4-2	.23	.31	.58	.58	1.35	1.39	2.16	2.28
4-3	.35	.27	.62	.54	1.75	.39	2.72	1.20
4-4	.67	.35	.54	.54	2.29	1.55	3.50	2.44
4-5	.25	.31	.58	.58	1.55	.35	2.38	1.24
5-1	.19	.39	.70	.54	.31	.39	1.20	1.32
5-2	.32	.39	.62	.58	.78	.47	1.72	1.44
5-3	.26	.31	.58	.54	3.10	1.67	3.44	2.52
5-4	.42	.39	.50	.54	.70	.78	1.62	1.71
5-5	.50	.47	.66	.47	1.55	.47	2.71	2.41

AXES CONSTANTS
(mm deflection/2-lb weight)

Vertical	2 mm
Lateral	10 mm
Frontal	2 mm

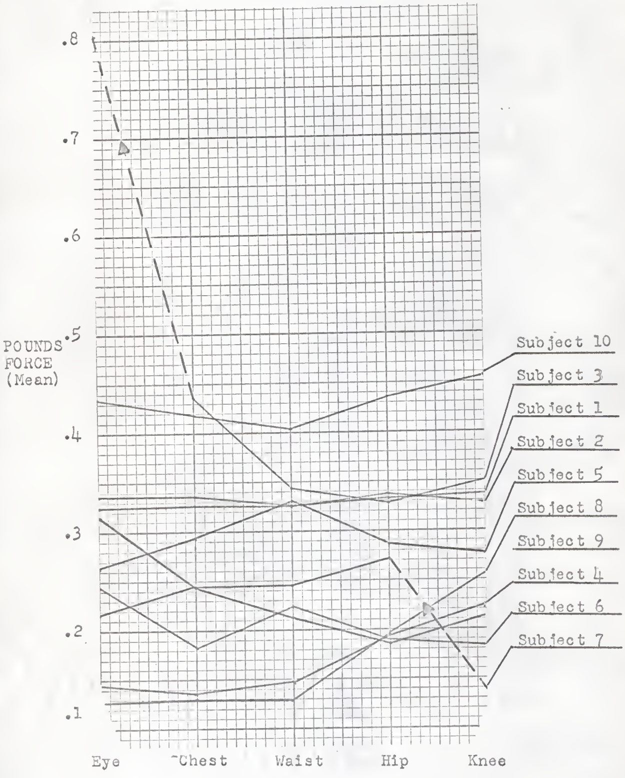
HANDLE PREFERENCE

HEIGHT	ORIENTATION
Eye	90°
Chest	45°
Waist	135°
Hip	0°
Knee	135°

APPENDIX III

GRAPH 1

LATERAL PLANE
SUBJECT-HEIGHT INTERACTION

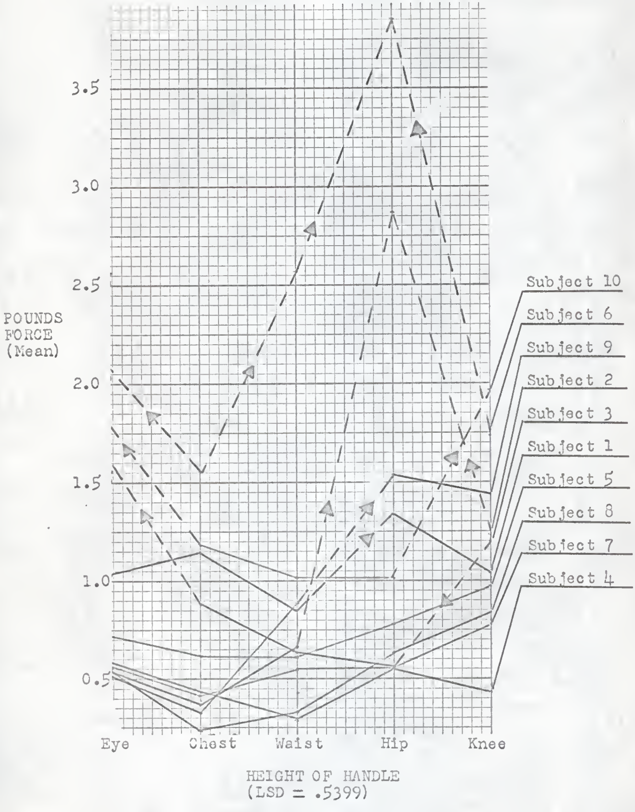


HEIGHT OF HANDLE
(LSD= .10879)

GRAPH 2

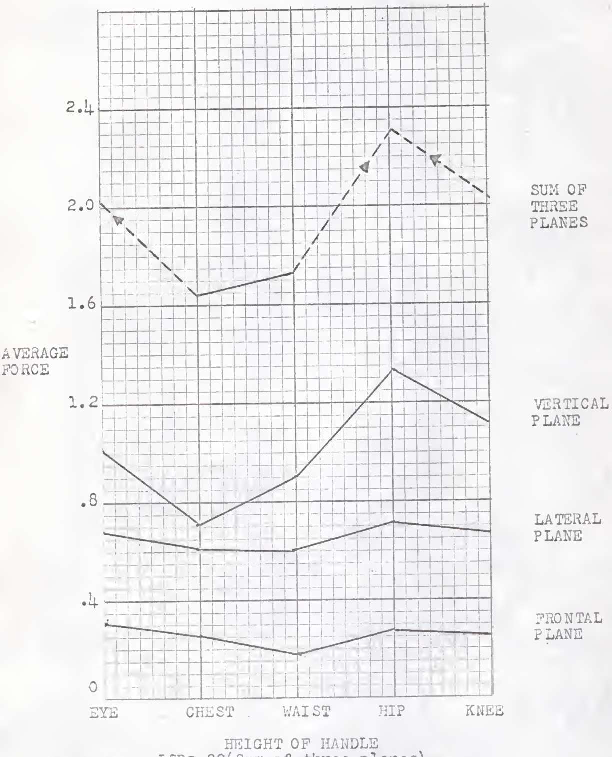
VERTICAL-PLANE

SUBJECT-HEIGHT INTERACTION



GRAPH 3

HEIGHT AVERAGE FORCE
PER PLANE



LSD=.22(Sum of three planes)

THE EFFECTS OF HAND-WRIST AND BODY ORIENTATION ON THE FORCE REQUIREMENTS TO PERFORM A PUSH-PULL TASK

by

ROBERT ALAN DAY

B. S. Emporia State Teachers College, 1960
B. S. Kansas State University, 1964

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirement for the degree

MASTER OF SCIENCE

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1965

ABSTRACT

The primary objective of this thesis was to investigate the amount of force exerted in three independent perpendicular planes by a person doing a simple push-pull task. The push-pull task was simulated by a specially constructed handle and spring arrangement which could be adjusted easily into five handle orientations and vertically to five working heights relative to each subject.

The force measuring apparatus was a force platform which is capable of measuring forces as small as a heart beat. Previous research studies using force platforms indicate that the platform's unique force differentiating characteristics can be used in many aspects of engineering and science.

Ten selected subjects, seven male and three female, performed the task at each handle orientation and at each working height. The order of task presentation was randomized and each subject performed the task sequence twice i.e., fifty observation per subject.

The data were statistically analyzed by an analysis of variance comparing handle orientations, working heights, and subjects and the mean values were tested by the Least Significant Difference (LSD) test.

The following results were obtained: