THE DIRECTION OF MOTION OF MACHINE TOOL CONTROLS

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SUMMARY

The experiments presented in this report were designed to measure the strength and direction of population stereotypes in the use of machine-tool handwheel controls. A close simulation of the real-life task was attempted.

It was found that, where stereotypes existed, experienced machine tool operators conformed with normal machine tool design practice in their expectations. Secondary school boys (potential operators) had no expectations: university students' expectations were not always in line with design practice. The stereotypes of apprentices were often weaker versions of those of operators.

The effects of allowing each subject to perform several different tasks involving handwheels were examined: expected directions of motion were not affected, but the overall tendency to respond clockwise was affected. There was some sequential dependence in the responses.

The conclusion is reached that standardization of control-display relations is important but in most cases there are no "natural" stereotypes (obvious ones were not studied) - the stereotypes are learned by the operators, from the machines they operate.

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SECTION 1 INTRODUCTION AND HISTORICAL SUMMARY

1.1 The Nature of the Problem

This study is concerned with the relations between the controls and displays which form the links between the human being and the hardware in any man/machine system. Two aspects of such relations which are of interest are the configuration - the relative positions of control, display and operator - and the direction-of-motion relation: which way does the display move in response to a given direction of movement of the control? The experiments to be reported later (Section 2, et. seq.) are concerned with specific tasks: handwheel-operated traversing motions of a simulated machine tool: but in this section the field of direction-of-motion relationship in general will be reviewed.

Typically, there are three requirements for any experiment in this field. First, a task involving a control and a display: this may or may not be abstracted from a task found in a "real-life" man-machine system. Secondly, a criterion by which to judge the worth of alternative configurations and relations of the control and display: this depends on the type of task but usually involves operating-time or error scores. Thirdly, a set of variable conditions is required. Either some features of the task may be varied or changes may be made in the conditions under which subjects attempt the task (stress, secondary task, etc.) or in the type of subject (age, experience, etc.).

1.2 Early Work at Cambridge.

Between 1944 and 1950, several experiments were carried out at Cambridge under the general title of "Direction of Movement of Machine Controls". Not all of these are still in print but examples are Vince (1944), Mitchell (1947), Mitchell (1949), Vince (1950), and Mitchell and Vince (1951).

The last is a summary paper which deals with the whole series of experiments. The work was started by the late K.J.W. Craik and carried on by Vince and Mitchell.

Initially a control-display configuration in which the sense of the "expected" direction-of-motion relation could be taken for granted was studied: Vince (1944). The display was a pointer which moved vertically, the task was to cause the pointer to follow a track on a revolving drum, and the control was a horizontal lever whose end moved vertically in a plane at right-angles to the operator's line of sight. (In fact, the lever could also be considered as a rotary control but the importance of this ambiguity was not to emerge until later, e.g. Simon and Fitts (1952)).

The purpose of the experiment was to measure the effect on task-accuracy of the "expected" and "unexpected" direction of motion relations. These were of course taken to be "up for up, down for down" and "up for down, down for up" respectively. It was found that the "unexpected" relation did indeed have a deleterious effect on performance (increased error score) in the two types of task studied: compensatory tracking and discrete binary switching, provided that a certain rate of stimulus - presentation was exceeded. It was further shown that performance on one direction-of-motion relation was degraded if the subject had previously practised on the opposite relation. The importance of this first paper in the field was that it formally verified the practical importance of an optimum control-display relation in tracking and continuous switching tasks, and pointed to the trouble which could arise if such relations were not standardized among tasks. The latter conclusion was missed by Hick (1945), who looked into factors affecting handwheel design (for a Naval gunnery application) and concluded from a literature survey that direction-of-motion relations were not important because they only affected the initial training stages of a task. Later, Fitts and Seeger (1953) were to show that such effects showed no sign of diminishing after 2½ months of daily practice.

Mitchell (1947) used the same set-up to measure performance on various control-display relations other than "up for up" and its opposite. The display remained "up/down" but the control was put in "left/right" and "to/from" positions, moving horizontally. These horizontal controls produced similar performance, giving an error-rate halfway between that for "up for up" and that for "up for down". The addition of a secondary task for the left hand (the main task was for the right hand) made very little difference to the rank order of the error scores for the different configurations.

Later (Mitchell, 1949) a two-handed tracking task was studied, still using the same apparatus. Only the right-hand task was scored, although to the subject the left was equally important. For the switching task the right-hand performance was made worse by the addition of the second task but, unexpectedly, in the compensatory tracking task, performance of the right hand task was improved when the left-hand task was performed as well. This was put down to a lack of motivation in the one-hand tracking task: it was "too easy".

Vince (1950) rounded off this pioneering series of experiments by looking at the effect of stress on the ability to retain a learned direction-of-motion relation. Of a dozen supposed stressors tried, only one caused a significant reversion to previously-learned stereotypes: the introduction of irrelevant and unexplained stimuli into the display. A by-product of this experiment was the discovery that measured intelligence was correlated with performance on the "unexpected" relation, but not on the "expected" one. (These were the same tasks that Vince used in her original 1944 experiment). Once again, motivation difficulties on the easier task were found to confuse the results.

1.3 Early Work in the U.S.A.

The starting point for human engineering as a separate discipline in the United States seems to have been the work of the late Paul M. Fitts and others on the causes of "pilot error" in military aircraft. The vital finding was that the faults were more often attributable to the design of the aircrafts' control and display systems than to the unfortunate pilots. One contributory factor was the prevalence of "incompatible" controls and displays, i.e. those having unexpected movement relations or configurations.

A new type of experimental method was introduced by Warrick (reviewed by Loveless, 1962) whose original 1947 paper is now difficult to obtain. Previous studies had measured the performance of subjects who were in a position to know what control-display relation was embodied in the task, either because they were allowed a practice session or simply because the task was scored over an extended interval of time. The "expected" relation was defined as the one under which the most accurate performance of the task occurred. Warrick, on the other hand, presented the subject with an unknown direction-of-motion relation: the sense of the <u>initial</u> response was recorded and thus the subject's "expected" relation was discovered. If a large enough majority of a sample of subjects responded in the same way, an expected relation for the population could be inferred. This later came to be called a "population stereotype". All Warrick's tasks involved a rotary control (a knob) and a linear display: a pointer moving against a straight uncalibrated scale. Where the axis of the knob was at right-angles to the plane of the display the "expected" relations were found to obey a general principle (later known as "Warrick's principle"): the pointer was expected to move in the same sense as the nearest part of the knob. Exceptions to this "rack-and-pinion" model have since been found (e.g. Thylen,1966).

In the cases where the axis of the knob was not at right-angles to the plane of the display, no significant expected relations were found.

1.4 Attempts to Quantify Compatibility.

Mitchell and Vince in their work and Warrick in his, used the performance of the subjects to determine which direction-of-motion relations were compatible. A different approach was taken by Morin and Grant (1953): they devised a task in which an a priori compatibility of the control and display could be calculated. Subjects' performance was measured separately so that the relation between compatibility and performance could be explored. In their experiments the display was a row of eight lamps and similar row of eight keys placed below the lamps constituted the control. Any key could be wired to any lamp, giving 8 possible control-display configurations. 23 of these combinations were used: one where each key operated the lamp above it, one where each key was connected to the lamp which was symmetrically opposite the key, about a central vertical axis, and 21 intermediate arrangements in seven groups of three, each group having the same calculated value of compatibility. The measure of inherent compatibility was Kendall's rank correlation coefficient (tau). Reaction time and errors were the performance criteria and the relation between these and the inherent compatibility turned out to be as follows: best performance on both time and errors was given by the direct connection of each key to the lamp above it (tau = 1.0); time and errors were doubled in the next-best arrangement, symmetrical cross-connection of keys and lamps (tau =-1.0); all other arrangements were worse still, reaching a quadrupling of time and errors for the three arrangements giving tau = -0.29 (Not tau = zero as might be expected).

This non-operational way of looking at control-display compatibility has not been followed up in later work, perhaps because the type of task to which it can be applied is not common in practical situations, and perhaps because the answer it gave was, from a practical design point of view, obvious anyway. The next work to be discussed concerns differences in configuration which it would be difficult to quantify. In fact, the attempt was not made, subject's performance being the measure of compatibility once again. The work in question is that of Fitts and Seeger (1953). Their aim was to "demonstrate the utility of the concept of stimulus - response compatibility". To this end they devised a measure of compatibility based on the application of the methods of information theory to the subjects' performance. The ratio of information lost in the passage from stimulus to response to the original uncertainty of the stimulus was the measure used.

The task consisted of various lamp-matrix displays and a number of stylus mazes which corresponded to the displays. All combinations of lamp-matrix and maze layout were tried separately and the groups of subjects were scored on reaction time, errors, and the information measure described above. All three measures were found to rank the nine tasks almost identically. In addition, the three tasks which were intuitively most compatible (similar geometry of lamp-matrix and maze layout) ranked highest on all the measures. As a conclusion the hypothesis was put forward that low compatibility involves extra steps of information coding, each step taking up time and containing the possibility of error. The most important finding resulted from a further experiment in which the same tasks were extended over 32 training sessions during a period of 2½ months: the differences among the nine tasks in terms of the three measures were maintained throughout this time and showed no sign of convergence at the end.

1.5 Exploration in Detail.

The early 1950's saw a change in the direction of research. It began to be realised that no one experiment was likely to produce a general theory of control-display compatibility: there were far too many variables present in a practical control situation for this to be possible. Expected relations had been shown to exist in various experimental set-ups.: effort now turned to the examination of these relations in experiments which resembled particular practical cases.

A good example is the interest which was now shown in the background of the subjects. Previously it had been quite common to omit all reference to the age and occupation of the subjects, as though any expected relations found in one group could be safely generalised to the whole population. Simon and Fitts (1952) graded their subjects on the basis of "sophistication" - a combination of age and experience which ranged from five-year old children to engineering students. They were interested in the problem of conflicting stereotypes: given a rotary control coupled to a circular dial there is a position of the pointer at which Warrick's principle would suggest one direction-of-motion relation("linear model") while a "clockwise-for-clockwise" rule would suggest the opposite relation ("curvilinear model"). The results of the experiment showed that with increasing sophistication there was a systematic shift from the linear to the curvilinear model. The task in this experiment was a pencil-and-paper simulation, a method that is frowned upon nowadays.

Norris and Spragg (1953) investigated a task on a standard piece of apparatus, the SAM two-handed co-ordination test. Here two handwheels were operated simultaneously to control the X and Y co-ordinates of the marker in a two-dimensional tracking task. The best positions and direction-of-motion relations for the two handwheels were found, for a population of students.

The expected relations were found to be:

Left hand: Clockwise for movement to the right.

Right hand: Clockwise for movement from the operator.

It is stated that these were already known to be the "natural" relations, but no evidence is quoted for this.

Bradley (1954) concentrated on a particular display device: the moving-scale indicator, in which the index mark is a hairline engraved on a window. Through the window can be seen part of the moving graduated scale. The three variables in this device are:

Direction-of-motion relation between rotary control and scale.

Direction of scale-number increase.

Relation between control direction and scale increase.

The last variable depends on the first two. As each has two values there are four combinations of the first two variables. Intuitively the "desirable" values are:

Direct drive (clockwise for clockwise).

Scale numbers increase from left to right.

Clockwise turn of control increases scale reading.

Three of the four combinations satisfy two of these conditions: the fourth satisfies none of them. A very thourough exploration was made of the types of error produced by the various combinations, and a development programme of modified and novel types of indicator was carried out. The result is a definitive design manual for moving-scale indicates which should be of direct practical use.

Holding (1955) attempted to summarize the known expected relationships for both linear and rotary controls and displays. He went on (1957a) to look at the effects of a new variable, initial pointer position. The effect was that if the pointer started from one end of the scale there was a weakening of the stereotype. The subjects were students and Warrick's single-response method was used.

In Holding (1957b) the cases where the axis of a rotary control lies parallel to a linear scale were investigated. Some significant stereotypes were found in cases where Warrick had found none (Loveless 1962). Nevertheless Holding concluded that the stereotypes were not sufficiently strong or reversible to warrant the use of such configurations. He also confirmed the overall clockwise bias in right-hand operation of rotary controls noted by Warrick.

Ross, Shepp, and Andrews (1955) applied the pencil-and-paper test method to a variety of control-display configuarations.

Humphries (1958) investigated the interaction between control-display relation and the position of the operator relative to the machine. He found that the control-display relation, specified in isolation, was not suffieient to guarantee adequate performance: the operator's position must be specified as well.

Bradley (1959) concerned himself with a non-moving display, namely a lamp whose brightness was controlled by a knob. He found a strong clockwise-to-increase/anticlockwise-to-decrease stereotype among male and female college students. In right-handed subjects there was also a stimulus-independent clockwise bias. This was not found in left-handed subjects. The stereotype was weakened when the instructions were given in negative form, e.g. "increase the dimness of the lamp".

Loveless (1959a) and Thylen (1966) were interested in the problem of conflicting stereotypes. Loveless tackled the circular dial/rotary control problem, featured in Simon and Fitts (1952), from a different standpoint. He verified a simultaneous-equation method for measuring the strengths of the co-acting stereotypes by working with a pointer in different quadrants of the circular dial. Thylen showed that Warrick's principle and a clockwise-for-right expectation could be made to conflict by arranging that a knob was mounted vertically above a horizontal straight dial. Either stereotype could be dominant, depending on the proximity of the pointer to the central part of the scale, immediately below the knob.

In McCross (1959) a similar arrangement was used, the knob being positioned either below or to the right of a horizontal and a vertical straight dial. The two knob positions produced stereotypes in the same sense. However, the stereotype was weaker when the line of action of the display passed through the centre of rotation of the knob, so that only a clockwise-for-right or a clockwise-for-up stereotype was possible, with no help from Warrick's principle.

The same control and display, in the same configurations, were used by Chapanis and Gropper (1968). They studied the effect of left-handedness, use of the non-preferred hand, and the direction of scale-numbering. They found that performance with the non-preferred hand deteriorated more for right-handers than for left-handers. (Measured as frequency of dial-setting errors). Both types of subject, when using the non-preferred hand, performed better when the scale numbers increased from right to left.

1.6 Conclusions from the Review.

While the work described above has advanced our knowledge of human behaviour, its applicability to the design of man-machine systems is rather limited. In particular, the types of display which have been investigated are few: lamps and dials being the almost exclusive choice of the experimenters.

No work has been done on the case where the display is a large moving piece of machinery, or where there is a one-sided aspect to the display: setting an indicator to a point which may not be passed. Since the present writer's interest is in machine tools, the experiment described in the remaining sections of this paper is concerned with the relations between the handwheel/crank controls of these machines with the relative movements of a workpiece/machine-table assembly and a spindle/cutter assembly. There is ample evidence to show that the stereotypes for this situation cannot be inferred from the dial-and-knob experiments. Furthermore the influence of experience cannot be ignored. Machine tools must be designed for actual and potential machine-tool operators, so these typesof subject must be used in any experiment in this field.

SECTION 2 THE DESIGN OF THE EXPERIMENT

2.1 The Range of Methods Available

Methods for the measurement of population stereotypes are not standardized, workers in this field having adapted the details of their methods to the requirements of the practical problems to which their results were to be applied. The main methodological differences are discussed below.

2.1.1 Initial-response versus continuous performance criteria.

Methods in which only the subject's initial response is recorded are very popular, because they arise from a problem which occurs frequently in practice. There are many situations in which some kind of cost accrues if an operator, in response to a stimulus, should move a control the 'wrong way': a tap or valve which must be closed in order to relieve a dangerous condition may instead be opened; a cutting tool which requires to be withdrawn from the vicinity of a workpiece may be plunged into that workpiece, etc. The common feature of such cases is that 'second thoughts' are too late - it is the initial response that is all-important.

When a situation of this kind is to be simulated in the laboratory it seems appropriate to take this initial response as the dependent variable and to ignore any subsequent behaviour.

There are other practical tasks in which the sense of the initial response assumes only minor importance and the main requirement is for continuously accurate performance over a period of time. These are generally tracking tasks, both compensatory and target-following, in one or two dimensions, or tasks involving steering along a path. The simulation of tasks of this type gives rise to experiments in which the initial response is not a criterion of performance and an appropriate time or error score is measured instead.

There are important differences between the two types of experiment but in both the conditions should be so arranged that the subjects will reproduce the behaviour which would occur in the corresponding 'real life' situation. One question which must be answered is, should the subject know which aspect of his behaviour is under scrutiny? If he does know (in cases where the initial-response criterion is in use) his response may be determined by conscious thought about the control-display relationship, whereas if he can be discouraged from thinking about this his responses are more likely to reflect his previous experience and innate response tendencies (if such exist), which may never consciously have been organized. Pencil-and-paper tests have sometimes been applied to the investigation of population stereotypes, and these necessarily involve the subject's knowing that the sense in which he would prefer to operate a control is to be recorded. On the other hand, it is often the operation of a control under time-stress that is of interest in the practical case: it is just when there is not time to think about which way a control should move that moving it the right way, first time, can be important.

When a continuous performance criterion is used the subject learns which control-display relation is built into the task very early in the trial but a case can still be made out for withholding knowledge of the objectives of the experiment, on the grounds that an initial preference for one particular control-display relation could have a differential effect on motivation.

An important methodological difference between experiments using the initial-response criterion and those using a continuous performance criterion is in the effect of submitting the same subject to a series of trials. In the former case the subject obviously cannot be given the same task twice: his first attempt gives him an opportunity to learn the correct response. An extension of this idea suggests that he should not be given two similar tasks in one experiment lest the experience of a trial on one task affects the response in the other. Some workers, even a majority, go further and state that the subject should never make more than one response, on one task, during the experiment and should never be re-tested, even on a different task. Continuous-performance experiments are not limited in this way so often, since it is possible to measure, and allow for, the effects of learning and of transfer of training between tasks.

Another basic difference arising from the limitations imposed on repeated testing is in the amount of information which can be obtained from each subject. Under the initial-response criterion, with a two choice response, only one bit per trial is generated. With continuous performance the amount of information is limited only by the length of the trial. This means that the random element in the responses can only be overcome in the former case by submitting a large number of subjects to one trial each on the same task while in the latter a significant difference between two control-display arrangements or two direction-of-motion relationships can be established for each subject. The result is that samples can be much smaller in a continuous performance experiment while still representing the population accurately.

From the foregoing discussion it can be seen that the various experimental methods in use actually estimate different parameters of population behaviour although these are all given the name 'population stereotype'. To summarize, the following questions are answered by different types of experiment:-

Given a particular control-display arrangement,

1. Which way do a majority of members of the population consciously think they would move the control in order to effect a given change in the display? (Pencil-and-paper tests and initial-response type experiments with knowledge of objectives.)

2. Which way would the majority actually move the control? (Initial-response experiments without knowledge of objectives.)
3. Which of the possible direction-of-motion relationships would allow a majority of the population to give the most accurate/ rapid performance? (Continuous performance experiments.)

2.1.2 Reversibility of Stereotypes

Most practicable control-display arrangements embody a two-way relationship between the control movements and the changes which occur in the display, e.g. if a lever is moved to the right to increase the reading on a dial then it must be moved to the left in order to reduce it: a switch that goes down for 'on' goes up for 'off' etc. Population stereotypes, however, are not always reversible. When confronted with the lever and the dial, 70 per cent of a group of people might move the lever to the right in order to increase the reading, but it does not follow that 30 per cent of the same group would have moved it to the left if they had been instructed to reduce the reading. It is well established that, in addition to preferred direction-of-motion relationships, there exist preferred responses. An example of a preferred response is the tendency, seen in several studies, for rotary controls operated by the right hand to be turned clockwise. Thus there are two parameters which must be measured in order to describe a population's expectations about a control-display arrangement; these are <u>correlation</u> between stimulus and response variables and <u>bias</u> amoung the values of the response variable. In experiments under the initial-response criterion it is necessary to make separate sets of tests, using different groups of subjects, for the different ways (usually two) in which the display may change (up/down, increase/ decrease, etc.)

2.1.3 Serial Effects

In any experimental situation the response to a particular stimulus depends not only on the nature of that stimulus but also, in varying degree, upon the whole history of the subject's perceptual experience. The strength of the effect that any given perceptual event exerts upon the response to the current stimulus will be a function of the vividness, frequency and recency of the event and of its relevance to the current situation. If, therefore, in any experiment the subject undertakes a series of similar tasks then, for all tasks except the first, there will be recent, relevant experiences whose effect upon the current response may be added to that of the current stimulus.

For example, an experiment may consist of a series of trials, one of which might be:

stimulus: instruction to move the display 'up' or 'down'

response: knob is turned either clockwise or anticlockwise.

There seem to be four variables in this trial which could affect the response to a subsequent trial on a different task. They are:

1. The spatial arrangement of the control and the display
2. The sense (up or down) of the stimulus
3. The sense (clockwise or anticlockwise) of the response
4. The outcome of the trial (display moves in 'correct' or 'error' sense).

The possible effects of one trial upon the response in a later trial are:

1. An increase in stimulus-response correlation, or in response bias.
2. A reduction (in extreme cases a reversal) in correlation, or bias.

These effects can be measured by controlling the order in which the four variables appear in a series of trials, but this has not been done hitherto.

2.1.4 Demarcation of Populations

The populations studied most consistently up to now have been students and the military. There is often no evidence to show that civilian or industrial populations have similar stereotypes to those of the groups in question. Students in particular are suspect because they are a selected group with a lower mean age and higher measured intelligence than the general population. An important question is, how finely must the general population be broken down in order to obtain sub-populations with reasonably homogenous stereotypes on a given type of task?

2.1.5 Realism and Simulation

Just as little is known about the validity of generalisations from one population to another, so there is a lack of data on generalisations amoung different types of task. Most studies concentrate on direction of motion as the main variable in the display but there are others which can be important, as the studies on direction of scale-numbering recognise. Thus a stereotype found in a dial-and-pointer experiment might not appear in a machine-tool task if direction of motion happened to be less important than increasing/reducing the depth of cut. The nature of the control is important in the same way: a control perceived as a potentiometer would be likely to give rise to different responses from a control which was taken to be a hydraulic valve, for example.

2.2 The experimental method in the present study

The purpose of this study was to obtain reliable data on population stereotypes which could be applied directly to the choice of control-display relationships commonly found in machine tools. A secondary purpose was to investigate the serial effects which occur when the same subject performs more than one task in an experiment.

To attempt to develop a general theory would have been beyond the scope of the study, although the absense of such a theory is surprising in view of the amount of research which has been done in the past. The reason for this is that nobody has attached enough importance to the problem to invest in it the prodigious amount of co-ordinated research which would be required in order to develop and test a comprehensive theory: studies have been diverse and application-orientated. The present work is no exception to this trend, in that it is confined to the study of handwheel-controls as applied to milling machines of the horizontal and vertical type only. The simulation of the real work situation is as realistic as circumstances would permit, but only a costly validation study could remove all doubt as to whether the level of realism is high enough to permit effective application of the results to be made.

2.2.1 The Variables

(a) Dependent Variables

The basic dependent variable was the 'response' produced by each subject on each task. This was the initial sense in which the handwheel was turned in response to a stimulus: it had two values, 0 = clockwise, 1 = anticlockwise.

For a group of subjects there were two further dependent variables, 'stimulus-response correlation' and 'response bias'. These were measures of the strength and direction of the stereotype and the strength of any 'overall clockwise' response-tendency respectively. They are described fully in section 2.2.6.

(b) Independent Variables

In the first of the two experiments which were performed there were two independent variables:

(i) Tasks (i.e. control-display configurations).

Each configuration involved a handwheel control and either a spindle-traverse or a table-traverse motion on the simulated machine tool. The twelve tasks are illustrated in Figure 2.1.

(ii) Subject's occupation. One group of subjects had no experience of machine tools, one had limited experience and one had extensive experience. Section 2.2.3 contains a full description of these groups (group number 2, 3 and 4).

This experiment measured the strength of any stereotypes for the twelve tasks and three groups of subjects. The second experiment was designed to emphasize some of the serial effects which might occur. It had the following independent variables:

(iii) Order of presentation of tasks.

Certain tasks were presented to the subject in two alternative positions, either at the beginning of the series of twelve or in the middle.

(iv) Previous errors (over five trials)

One task was always presented to the subject at the end of his series of twelve. The outcomes of the previous five trials were controlled by the experimenter so that the subject experienced either five correct or five error outcomes consecutively, and then attempted the final task.

(v) Subject's occupation.

One group had no experience and the other had extensive experience of machine tools. (Groups 1 and 5 in section 2.2.3). After both experiments had been carried out, the results of the first experiment were re-analysed in order to obtain further information about serial effects. Two further independent variables were involved namely:

(vi) Previous errors (over one trial).

All the tasks were grouped together and the results were classified according to whether they came from a trial following one with a correct or an error outcome. Any general change in the strength of correlation or bias which was related to the previous-trial outcome could then be seen.

(vii) Previous response (over one trial)

In this case all the results (from all tasks) were classified in terms of the response (clockwise or anticlockwise) which occurred for the same subject on the previous trial.

Taken together, the two experiments provided information about the strength of stereotypes and of response biases in twelve tasks, the variations in these resulting from different occupational experience, the effect on some of them of varying the order of presentation of the tasks and the effects of two parameters of the preceding task: the outcome and the response. For one task only, the effect of a run of identical outcomes on the previous five tasks could be studied.

The two remaining previous task parameters, control-display configuration and stimulus sense, were not investigated: the former had too many values (twelve) to produce usefully large samples; the latter was held constant for each subject. It would be possible to design further experiments wherein these variables were studied.

2.2.2 The Simulation

Loveless (1962) concluded that motion stereotypes are vulnerable to minor configural changes. It follows that the results of experiments upon knobs should not be applied to the design of a machine containing handwheels, and experiments involving dials are not necessarily relevant to machines in which the display is a moving cutting-tool or workpiece.

If the results are to be applied to practical designs, the experiment should resemble the appropriate work situation as closely as may be contrived. It is the responsibility of the designer making the application to judge whether the experiment adequately simulates the real-life situation: that is why the conditions of the experiment and the design of the apparatus are presented in fairly full detail in this report.

When the simulation is close the field of application is correspondingly limited. The present study is concerned with twelve specific control-display configurations, all involving a handwheel linked to a machine-tool manual-traverse motion. The tasks are illustrated in Figure 2.1. In six of them the machine table and workpiece are moved by the handwheel: in the remainder it is the spindle/cutter assembly which moves. All the tasks resemble real-life configurations to be found in various types of milling and drilling machines, and the apparatus was designed to look and to handle as much like a machine-tool as possible within practical limits. Its construction is described in section 3.

Figure 2.2 illustrates the nature of the subject's task: from a 'stimulus' configuration (e.g. Figure 2.2., left), in which either the cutter or the workpiece has been offset in any direction, the subject responds by turning a given handwheel so as to return the element which moved to the symmetrical 'target' position. The procedure is described in detail in section 2.2.5.

2.2.3 The Organisation of Experiments I and II

An important feature of the experiments was that the outcome of each trial could be controlled. That is, the experimenter could determine in advance whether the subject's initial response would cause the display to move towards the target position (correct outcome) or away from the target position (error outcome). Different ways of manipulating this variable, and of manipulating the order of presentation of the tasks, constitute the differences between the two experiments.

Experiment I (subject groups 2, 3 and 4; as defined in section 2.2.4)

In this first experiment the straightforward measurement of stereotypes was attempted, so that serial effects had to be minimised by making them cancel out. The tasks were, therefore, presented to the subjects in an order determined by random permutations of twelve numbers. The subjects in each group were taken in pairs and the members of each pair performed the tasks in the same (random) order, one of them being presented with the '0' sense of each stimulus and the other with the '1' sense (as defined in Table 2.1).

The order in which controlled correct or error outcomes were to occur was chosen so that it would be uncorrelated with the task-order, as well as realistic from the subject's point of view. Since the task-order was random, the sequence of outcomes could be fixed: errors were made to occur on whichever tasks fell in second, fifth and tenth places, an approximately logarithmic order such as would be experienced by a subject successfully learning a skilled task. (Had all twelve outcomes been the same, and in some cases if the outcomes had been uncontrolled or random, the subjects might have concluded that unusual directional relations were present, and modified their responses accordingly).

Experiment II (Subject groups 1 and 5, as defined in section 2.2.4)

The object of the second experiment was to observe the effects of submitting each subject to a series of similar tasks rather than to a single task, the latter procedure being one that is often recommended while the former had been used in Experiment I.

Particular tasks which had yielded significant stereotypes in the first experiment were held in fixed positions in the task order, as shown in table 2.2. Each group of subjects, as well as being paired and split into subgroups so that the two values of stimulus-sense could be presented, was further subdivided into the groups 'a' and 'b' shown. Selected tasks were placed at the beginning or in the middle of the task order for the respective groups so that the two methods mentioned above might be compared. In addition, the last six positions in the order (irrelevant to this variable) were arranged so that one particular task always lay in position twelve: the outcomes of the previous five tasks were controlled - all correct for one group and all errors for the other, to demonstrate the effect of runs of similar outcomes.

<u>2.2.4</u> The Subjects

Five groups of subjects were employed. They were engaged in different occupations and consequently had had varying amounts of machine-tool experience, as follows:-

Experiment II, Group 1: 76 schoolboys aged 14 - 15 from a secondary modern school. All the boys had studied metalwork, but none had operated a machine tool.

Group 5: 62 experienced production machine-tool operators working in two machine-tool manufacturing companies. The men were mainly millers and turners, together with a few older apprentices to these trades.

Experiment II, Group 2: 66 undergraduates reading non-engineering subjects. Only male students without machine-tool experience were included.

Group 3: 34 engineering apprentices in the training school of a light engineering company. Their general machine-tool experience ranged from six to 24 months.

Group 4: 58 fitters and technicians. These were time-served craftsmen drawn from a machine shop in a research establishment, a tool room in an engineering works, and a university production-engineering department. In all cases these men had general machine-tool experience amounting to several years.

2.2.5 The Experimental Procedure

Each experimental trial was conducted in the following way:-

The experimenter selected the handwheel to be used by means of the 11-position handwheel switch (control channel selector) at the left of Figure 3.2. By means of the 5-position display-direction selector he then selected one of the five motions of the machine, and with the 'sense' switch he determined which way the subject would be instructed to move the machine element. Next he set the 'response' switch to 'correct' or 'error' and extinguished the 'response' lamps by means of the 'reset' button. He then gave the following standardized instructions to the subject:-

'This is a model of a machine tool. It doesn't cut metal, but it goes through all the motions. What we are studying is the way people in different occupations handle this machine. I would like you to make some simple positioning movements with it. What happens is this: this is the cutting tool, and this block represents the workpiece. At the moment the cutter is in a symmetrical position, in the centre of these two slots, and the end of the cutter is level with the top of the block. I am going to make either the cutter or the block move to a different position. After it has moved, and when it stops, one of these yellow lights will come on, to show you which handwheel I want you to use. All I want you to do is to wind the cutter or the block back, slowly and carefully, into the position it's in now, as accurately as you can judge it by eye. All right? '

The experimenter then answered any questions put by the subject. If they asked 'Which way do the handwheels turn? ' the answer was 'It doesn't matter, some go one way and some another, you will find out when you try them'. When the subject appeared to understand the instructions he was told 'we are going to do this twelve times. Ready? Here is the first movement ... and the first handwheel is ... this one.' While saying this the experimenter first pressed the 'move' button, Figure 3.2, and held if until the selected machine element had moved approximately one inch. He then switched on the 'pilot lamps' switch, illuminating one of the eleven pilot lamps, adjacent to the selected handwheel. The subject responded by turning the handwheel. If the 'response' switch was in the position marked 'correct' the initial handwheel movement caused the cutter or the workpiece to return towards the symmetrical target position, but if it was in the 'error' position, the movement initially was away from symmetry. These initial display movements were independent of the sense, clockwise or anticlockwise, in which the first handwheel movement was made. Thus the control-display relationship was indeterminate until the handwheel began its first movement, and the relationship was then immediately determined by a combination of three factors:

1. The sense of the original 'stimulus' movement,
2. The sense of the initial response,
3. The position of the 'error' switch,

Subsequent reversals of the handwheel caused the machine element to reverse its motion, as if there had been a fixed mechanical linkage between control and display.

The sense of the initial response was recorded by the illumination of one of the 'response' indicator lamps on the experimenter's panel.

The subject went on to adjust the position of the cutter or workpiece until he judged that the initial configuration had been re-established, and the next trial proceeded without further instructions. Each subject carried out twelve trials, each with a different control-display combination. From the 55 possible control-display combinations, the twelve selected as tasks for the experiment were as shown in Table 2.1 and Figure 2.1. The numbering of the controls and the definitions of the display directions are given in Figure 3.3.

Each group of subjects was divided into two equal sub-groups, one of which moved the displays in sense '0' and the other in sense '1'. The subjects from the sub-groups were paired, and the members of each pair carried out the tasks in the same order. For groups 2, 3 and 4 this order was determined by the use of a table of random permutations, so that it was different for each pair of subjects.

Table 2.1 Description of tasks used in the experiments

Control	Display	Display-sense	
		'0'	'1'
1	Workpiece	up	down
2	"	to	from
3	"	up	down
4	"	right	left
5	"	right	left
6	"	right	left
7	cutter	down	up
8	"	down	up
9	"	down	up
10	"	down	up
11	"	down	up
11	"	to	from

Note: the sense shown is the sense of the required response.

Table 2.2 Arrangement of tasks and errors in experiment II

Group 1a												
Task order	3	r	r	r	r	2	r	r	r	r	r	10
Outcome order	0	0	0	0	0	0	0	0	0	0	0	0
Group 1b												
Task order	2	r	r	r	r	3	r	r	r	r	r	10
Outcome order	0	0	0	0	0	0	1	1	1	1	1	1
Group 5a												
Task order	2	r	r	r	r	r	5	r	r	r	r	10
Outcome order	0	0	0	0	0	0	0	0	0	0	0	0
Group 5b												
Task order	5	r	r	r	r	r	2	r	r	r	r	10
Outcome order	0	0	0	0	0	0	1	1	1	1	1	1

Key r: task selected at random.

0: correct outcome

1: error outcome

2.2.6 The Method of Analysis

For each combination of task and subject group, the responses were added up to form a 2 * 2 contingency table:

		Response	
		clock	anticlock
Stimulus	'1'	a	b
Sense	'0'	c	d

(a + b + c + d = n)

The values a, b, c and d are the frequencies with which the four possible stimulus-response pairs occurred in the experiment. The measure of a population stereotype is taken to be the degree of correlation between stimulus and response, in order to allow both reversible and irreversible stereotypes to be counted. Any monotonically increasing function of a and d which also decreased monotonically with b and c would be a suitable measure of correlation: the chi-square test, for instance, depends on (a * d - b * c). For the purpose of graphical presentation of the results in this study the measure ((a + d) - (b + c)) * 100/n is used. Complete correlation (all subjects follow the same reversible stereotype) gives a measure of +100 or -100 and complete absence of correlation gives a measure of zero.

The other measure of interest is the response bias. This is calculated as ((a + c) - (b +d)) * 100/n, giving +100 for 100 per cent clockwise responses, -100 for 100 per cent anticlockwise, and zero for equal frequencies of clockwise and anticlockwise. The last result is the expected one on a hypothesis of 'no bias', since the frequencies of stimulus-sense values '0' and '1' were made equal in the design of the experiment.

As well as measures of correlation and bias, tests of significance are required. For each contingency table the null hypotheses are:-

a) 'No correlation between stimulus and response' $a + d = b + c$

b) 'No bias in favour of one value of the response' $a + c = b + d$

The choice of a test of hypothesis (a) lies between the chi-square test and Fisher's exact probability test (Siegel, 1956). Neither of these has maximum power for the particular experimental design in use, because they both assume that the row and column totals are fixed when enumerating the 'possible' results. Barnard (1947) has pointed this out and indicated a superior test, but the necessary tables for its use in the present case have not apparently been calculated and it could not, therefore, be used.

The assumptions of the chi-square test are violated by the experimental design of the present study (Lewis and Burke, 1949) and, therefore, Fisher's test has been applied throughout.

For hypothesis (b) a modification of Fisher's test has been used. Instead of the row and column totals being fixed in order to define the sample space, the row and <u>diagonal</u> totals are considered to be fixed at the values found in the experiment. The total probability of all possible results under this constraint which show more <u>bias</u> ($a + c \neq b + d$) is then the two-tail rejection probability for hypothesis (b). (In practice it was necessary merely to interchange the values of c and d in the table before going through a normal Fisher test.)

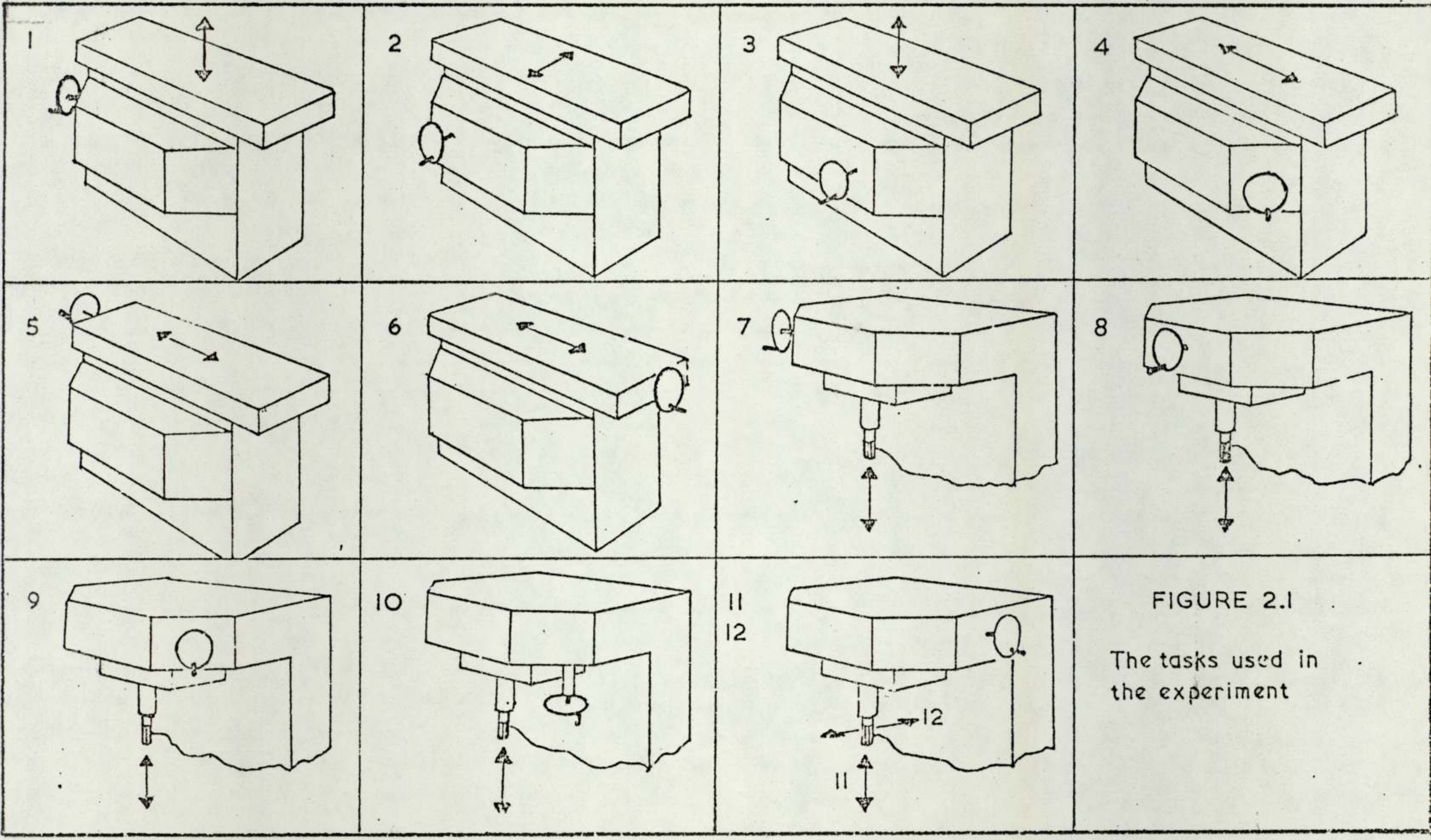
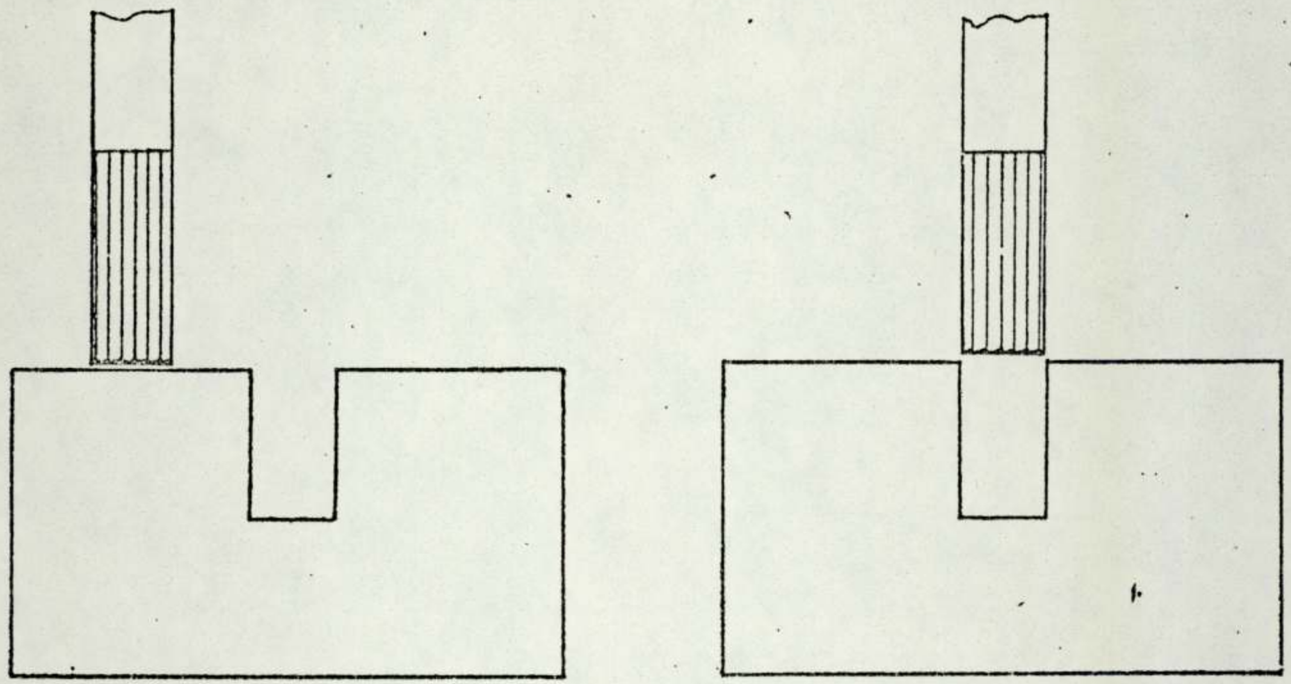


FIGURE 2.1

The tasks used in the experiment



Example of display configuration

stimulus position

target position

FIGURE 2.2

SECTION 3 DESCRIPTION OF APPARATUS

Figure 3.1 is a general view of the apparatus, which was specially built for this study. It comprises a simulated machine tool (left) and an experimenter's control box (right). When it is in use the subject stands in front of the machine and the control box is positioned where the subject cannot see it.

The lighter-coloured parts of the machine are the moveable elements: the head, the spindle, the table and the knee. The cross-slide, which is also moveable, is just visible below the table. There are eleven combined handwheel/crank controls: four are mounted on the body of the machine, above the head; one projects downward, beside the head; two are mounted on the ends of the table and four are on the knee.

The machine can simulate five linear traverse motions as found on horizontal and vertical milling machines. These are:-

Table up/down (knee moves)

Table left/right (table moves)

Table to/from operator (cross-slide moves)

Spindle to/from operator (head moves)

Spindle down/up (spindle moves)

Any one of the eleven handwheels may be coupled to any one of the five traverse motions. A pilot lamp close to each handwheel can be illuminated to show that that handwheel is coupled to one of the motions.

All combinations of handwheel and motion have the same control-display ratio: one revolution of the handwheel moves the machine element through a distance of 0.125 inches.

Because different motions must be coupled to the same handwheel, and because the direction-of-motion relationship of handwheel to motion is not determined until the handwheel has begun to turn, the coupling between handwheels and motions is electrical, the machine elements being driven by stepping motors and leadscrews. Each handwheel drives a pulse generator (shown in Figure 3.4) giving 90 pulses per revolution. The pulses are output on three lines in turn so that rotation in either sense gives a unique phase relationship among the pulse trains on the three lines.

Figure 3.5 shows how, by means of a solid-state logic circuit, the pulse trains on the three inputs are combined and channelled to one of two outputs: output 'X' for clockwise rotation or output 'Y' for anticlockwise rotation. After the memory circuits have been reset manually two pulses are required in order to define the phase relationship of the input pulse trains. Pulses on A, B or B, C or C, A define clockwise rotation and on A, C or C, B or B, A anticlockwise rotation. This means that the first input pulse is stored for comparison with the second pulse, but does not generate an output pulse: the first output is produced by the second input pulse, and the consequent delay is perceived by the subject as backlash in the drive. The magnitude of the backlash (up to 8°) is no greater than that found in real machine tools.

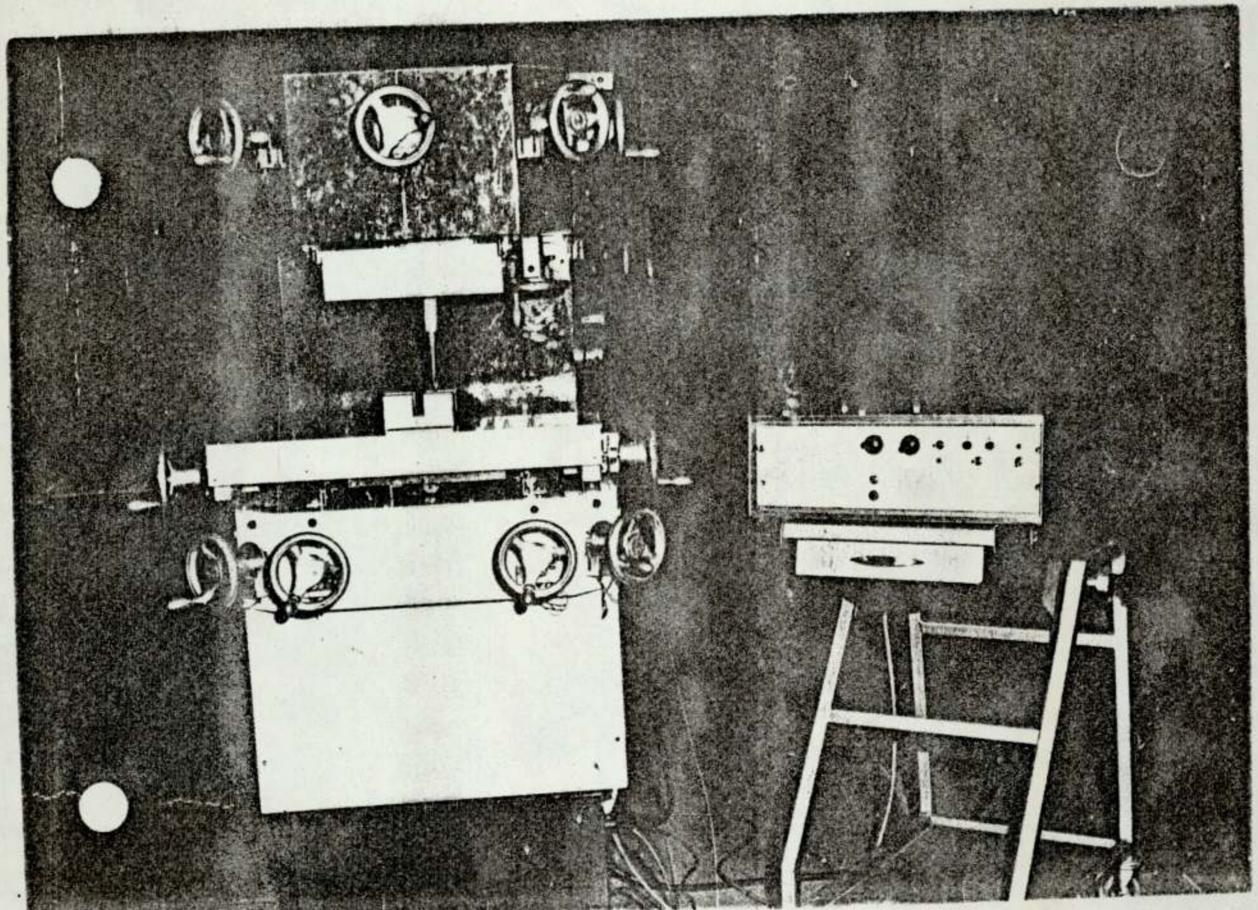
The pulses appearing on lines A, B and C are of sufficient duration to create a danger of overlapping when combined into output X or Y. For this reason the circuit of Figure 3.5 is arranged so that the leading edge of each input pulse generates a shorter output pulse of fixed time-duration. Overlapping pulses cannot be output unless the handwheel is turned at a higher speed than is humanly possible (about 250 r.p.m.).

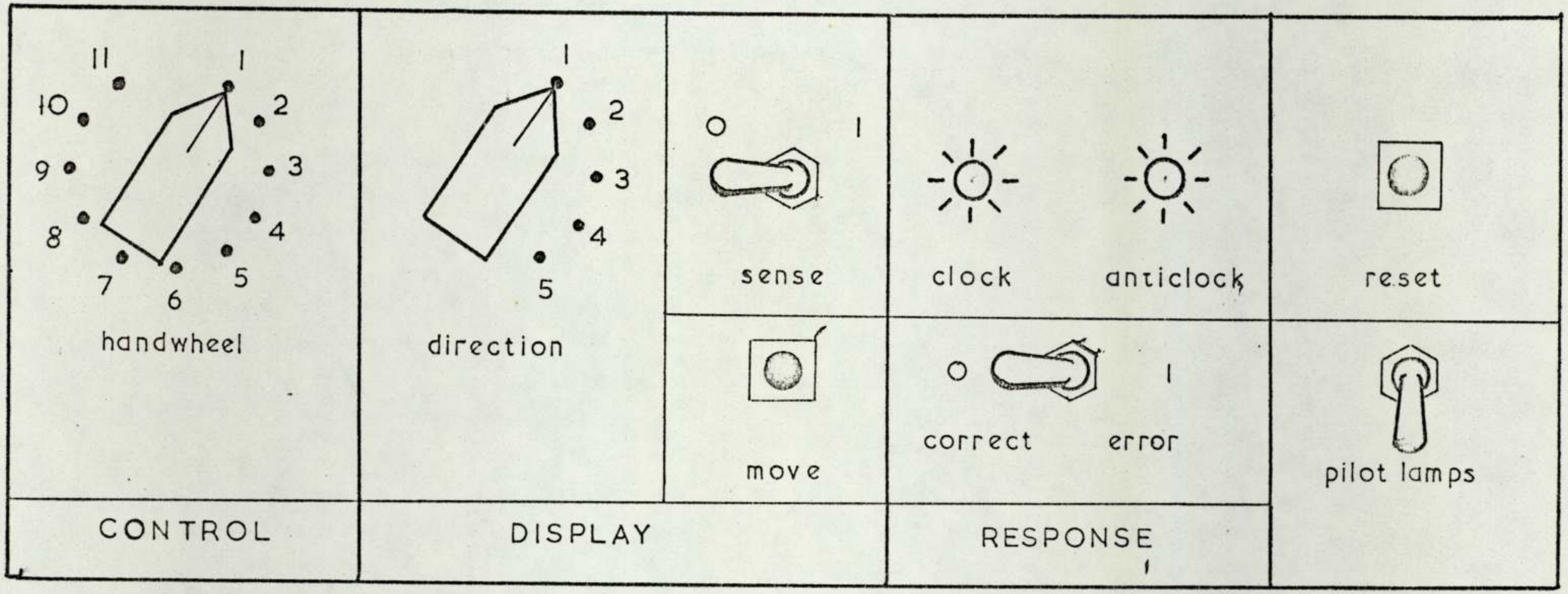
A second logic circuit (Figure 3.6) selects the requisite direction-of-motion relationship between the handwheel and the machine element. The experimental design requires that the outcome of a trial be always 'forced'. If an 'error' outcome is forced then the initial rotation of the handwheel causes the machine element to move in the same sense as the stimulus movement while if a 'correct' outcome is forced the movement is in the opposite sense. Thereafter, any reversal of the handwheel must reverse the sense of the machine movement. Figure 3.6 shows how this is effected. There are three points at which the connections between the inputs X, Y and the outputs to the stepping motor may be reversed. The first reversal is governed by the sense of the initial rotation of the handwheel: the circuit at the top of Figure 3.6 'remembers' whether the first pulse arrived on input X or input Y and reverses the connections permanently if it was on input X. At the same time an indicator lamp on the experimenter's panel shows which input received the first pulse. Further reversals of the input-output connections occur if the 'sense' switch, which controls the sense of the stimulus, is in position 1, or if the 'error' switch is in position 0 (forcing a correct response).

The experimenter-controlled stimulus movement is produced by the square-wave oscillator shown. It causes the selected machine element to traverse at approximately one foot per minute in the sense determined by the 'sense' switch.

Because the electrical coupling imposes no load on the handwheels they are provided with artificial 'feel' in the form of added viscous friction. Each handwheel is mounted on the shaft of a continuous rotary dashpot, set to give a friction torque of two lb-in. at 1.0 radian per second (approximately).

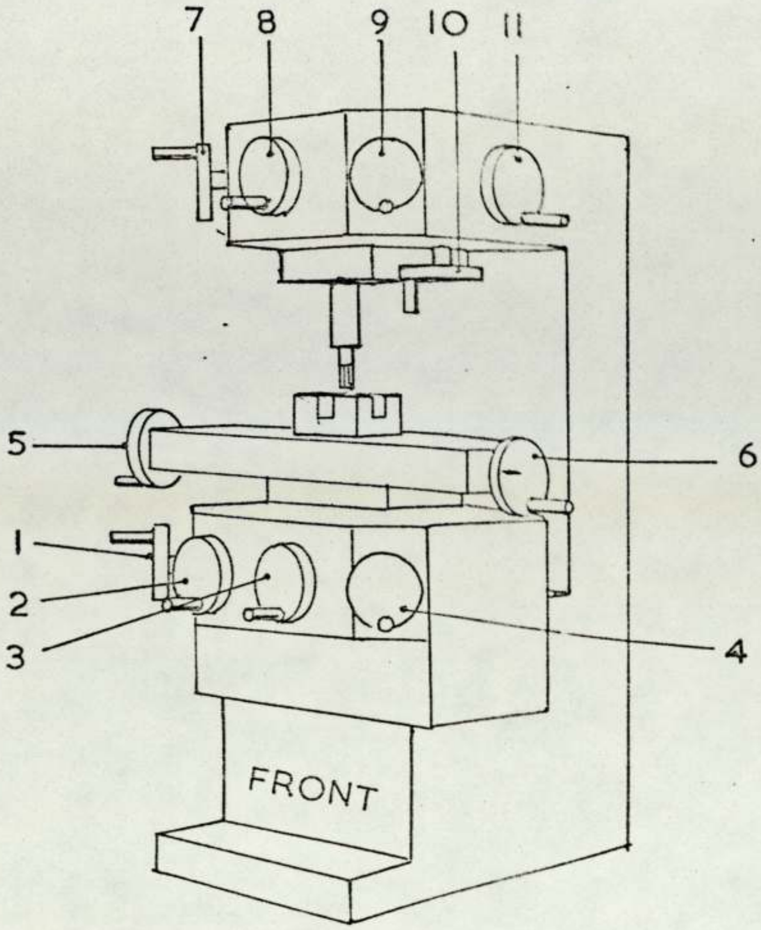
The diameter of the handwheels is five inches, each handwheel being fitted with a fixed crank at right-angles to the rim, 2.5 inches long.



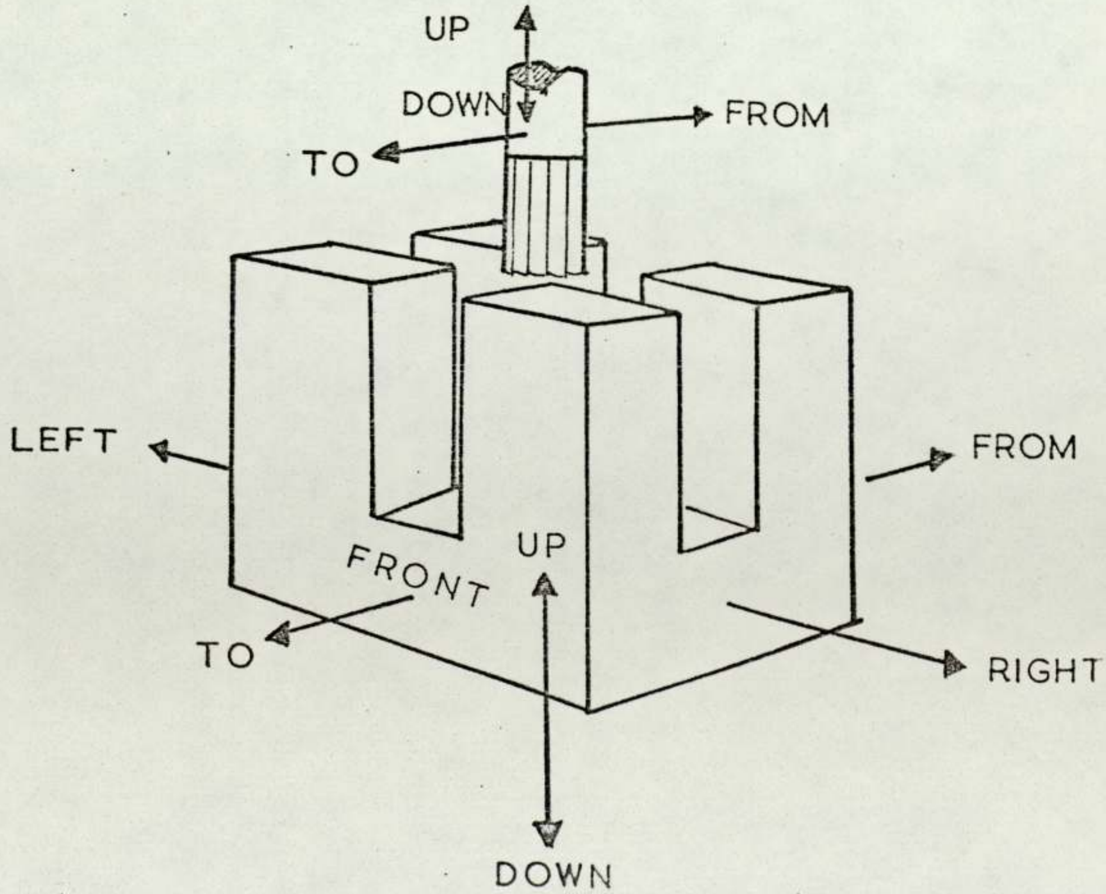


Experimenter's control panel

FIGURE 3.3



NOMENCLATURE Above: control positions
Below: display directions



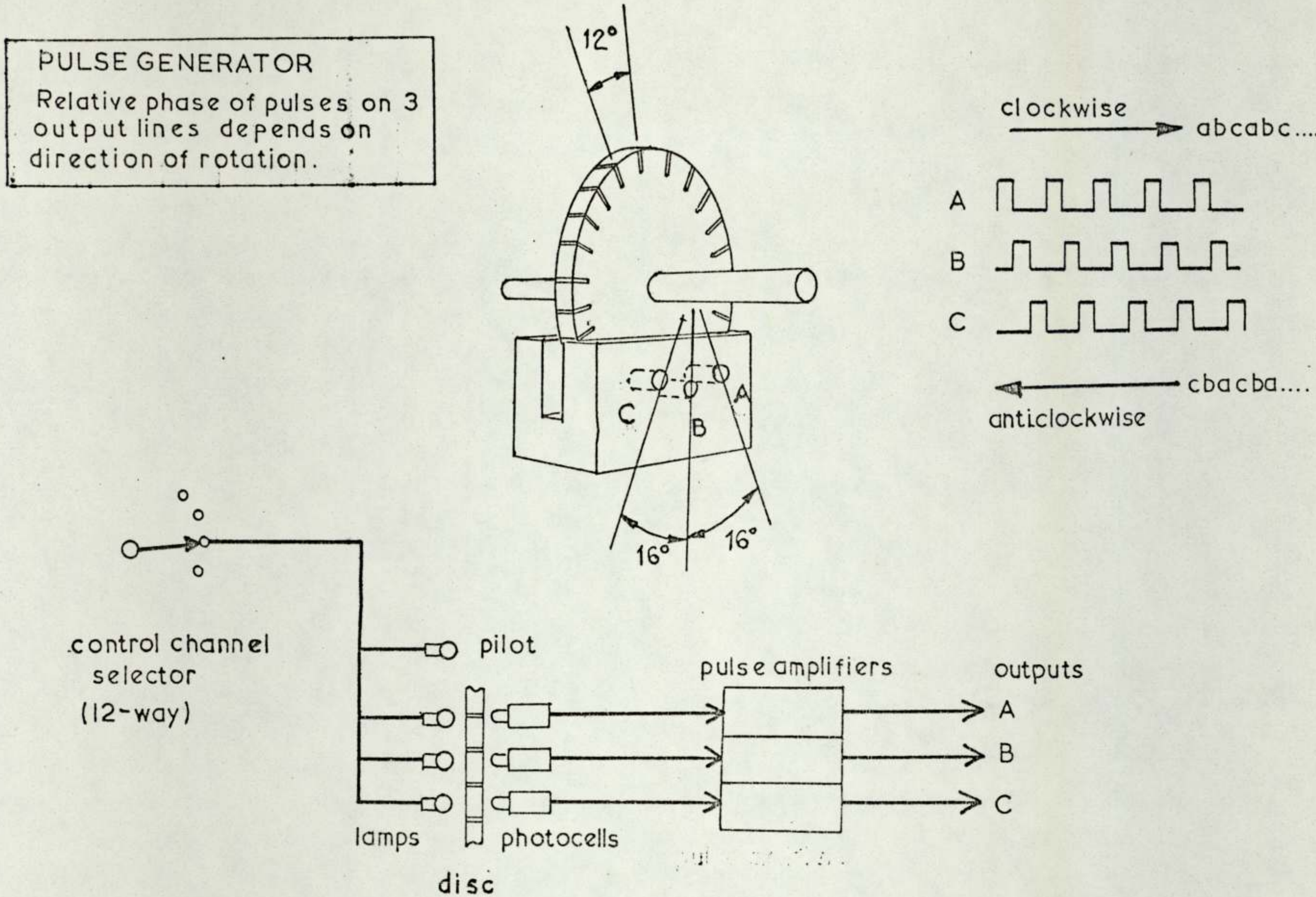

PULSE GENERATOR
Relative phase of pulses on 3 output lines depends on direction of rotation.
12°
clockwise
abcabc....
A
B
C
cbacba....
anticlockwise
C
B
A
16°
16°
control channel selector (12-way)
pilot
pulse amplifiers
outputs
A
B
C
lamps
photocells
disc

FIGURE 3.4

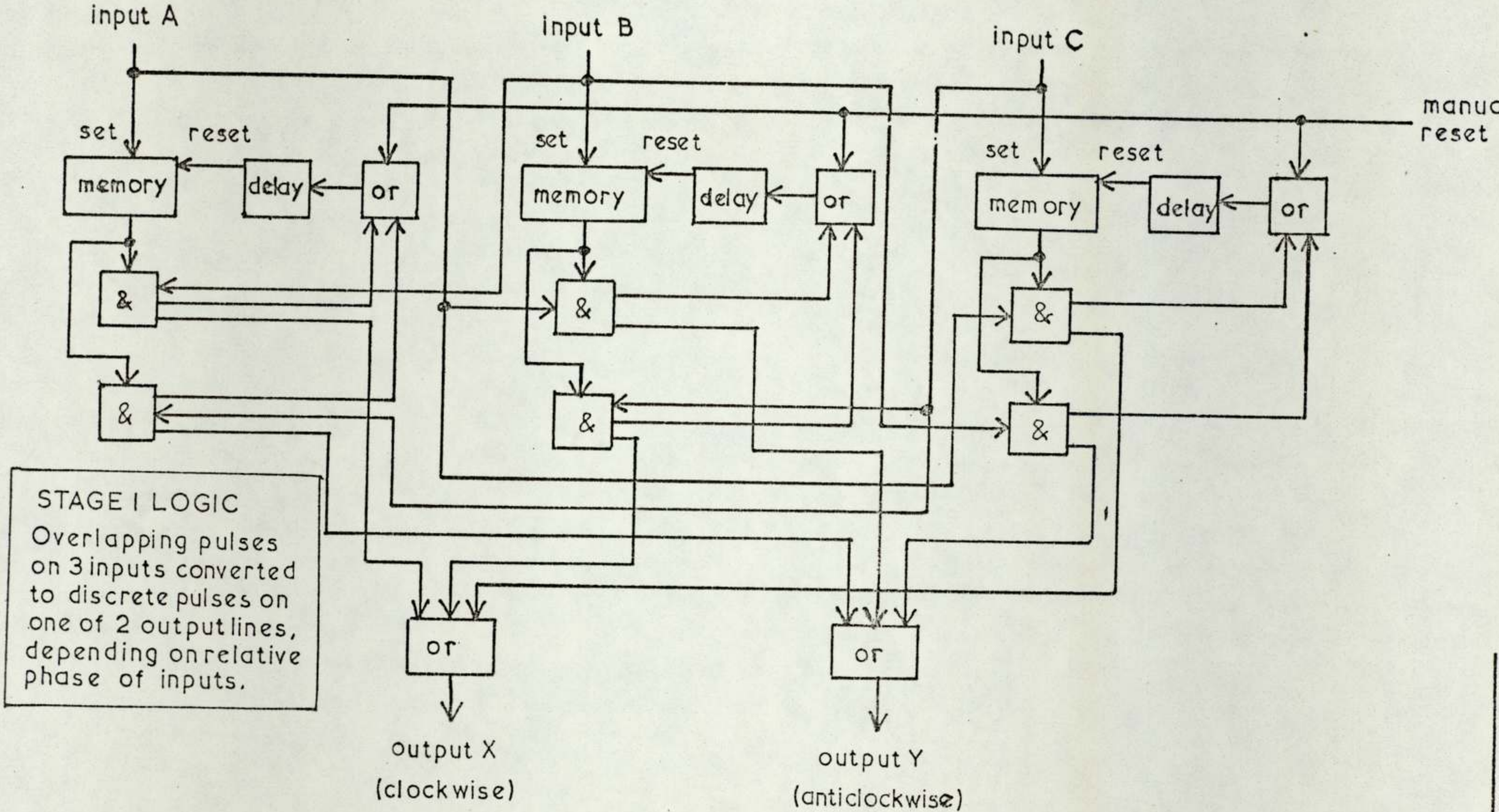
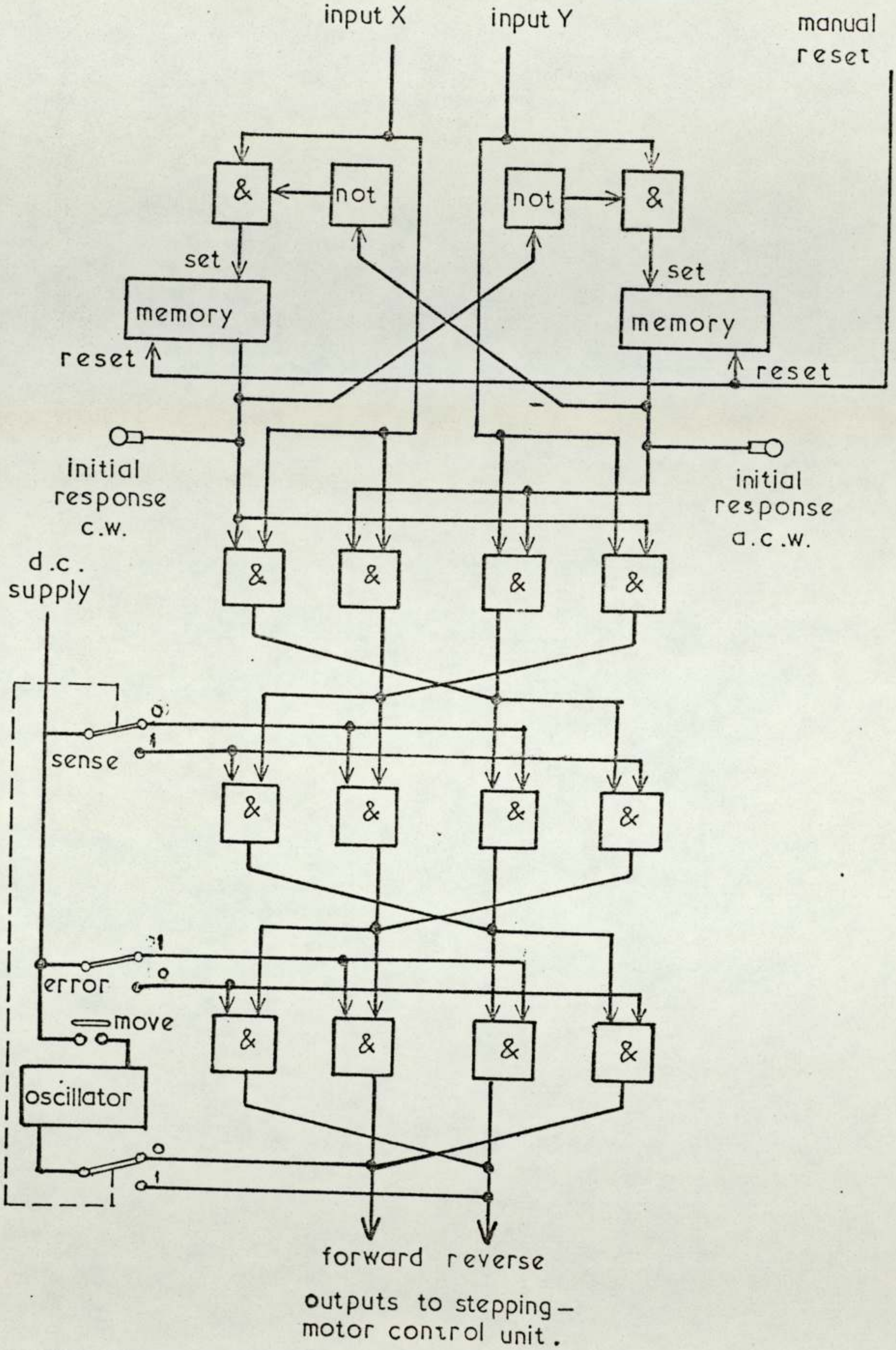

input A
input B
input C
manual reset
set
reset
memory
delay
or
&
output X (clockwise)
output Y (anticlockwise)
STAGE I LOGIC
Overlapping pulses on 3 inputs converted to discrete pulses on one of 2 output lines, depending on relative phase of inputs.

FIGURE 3.5

FIGURE 3.6



STAGE 2 LOGIC

Input/output connections may be reversed by:-

1. <u>First</u> pulse arriving on line "X" (not "Y")
2. Sense switch at "1"
3. Error switch at "O"

SECTION 4 RESULTS

4.1 Original Data

The twelve trials with each subject produced a block of data consisting of:

Subject Number	(1 - 300)	
Occupation category	(14 groups reduced to five for the present analysis)	
Length of experience code	Not used in the present analysis	
Preferred hand code		
Stimulus sense	(0 or 1. see Table 2.1)	
Repeat 12 times	Task No. (1 - 12)	
	Outcome code (0 = correct, 1 = error)	
	Response code (1 = clockwise, 2 = anticlockwise)	
Computer stop code	(-10 = no more date, -9 = more data to come)	

The original data is filed in the Department of Applied Psychology. An example of the format is shown in the appendix.

4.2 Effect of control-display configuration

Each of the twelve tasks embodied a different control-display configuration. The results obtained on the twelve tasks are shown in Table 4.1, which is a direct tabulation from the original data.

The table shows the results of two different experiments, the first of which involved occupation-groups 2, 3 and 4 * with the tasks in random order and a fixed, logarithmic arrangement of error outcomes, as explained in section 2.25. The results of the second experiment, on groups 1 and 5, are included in the table although the purpose of this experiment was to study serial effects, and the random order of the tasks is disturbed. (See note at the end of the next section.) Table 2.2 shows which tasks were in fixed positions, and which were in random positions. The serial-effect variables are ignored in this tabulation.

* The occupation-groups are defined in section 2.2.3.

The first column in Table 4.1, labelled group gives the occupation-group. The second column 'N' is the number of subjects in that group. Columns 4 to 7 give the number of subjects whose initial response fell into each of the four stimulus-response categories. These are the a, b, c and d frequencies of section 2.2.6. They are given as percentages of N, for ease of comparison between the groups. Column 8, 'cor' is the stimulus-response correlation measure, which when positive indicates a greater correlation in the sense of the headings of columns a and d and when negative shows a greater correlation in the opposite sense, i.e. that of columns b and c.

Similarly, column 9, 'bias', shows the strength and sense of the response-bias, positive for clockwise (majority of results in columns a and c) and negative for anticlockwise (majority in columns b and d). The last two columns give the significance level of the correlation and bias, respectively, calculated by Fisher's exact probability test with 2-tail rejection region.

Figures 4.1 to 4.3 illustrate the correlation and bias measures found for each task, in graphical form.

4.3 Serial Effects - separate experiment

The second experiment involved groups 1 and 5 only, and was designed to show the effect of a) position of a task in the trial order, and b) a series of consecutive 'error' outcomes, on a subsequent trial. The results of this experiment are shown in Table 4.2 and illustrated graphically in Figure 4.4. For tasks 2, 3 and 5 the subjects were divided into two equal sub-groups. One group always performed the relevant task as the first of twelve, while the other came to the same task as the sixth or seventh of twelve. Both groups were forced into 'correct' outcomes throughout this first part of the series as shown in Table 2.2. For tasks 2, 3 and 5 the third column, 'pos', gives the position in the series at which the group came to the task.

The tasks apart from tasks 2, 3, 5 and 10 were allocated at random to positions other than those mentioned above. Note that the distortions of task order and outcome order in the second experiment lessen the validity of the results for groups 1 and 5 in the context of Table 4.1. Those combinations of task and group that appear in Table 4.2 will be the worst affected. (The Table 4.1 frequencies for these are equal to the sums of the frequencies for the two sub-groups in Table 4.2.)

FIGURE 4.1

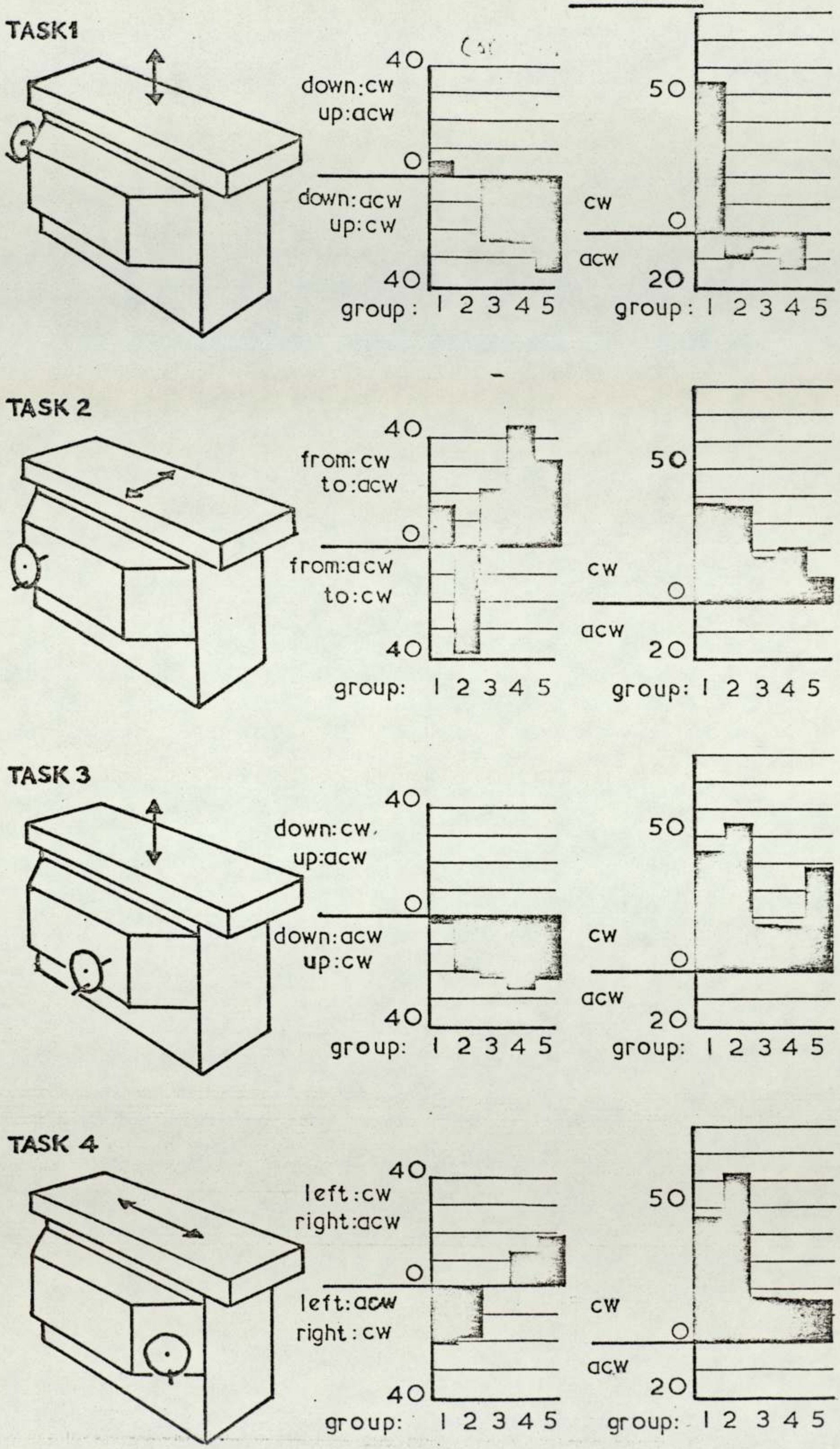
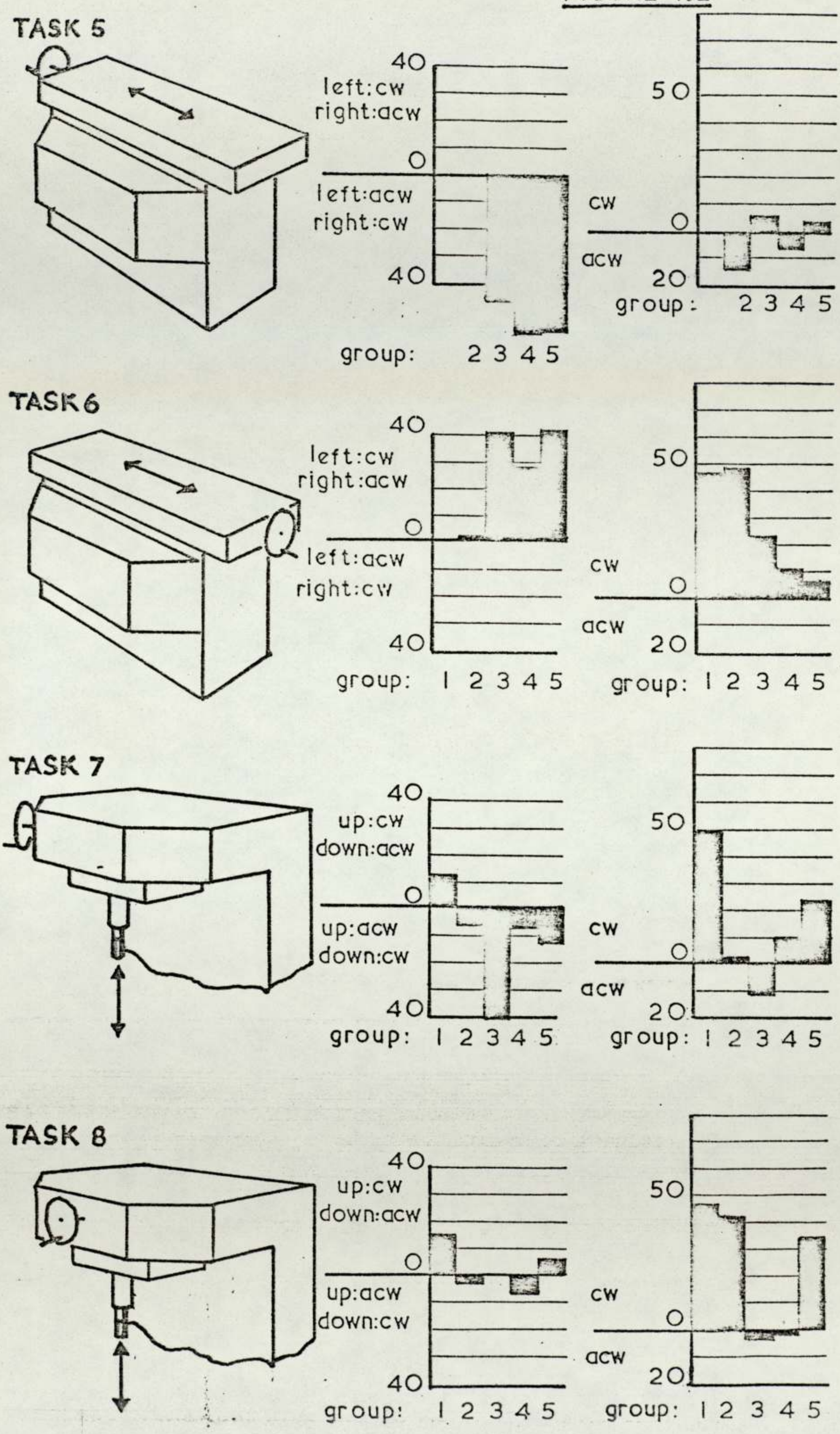

TASK1
40
down:cw
up:acw
0
down:acw
up:cw
40
group: 1 2 3 4 5
50
cw
0
acw
20
group: 1 2 3 4 5
TASK 2
40
from:cw
to:acw
0
from:acw
to:cw
40
group: 1 2 3 4 5
50
cw
0
acw
20
group: 1 2 3 4 5
TASK 3
40
down:cw
up:acw
0
down:acw
up:cw
40
group: 1 2 3 4 5
50
cw
0
acw
20
group: 1 2 3 4 5
TASK 4
40
left:cw
right:acw
0
left:acw
right:cw
40
group: 1 2 3 4 5
50
cw
0
acw
20
group: 1 2 3 4 5

FIGURE 4.2



TASK 5
40
left:cw
right:acw
0
left:acw
right:cw
40
group: 2 3 4 5
50
cw
0
acw
20
group: 2 3 4 5
TASK 6
40
left:cw
right:acw
0
left:acw
right:cw
40
group: 1 2 3 4 5
50
cw
0
acw
20
group: 1 2 3 4 5
TASK 7
40
up:cw
down:acw
0
up:acw
down:cw
40
group: 1 2 3 4 5
50
cw
0
acw
20
group: 1 2 3 4 5
TASK 8
40
up:cw
down:acw
0
up:acw
down:cw
40
group: 1 2 3 4 5
50
cw
0
acw
20
group: 1 2 3 4 5

FIGURE 4.3

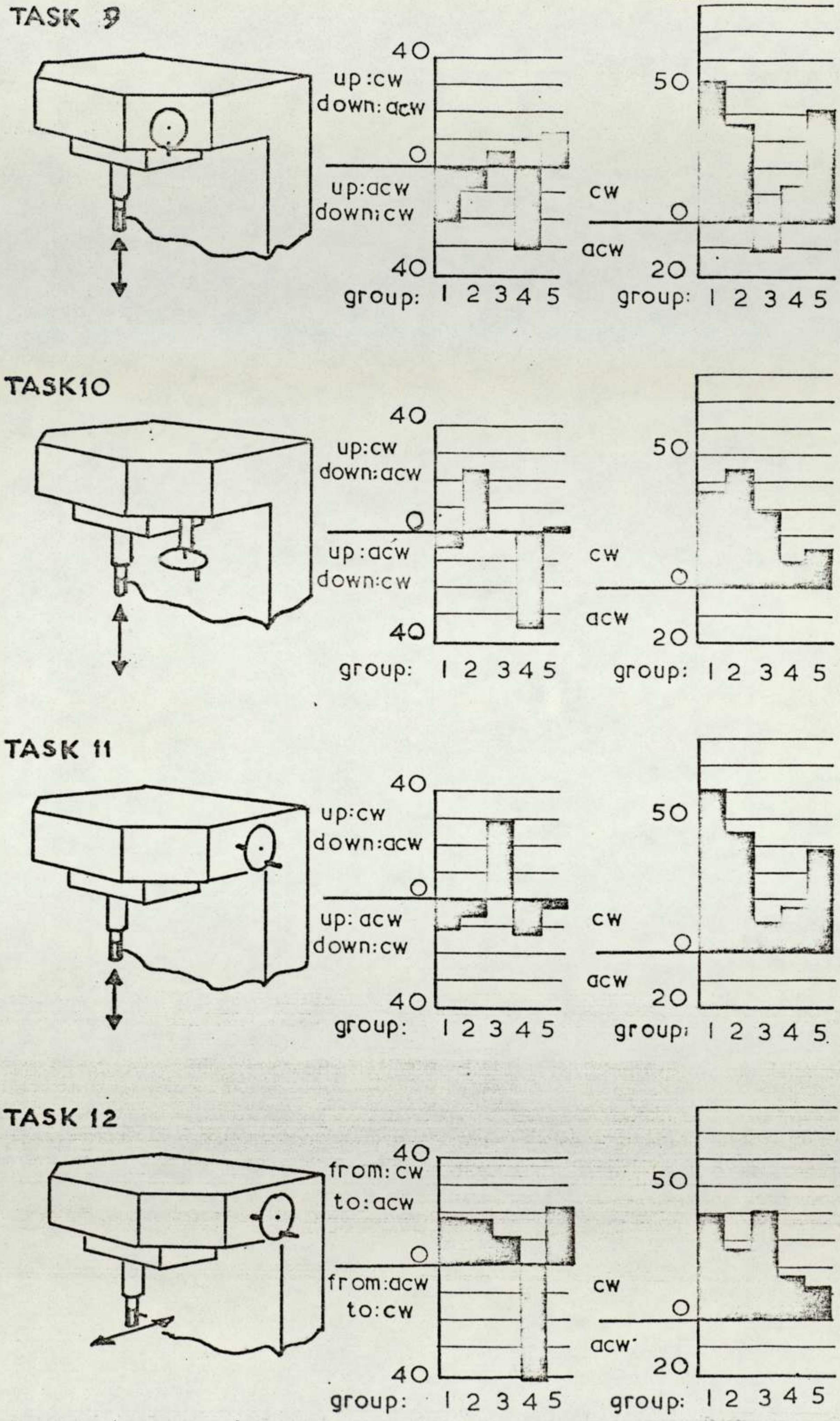
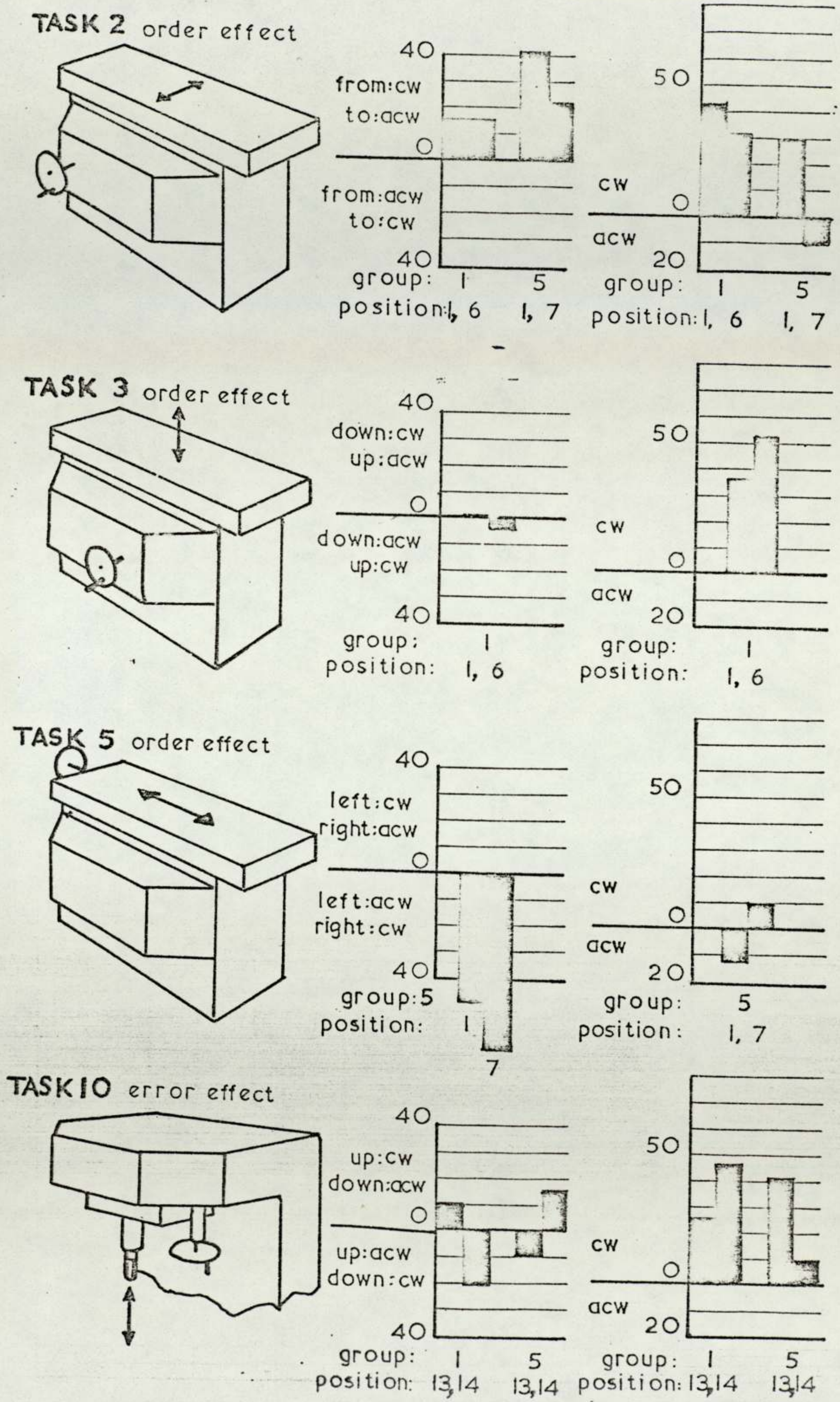

TASK 9
40
up:cw
down:acw
0
up:acw
down:cw
40
group: 1 2 3 4 5
50
cw
0
acw
20
group: 1 2 3 4 5
TASK10
40
up:cw
down:acw
0
up:acw
down:cw
40
group: 1 2 3 4 5
50
cw
0
acw
20
group: 1 2 3 4 5
TASK 11
40
up:cw
down:acw
0
up: acw
down:cw
40
group: 1 2 3 4 5
50
cw
0
acw
20
group: 1 2 3 4 5
TASK 12
40
from:cw
to:acw
0
from:acw
to:cw
40
group: 1 2 3 4 5
50
cw
0
acw
20
group: 1 2 3 4 5

FIGURE 4.4



TASK 2 order effect
40
from:cw
to:acw
0
from:acw
to:cw
40
group: 1 5
position: 1, 6 1, 7
50
cw
0
acw
20
group: 1 5
position: 1, 6 1, 7
TASK 3 order effect
40
down:cw
up:acw
0
down:acw
up:cw
40
group: 1
position: 1, 6
50
cw
0
acw
20
group: 1
position: 1, 6
TASK 5 order effect
40
left:cw
right:acw
0
left:acw
right:cw
40
group:5
position: 1
7
50
cw
0
acw
20
group: 5
position: 1, 7
TASK 10 error effect
40
up:cw
down:acw
0
up:acw
down:cw
40
group: 1 5
position: 13,14 13,14
50
cw
0
acw
20
group: 1 5
position: 13,14 13,14

TASK	MACHINE TYPE	DIRECTION OF CORRELATION (as defined in figure 4.1.-4.3)										
		Experimental ($p < 0{\cdot}1$)					Existing	Standards				
		grp: 1	2	3	4	5	m/c practice	I.S.O.	Bri.	Ind.	Rus.	
2	Horizontal miller	o	−	o	+	+	+	+	+	+	+	
3	Vertical miller	o	−	o	−	−	−	−	−	−	−	
5	Horizontal miller	o	o	−	−	−	−	−	−	−	−	
	Vertical miller	o	o	−	−	−	−	−	−	−	−	
6	Slotting machine	o	o	+	+	+	o	+	+	+	+	
8	Jig Borer	o	o	o	o	o	−	+	o	−	−	
	Radial arm drill	o	o	o	o	o	−	+	+	−	−	
	Table drill	o	o	o	o	o	+	+	−	*	+	
10	Radial arm drill	o	o	+	o	−	−	+	+	−	−	
11	Vertical miller	o	o	o	o	o	+	+	+	−	+	
	Jig borer	o	o	o	o	o	+	+	o	+	o	

*ambiguous

COMPARISON of experimental results with I.S.O., British, Indian and Russian standards, and with existing machines.

FIGURE 4.5

TABLE 4.1

TASK 1

GROUP	N	DOWN:CW	DOWN:ACW	UP:CW	UP:ACW	COR	BIAS	P(C)	P(B)
1	80	40.0%	10.0%	37.5%	12.5%	5.00	55.0	.790	0.00
2	66	22.7%	27.3%	22.7%	27.3%	0.00	-9.20	1.00	.623
3	34	17.6%	32.4%	29.4%	20.6%	-23.6	-6.00	.303	1.00
4	58	15.5%	34.5%	27.6%	22.4%	-24.2	-13.8	.111	.417
5	62	16.1%	33.9%	33.9%	16.1%	-35.6	0.00	.010	1.00

TASK 2

GROUP	N	FROM:CW	FROM:ACW	TO:CW	TO:ACW	COR	BIAS	P(C)	P(B)
1	76	38.2%	11.8%	30.3%	19.7%	15.8	37.0	.217	.002
2	66	24.2%	25.8%	43.9%	6.06%	-39.4	36.2	.001	.003
3	34	32.4%	17.6%	26.5%	23.5%	21.8	17.8	.728	.491
4	58	41.4%	8.62%	19.0%	31.0%	44.8	20.8	.001	.141
5	62	35.5%	14.5%	19.4%	30.6%	32.2	9.80	.021	.592

TASK 3

GROUP	N	DOWN:CW	DOWN:ACW	UP:CW	UP:ACW	COR	BIAS	P(C)	P(B)
1	76	35.5%	14.5%	36.8%	13.2%	-2.60	44.6	1.00	0.00
2	66	33.3%	16.7%	43.9%	6.06%	-21.2	54.4	.076	0.00
3	34	23.5%	26.5%	35.3%	14.7%	-23.6	17.6	.296	.481
4	58	22.4%	27.6%	36.2%	13.8%	-27.6	17.2	.061	.274
5	62	29.0%	21.0%	40.3%	9.68%	-22.6	38.6	.097	.004

TASK 4

GROUP	N	LEFT:CW	LEFT:ACW	RIGHT:CW	RIGHT:ACW	COR	BIAS	P(C)	P(B)
1	76	31.6%	18.4%	42.1%	7.89%	-21.0	47.4	.067	0.00
2	66	36.4%	13.6%	45.5%	4.55%	-18.1	63.7	.108	0.00
3	34	29.4%	20.6%	29.4%	20.6%	0.00	17.6	1.00	.494
4	58	32.8%	17.2%	25.9%	24.1%	13.8	17.4	.424	.289
5	62	33.9%	16.1%	24.2%	25.8%	19.4	16.2	.198	.300

CONTINUED....

TABLE 4.1 (CONTINUED)

TASK 5

GROUP	N	LEFT:CW	LEFT:ACW	RIGHT:CW	RIGHT:ACW	COR	BIAS	P(C)	P(B)
1									
2	66	21.2%	28.8%	21.2%	28.8%	0.00	-15.2	1.00	.325
3	34	14.7%	35.3%	38.2%	11.8%	-47.0	5.80	.015	1.00
4	58	8.62%	41.4%	37.9%	12.1%	-58.6	-7.00	0.00	.747
5	62	11.3%	38.7%	40.3%	9.68%	-58.0	3.20	0.00	1.00

TASK 6

GROUP	N	LEFT:CW	LEFT:ACW	RIGHT:CW	RIGHT:ACW	COR	BIAS	P(C)	P(B)
1	76	36.8%	13.2%	36.8%	13.2%	0.00	47.2	1.00	0.00
2	66	37.9%	12.1%	36.4%	13.6%	3.00	48.6	1.00	0.00
3	34	41.2%	8.82%	20.6%	29.4%	41.2	23.6	.032	.259
4	58	34.5%	15.5%	20.7%	29.3%	28.5	11.3	.064	.585
5	62	37.1%	12.9%	16.1%	33.9%	42.0	6.40	.002	.780

TASK 7

GROUP	N	UP:CW	UP:ACW	DOWN:CW	DOWN:ACW	COR	BIAS	P(C)	P(B)
1	76	40.8%	9.21%	34.2%	15.8%	13.2	50.0	.289	0.00
2	66	24.2%	25.8%	27.3%	22.7%	-6.20	3.00	.806	1.00
3	34	11.8%	38.2%	32.4%	17.6%	-41.2	-11.6	.037	.708
4	58	25.9%	24.1%	29.3%	20.7%	-6.80	10.4	.792	.599
5	62	27.4%	22.6%	33.9%	16.1%	-13.0	22.6	.434	.124

TASK 8

GROUP	N	UP:CW	UP:ACW	DOWN:CW	DOWN:ACW	COR	BIAS	P(C)	P(B)
1	76	40.8%	9.21%	32.9%	17.1%	15.8	47.4	.192	0.00
2	66	34.8%	15.2%	36.4%	13.6%	-3.20	42.4	1.00	.001
3	34	23.5%	26.5%	23.5%	26.5%	0.00	-6.00	1.00	1.00
4	58	22.4%	27.6%	25.9%	24.1%	-7.00	-3.40	.793	1.00
5	62	35.5%	14.5%	32.3%	17.7%	6.40	35.6	.786	.010

CONTINUED....

TABLE 4.1 (CONTINUED)

TASK 9

GROUP	N	UP:CW	UP:ACW	DOWN:CW	DOWN:ACW	COR	BIAS	P(C)	P(B)
1	76	32.9%	17.1%	43.4%	6.58%	-21.0	52.6	.057	0.00
2	66	31.8%	18.2%	36.4%	13.6%	-9.20	36.4	.598	.006
3	34	23.5%	26.5%	20.6%	29.4%	5.80	-11.5	1.00	.732
4	58	20.7%	29.3%	36.2%	13.8%	-31.0	13.8	.033	.408
5	62	38.7%	11.3%	32.3%	17.7%	12.8	42.0	.402	.002

TASK 10

GROUP	N	UP:CW	UP:ACW	DOWN:CW	DOWN:ACW	COR	BIAS	P(C)	P(B)
1	76	32.9%	17.1%	35.5%	14.5%	-5.20	36.8	.805	.003
2	66	42.4%	7.58%	30.3%	19.7%	24.2	45.4	.051	0.00
3	34	32.4%	17.6%	32.4%	17.6%	0.00	29.6	1.00	.169
4	58	19.0%	31.0%	36.2%	13.8%	-34.4	10.4	.017	.576
5	62	32.3%	17.7%	30.6%	19.4%	3.40	15.8	1.00	.074

TASK 11

GROUP	N	UP:CW	UP:ACW	DOWN:CW	DOWN:ACW	COR	BIAS	P(C)	P(B)
1	72	37.5%	12.5%	43.1%	6.94%	-11.2	61.2	.372	0.00
2	66	34.8%	15.2%	37.9%	12.1%	-6.20	45.4	.783	0.00
3	34	35.3%	14.7%	20.6%	29.4%	29.4	11.8	.166	.721
4	58	25.9%	24.1%	32.8%	17.2%	-13.8	17.4	.424	.289
5	62	33.9%	16.1%	35.5%	14.5%	-3.20	38.8	1.00	.005

TASK 12

GROUP	N	FROM:CW	FROM:ACW	TO:CW	TO:ACW	COR	BIAS	P(C)	P(B)
1	76	39.5%	10.5%	30.3%	19.7%	18.4	39.6	.133	.001
2	66	36.4%	13.6%	27.3%	22.7%	18.2	27.4	.200	.044
3	34	38.2%	11.8%	32.4%	17.6%	11.6	41.2	.708	.037
4	58	19.0%	31.0%	39.7%	10.3%	-41.4	17.4	.003	.248
5	62	33.9%	16.1%	24.2%	25.8%	22.1	13.5	.198	.300

END OF TABLE 4.1

TABLE 4.2

TASK 2

GROUP	N	POS	FROM:CW	FROM:ACW	TO:CW	TO:ACW	COR	BIAS	P(C)	P(B)
1	38	1	39.5%	10.5%	31.6%	18.4%	15.8	42.2	.476	.020
1	38	6	36.8%	13.2%	28.9%	21.1%	15.8	31.4	.495	.099
5	31	1	41.9%	6.45%	22.6%	29.0%	41.8	29.0	.031	.139
5	31	7	29.0%	22.6%	16.1%	32.3%	22.6	-9.8	.358	.822

TASK 3

GROUP	N	POS	DOWN:CW	DOWN:ACW	UP:CW	UP:ACW	COR	BIAS	P(C)	P(B)
1	38	1	34.2%	15.8%	34.2%	15.8%	0.0	36.8	1.00	.050
1	38	6	36.8%	13.1%	39.5%	10.5%	-5.3	52.7	1.00	.003

TASK 5

GROUP	N	POS	LEFT:CW	LEFT:ACW	RIGHT:CW	RT:ACW	COR	BIAS	P(C)	P(B)
5	31	1	12.9%	38.7%	35.5%	12.9%	-48.4	-13.2	.018	1.00
5	31	7	9.68%	38.7%	45.2%	6.45%	-67.8	9.7	.000	.935

TASK 10

GROUP	N	POS	UP:CW	UP:ACW	DOWN:CW	DOWN:ACW	COR	BIAS	P(C)	P(B)
1	38	13	34.2%	15.8%	28.9%	21.1%	10.6	26.2	.737	.191
1	38	14	31.6%	18.4%	42.1%	7.89%	-21.0	47.4	.269	.007
5	31	13	32.3%	16.1%	38.7%	12.9%	-9.6	42.0	.908	.047
5	31	14	32.3%	19.4%	22.6%	25.8%	16.1	9.7	.601	.879

END OF TABLE 4.2

TABLE 4.3

TASK 1

GROUP	PRE ERR	N	DN:CW	DN:ACW	UP:CW	UP:ACW	COR	BIAS
2	0	42	23.8%	31.0%	23.8%	21.4%	-9.52	-4.76
	1	18	11.1%	27.8%	22.2%	38.9%	0.00	-33.3
3	0	27	18.5%	29.6%	29.6%	22.2%	-18.5	-3.70
	1	5	0.00%	60.0%	40.0%	0.00%	-100	-20.0
4	0	40	20.0%	32.5%	30.0%	17.5%	-25.0	0.00
	1	16	0.00%	43.7%	18.7%	37.5%	-25.0	-62.5

TASK 2

GROUP	PRE ERR	N	FR:CW	FR:ACW	TO:CW	TO:ACW	COR	BIAS
2	0	35	31.4%	22.9%	45.7%	0.00%	-37.1	54.3
	1	25	8.00%	36.0%	40.0%	16.0%	-52.0	-4.00
3	0	23	30.4%	21.7%	30.4%	17.4%	-4.35	21.7
	1	9	33.3%	11.1%	11.1%	44.4%	55.6	-11.1
4	0	42	45.2%	4.76%	21.4%	28.6%	47.6	33.3
	1	12	25.0%	25.0%	16.7%	33.3%	16.7	-16.7

TASK 3

GROUP	PRE ERR	N	DN:CW	DN:ACW	UP:CW	UP:ACW	COR	BIAS
2	0	46	30.4%	17.4%	50.0%	2.17%	-34.8	60.9
	1	13	30.8%	23.1%	23.1%	23.1%	7.69	7.69
3	0	22	31.8%	18.2%	36.4%	13.6%	-9.09	36.4
	1	10	0.00%	50.0%	30.0%	20.0%	-60.0	-40.0
4	0	39	20.5%	30.8%	35.9%	12.8%	-33.3	12.8
	1	13	23.1%	23.1%	38.5%	15.4%	-23.1	23.1

TASK 4

GROUP	PRE ERR	N	LT:CW	LT:ACW	RT:CW	RT:ACW	COR	BIAS
2	0	44	38.6%	11.4%	47.7%	2.27%	-18.2	72.7
	1	18	27.8%	22.2%	38.9%	11.1%	-22.2	33.3
3	0	21	28.6%	23.8%	33.3%	14.3%	-14.3	23.8
	1	11	27.3%	18.2%	18.2%	36.4%	27.3	-9.09
4	0	39	35.9%	15.4%	25.6%	23.1%	17.9	23.1
	1	13	15.4%	30.8%	38.5%	15.4%	-38.5	7.69

CONTINUED....

TABLE 4.3 (CONTINUED)

TASK 5

GROUP	PRE ERR	N	LT:CW	LT:ACW	RT:CW	RT:ACW	COR	BIAS
2	0	42	21.4%	26.2%	21.4%	31.0%	4.76	-14.3
	1	18	22.2%	33.3%	16.7%	27.8%	0.00	-22.2
3	0	22	13.6%	31.8%	45.5%	9.09%	-54.5	18.2
	1	10	10.0%	50.0%	20.0%	20.0%	-40.0	-40.0
4	0	35	5.71%	40.0%	40.0%	14.3%	-60.0	-8.57
	1	17	17.6%	41.2%	41.2%	0.00%	-64.7	17.6

TASK 6

GROUP	PRE ERR	N	LT:CW	LT:ACW	RT:CW	RT:ACW	COR	BIAS
2	0	40	27.5%	17.5%	40.0%	15.0%	-15.0	35.0
	1	22	54.5%	4.55%	31.8%	9.09%	27.3	72.7
3	0	24	41.7%	8.33%	20.8%	29.2%	41.7	25.0
	1	8	37.5%	12.5%	12.5%	37.5%	50.0	0.00
4	0	37	29.7%	18.9%	18.9%	32.4%	24.3	-2.70
	1	15	46.7%	6.67%	20.0%	26.7%	46.7	33.3

TASK 7

GROUP	PRE ERR	N	UP:CW	UP:ACW	DN:CW	DN:ACW	COR	BIAS
2	0	42	26.2%	23.8%	23.8%	26.2%	4.76	0.00
	1	18	22.2%	27.8%	27.8%	22.2%	-11.1	0.00
3	0	21	14.3%	42.9%	23.8%	19.0%	-33.3	-23.8
	1	11	9.09%	27.3%	45.5%	18.2%	-45.5	9.09
4	0	32	28.1%	15.6%	37.5%	18.7%	-6.25	31.2
	1	18	22.2%	38.9%	16.7%	22.2%	-11.1	-22.2

TASK 8

GROUP	PRE ERR	N	UP:CW	UP:ACW	DN:CW	DN:ACW	COR	BIAS
2	0	38	44.7%	7.89%	31.6%	15.8%	21.1	52.6
	1	22	22.7%	22.7%	40.9%	13.6%	-27.3	27.3
3	0	22	22.7%	22.7%	31.8%	22.7%	-9.09	9.09
	1	8	12.5%	50.0%	0.00%	37.5%	0.00	-75.0
4	0	33	21.2%	30.3%	18.2%	30.3%	3.03	-21.2
	1	17	17.6%	29.4%	41.2%	11.8%	-41.2	17.6

TABLE 4.3 (CONTINUED)

TASK 9

GROUP	PRE ERR	N	UP:CW	UP:ACW	DN:CW	DN:ACW	COR	BIAS
2	0	38	36.8%	13.2%	34.2%	15.8%	5.26	42.1
	1	23	30.4%	21.7%	34.8%	13.0%	-13.0	30.4
3	0	21	23.8%	19.0%	23.8%	33.3%	14.3	-4.76
	1	9	22.2%	44.4%	22.2%	11.1%	-33.3	-11.1
4	0	42	23.8%	28.6%	35.7%	11.9%	-28.6	19.0
	1	14	14.3%	28.6%	35.7%	21.4%	-28.6	0.00

TASK 10

GROUP	PRE ERR	N	UP:CW	UP:ACW	DN:CW	DN:ACW	COR	BIAS
2	0	37	45.9%	8.11%	32.4%	13.5%	18.9	56.8
	1	27	37.0%	7.41%	29.6%	25.9%	25.9	33.3
3	0	17	29.4%	23.5%	35.3%	11.8%	-17.6	29.4
	1	13	30.8%	15.4%	38.5%	15.4%	-7.69	38.5
4	0	36	13.9%	36.1%	36.1%	13.9%	-44.4	0.00
	1	18	33.3%	16.7%	44.4%	5.56%	-22.2	55.6

TASK 11

GROUP	PRE ERR	N	UP:CW	UP:ACW	DN:CW	DN:ACW	COR	BIAS
2	0	41	36.6%	12.2%	41.5%	9.76%	-7.32	56.1
	1	20	30.0%	20.0%	30.0%	20.0%	0.00	20.0
3	0	17	35.3%	23.5%	17.6%	23.5%	17.6	5.88
	1	13	30.8%	7.69%	23.1%	38.5%	38.5	7.69
4	0	35	20.0%	31.4%	31.4%	17.1%	-25.7	2.86
	1	19	31.6%	15.8%	36.8%	15.8%	-5.26	36.8

TASK 12

GROUP	PRE ERR	N	FR:CW	FR:ACW	TO:CW	TO:ACW	COR	BIAS
2	0	33	39.4%	15.2%	18.2%	27.3%	33.3	15.2
	1	24	33.3%	12.5%	33.3%	20.8%	8.33	33.3
3	0	20	35.0%	10.0%	40.0%	15.0%	0.00	50.0
	1	10	40.0%	20.0%	20.0%	20.0%	20.0	20.0
4	0	36	19.4%	27.8%	38.9%	13.9%	-33.3	16.7
	1	20	20.0%	35.0%	40.0%	5.00%	-50.0	20.0

END OF TABLE 4.3

TABLE 4.4

TASK 1

GROUP	PRE RES	N	DN:CW	DN:ACW	UP:CW	UP:ACW	COR	BIAS
2	C	45	20.0%	31.1%	24.4%	24.4%	-11.1	-11.1
	A	15	20.0%	26.7%	20.0%	33.3%	6.67	-20.0
3	C	18	11.1%	38.9%	38.9%	11.1%	-55.6	0.00
	A	14	21.4%	28.6%	21.4%	28.6%	0.00	-14.3
4	C	28	14.3%	35.7%	28.6%	21.4%	-28.6	-14.3
	A	28	14.3%	35.7%	25.0%	25.0%	-21.4	-21.4

TASK 2

GROUP	PRE RES	N	FR:CW	FR:ACW	TO:CW	TO:ACW	COR	BIAS
2	C	41	22.0%	34.1%	36.6%	7.32%	-41.5	17.1
	A	19	21.1%	15.8%	57.9%	5.26%	-47.4	57.9
3	C	16	25.0%	12.5%	31.2%	31.2%	12.5	12.5
	A	16	37.5%	25.0%	18.7%	18.7%	12.5	12.5
4	C	31	19.4%	9.68%	35.5%	35.5%	9.68	9.68
	A	23	69.6%	8.70%	0.00%	21.7%	82.6	39.1

TASK 3

GROUP	PRE RES	N	DN:CW	DN:ACW	UP:CW	UP:ACW	COR	BIAS
2	C	35	28.6%	14.3%	51.4%	5.71%	-31.4	60.0
	A	24	33.3%	25.0%	33.3%	8.33%	-16.7	33.3
3	C	18	27.8%	33.3%	22.2%	16.7%	-11.1	0.00
	A	14	14.3%	21.4%	50.0%	14.3%	-42.9	28.6
4	C	29	20.7%	17.2%	44.8%	17.2%	-24.1	31.0
	A	23	21.7%	43.5%	26.1%	8.70%	-39.1	-4.35

TASK 4

GROUP	PRE RES	N	LT:CW	LT:ACW	RT:CW	RT:ACW	COR	BIAS
2	C	36	33.3%	11.1%	47.2%	8.33%	-16.7	61.1
	A	26	38.5%	19.2%	42.3%	0.00%	-23.1	61.5
3	C	17	17.6%	23.5%	35.3%	23.5%	-17.6	5.88
	A	15	40.0%	20.0%	20.0%	20.0%	20.0	20.0
4	C	26	26.9%	11.5%	46.2%	15.4%	-15.4	46.2
	A	26	34.6%	26.9%	11.5%	26.9%	23.1	-7.69

CONTINUED....

TABLE 4.4 (CONTINUED)

TASK 5

GROUP	PRE RES	N	LT:CW	LT:ACW	RT:CW	RT:ACW	COR	BIAS
2	C	44	25.0%	22.7%	20.5%	31.8%	13.6	-9.09
	A	16	12.5%	43.7%	18.7%	25.0%	-25.0	-37.5
3	C	12	16.7%	25.0%	50.0%	8.33%	-50.0	33.3
	A	20	10.0%	45.0%	30.0%	15.0%	-50.0	-20.0
4	C	31	9.68%	32.3%	45.2%	12.9%	-54.8	9.68
	A	21	9.52%	52.4%	33.3%	4.76%	-71.4	-14.3

TASK 6

GROUP	PRE RES	N	LT:CW	LT:ACW	RT:CW	RT:ACW	COR	BIAS
2	C	38	34.2%	13.2%	47.4%	5.26%	-21.1	63.2
	A	24	41.7%	12.5%	20.8%	25.0%	33.3	25.0
3	C	19	36.8%	0.00%	21.1%	42.1%	57.9	15.8
	A	13	46.2%	23.1%	15.4%	15.4%	23.1	23.1
4	C	31	22.6%	19.4%	25.8%	32.3%	9.68	-3.23
	A	21	52.4%	9.52%	9.52%	28.6%	61.9	23.8

TASK 7

GROUP	PRE RES	N	UP:CW	UP:ACW	DN:CW	DN:ACW	COR	BIAS
2	C	46	28.3%	19.6%	30.4%	21.7%	0.00	17.4
	[illegible]	14	14.3%	42.9%	7.14%	35.7%	0.00	-57.1
3	C	18	16.7%	38.9%	22.2%	22.2%	-22.2	-22.2
	A	14	7.14%	35.7%	42.9%	14.3%	-57.1	0.00
4	C	31	25.8%	19.4%	38.7%	16.1%	-16.1	29.0
	A	19	26.3%	31.6%	15.8%	26.3%	5.26	-15.8

TASK 8

GROUP	PRE RES	N	UP:CW	UP:ACW	DN:CW	DN:ACW	COR	BIAS
2	C	35	34.3%	5.71%	42.9%	17.1%	2.86	54.3
	A	25	40.0%	24.0%	24.0%	12.0%	4.00	28.0
3	C	17	23.5%	29.4%	29.4%	17.6%	-17.6	5.88
	A	13	15.4%	30.8%	15.4%	38.5%	7.69	-38.5
4	C	24	25.0%	20.8%	29.2%	25.0%	0.00	8.33
	A	26	15.4%	38.5%	23.1%	23.1%	-23.1	-23.1

CONTINUED....

TABLE 4.4 (CONTINUED)

TASK 9

GROUP	PRE RES	N	UP:CW	UP:ACW	DN:CW	DN:ACW	COR	BIAS
2	C	41	41.5%	19.5%	29.3%	9.76%	2.44	41.5
	A	20	20.0%	10.0%	45.0%	25.0%	-10.0	30.0
3	C	19	26.3%	26.3%	26.3%	21.1%	-5.26	5.26
	A	11	18.2%	27.3%	18.2%	36.4%	9.09	-27.3
4	C	37	21.6%	29.7%	37.8%	10.8%	-35.1	18.9
	A	19	21.1%	26.3%	31.6%	21.1%	-15.8	5.26

TASK 10

GROUP	PRE RES	N	UP:CW	UP:ACW	DN:CW	DN:ACW	COR	BIAS
2	C	43	37.2%	9.30%	32.6%	20.9%	16.3	39.5
	A	21	52.4%	4.76%	28.6%	14.3%	33.3	61.9
3	C	16	31.2%	18.7%	50.0%	0.00%	-37.5	62.5
	A	14	28.6%	21.4%	21.4%	28.6%	14.3	0.00
4	C	30	13.3%	26.7%	46.7%	13.3%	-46.7	20.0
	A	24	29.2%	33.3%	29.2%	8.33%	-25.0	16.7

TASK 11

GROUP	PRE RES	N	UP:CW	UP:ACW	DN:CW	DN:ACW	COR	BIAS
2	C	40	37.5%	10.0%	37.5%	15.0%	5.00	50.0
	A	21	28.6%	23.8%	38.1%	9.52%	-23.8	33.3
3	C	20	30.0%	15.0%	30.0%	25.0%	10.0	20.0
	A	10	40.0%	20.0%	0.00%	40.0%	60.0	-20.0
4	C	26	23.1%	15.4%	34.6%	26.9%	0.00	15.4
	A	28	25.0%	35.7%	32.1%	7.14%	-35.7	14.3

TASK 12

GROUP	PRE RES	N	FR:CW	FR:ACW	TO:CW	TO:ACW	COR	BIAS
2	C	37	35.1%	10.8%	29.7%	24.3%	18.9	29.7
	A	20	40.0%	20.0%	15.0%	25.0%	30.0	10.0
3	C	19	42.1%	10.5%	26.3%	21.1%	26.3	36.8
	A	11	27.3%	18.2%	45.5%	9.09%	-27.3	45.5
4	C	25	20.0%	40.0%	40.0%	0.00%	-60.0	20.0
	A	31	19.4%	22.6%	38.7%	19.4%	-22.6	16.1

END OF TABLE 4.4

TABLE 4.5

EFFECT OF PREVIOUS OUTCOME ON CORRELATION (MEDIAN FOR 12 TASKS)

GROUP	CORRELATION WHEN PREVIOUS OUTCOME IS "CORRECT"	CORRELATION WHEN PREVIOUS OUTCOME IS "ERROR"	PR. OUTCOME ASSOCIATED WITH HIGHER CORRELATION	N	U	SIGNIFICANCE ON 2-TAIL MANN-WHITNEY "U" TEST
2	16.600	12.050	"CORRECT"	12	66.0	-
3	15.950	39.250	"ERROR"	12	36.0	P<0.05
4	27.150	26.800	"CORRECT"	12	71.0	-
ALL	18.350	26.600	"ERROR"	36	530.0	-

TABLE 4.6

EFFECT OF PREVIOUS OUTCOME ON CLOCKWISE BIAS (MEDIAN FOR 12 TASKS)

GROUP	CW BIAS WHEN PREVIOUS OUTCOME IS "CORRECT"	CW BIAS WHEN PREVIOUS OUTCOME IS "ERROR"	PR. OUTCOME ASSOCIATED WITH HIGHER CW BIAS	N	U	SIGNIFICANCE ON 2-TAIL MANN-WHITNEY "U" TEST
2	47.350	23.600	"CORRECT"	12	43.5	-
3	19.950	-10.095	"CORRECT"	12	36.5	P<0.05
4	14.750	17.600	"ERROR"	12	69.0	-
ALL	18.600	7.6900	"CORRECT"	36	486.5	P=0.06

TABLE 4.7

EFFECT OF PREVIOUS RESPONSE ON CORRELATION (MEDIAN FOR 12 TASKS)

GROUP	CORRELATION WHEN PREVIOUS RESPONSE IS CLOCKWISE	CORRELATION WHEN PREVIOUS RESPONSE IS ANTICLOCKWISE	PREV. RESP. ASSOCIATED WITH HIGHER CORRELATION	N	U	SIGNIFICANCE ON 2-TAIL MANN-WHITNEY "U" TEST
2	14.950	23.450	ACW	12	51.0	-
3	17.600	21.550	ACW	12	66.0	-
4	20.100	24.050	ACW	12	52.0	-
ALL	17.150	23.100	ACW	36	531.0	-

TABLE 4.8

EFFECT OF PREVIOUS RESPONSE ON CLOCKWISE BIAS (MEDIAN FOR 12 TASKS)

GROUP	CW BIAS WHEN PREVIOUS RESPONSE IS CLOCKWISE	CW BIAS WHEN PREVIOUS RESPONSE IS ANTICLOCKWISE	PREV. RESP. ASSOCIATED WITH HIGHER CW BIAS	N	U	SIGNIFICANCE ON 1-TAIL MANN-WHITNEY "U" TEST
2	40.500	29.000	CW	12	56.0	-
3	9.1900	0.0000	CW	12	51.0	-
4	17.150	0.4550	CW	12	41.5	P<0.05
ALL	18.150	11.250	CW	36	469.5	P=0.02

SECTION 5 DISCUSSION OF RESULTS

5.1 Introduction

The strengths of the stereotypes found for the five occupational groups on the twelve tasks constitute the main results of this study. They are listed in Table 4.1 and illustrated in Figures 4.1 to 4.3, but before they are discussed the conditions under which they were obtained will be recapitulated. The occupational groups were schoolboys, students, apprentices, general operators and production operators, numbered as group (or cat.) 1 to 5 respectively. Groups 2,3 and 4 were studied in Experiment 1, the main experiment, in which the order of presentation of the tasks was random and errors were made to occur in positions 2,5 and 10 in the series. Groups 1 and 5 took part only in Experiment 2, the subsidiary experiment concerned with serial effects. Group 1 was presented with tasks 2 and 3 in positions 1 and 6 or positions 6 and 1. Group 5 had tasks 2 and 5 in positions 1 and 7 or positions 7 and 1. Both groups were given task 10 in position 12, and a series of five all-correct or all-error trials were given on other tasks leading up to this.

5.2 The Strength of the Stereotypes Found

Holding (1957) suggests that a division of responses between clock-wise and anti-clockwise should be at least as extreme as 70:30 if it is to be of importance to engineering design. A reversible stereotype of this strength would give a correlation of +40 or -40 by the method of measurement employed in the present experiments. Out of the 60 correlations shown in table 4.1 only nine reach this level: it follows that useful stereotypes were not generally found in this study. For the set of control-display configurations tested, few strongly-preferred control-display relationships seem to exist.

5.3 The Significance of the Stereotypes Found

60 correlations were measured: 14 were significantly different from zero at the .05 level, when tested by Fisher's Exact Probability Test. 60 measures of clockwise bias were associated with these correlations: 25 were significant at the .05 level, according to a modification of the same test. Three of each measure (5%) would be expected to reach this level by chance. However, when several groups produce correlation or bias measures which are all in the same sense for a particular task, the combined result can be significant when the individual measures are not. Formally, it is illegitimate to combine the results in this way: the results to be combined would be selected in order to justify a post-hoc hypothesis: but it does allow the tentative inference of certain trends from the data.

5.4 The Effect of Experience.

In terms of length of exposure to machine tools, groups 1 and 2 had no experience, group 3 had from six to eighteen months and groups 5 and 6 had several years.

In tasks 1 to 6 the trend is for stereotypes to increase in strength with increasing experience, as shown by the correlation diagrams in Figures 4.1 and 4.2. A notable exception is task 4, which shows a progressive reversal of the sense of the correlation. Also the result for task 2, group 2 is anomalous. (and significant at p = .001). Task 10 is indicative, too, of a reversal of the stereotype with experience. In tasks 2 and 10 the reversal occurs in the direction of increased conformity with machine-tool design practice as experience increases. Unfortunately, task 4 does not correspond with any real machine-tool configuration, but it is interesting in that it lies between a "rack-and-pinion" layout and a"right-hand-screw" layout like task 6. The less-experienced groups see it is a rack-and-pinion configuration while the more-experienced obey the right-hand-screw principle, turning "clockwise for left".

There was a noticeable lack of consistency in the tasks involving a moving cutter/spindle assembly, just as there is in the design of machine-tools in this area. The fact that occasional highly-significant correlations appear might be put down to the experience of particular groups with particular machines, but no evidence on this point was sought.

5.5 Clockwise Bias in the Responses

The bias measure in Figures 4.1 to 4.3 is related to the correlation measure in that the observed value of each controls the limits within which the other may vary. In the absence of other factors, low correlation tends to be associated with high bias and vice-versa.

Group 1 has significant clockwise bias on all the tasks (except task 5, which was not measured). The bias results in general confirm that an overall clockwise-turning tendency exists, regardless of the nature of the stimulus. Where anti-clockwise bias occurs, it is found (with one exceptio task 9: group 3) on handwheels positioned at the left-hand side of the machine, but the values are much lower than those of the clockwise bias seen on the other handwheels. A possible explanation of these findings is that a strong clockwise tendency and a weaker wrist-supination tendency coexist for all the tasks.

5.6 Comparison of Results with Design Practice

In Figure 4.5 the experimental results are compared with data compiled by Houldsworth (1968) on some control-display relationships found in machine-tool design practice, and in various published standards. In order to look at the general picture, a significance level of 0.1 was adopted for this illustration only.

For tasks 2, 3, 4, 5 and 6, all of which involved movement of the table/ workpiece assembly, there was good agreement between the expectations of groups 4 and 5 on the one hand and existing practice and standards on the other.

The less-experienced groups show less agreement: no expectations for group 1, two for group 2: one with and one against existing practice, and three for group 3, all in agreement with existing practice. This suggests that, in the particular context of machine-tools, stereotypes are acquired "on the job". Group 1 comprised subjects from the same academic/social background as the men in groups 4 and 5, who were machine tool operators. Thus the lack of significant stereotypes in group 1 suggests that "pre-experience" operators have not learned any expectations about the direction-of-motion relations. Luckily, the subjects of group 2, university (non-engineering) students, are unlikely to become machine tool operators: some of their expectations are at variance with machine-tool practice. In the tasks involving movement of the cutter/spindle assembly there is disagreement among the published standards and existing practice is not as consistent as Figure 4.5 would suggest. The lack of significant stereotypes in this sector is notable. Taken in conjunction, the two sets of results suggest that consistency of practice and standards is much more important than "right" or "wrong" direction-of-motion relations.

5.7 Serial Effects - Experiment 11.

Figure 4.4 shows the results of experiment 11. Numerical values and significance levels are given in Table 4.2.

5.7.1 Effect of Task Order on S - R Correlation.

Reference to the left-hand column of Figure 4.4 will show that the direction of the correlation was the same whether the task was presented at the beginning of the order or in the middle, for the four combinations of task and subject group tested: 2/1, 2/5, 3/1 and 5/5.

This was confirmed by ranking the two sets of correlations: the rank order of the four cases is identical whether they are ranked by first-position correlations or middle-position correlations, giving a Spearman's rank correlation coefficient of 1.0, significant at the 0.1 level for n = 4 (2 - tail).

That is to say, there is less than one chance in ten that task order affected the strength of the stereotypes in the main experiment.

5.7.2 Effect of Task Order on Response Bias.

The results for the bias measure (Figure 4.4, right-hand column) are not so clear-cut. For group 1, both tasks showed significant clockwise bias in both conditions. For group 5, on the other hand, the sense of the bias was reversed between conditions in both tasks tested. There is thus a suggestion, far short of statistical proof, that the response bias of more experienced subjects is affected by task order.

5.7.3 Effect of Consistent Previous Outcomes on Correlation.

The fourth row in Figure 4.4 shows the results for task 10 when the outcomes of the five preceding trials were controlled.

To explain the nomenclature, "position 13" means that the task was presented in position 12 and the outcomes of the five preceding trials were nominally "correct", while Position 14" means that the task was presented in position 12, but in this case it followed five controlled "error" outcomes on other tasks.

Task 10 was chosen for this test on the assumption, since shown to be erroneous, that groups 1 and 5 would behave like groups 2 and 4 respectively, since they were matched for machine-tool experience. As is evident from Figure 4.3, row 2, the latter groups produced strong stereotypes on this task, but groups 1 and 5 did not. Figure 4.4 shows that both these groups reversed their expectations between the two previous-outcome conditions, but unfortunately all four correlation values, and the reversal itself, were non-significant.

5.7.4 Effect of Previous Outcomes on Response Bias.

Group 1 showed greater clockwise bias under the "previous-error" condition: group 5 had greater bias under the other condition. The differences were not significant.

5.8 Serial Effects - Further Analysis of Experiment 1

Experiment 11 was designed to emphasise the serial effects which were arranged to cancel out in experiment 1. However, it was found to be possible to add up the results of the first experiment in a different way in order to throw a little more light on these effects.

5.8.1 Effect of Previous Outcome.

Table 4.3 contains the same results that made up table 4.1, with the difference that they are classified into two sets. For each task/group combination the response frequencies are split into two: line "0" contains all the responses to tasks which happened to follow a task with a "correct" outcome and line "1" contains the responses to tasks which immediately followed a task where the outcome was an "error". It will at once be obvious that the frequencies in each line are very low, particularly in the "error" line. The correlation and bias measures are therefore significant only in rare cases. However, it is possible to combine the correlation and bias scores of all twelve tasks and so examine any general effects of the "previous outcome" variable. This procedure is carried out in Table 4.5 for the correlations and in Table 4.6 for the bias results. In Table 4.5 only the magnitudes (ignoring sign) of the correlations have been considered, because the signs are arbitrary- they have different meanings in the different tasks. The correlations shown in the table are medians for 12 tasks, for groups 2,3 and 4 separately and combined. A Mann - Whitney "U" test shows that group 3 produced stronger stereotypes when performing on tasks which followed a previous-task "error" outcome than when the previous outcome was "correct". There is thus reason to suspect, for this group only, that previous outcome has an effect on the response in the subsequent trial.

In Table 4.6 the bias results are treated in the same way, except that the sign is taken into account ("+" means clockwise; "-" means anticlockwise). Again it is group 3 which shows a significant effect: the group shows clockwise bias on tasks following a "correct" outcome and anticlockwise bias after an"error" outcome.

What characteristic of this group caused it to be sensitive to this particular previous-task parameter? A possible hypothesis is that because group 3 was a group of apprentices (and undergoing training in the operation of machine tools) they were in the habit of observing their own performance and modifying their strategies in order to improve it. Thus an "error" outcome would cause them to take thought about all aspects of the next trial so that their expected direction-of-motion relation would be more in line with their experience of machine tools, and hence more consistent within the group. This would explain Table 4.5. If they also tended to reverse their response compared with the response on the previous trial, when that trial had an "error" outcome, the reversal of bias seen in Table 4.6 would result.

5.8.2 Effect of Previous Response.

One of the most probable effects that one trial can have on another is that consecutive responses will tend to be the same (both clockwise or both anticlockwise), regardless of the sense of the stimulus and the nature of the task. In order to check whether such an effect occurred in experiment 1, Table 4.4 was compiled. This splitsthe response frequencies into two groups, as before, but now the criterion is the sense of the immediately preceding response. Lines "C" are for the case where the previous response was clockwise and those marked "A" are for anticlockwise previous responses. As in the case of Table 4.3, the split frequencies in Table 4.4 are too small to give significant results so all 12 tasks have been combined: the median correlation and bias for the combined tasks are shown in Tables 4.7 and 4.8 respectively.

In Table 4.7 the magnitude of the median correlation, for all three groups, is higher after an anticlockwise response, but not significantly so. Table 4.8 shows, however, that the previous response does have a significant effect on the bias which is, as expected, greater in the clockwise sense for the set of trials which followed previous clockwise responses. For groups 3 and 4 the bias approximately vanishes for the set of trials where the previous response was anticlockwise. The effect is significant for group 4 alone and for the three groups combined. It is therefore established that sequential dependence occurred among the responses.

SECTION 6 : CONCLUSIONS

6.1 Conclusions about the Method.

It has been shown that the device of allowing each subject to provide data for several tasks does lead to effects involving the influence of one trial upon another. However, stereotypes measured in the middle of a series of 12 tasks were not weaker than those measured first, when the subject was completely new to the experiment. The effect seems to have been chiefly confined to the measure of clockwise bias in the responses: this is strongly affected by the response to a previous trial.

The group of apprentices were particularly susceptible to these effects. For practical purposes, however, the amount of clockwise bias is much less important than the sense of the stereotypes, which does not appear to have been affected by serial effects. There is some rather weak evidence to show that the stereotype may be affected by long series of consecutive errors on previous trials, but the effect of isolated errors was shown to be mild.

6.2 Conclusions about the Choice of Subjects.

It is clear from the results that the measurement of population stereotypes is dependent on the selection of subjects who really represent the population concerned. As well as the appropriate degree of relevant experience it is necessary to choose subjects with a suitable general background. There were differences between the schoolboy and student groups even though neither were experienced in the tasks studied.

6.3 The Effect of Experience.

In most of the tasks, inexperienced subjects showed a stronger tendency to turn everything clockwise than experienced subjects did. For the moving-workpiece tasks, inexperienced subjects showed generally weaker stereotypes than experienced ones. Two or three tasks suggested that a reversal of the stereotype can occur between experienced and inexperienced subjects.

6.4 Recommendations for Design.

Tasks 1 and 3 show that if a handwheel/crank control is used to raise and lower the machine table, it should be connected in the sense "clockwise-for-up".

Task 2 shows that the "right-hand screw rule", i.e. "clockwise-for-away" is obeyed by operators and less strongly by apprentices, but strongly reversed by the students. It is suggested that the latter may have noticed that it requires a left-hand thread on the leadscrew to produce this right-hand screw effect. Where the handwheel travels with the display element this anomaly does not occur: in tasks 5 and 6 the inexperienced groups showed no stereotype. The experienced groups showed stronger stereotypes on task 5 than on task 6: table traverse handwheels are therefore move effective if mounted on the left-hand end of the table. The best solution for cross-traverse handwheels (task 2) is not easy to determine. The logical relation between control and display leads to conflict with the logical arrangement for handwheels which travel with the table, and so the existing practice of using a left-hand thread may be better.

Task 4 clearly shows the confusion which can be caused when a conflict of stereotypes occurs. Such conflicts should be avoided by fitting a different type of control or repositioning the handwheel.

Tasks 7 to 12 indicate that for some reason clear stereotype do not emerge for the spindle-traverse controls mounted in the usual positions on the head of the machine. There was disagreement among the three experienced groups in the results for these tasks. It follows that handwheels are not the ideal type of controls, for these tasks.

In general then, existing practice should be followed in the design of table-traverse handwheels, non-conforming machines being brought into line with the majority. For the spindle-traverse controls, handwheels should be avoided unless standardised locations and direction-of-motion relations can be adopted. It does not seem to matter which particular relations are

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