O heaven! were man

But constant, he were perfect.

W. Shakespeare

Two Gentlemen of Verona

IV.ii.40

Tom Barton Leamon

AN INVESTIGATION INTO THE EFFECTS OF FEEDBACK OF KNOWLEDGE OF RESULTS ON OPERATOR PERFORMANCE

Master of Science

October 1969

I SUMMARY

Previous work on Knowledge of Results was surveyed and certain common effects were identified, together with certain anomalies. Particularly, the effects of Knowledge of Results on an industrial task were in doubt. The present investigation was designed to reduce this doubt and to examine the effects in the field in a production section of industry. Problems of field work arose, but effects of KR on the performance of seven S, occupied on sedentary hand work, was investigated over an eight-week period.

Knowledge of Results was found to exert an influence on the performance of all S and this influence extended to a condition where Knowledge of Results was withdrawn. Performance, in the latter condition, was significantly higher than in a true No-Knowledge of Results condition.

These effects were explained in the light of a hypothesised mechanism to explain the effects of Knowledge of Results on Human Performance.

The hypothesis appeared to have a general application and was used to offer explanations of the main effects and anomalies reported in the literature.

C O N T E N T S

XII GRAPHS

XIII ACKNOWLEDGEMENTS

II INTRODUCTION

Many investigations have consistently shown that provision of Knowledge of Results, (KR), produced very significant changes in the performance of a variety of tasks in the laboratory and some of these are outlined in III. Largely, it is believed, as a result of an acquaintance with the research literature, the provision of feedback, or KR to industrial operators, is widely advocated in Management Texts as being beneficial. It did not prove possible to locate any investigation into the efficacy of such advice. In addition, it is not made explicit that provision of KR usually involves costs both in the collection and the presentation of such information; thus the introduction of a system for the provision of KR to augment existing information feedback must be assessed in terms acceptable to the authorising body. The primary benefit sought in industry is an improvement of performance level or performance consistency.

It rapidly becomes apparent that knowledge of the method in which KR may influence performance is essential in a consideration of the industrial context. For example, if the KR acts in a motivational manner, provision of data poor in information content, which is often less expensive, may be sufficient. Thus, process data which is easy to collect might be used in preference to more elusive data of a more pertinent informational character.

Can KR be safely delayed to the end of a work period and still affect performance, or must it be presented at short intervals? Does the manner of presentation affect the utility of KR? Understanding of the process involved when KR alters performance of industrial tasks is essential before KR may be assessed in its role of a management tool.

Finally, most of the findings of the literature are relevant to short duration, highly artificial situations and the first stage of

investigation must be to examine a real industrial situation for effects of KR on performance. Two half-way, (that is, simulated industrial), tasks have been investigated by Gibbs and Brown (1956) and by Chapanis (1964), who obtained very different results by providing KR. This arose not through interpretation, but simply that in one situation massive improvement took place and in the second no effect was found.

The present investigation is an attempt to move the study in this field into a true industrial situation, where S are actually earning their livelihood by working from 08.00 hours to 16.30 hours each day of each week, where bonus schemes and management supervision exist and where the task is often unattractive.

However, such conditions, rather than reduce the amount of experimental design and afore-thought, exchange the problems of treatment layout for a detailed and massive examination of the total working situation which is outlined in IV and V, to avoid the problems outlined in the literature.

In addition to a demonstration of the effect of KR in an industrial situation, a need for a description in general, to explain the effect of KR on performance, arose and such a mechanism was outlined in VIII.1. The present findings, a comparison with other appropriate investigations and the effects described in laboratory situations in the literature, are all discussed, in relationship to this hypothesis, in successive sections of this chapter.

III SURVEY OF THE GENERAL EFFECTS OF KNOWLEDGE OF RESULTS

Information describing the effect of a S's control actions or responses may be termed Knowledge of Results (KR) and such information has been of interest to, and has been investigated by psychologists since the turn of the century. However there are still no defined parameters to describe in general KR, although a tentative scheme is outlined later, (Holding 1965). The confusion which has arisen has surely hindered the development of a unified explanation of the effects of KR on human performance; as late as 1956, Gibbs and Brown refer to KR as though this were a unique description of an experimental variable. Infact a very diverse collection of information carrying stimuli have been termed KR, ranging from avoidance of a painful electric shock through light and sound signals to "verbal encouragement". This lack of control has resulted in like and unlike being compared and frequently the lack of insight into possible separate effects of KR and the methods of presentation has hindered the development of knowledge of the subject.

KR has been demonstrated to increase performance on a vigilance task and also in some cases to reduce the typical vigilance decrement of performance with time (Mackworth 1950), although this latter finding is far from universal (Weidenfeller et als 1962).

Baker (1959) suggested that KR enabled S to learn the temporal characteristics of signals in a vigilance situation. This explanation is supported by results of an industrial investigation (Leamon 1965), the chance of a fault being detected in an inspection task was found to correlate very highly with the rate of arrival of

rejectable faults; rapid learning of changes in temporal patterns would facilitate effective performance in such situations.

Hardesty et als (1963) explain the results of Mackworth by separate alternatives, either in terms of increased information input or, in terms of increased stimulation leading to higher arousal levels. Hebb (1966) postulates that in general arousal affects performance in an inverted U form: performance increasing to a maximum with increasing arousal and then falling as the arousal increases - presumably as a result of disorganisation.

J. F. Mackworth (1964) and others have found that false KR, (that is S in a Mackworth - clock like situation was given K.R. of missed signals by means of a lamp, when infact no signal had occured), produced an improved performance over a no - KR situation. However the improvement was less than a normal KR situation and this false K.R. did not prevent decrement in performance with time occuring. J. F. Mackworth also found that in trials following KR treatments, but without this feedback, performance was improved for people trained in KR conditions; she suggests S has, "learned something about the task". This "something" probably includes the temporal characteristics as suggested by Baker and may-be signal characteristics which enable signals to be more readily distinguished from the noise of the system. The testing lasted forty minutes.

Hardesty et als (1963) attempted to distinguish between the motivational aspects of KR and the informational effects using the Mackworth clock situation. KR was presented either orally by an observer or mechanically by signal lamps. The results showed that observer presented KR improved performance, but mechanically presented

KR did not, for the forty minute trial. In subsequent testing in the no KR condition, the superiority of the group with observer presented KR persisted. Hardesty concludes from the continuation effect that the motivational nature and not the informational nature of KR is important in this case. Montague and Webber (1965) present the opposite conclusion.

Whilst it is impossible to check the significance of the observation it appears from the figure 1A in this paper that mechanically presented KR drastically reduced the performance decrement found on this task with the no - KR condition. It also appears likely that the observer presented KR contained all the informational content as well as an apparent judgement of an individuals performance. The observer said "right" or "wrong", a better signal might have been "hit" or "miss" or two appropriate nonsense syllables as used elsewhere. From the presented data it is justifiable to postulate an alternative hypothesis; that the informational nature provides the essential input to a mechanism by which performance is improved, the observer merely creates the motivation to utilise such a mechanism. It would follow that the motivation could be provided by many other means: monetary reward, comparison between peers and interestingly, the information might itself stimulate intra-subject comparison which would increase motivation, thus the KR would provide both information and motivation, but the latter as a consequence of the former. If this were the case the form of presentation itself would be important - later this is shown to be the case.

Wilkinson (1961) found that in a simple repetitive task, the 5 - Choice Test of Serial Reaction, sleep deprivation produced a performance decrement with time on task, (a result he compares to the

decrement resulting from, "the stress" of no - KR). KR removed this decrement.

However it must be noted that in addition to the mechanical signal which provided KR, the observer also assessed each 5 minute period as, "Better", "Worse" or "No Change" and this information was presented orally.

Because the effect of KR, as described, was disproportionally large in S with sleep deprivation, it is suggested this state represents a low level of motivation and, "gives KR more to work on", (sic).

The informational nature of KR is ignored and it is further postulated that the increase in motivation due to KR, acts directly on arousal and the increase of arousal is causal in the performance improvement.

R. G. Stennett (1957) investigated performance level and arousal level using EMG and palmar conductance on an audio tracking task. This investigation supports the hypothesis for an inverted - U relationship between performance and arousal. The KR given was heavily contaminated, as Stennett wished S to pass the maximum on the inverted - U curve, with 5 dollar and (2 dollar + avoidance of a 150 v. shock) rewards.

However the mean conductance was lower in a no - KR situation than in this exceptional KR condition. Also the mean level of EMG was higher under this condition.

Montague and Webber (1965) found that a high performance which resulted from a KR condition persisted into subsequent no - KR trials. This was considered to be evidence against the motivational. explanation of KR and for an explanation based upon the informational

effect in a stimuli learning situation. It was found that over six hour tests in a monitoring situation error rates and response latency increased. KR and monetary reward condition increased the overall level of performance but did not remove the decrement. This combined condition was found to be superior to KR alone, which demonstrated the motivational effectiveness of monetary reward in this case. Performance improvement due to the combined condition did not carry over into a no - KR condition. The KR was signalled by a lamp and consisted of three categories, "superior", "adequate" and "poor", this was with respect to response time unfortunately "superior" consisted of values of the 5% ile or lower and (presumably from the range indicated) "poor" indicated values greater than the 50% ile. Missed signals were also indicated. KR alone was found not to improve performance or reduce performance decrement with time. Montague and Webber point out that this last finding is at variance with the work of Adams and Humes (1963) who used quantitative KR measures.

Johnson and Payne (1966) investigated the effect of frequency of KR on a vigilance task and found KR did not affect performance decrement with time, but found that frequency of presentation of KR did affect significantly overall performance on task. S performed in <u>total</u> one hour in the test situation.

Bilodeau and Ryan (1960) disagreed, (in the light of earlier work by Bilodeau and Bilodeau (1958)) with Greenspoon and Foreman (1956) on the findings of the latter rather than their interpretation. Greenspoon and Foreman found a significant effect in a line drawing learning task, to be produced by delaying KR, which consisted of

"long", "short" or "right" Bilodeau and Ryan repeated the experiment and found no difference attributable to delay of KR. They considered that the "maintain" condition of Greenspoon et al introduced a significant physical fatigue, (essentially S had to maintain an unsupported arm for half an hour) which interfered with the task. In spite of this finding and the earlier findings of Greenspoon in conjunction with Saltzman and Kanfer (1955) this "evidence" is widely quoted, often without qualification, in the literature.

Landsman and Turkewitz (1962) found in a "cognitive task", (learning certain random numbers) that a group whose KR was delayed six seconds required significantly more training to reach an arbitrary standard than did a group immediately given their KR, however two four digit numbers were displayed at a time and the report does not disclose the method and timing of the presentation, which thus does not allow the possible effects and rehearsal to be assessed.

Church and Camp (1963) found that KR significantly reduced reaction time; the KR was presented by lamps indicating "faster" or "slower" than a criterion. This criterion was altered daily and referred to by the previous best response. S without KR were, (observationally) more bored whilst in the most extreme case of with KR, S shouted and banged the table during the trial.

McCormack and Mc. Elheran (1963) found KR in such a task prevented decrement of performance with time, provided KR was applied to certain proportion of the responses. The minimum proportion to establish this effect lay between 20% - 30% of the responses, in this case KR was "faster" or "slower" and this referred to the previous response.

In a study of the judgement of weights, Larimer and White (1964) found that KR increased accuracy of judgement and a monetary reward condition did not produce results significantly different to the KR condition. The reward was dispensed by a machine and thus gave exactly the same KR to this group, as did the lamp to the KR group.

Bergum and Lehr (1964) showed that the initial performance in a vigilance situation was improved by a monetary reward, but this initial improvement deteriated rapidly to the no reward level. No KR was given in either case.

Rabson showed that addition of a monetary reward could impair performance in a task.

Crawley (1926) is reported in Woodworth and Schlosberg (1954) to have extended performance by use of KR. In a heavy physical task the responses were recorded on a kymograph and the S was encouraged to work to exhaustion. When the experiment was repeated with the previous best effort indicated on the record, (which was made visible to S), four S were able to increase the number of cycles by an average of 13%.

Gagné and Fleishman (1959) state categorically that "knowledge of progress functions as an incentive for the performance of previously learned skills".

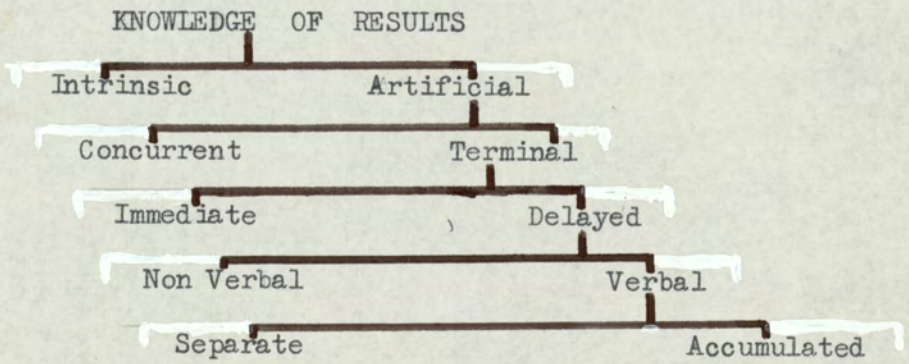
Lavery (1962) investigated the effect of KR on both acquisition and retention of skill in simple motor tasks. A distinction is made between immediate KR for each response and KR given at the end of each daily trial. Performance was studied over a ten day period. The evidence supported the hypothesis that concurrent KR favours acquisition but hinders retention of skills. The explanation offered is that the augmented KR, (immediate single response KR), causes S to attend to KR

to exclusion of cues which are intrinsic to the task. This explanation was originated by Annett and Kay (1956 & 1957).

Examination of two figures from this work, each a graphical representation of performance with successive trials (% correct v. days) reveals a most interesting phenomina. In each case after six days all KR was stopped and each figure shows that the performance of two groups, (KR for each response) and (KR for each response and KR of trial performance) fell. But in each case groups given KR of trial performance only, showed no decrement - indeed performance appeared to improve slightly.

Suddon and Lavery (1962) also found on increase in performance during no KR trials following KR trials, however this improvement was not sufficient to remove the decrement which occured as a result of the removal of KR. This was found only for groups which received KR following a 5 trial delay. S from trials with immediate KR after each response failed to display this effect, their initial performance in no KR trials was inferior and deteriated throughout these trials.

Holding (1965) has categorised KR systematically and his outline is reporoduced here:



Examination of such a scheme reveals it to be largely descriptive of the means of presenting KR and hypothesised mechanisms are avoided, this then appears to be only a first step, (however a useful one) in the description of KR.

Gibbs and Brown (1956) report large increases in production output on a monotonous repetitive task, designed to represent the industrial situation. They conclude that up to 25% increase in output can be obtained by the introduction of mechanically presented KR. The experimental design is unfortunate in view of the suggested results and is discussed fully later, as it should have a direct relevance to the present work.

However, Chapanis (1963) points out that the work of Gibbs and Brown, despite its immense consequences to industry, which are outlined in much detail in the original paper, have not been duplicated or tested. Whilst this work will be related in detail to the present investigation later, Chapanis' findings were not compatible on three counts to those of Gibbs and Brown:

i) No improved output occurred with KR

ii) A learning effect showed over the period

iii) There were significant performance changes over the trial period

IV. SELECTION OF EXPERIMENTAL SITUATION

IV.1. Selection of Experimental Job.

There are two working situations of interest, with respect to K.R. to the industrially based ergonomist. Although they are on a continuum they can readily be distinguished at the extremes of the range and these extremes may be regarded as qualitatively different for the purpose of this investigation.

IV.1.1. Firstly there is the process control job which may be recognised by having some or all of the following characteristics:

a) The process is a continuous one and is controlled by a series of operators who operate in shifts. This leads to the recognition of the importance of the change-over or adaption period since the operator must enter into an on-line system. The operator must have the means of rapidly assessing the state of the process and of the control system since, owing to system lags, historical control action may affect or be affecting, future process parameters.

b) K.R. of the effects of a particular control action is not readily available from the system because of interactions with other parts of the system.

c) Control actions are often not the major variables in process performance; material, energy or equipment variations exert large variable components to performance.

d) K.R. as exists may be expressed in terms of a team's performance, which effectively removes the learning situation from individual operators.

e) K.R. may be pooled over time and consequently cannot be related to individual control actions.

f) K.R. may be delayed which reduces its value to the operator, (section II), in a similar manner to IV.1.c.

g) The ratio of control action time : elapsed time is low.

h) Detection or prediction and speed of correction of system errors is an important part of operator performance.

i) For many of the reasons given above, "incentive" payments are often fixed or related to easily measured gross system parameters.

A description of such a job, together with a K.R. system which overcomes many of the problems enumerated is contained in VI.2. Problems of Industrial Field Work.

IV.1.2. At the other end of the continuum is the light sedentary hand work which has some or all of the following properties.

a) Short cycle time and repetitive operations.

b) Involves special purpose sensory motor skills which have developed at the end of training or in spite of training.

c) Often regarded as monotonous or boring.

d) Usually the job is under a direct financial "incentive" scheme which is applied to individual performances.

e) K.R. can be gained by operators from consideration of work completed bins or work to start bins.

f) Often regarded as closely supervised.

g) Standards of performance based on historical achievements.

A job in this category was used as the experimental job.

IV.1.3. A survey of the jobs of over 12,000 employees was carried out and a selection made with the following criteria:

a) Repetitive

b) Light physical effort required

c) Short individual cycles

d) Individual bonus scheme without gearing (VI).

e) Self paced.

f) No perceptual demands of the sort required to make critical subjective estimates of quality.

g) Individual disposal of completed work.

The list was reduced to two by the extra conditions:

h) Geographic position for ease of supervision.

i) Small group size for data manipulation.

j) Existing suitable measurement scheme (IV.2).

One job is described under and the remaining job "frame-cutting" is being investigated as an extension of the research described here.

IV.1.4. The examination and packing of fibreglass battery separators.

A battery separator consists of a sheet of glass fibres held in a resin matrix which is used in the construction of electrical storage cells. In thickness these separators range from 0.010" to 0.070" and the remaining dimensions are illustrated in section VII.

In detail the task consists of:

i) Collect a box of loose separators.

ii) Select a handful and 'knock-up' on the work bench to align lengths and breadth in the same orientation.

iii) Count out into 25s, 50s, or 100s examining for holes or lumps of glass on the surfaces.

iv) Knock up and examine the pack for faulty edges.

v) Tape the pack with a paper strip

or vi) Wrap in brown paper.

vii) Put into carton.

It is, however, possible for the operator to be called upon to carry out only one operation, e.g., examine only, tape or wrap only or even pack only.

IV.2. Type of feedback.

IV.2.1. Three commonly available performance measures were revealed during this survey which agreed with the author's experience in several industries.

a) Fault Rate.

b) Production units completed.

c) Labour time content of production

a) Fault Rate interacts in the industrial situation with rate of performance and is itself a product of an interaction. The two types of fault rate : the fault of passing a reject and the fault of rejecting a standard quality item are related and the trade-off can be influenced by such things as the emphasis of a bonus scheme or of supervision and it was felt that for these reasons fault rate should not be used as a performance measure. As a result of the interaction of fault rate with time it is necessary to remove the effect as much as possible rather than merely choose

another measure. This was done by selecting, in the case of the hand work job, a situation where the examination was fairly gross, where there was no further quality check required and where a low error rate would have little effect on the final application.

The process control task described in VI.2. avoids this interaction by having only a dichotomous arrangement - a 'faulty' operation could not exist in that system.

b) Production Units Completed.

This would be an ideal basis on which to derive K.R. provided:

i) The product units were identical for the whole of experiment, otherwise the number units would not have the property of additivity.

ii) The operations demanded by each unit were identical.

iii) The operations required were short to enable the K.R. to be used in short periods with significance; thus any job such as radio receiver wiring where a very few units are completed per day would be unsuitable.

c) Labour Time Content of Production.

Directly measured estimates, (utilising mean and

standard deviation) of the time to perform the task were discarded for two reasons:

i) It would have proved impossible to obtain a reasonable sample size to cover the range of packs, sizes, and thicknesses. The histogram of the product mix variation, in terms of time allowed, which is displayed in section VII reveals that in an eight week period many products appeared rarely and some not at all.

ii) Throughout the experiment attempts were consistently made to alter the situation as little as possible to minimise any effects which might be confused with the main treatment effects. The appearance of several men making direct observations with stop clocks over an extended period did not seem to accord with these objectives.

Finally a scale of 'ergonomic work units' was arrived at based upon a particular system of synthetic predetermined motion times, M.T.M., (the Methods Time Measurement). Some of the limitations of such a system are outlined in IV.3. but it was considered that in a comparative situation such as this, the particular scale developed was suitable.

IV.2.2. Predetermined Motion Times.

The particular system of predetermined motion time used was Methods Time Measurement (M.T.M.) which is defined as

" a procedure which analyses any manual operation or method into the basic motions required to perform it and assigns to each motion a pre-determined time standard which is determined by the nature of the motion and the conditions under which it is made. " (Maynard 1956).

There are many objections to the blanket useage of these data which are ignored by the work of Maynard, Stegemerton and Schwab who recommend its use in an absolute measurement sense. However, many of the criticisms outlined below may be invalidated by a suitable experimental design which results in a comparative situation; a technique utilised in this investigation.

a) Even in the application of M.T.M. data there is considerable emphasis on subjective assessment. For example the 'Disengage' element must be subjectively categorised into "Loose", "Close" or "Tight". This assessment is not without importance as can be seen from the appropriate values assigned to the respective categories 5.7, 11.8, 34.7 (all x 10^{-5} hours).

b) Work of Stetson & McDill, Woodworth and others reported in Stevens S.S. (1951) suggests that skilled movements in continuous tasks are not made

under continuous visual control, but like elements in discreet corrective movements are triggered off in units. This is relevant to M.T.M. data since the scale of the data is the same as the scale of these indivisible units and thus some of the M.T.M. elemental divisions are probably arbitrary and hypothetical.

c) Eye fixation time is allowed at .2628 secs. in M.T.M. data whereas average eye fixation time is probably nearer 0.4 - 1.1 seconds, (James, Mitton & Fitz). This no doubt arises from the collection of data using 16 frames per second cine film and the difficulty of tracing eye movements by this technique, together with the comparatively coarse timing scale available.

d) The effect of material and equipment on M.T.M. cannot easily be accommodated. For example the difference in 'knocking up' 0.010" thick and 0.070" thick separators, must be interpreted as having the same labour content.

e) There was a very large inter-reading variation found in the compilation of the M.T.M. data which appears to have been removed by using a "by eye" best fitting straight line technique, (Barnes, R.N.). This technique was investigated by Spencer (1961) and found to become less accurate with increase in range of variation. (Barnes, R.N.).

f) The derivation of distances moved, resulted from interpretation of cine film, rather than by direct measurement in the work situation : this could lead to errors of at least 1" and possibly considerably more.

g) A characteristic of high speed repetitive jobs is that in the long term, training effects continue such as those found by Murrell and others. This may directly alter the M.T.M. description of the task with a consequent alteration in the time allowed.

For example using M.T.M. elemental descriptions:

At end of training:

1.	6" reach to a single object whose position may vary	R6B = 8.6
2.	Pick up easily grasped object	G1A = 2.0
3.	Move 10" to approximate location	M10B = 12.2
		22.8

after long practice this could become:

1.	Moving hand 6" to single object	R6BM = 5.7
2.	Hook grasp	G5 = 0.0
3.	Moving hand 10" to approximate location	M10BM = 8.6
		14.3

(all units x 10^{-5} hours).

h) The assumption that elements are independent and are additive has been shown to be false : preceding and successive elements exert an influence as was

shown independently by K.C. White (1950) and Raju (1959).

j) A comparison of various predetermined motion time systems, (Nadler, G. 1955) showed little agreement between the different systems for the same elements. In addition the variation was not consistent, which indicates that the differences cannot be explained in terms of work rating levels.

There are other grounds for doubting the absolute validity of such systems of data, e.g., age of populations, sex differences etc., which are known to exert an effect on movement times and are reported throughout the classical literature. However, following the experimental design these problems were considered to have been avoided (V).

IV.2.3. Derivation of actual scale used in K.R.

The scale of "ergonomic units" was derived by analysis of the summary sheets of the M.T.M. application which were obtained from the respective time study department. The published "Final Work Values" were not used since they could contain notional additions for bonus payment reasons. Such notional additions would include the so called "compensating relaxation" allowance and any "policy allowance" which might be included as a minimum "compensating relaxation" allowance level. There are no grounds for the inclusion of such data as they represent an attempt at describing reasons for variations in performance and an attempt to remove, or account for such variations.

Values were then derived utilising only the directly applicable elemental times and a small value added to cover an average of the incidental operations which occurred during the original study and which might reasonably be expected to be part of the job. The values, now in T.M.U. (T.M.U. = Time Measurement Unit = 1×10^{-5} hours = 0.036 secs.) were converted to seconds and a series of charts was constructed to allow these values to be readily applied in the experimental situation. The eleven charts are shown in the appendix.

IV.3. Method of Presentation of K.R.

IV.3.1. Derivation of Information.

Examination of past work sheets showed a very wide variation in individual order sizes from single bundles up to very long runs. Since the collection of new work and the disposal of cartons of bundles was 'on demand' it was clear that a continuous survey of the working section was necessary to ensure that the work completed in any period was correctly allocated to that period. That this was necessary was borne out during the investigation: on at least one occasion an operator passed completed work to a friend for inclusion on the latter's work sheet. This occurrence was not investigated, but the performance data was adjusted to accommodate the exchange.

The alternative of having the operators put aside the

work in any period until the end of that period was discarded for two reasons:

a) The experiment aimed at preserving the normal working attitudes as far as possible and at reducing the impression of a short term experiment which the operators might have gained. It was thought that both these results would have affected performance which might then have been spuriously related to the experimental conditions.

b) The piles would have formed a basis of K.R. which had not normally been available and the effectiveness of such K.R. might have been improved by the use of constant periods.

The work completed record for each subject for each period was translated into 'ergonomic units' by the use of the conversion tables mentioned earlier. This value was then converted to an hourly rate to remove variations in period length, for example some periods contained a ten minute tea break and occasionally some time from a period was spent on official business, for example discussions with chargehand. This hourly rate formed the basis of the K.R.

IV.3.2. Display of K.R.

IV.3.2a. Two systems of presentation were considered: a simple

mechanical, or electro-mechanical device and a pencil and paper method. In many situations which might be used to investigate K.R. a mechanical device would have the following advantages:

i) Remote operation by the experimenter would reduce the observer influence which might be considerable; as is illustrated in the example below which is used by Singleton, W.T., for this purpose.

Example:

The Effect of An Observer on Operator's Activity

	Observer		
	Present	Absent	Change.
Main Drive events/hour	996	749	-25%
Auxilliary Drive events/hour	359	104	-71%

It is important to note the differing effects found in main events and auxilliary events which would result in important changes in the pattern of work.

ii) Such devices can often be incorporated into the data collection system. One particular method is to photograph the display, (or a slave display), at regular intervals and obtain the data from the filmed record. This system has the advantage of equipment cost over

the direct production of the data, say on a punched paper tape compatible with the final data processing unit.

iii) It is often possible to use the production system itself to produce signals which when combined with a timing system will derive and present K.R. remotely. Such a system was designed for investigation of the process control situation and is described in VI.2.

A paper and pencil system was finally chosen as:

a) The data had to be collected by an observer (IV.3.1.).

b) As the observer had to collate and process the data it was convenient for him to record this.

c) The process produced no signals which might be used as suggested in IV.3.2.a.iii.

IV.3.2b. Two systems of display using a pencil and paper method were considered, equivalent to a digital and analogue displays.

The digital method consisted of a series of four digit numbers corresponding to performance rates in particular periods this appeared to have two advantages:

a) It was not open to the interpretation errors which an analogue system may introduce.

b) It was a mere precise measure which might have an importance in very high levels of performance.

However, the analogue or graphical method of display was chosen. When examples of both systems were compared, the daily work pattern which seems to exist in all S confuses the interpretation of trends in the digital data, this is not so pronounced in the graphical presentation. Examination of the interperiod variability in the tables of results suggests that the loss in precision in the graphical presentation is not of importance. The loss in precision can be seen in the example of the display material in the appendix.

IV.4.IV.3.Selection of Observer.

An elective choice not to use the experimenter(E) as observer was made in the light of Chapanis' criticisms outlined in III because:

a) E was currently Ergonomics Manager and was known to the operators of this section. The presence of management carrying out observations on a shop floor section for eight consecutive weeks would have been most unusual.

b) A general explanation of the investigation was

given to the operators, (E) which was not inclusive of the purpose of the experiment. It was felt to be feasible to have a Technician claim to have only the same information as the operators.

c) Most operators in this firm have experience of technical investigations.

The acceptance of the technician/observer appears to have been complete, he himself, "felt like a piece of the furniture", (sic) at the beginning of the second week.

IV.5. Pre-experimental Organisation.

The system for gaining approval for research in a production department of a firm is discussed in VI. Problems of Field Work. In this particular case the Company Executive Board had sanctioned the investigation described in VI and following the development outlined in IV.1. extended their approval to cover the Examination of and Packing of Battery Separators.

The approval of each level of the organisation was gained as indicated in VI, which is a time consuming operation. This was regarded as an investment and as no problem of acceptance arose subsequent to the initial round of talks, it appears this investment was justified.

The explanation to the operators was designed to be as

candid and truthful as possible whilst concealing the nature of the experiment. This explanation was discussed with the observer who was then coached to present it to the operatives. The essential points in this introduction were:

a) This was an investigation into variations in production for this section.

b) This information was needed for planning.

c) It would be necessary to record the section's output and he, (the observer) would be doing this.

d) The records would be confidential to the Ergonomics Section and Production Management would not have access to an individual's work output records.

e) To 'ensure' this, the observer would use a letter code for his own benefit when adding the outputs.

f) In any case the figures would not be in Time Study figures but in Ergonomic numbers.

g) The investigation was not connected with any incentive scheme in any way.

h) The investigation would last two months.

No mention was made that an individual would have access to her performance figures.

The departmental manager called a meeting on the shop

floor and announced that, following discussions with the shop steward, Mr. Smith, (the observer), was to carry out an investigation for the Ergonomics Section. The observer explained his task as outlined above.

Great care was taken throughout this initial period to suggest an indifference on the observer's part towards individual performances. His job was to fill the records in as instructed and to obtain section production figures "for Ergonomics". This was necessary as the observer's work place was positioned to enable a complete and continuous watch to be kept on the whole of the section; thus any hint of management involvement would have transformed the observer into some sort of over-looker, a metamorphosis which might be expected to alter the performance of the section.

For similar reasons E made no comment on any particularly high or low performances found during the experiment.

V EXPERIMENTAL DESIGN

V.I Subjects

V.I.I Sample size

The number of S used for this investigation was limited to preserve the integrity of the data. As few modifications to the work situation as possible were made throughout, consequently the experimental situation did not facilitate data collection. In particular it was necessary for E to be able to see the work output of the whole section for the length of any trial, the reasons for this are outlined earlier. It was considered originally that the most suitable size lay between 5 and 10, in fact the sample investigated was seven. It was also thought desirable for the sample to be geographically complete; the alternative of sampling from a larger population might introduce spurious effects due to intergroup comparison.

V.I.2 Length of service

The length of service of the S in this department was

S_1	5.5	years
S_2	4.4	years
S_3	5.5	years
S_4	0.1	years
S_5	0.4	years
S_6	0.1	years
S_7	26.6	years

All S were female.

V.2 KR Treatments

Neither of the investigations into the effects of KR in a "working" situation extended their experiments beyond a comparison of : (with KR) and(no KR). In the light of other work this extension might have produced interesting effects with possible bearing on the mechanism at work. However, in the first instance Gibbs and Brown were primarily interested in demonstrating possible effects, and Chapanis was attempting strengthening their conclusions in a more tightly controlled extension. The present investigation is an attempt to validate the effects in a true field experiment and to investigate the discrepancies between the two investigations and in addition to attempt to promulgate a hypothesis. Consequently a third condition was added the withdrawal of KR. Thus the three conditions used were

(r =)	1	no KR
(r =)	2	KR
(r =)	3	no KR

Conditions 1 and 3 were not expected to be the same and no attempt to combine the data was considered, the conditions were no KR and withdrawal of KR respectively.

V.2.I Order of Treatments

The treatments were presented to all S in the same order; that outlined above. One prediction was that KR would have a long term effect on performance and consequently it was necessary to obtain a measure of performance before the influence

of any treatment became evident and this formed the no KR condition. By definition it was necessary to introduce the withdrawal of KR following the KR condition.

V.2.2 Introduction of Treatments

As outlined in IV the whole investigation was introduced to the section. No further instructions were given at the beginning of any treatment, that is on first presenting the KR data or on the cessation of this activity. In response to direct questions at the beginning of the KR treatment E indicated that the graphs showed how production varied and that was the information "Ergonomics" wanted. At the next stage E said "He'd stopped doing the graphs now". These introductions appeared to satisfy the S.

V.3 Periods

V.3.1 Treatment periods

The length of the treatment periods in past work has been very variable, some investigations have examined only 1 hours performance per S and it was felt this might have created a non-typical situation. The present investigation covered an eight week period, which gave forty days for investigation. The treatment periods were of unequal length. Ten days were assigned to treatment 1, the purpose of which was to establish existing work patterns and levels for the S.

Chapanis had found an increase in performance with time and the KR condition was set at a twenty day period, to allow evidence of any such effect to be collected. The remaining ten day

period was assigned to the withdrawal of KR condition.

V.3.2 Trial length

A valid criticism of the extension to the field of some laboratory findings may be made on the basis of very different trial lengths. That which produces significant change over a one hour trial may produce very different effects, if any, over a full working period. It was essential in this investigation to investigate effects of KR on the actual working situation, which includes an eight hour working day. Thus the whole of each day was considered in the collection of data.

V.3.3 Length of data collection periods

The information for KR was collected over half hour periods and presented to S at the same frequency. The duration of 30 minutes was arrived at, largely from experience in industry and consideration of among other things, the desire to enable the effect of small changes to be determined for S before the continuation of the trial, to reduce the variability which would result from shorter periods so that a trend might be distinguished by S and conversely to avoid the insensitivity of the measure which would occur if long periods were used.

V.4 Layout of section

These operators did not work in isolation but in a group of work places and this might influence the motivation of individuals. The layout of this section is described in Appendix 1, which also shows the work place in detail.

V.5 Control of Experiment

For many reasons which include the relationship of the treatment conditions and the lack of similar but isolated working groups each S was subjected to each treatment and effectively was her own control. This together with the exclusive consideration of one specific job produced the comparative situation which was demanded in the discussion in IV.3.

VI PROBLEMS OF FIELD WORK

Field work imposes extra constraints upon experimental procedures which are removed from the laboratory situation. Some of these constraints, together with suggested ways of accommodating them have been illustrated in some detail in the preceding sections. A brief examination of the more important aspects is outlined under, together with an example of how serious such constraints may become.

VI.1. Aspects of Field Work

VI.1.1. Approval and Co-operation for Experiment

Approval and co-operation for experimentation must be obtained from, normally not less than, seven levels in the company structure. The reasons for the many approaches vary, but all are important if the investigation is to avoid the possibility of disruption.

a) Board Level approval is necessary where publication of field results is anticipated, as such results often include commercially valuable information. For example fault rates leading to reject rates could be used to drastically reduce the uncertainty of a competitor's assessment of profit margins and consequently allow such a competitor better to predict a response to his own marketing policy.

b) Divisional Management can be seriously concerned with internal publication of performance assessment. This is particularly important when the investigation is of a general nature, (such as this one) and when the results might have implications to other divisions. Thus an investigation which reveals that supervision of a division tacitly allows an 80% increase in tea breaks might reflect damagingly upon a division, when in fact the apparent measurement scale is an ordinal one and 80% might be the lowest of any (uninvestigated) division.

c) Works Management approval will be obtained only after the effects of the investigation on production have been assessed and found to be minimal or at least acceptable. In practice, investigations seek to identify and assess factors which reflect upon the present or future functioning of a particular plant, thus there may often be benefits from an investigation which would accrue at works management level.

d) Shop Management approval may be required if the investifation is likely to interfere with production, but even more importantly the organisation of the investigation will depend

greatly upon this level of management. The case for the investigation must be presented in detail at this stage as the responsibility for delays caused by the investigation rests at this level of management and the fullest degree of co-operation possible should be the target. Full information throughout the investigation should be provided for this level of management to allow the fullest warning in the event of any contingency arising.

e) Supervision is the normal channel of communication between the operators and management and this arrangement should be respected wherever possible. If strenuous attempts are made to do this the response from supervision is very good: often the response can be embarrassing as the supervision may try to ensure that the investigation is a "success". A consequence of this is that the information provided to supervision must be carefully controlled to reduce the probability of spurious additions to the planned experimental conditions.

f) Trades Union Organisers will normally be consulted before an investigation reaches the shop floor. Usually such an organiser is concerned primarily, if not solely, with the question of encroachment upon the operators agreed conditions.

Thus consultation may be restricted to those points which appear to be relevant to this point of view. Protection of individuals from surveillance for management purposes is always a prime consideration and assurance on this point should be planned into the experimental design at the earliest stages.

It has been observed that trades union officers appreciate information on the progress of an investigation, where this is possible; this was not felt feasible in the present investigation. In general this should be catered for and also the associated desire, which has been observed, to be seen to be taking an interest in the investigation should be accommodated. This is particularly noticeable during the taking of physiological measurements, such as cardiac rate or rectal temperature.

g) Operators should always be introduced gradually to an investigation by means of an explanation, in particular they should be given a chance to ask questions. It cannot be over emphasised that the volunteer S in the laboratory bears little resemblance to the S involved in earning his livelihood. Any situation can rapidly become threatening to S, the threat may be to be directed at earnings, discovering 'mal-practices' or individual weaknesses, and free communication

appears to be a good way of allaying and preventing such fears. The extent to which this fear may interfere with performance was well illustrated during a study by the author on, among other things, a 'resting' cardiac rate for seated, clothed operators. In a sample of some fourhundred and eighty S, a middle aged man was asked to take a seat and wait a moment. To the experimenter's consternation S ignored the anthropometric rig and seated himself in a wash-hand basin, complete with taps, which was close by. The cardiac rate of this S was 128 p.p.m.

The explanation and discussion also provide an admirable chance for the experimentor, or the observer, to display the courtesy which should be the hallmark of a field investigator. Whilst in the laboratory it may be assumed S are reasonably motivated towards the objectives of the study - this is by no means the case on the shop floor. It is for example possible that S will deliberately and consistently interfere with the experiment even to the extent of damaging equipment. Fortunately it is the author's opinion that the obstructiveness which has become legendary on the shop floor, usually arises as a result of the 'provocation' of the operator, which can usually be avoided.

VI.1.2 Direct Interference

Supervision may directly interfere with the results of an investigation, the whole pattern of supervision may change, the supervisor allocating almost all of his time to the section being studied in a conscious effort to ensure a favourable assessment of the section. Alternatively, supervision may, on rare occasions, resent the intrusion of an investigation and may attempt to organise the S in his own preconceived system. This interference must be looked for throughout an experiment, as excuses such as "I only wanted to help" or "its only the end of the investigation" are poor consolation for a wrecked experimental design.

Care must also be taken to prevent service operators affecting the findings. For example during an investigation into a small packing operation, large differences in performance could be traced to two service operators, one who carefully arranged piles of work and one who merely off-loaded the work to a pile.

Similar care must be taken to remove the effects of preceding and succeeding operators in the production process, for example the performance in a packing section was found to vary directly with the quality level of the product - the quality was the result of the preceding examination operation.

Finally the demands of the production facility may cause direct, unavoidable interference with an investigation; S may be required to be withdrawn

totally from the investigation, for production requirements.

VI.1.3 Indirect interference

Usually in the industrial situation S have established performance patterns and novelty becomes a more significant variable. A resistance to a new method may be difficult to overcome, the mere fact of an investigation being carried out may cause performance change to occur, temporary changes may be accommodated for a short time by S. Consultation and explanations, examination of past records for the immediately preceding period and treatments concerning the entire working period respectively, are the suggested means of overcoming such effects in a field investigation.

In investigations into performance, the bonus scheme may play an important part in altering motivation, for example some schemes are termed 'geared' which means that beyond a certain level of performance the reward is either proportionally larger or small than below that level. Similarly the bonus scheme may set false objectives, objectives neither of the management nor of the investigator. An example, which was included in an investigation by the author, rewarded increased output without limit, but imposed a maximum to the reduction in the reward due to faulty work. This resulted in one S producing faulty work which amounted to between five and ten times his wages and earning a high bonus. Thus all bonus schemes should be closely examined before an experimental situation is chosen.

VI.1.4 Extra Investigational Interference

It must be recognised that major policies of finance, marketing or production are unlikely to be modified or delayed because of a field investigation. During the present investigation a policy change resulted in many weeks work being abandoned; this is reported briefly in Section VI.2.

VI.1.5 Lack of Control during the Organisation of the Investigation

During the organisation of a field investigation, the problems normally encountered in the laboratory may become exacerbated. In particular the lead time on modifications to equipment and installation of equipment may become excessively long; service departments invariably indicating production requirements as the cause of delay. A contributary factor may be trades union demarcations - installation of simple equipment requiring the attentions of several tradesmen, each with his own work schedules and priorities. Thus it is preferable for any equipment to be built and tested as far as possible, off the production line.

A lack of control over working hours is also evident, there is strong resistance to changing lunch breaks and tea breaks. Any such changes should be agreed with operators, an authoritarian approach may well affect the results of subsequent trials. In some circumstances, such as the present investigation, such negotiations are not possible and the work arrangement had to be accepted as it was.

VI.1.6 Need for Control

A danger of close co-operation with management which is often a possibility, arises from managements lack of interest in control. Management exercises pragmatical decision making during its normal activity and this may carry over to the experimental situation, as the effects of training under treatments, the mechanisms of a process, and null solutions have a tendency to be disregarded. This results in non-generality of solutions, which results in separate trials for subsequent modifications with little or no priori reasoning for such trials. In a consideration of lighting for an inspection task, lasting several years, each 'new' development; higher intensity, point sources, line sources, monochromatic sources were all tested and yet at this stage a new high intensity monochromatic point source would have to be tested against a high intensity monochromatic line source in a field trial, because of the pragmatic nature of earlier trials.

This tendency should be guarded against and information regarding human variability should be included in discussions with management.

VI.1.7 Collection of Data

It has been shown that the design of an experimental situation in the field often amounts to the selection of the most suitable working section. This means that the sources and nature of the data to be collected have not

been designed for the investigators purposes. This was certainly the case in the present investigation, where the observer was required to carry out a demanding, repetitious and boring task which could have been avoided if the investigation had allowed the data collection system to be designed for the specific purpose.

All equipment used should be made robust, as the environmental conditions and the chances of accidental damage are more severe in the field. Reliability is also vital, especially in a situation when premature revelation of the full terms of an investigation might ruin the data from quite an elaborate experimental design. Once a field situation is exposed it is frequently difficult to repeat an investigation in the same factory, since uncontrolled variables are rapidly introduced by operator interactions which serves to emphasise the need for reliability and also for very detailed prior planning, often without the benefit of an exploratory preliminary investigation.

VI.2 An Investigation of the Effects of KR on a Process Operators Performance

The investigation outlined was abandoned after more than a years preliminary organisation owing to a change in Production Policy at Board Level.

VI.2.1 Description of Working Situation

The process for the formation of glass fibres is a continuous one. Glass is melted in large tanks, or furnaces, and is allowed to leave through platinum plates with many hundreds of perfor-ations, set in the bottom of the tank. The molten glass leaves the tank under the force of gravity but the emergent, thick and irregular fibres are drawn onto a winding drum, which as it revolves at high speed attenuates the fibre in the molten phase. During this attentuation the glass solidifies, is cooled by a water spray and is coated with a water based emulsion which has a significance to its future use.

The resultant fibre is wound onto a revolving drum at high speed on a lower floor; the reel or cake of wound fibre is the end product of this process.

Two operators are employed to control several units of this process. A bushing (the unit containing the platinum plate) operator is responsible for restoring the process should a break in the fibre occur. If a single fibre breaks, the resultant small glob of glass will damage adjacent fibres and the break will rapidly spread across the whole of the bushing. The speed with which a bushing operator can repair a break and restore the fibre run condition is very critical. If left, the bushing over-heats and becomes more prone to other breaks and, as the glass leaves the tank whether it is formed into fibre or not, a considerable financial

penalty is attached to long repair times. This operator is located on a platform, level with the bushings.

On the floor below a winder operator is responsible for winding the filament onto paper cores and replacing the full ones as appropriate. As it is essential to maintain attenuation to prevent a break occurring, when a core is full, this operator places the filament between two rollers (termed "pull-rolls") which revolve and draw down the fibre to waste while he off loads the full core and replaces it.

VI.2.2 Performance measures

The speed of replacement affects the overall performance of the process measured in terms of pounds of good filament produced. The KR consisted of number of breaks and repairs, (or cores replaced).

The two part measurement was necessary since the number of breaks was uncontrollable and the time to repair isolated breaks was considered to be different to the time per break when several breaks occurred more or less simultaneously.

In both cases the time to perform the task (10 - 90 seconds normally) is important to enable an operator to assess his performance, or indeed for management to assess an operator's performance. This information was not available and the variability of the task would prohibit a subjective assessment being made. An

investigation was designed to study the nature of any effects produced by provision of such data.

VI.2.3 Presentation of KR

It was proposed that the display of KR would be mechanical and automatic to reduce variations due to presentation. It was not possible to use a carefully trained observer in this situation, since the 4 set : 3 shift system of working would have demanded the training and maintenance of a minimum of four full-time observers.

VI.2.4 Pre-experimental Organisation

The co-operation necessary was obtained in a similar manner to that outlined in VI.1, a process which took over five months. The performance of the two operators is of course linked and interference is common. That is, after repairing a bushing, the bushing operator may have to wait a considerable time before the winding operator can complete a change and attend to the particular bushing, thus releasing the bushing operator to attend to other units. It was necessary to devise a method of separating these two tasks.

After development work, which extended in all to some eight months, the feasibility of high level pull rolls was demonstrated. Namely a modification to the siting, operation and control of the pull rolls was

developed which enabled the bushing operator to open, insert the repaired filament and close the pull rolls without reference to the winding operator. The same facility, necessary for core-changing, was preserved for the winding operator.

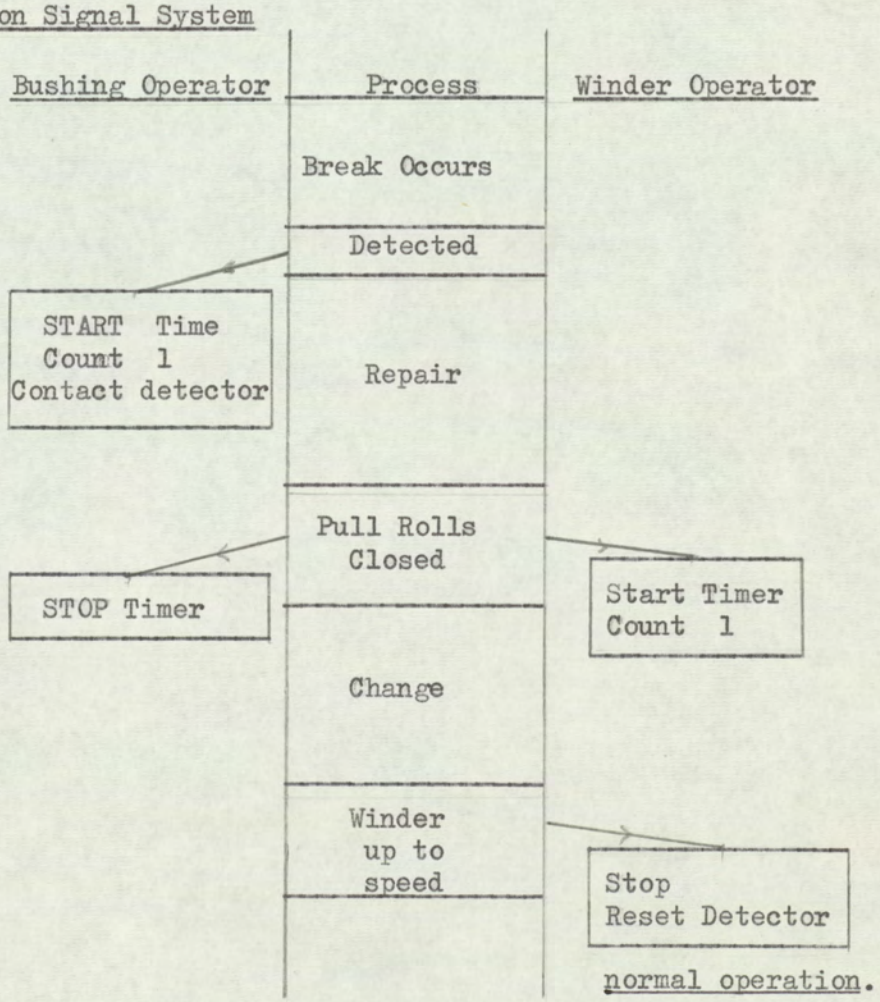
VI.2.5 Data Collection

If the process of collecting and displaying the KR was to be automatic, the process itself would have to produce signals to the mechanism. This involved the development of a filament break detector which took some six months. Ultrasonics, proximity detectors, thermocouples, and a fluidics sensor, were obtained and put to trial. The only possible receptor was a fluidic unit which detected air flow, (resulting from entrainment by the moving fibres) by the interference of such flows on a laminar-flow jet of air. Thus the presence of moving filament could be detected and an electrical signal obtained. The other signals necessary to measure the performances necessary were much easier to obtain. However, it was considered very important to ensure that the equipment could not be tampered with to produce results favourable to S. KR and performance measurement were in terms of number of breaks repaired (or cores changed) and average time for each repair. Thus it can be seen that if the design of the automatic KR equipment is not designed carefully, it is possible for S to falsify his performance. For example, if half way through a repair S blew on the

detector this would register another 'break' and halve the time spent on repairing these two breaks; conversely if the correctly running filament was withdrawn momentarily from the detectors a false break with a very fast 'repair' time would be registered.

A system which overcomes these problems is described in the figure. Mal-practices are prevented as any non-sequential activity breaks the filament or creates an extra load for the other operator, from which he cannot benefit.

Data Collection Signal System



A normal core change utilises the lower part of this system.

a) If the good filament is momentarily removed from the detector the timer may not be started by replacing the filament but only by closing the pull rolls. The speed of winding is much greater than the pull roll speed, thus the filament is broken and the core must be replaced, in addition time begins to be counted against the winder operator.

b) If the pull rolls are closed by bushing operator before a repair is completed then time is counted against winder operator.

c) The winder cannot signal the completion of a change as this signal is taken from a contact at the end of the winder acceleration stage and not from the start control itself.

The system was constructed and demonstrated in June 1967, in May 1968 the possibility of extending the system for the number of bushings which are one operator's responsibility, was ruled out by a Board Decision affecting the whole of the Division in which the investigation was sited.

VII RESULTS AND DATA ANALYSIS

The results, which comprise the output of each operator summed for each half hour period are contained in Appendix 3. The raw data has been deposited with the Department of Applied Psychology. The results were analysed in a 7 x 16 x 3 analysis of variance and this analysis is shown below in detail. The modifications for unbalanced cell contents and the method of estimating the contents of cells for which no observations were possible is also shown below.

VII.1. Analysis of Variance

The experimental data was analysed as a p x q x r, (7x16x3) factorial experiment where the factors were:

factor A 7 subjects

factor B 16 working periods

factor C 3 Kr conditions i) No KR

ii) KR for each 30 minute working period

iii) Withdrawal of KR

The general form and the notation used in this analysis is illustrated in figure 1, (Winer, 1962).

	c_1			c_2 ..... c_r					
	b_1	b_2	b_3....b_q	b_1	b_2	b_3.....b_q	b_1	b_2	b_3.....
a_1									
a_2									
a_3									
⋮									
a_p									

figure 1

Thus the typical cell entry is designated abc_{ijk}, that is i indicates the level of factor A, j the level of factor B and k the level of factor C.

Hence the n observations of cell abc_{ijk} are:

$$(X_{ijk1}\ X_{ijk2} \cdots\cdots\cdots X_{ijkm} \cdots\cdots X_{ijkn})$$

and ABC_{ijk} represents the sum of the n observations in cell abc_{ijk}

These sims may be tabulated as outlined in figure 1, this table is then termed the ABC Summary Table.

The sums resulting from the additions of the values from each of the columns are: $BC_{jk} = \sum_i ABC_{ijk} = \sum_i \sum_m X_{ijkm}$

thus BC_{jk} is the sum of all observations under treatment bc_{jk}, the levels of factor A being disregarded. The BC summary table is of the form:

	b_1	b_2	b_3	b_4	$b_5 \ldots\ldots\ldots\ldots b_q$	total
c_1						C_1
c_2						C_2
c_3						C_3
c_r						C_r
total	B_1	B_2	B_3	B_4	$B_5 \ldots\ldots\ldots\ldots B_q$	G

figure 2

Simmilar summary tables can be constructed for AC and AB by forming the appropriate combination of two factors and disregarding the remaining factor.

The computational symbols used in the analysis are defined in figure 3

figure 3

1) $G^2/npqr$

2) $\sum X^2_{ijkm}$

3) $(\sum A^2_i)/nqr$

4) $(\sum B^2_j)/npr$

5) $(\sum C^2_k)/npq$

6) $\sum(AB_{ij})^2/nr$

7) $\sum(AC_{ik})^2/nq$

8) $\sum(BC_{jk})^2/np$

9) $\sum(ABC_{ijk})^2/n$

The sums of squares may now be calculated using these definitions:

$$SS_a = nqr\sum(\bar{A}_i - \bar{G})^2 = (3) - (1)$$

$$SS_b = npr\sum(\bar{B}_j - \bar{G})^2 = (4) - (1)$$

$$SS_c = npq\sum(\bar{C}_k - \bar{G})^2 = (5) - (1)$$

$$SS_{ab} = nr\sum(\overline{AB}_{ij} - \bar{A}_i - \bar{B}_j + \bar{G})^2 = (6) - (3) - (4) + (1)$$

$$SS_{ac} = nq\sum(\overline{AC}_{ik} - \bar{A}_i - \bar{C}_k + \bar{G})^2 = (7) - (3) - (5) + (1)$$

$$SS_{bc} = np\sum(\overline{BC}_{jk} - \overline{B}_j - \overline{C}_k + \overline{G})^2 = (8) - (4) - (5) + (1)$$

$$SS_{abc} = n\sum(\overline{ABC}_{ijk} - \overline{AB}_{ij} - \overline{AC}_{ik} - \overline{BC}_{jk} + \overline{A}_i + \overline{B}_j + \overline{C}_k - \overline{G})^2$$

$$= (9) - (6) - (7) - (8) + (3) + (4) + (5) - (1)$$

$$SS_{w.cell} = \sum(X_{ijkm} - \overline{ABC}_{ijk})^2 = (2) - (9)$$

$$SS_{tot} = \sum(X_{ijkm} - \overline{G})^2 = (2) - (1)$$

However in the present experiment it was not possible to collect an equal number of observations per cell, the procedure outlined above was modified to account for these unequal sample sizes.

It was believed that the loss of observations from these cells was essentially random and an unweighted means modification was utilised. The actual number of observations in each cell is indicated in table 3.2 in the appendix.

From this table the harmonic mean of the numbers of the observations per cell was calculated:

$$\bar{n}_h = \frac{p.q.r}{(1/n_{111}) + (1/n_{112}) + (1/n_{113}) + \ldots\ldots (1/n_{pqr})}$$

$$= \frac{pqr}{\sum\sum\sum(1/n_{ijk})}$$

The pooled with-in cell variation is modified to

$$SS_{w.cell} = \sum\sum\sum SS_{ijk}$$

The summary tables, ABC, BC, AB, and AC are constructed using the mean of the respective n_{ijk} observations actually made within each cell.

Each of these values of cell means was now considered as a single observation and the tables over, now corespond to the general case already outlined with n = 1.

It was however necessary to modify the computational definitions:

1) G^2/pqr
2) $(\sum \bar{X}^2)_{ijk}$
3) $(\sum A_i^2)/qr$
4) $(\sum B_j^2)/pr$
5) $(\sum C_k^2)/pq$
6) $\sum(AB_{ij})/r$
7) $\sum(AC_{ik})/q$
8) $\sum(BC_{jk})/p$
9) $\sum(ABC_{ijk})$

The sum of squares were then calculated:

$SS_a = ((3) - (1))\bar{n}_h$

$SS_b = ((4) - (1))\bar{n}_h$

$SS_c = ((5) - (1))\bar{n}_h$

$SS_{ac} = ((7) - (3) - (5) + (1))\bar{n}_h$

$SS_{bc} = ((8) - (4) - (5) + (1))\bar{n}_h$

$SS_{ab} = ((6) - (3) - (4) + (1))\bar{n}_h$

$SS_{w.cell}$ was calculated as shown earlier

ABC SUMMARY TABLE r = 1

p \ q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Σ
1	5129	5140	4308	4130	6292	7937	6815	5643	5924	5222	3470	6590	5249	3873	5646	3588	84956
2	5537	6789	7430	5393	5483	8838	6575	5307	6547	6338	6510	5677	5536	4031	6462	3631	96084
3	2520	6365	3285	5072	3899	8376	6842	6420	5127	6709	4878	7555	5163	3799	7106	3808	86924
4	5076	6060	4999	4196	5253	6469	7364	5149	5879	6352	4609	5619	6212	3987	4846	3034	85104
5	5826	4549	2189	5345	4576	5759	8380	5820	5011	5337	3317	6065	4983	2172	5527	1951	76807
6	4193	4715	3237	2901	2214	4543	3590	3077	3894	3017	3971	5400	3335	2410	5232	3848	60577
7	7523	5934	5131	5290	3410	5541	6527	6157	6173	3717	6542	3899	5772	5140	6537	5960	89258
Σ	35804	39557	30579	32327	31127	47463	46093	37573	38555	37692	33297	40805	36250	25412	41356	25820	579710

ABC SUMMARY TABLE r = 2

q / p	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Σ
1	6785	6216	5148	5015	3778	6077	6419	4896	6033	6025	4210	6360	6167	6261	7403	3799	90592
2	6838	6793	7115	5462	3758	7667	7267	5831	6996	7288	7267	6868	7102	4239	8186	4737	10241
3	2829	7659	4949	6025	2178	9540	4900	9060	7287	8540	3683	7870	7481	4168	9495	4668	100332
4	7162	6687	6345	5425	4167	8039	7748	7351	7883	8373	6286	5440	7238	4698	8992	4691	106525
5	6126	5021	5261	5941	3113	6317	6241	5045	5916	5793	3576	5518	5523	3949	8013	3166	84519
6	5560	5403	4471	3969	2832	5912	5462	4789	4997	5396	4599	3331	4756	2500	4970	3447	72394
7	7221	7646	7046	6163	3763	8255	6883	7625	7276	7968	6991	6900	6843	3841	7282	4420	106123
Σ	42521	45425	40335	38000	23589	51807	44920	44597	46388	49383	36612	42287	45110	29656	53341	28928	662899

ABC SUMMARY TABLE r = 3

p \ q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Σ
1	6270	7689	4749	5930	4419	7130	5116	7078	6200	8603	4877	6766	6557	4650	6666	6086	74148
2	7966	8816	7540	7277	4047	10316	7800	6357	7636	7615	6993	6720	8159	4768	8270	4471	114751
3	2170	7587	3861	9205	3255	9300	3822	8656	6300	8830	1898	11200	7355	4515	13726	6176	107856
4	7068	7875	4329	6875	4149	9040	7214	9033	8730	9272	6021	6789	8503	4101	9567	4813	113379
5	5800	7498	5508	6845	3883	8608	6773	7315	6937	8109	5976	7116	7082	4141	9557	5202	106350
6	4267	5873	4056	4441	3175	6218	7314	6098	5428	6770	7174	4151	4896	3202	8192	3770	85025
7	7530	7343	7756	6430	4267	9649	9358	6673	7328	7568	8882	7074	7023	3613	10924	5897	117315
Σ	41071	52681	37799	47003	27195	60261	47397	51210	48559	56767	41821	49816	49575	28990	66902	36415	743462

p \ q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Σ
1	18184	19045	14205	15075	14489	21144	18350	17617	18157	19850	12557	19716	17973	14784	19715	13474	274,334
2	20341	22398	22085	18132	13288	26821	21642	17495	21179	21241	20770	19265	20797	13038	21918	12839	313,249
3	7519	21611	12095	20302	9332	27216	15564	24136	18714	24079	10459	26625	19999	12482	30327	14652	295,112
4	19306	20622	15673	16496	13569	23548	22326	21533	22492	23997	16916	17848	21953	12786	23405	12538	305,008
5	17752	17068	12958	18131	11572	20684	21394	18180	17864	19239	12869	18699	17588	10262	23097	10319	267,676
6	14020	15991	11764	11311	8221	16673	16366	13964	14319	16183	15744	12882	12987	8112	18394	11065	217,996
7	22274	20928	19933	17883	11440	23445	22768	20455	20777	19253	22415	17873	19638	12594	24743	16277	312,696
Σ	119396	137663	108713	117330	81911	159531	138410	133380	133502	143842	111730	132908	130935	84058	161599	91163	1986,071

AC SUMMARY TABLE

p \ r	1	2	3	Σ
1	85956	90592	98786	274,334
2	96084	102414	114751	313,249
3	86924	100332	107856	295,112
4	85104	106525	113379	305,008
5	76807	84159	106350	267,676
6	60577	72394	85025	217,996
7	89258	106123	117315	312,696
Σ	579710	662899	743462	1,986,071

BC SUMMARY TABLE

r \ q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Σ
1	35804	39557	30579	32327	31127	47463	46093	37573	38555	37692	33297	40805	36250	25412	41356	25820	579,710
2	42521	45425	40335	38000	23589	51807	44920	44597	46388	49383	36612	42287	45110	29656	53341	28928	662,899
3	41071	52681	37799	47003	27195	60261	47397	51210	48559	56767	41821	49816	49575	28990	66902	36415	743,462
	119396	137663	108713	117330	81911	159531	138410	133380	133502	143842	111730	132908	130935	84058	161599	91163	1986,071

FREQUENCIES SUMMARY TABLE

Period		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
S	r																
1	1	5	5	6	6	6	5	5	5	6	6	5	5	5	4	4	4
	2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5
	3	2	2	2	2	1	1	1	1	2	2	2	2	2	1	1	1
2	1	8	8	8	8	7	8	8	8	8	8	8	8	8	7	7	7
	2	13	13	13	13	13	13	13	13	13	13	14	14	14	14	14	13
	3	9	9	9	9	8	8	8	8	7	7	7	8	8	8	8	8
3	1	2	3	3	3	3	4	4	4	4	4	3	3	3	2	2	2
	2	3	5	5	5	5	5	5	5	6	6	7	7	7	7	6	6
	3	1	2	2	2	1	1	1	1	1	1	1	2	2	2	2	2
4	1	7	7	7	7	7	7	7	7	7	7	7	7	7	6	6	6
	2	16	16	15	15	15	15	15	16	15	15	16	16	16	15	15	14
	3	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
5	1	3	3	2	2	2	2	3	3	3	3	3	3	3	3	3	3
	2	8	8	8	8	8	8	8	8	7	7	7	7	6	6	6	6
	3	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5
	2	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
	3	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
7	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	2	5	5	5	6	6	6	6	5	5	5	5	5	6	6	6	6
	3	5	5	5	5	5	5	4	4	4	4	5	5	4	5	5	5

In the ABC summary table certain cells are empty, that is in certain cases in the withdrawal of KR condition no observations were possible. In order to complete the analysis as outlined above it was necessary to make estimates of the values of these cells. This was done and the estimates can be identified in the ABC summary table by an underline thus: 1234.

Information from adjacent rows and columns was used to estimate these values by this arrangement:

$$\underline{\overline{ABC}}'_{ijk} = \bar{A}' + \bar{B}' + \bar{C}' - 2\bar{G}'$$

where $\bar{A}'_i$ is the mean of the observations made under level a_i and similar means can be calculated for the other conditions.

This estimate does not account for any trend in the rows or the columns from which the estimate was derived, this should result in a conservative conclusion and an increase in the probability of a type II error.

NUMERICAL DATA

1) $= G^2/pqr$ = 11,739,517,907

2) $= \sum x^2_{ijkm}$ = 862,407,058,664

3) $= (\sum A_i^2)/qr$ = 11,881,901,624

4) $= \sum B_j^2/pr$ = 12,152,121,015

5) $= \sum C_k^2/pq$ = 11,859,236,730

6) $= \sum AB_{ij}^{\ 2}/r$ = 12,341,862,613

7) $= \sum AC_{ik}^{\ 2}/q$ = 12,016,039,892

8) $= \sum BC_{jk}^{\ 2}/p$ = 12,336,965,488

9) $= \sum ABC_{ijk}$ = 12,833,282,262

$$\bar{n}_h = \frac{pqr}{\sum\sum\sum(1/n_{ijk})} = 4.42$$

Substitution gave the following:

$SS_A = (3-1)\bar{n}$ = 629,336,025

$SS_B = (4-1)\bar{n}$ = 1,823,705,733

$SS_C = (5-1)\bar{n}$ = 529,157,193

$SS_{AB} = (6-3-4+1)\bar{n}$ = 209,321,840

$SS_{AC} = (7-3-5+1)\bar{n}$ = 63,733,950

$SS_{BC} = (8-4-5+1)\bar{n}$ = 287,855,376

$SS_{ABC} = (9-6-7-8+3+4+5-1)\bar{n}$ = 292,155,734

$SS_{\text{within cell}}$ = 5,296,335,403

$SS_{\text{total}} = (2-1)\bar{n}$ = 3,759,959,370,142

SUMMARY OF ANALYSIS OF VARIANCE

Source of Variation	S.S.	df.	M S	F ratio	$F_{.99}$	Sign
A	629,336,025	(p-1) = 6	104,889,337	37.29	2.80	*
B	1,823,705,733	(q-1) = 15	121,580,382	43,22	2.04	*
C	529,157,193	(r-1) = 2	264,578,596	94.07	4.61	*
AB	209,321,850	(p-1)(q-1) = 90	2,325,798	.826	1.37	
AC	63,733,950	(p-1)(r-1) = 12	5,311,162	1.89	2.18	
BC	287,855,376	(q-1)(r-1) = 30	9,595,179	3.41	1.7	*
ABC	292,155,734	(p-1)(q-1)(r-1) = 180	1,623,087	0.577	1.25	
Within Cell	5,296,335,403	=1883	2,812,711			

VII.2

The significant differences found in operators output and shown in table VII.1.iii may be clearly seen in Graph 1. The S have been ranked with respect to initial performance, purely as a means of facilitating the observation of the relationship of periods 1 - 3. (Similarly the points have been joined, not to suggest a relationship which exists between S, but to present more readily the relationships between r_1, r_2 and r_3). This result was not unexpected as the pre-experimental production data had been examined.

The period on shift was also found to be highly significant and the pattern of performance level for time on shift may be seen for individual S in Graphs 2 - 8, which is in accordance with classical work on performance patterns over a working period.

The KR condition was found to be a highly significant source of variation and this can readily be seen in Graph 1. In no case does any S contradict the general finding that KR gave superior performance to no KR and the withdrawn KR gave results superior to KR.

The only significant finding of an interaction was between period and KR. This is not recognisable from examination of Graphs 2 - 8, in fact the patterns of performance appear to be little changed by the application of KR.

The Daily Average Performance for all S combined is shown in Graph 9 and the individual Daily Average Performance Curves for S_1 - S_7 are shown in Graphs 10 - 16 respectively.

VIII DISCUSSION OF RESULTS

It is the intention to discuss the results of this investiation in relationship to a hypothesis to be offered as a general explanation of the way that KR modifies the performance of S on a wide range of tasks. The hypothesis will be used to explain all the major effects and experimental differences which were outlined in Section III.

In particular, the present work will be examined by use of this hypothesis and in relation to the previously mentioned work of Gibbs and Brown and Chapanis.

Finally, certain effects are necessarily concomitant with the hypothesis, these appear to be amenable to experimental testing and this is discussed separately in Section IX, "Proposals for the Extension of the Investigation".

VIII.1. A Hypothesised Mechanism for the Manner in which Provision of Knowledge of Results Alters Human Performance

It is suggested that KR does not provide a motivational and informational input to S as has been suggested. Instead the function of KR is purely informational. Much of the confusion and single situation explanations of the effects of KR may be explained by an analogy. If the properties of a strong acid are examined it will be found that adding such an acid to a metal may frequently give varying rates of chemical change and not

infrequently dissimilar end products. How can this be? Modern chemical theory can explain these phenomena by hypothesising a molecular or sub-molecular mechanism, in which the water of solution plays an essential part and consideration of the acid dilution offers a tenable explanation.

Similarly, it is suggested, often not KR, but a mixture of varying proportions of KR and motivating factors have been used and confusion arises when 'KR' from one experiment is equated with 'KR' from another, apples being compared with fruit.

The hypothesis proposed suggests the existence of three sequential stages to the mechanism resulting in performance changes through provision of KR.

1. Information transfer (KR)
2. A mechanism which functions by utilisation of this information
3. A choice of employing the mechanism or not, which is controlled by a motivational level.

By analogy, KR provides power, a mechanism utilises this power and the state of the system output control is determined by a motivational level. This very simple way of examining KR suggests new explanations for all the main findings and anomalies outlined in Section III. Whilst it is clear that these explanations are members of a

population of explanations and as such must be confirmed by the prediction and testing of effects unique to this hypothesis, it is thought significant that the single hypothesised mechanism covers such a variety of results.

The hypothesis may be stated:

1. KR provides information to S specific to a particular mechanism for the alteration of performance.

2. The subsequent effective utilisation of the output of such a mechanism is determined by a motivational level of S.

The proposed mechanism is outlined in the block diagram:

S_1 is the stimulus, internal or external to initiate the open-loop control system.

Any control action interacts with the controlled process to produce the process output.

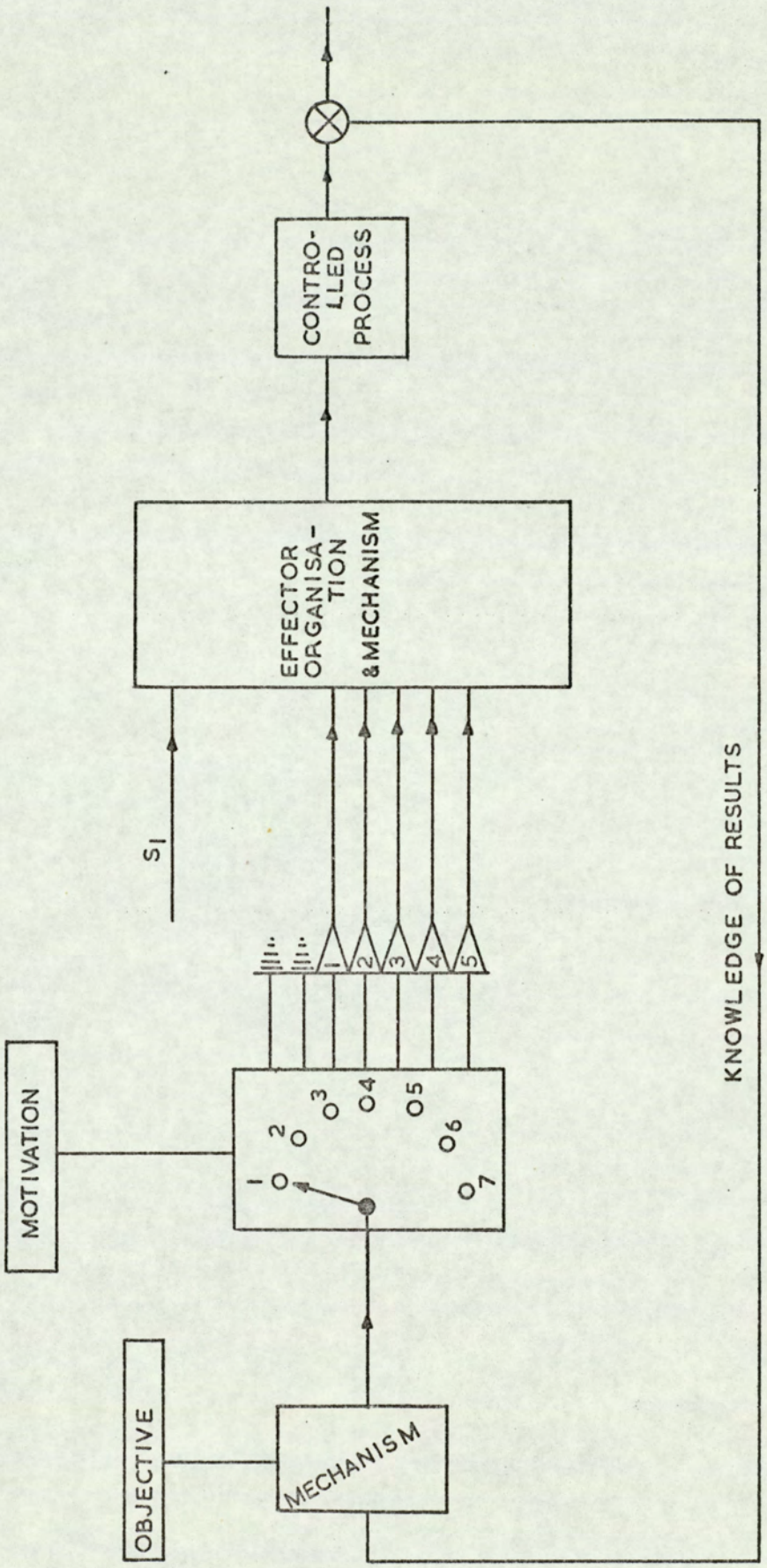
Measurement is taken and fed back as KR to the appropriate mechanism, subject to the normal restraints of S's attendance to signals etc.

The output of this mechanism, however efficient, then becomes available for the use of the effector organisation and mechanism through which any performance is achieved.

However, the progress of this output is interrupted in a particular manner; dependent upon the specific level of

motivation, this output might be discarded, reduced or utilised fully. In the diagram options 1 - 7 represent positions set by increasing motivational levels, at low levels, (e.g. 1 and 2) the closed loop is opened, at higher levels the remaining outputs are routed through attenuating amplifiers 1 - 5, the optimum being a 1:1 device which transmits the full input.

The mechanism which is down stream of this hypothetical 'switching device' also receives an input as a result of the objectives of the system, such an input would determine how the information flow is processed and the type of information leaving this mechanism. For example a simple difference, between desired value and actual, might be appropriate to some tasks, whilst others would demand a more complex transformation to be carried out.



PROPOSED MECHANISM FOR THE EFFECT OF KR ON PERFORMANCE

There are several requirements of such a mechanism, the KR must provide information which is appropriate to the S. For example KR provided by a continuously varying pitch might be confounded by S's inapptitude in the making of absolute judgements of pitch. In addition the KR should not, in itself, introduce problems of attention, since by lack of attention KR may be negated before the organism receives any information. The KR must be related to the process in a manner which is meaningful to S, ie. from the S viewpoint input data must have an informational content. This has important consequences when investigating the effects found in experiments utilising false KR. It is also important to ensure that KR is process orientated and not S orientated, for example information on EMG or GSR on a tracking task would not be appropriate. (The way such data might be predicted to improve and alter performance is a separate question which will be discussed.

The information must be sufficient for the mechanism to function, the amount required would presumably vary according to both the internal mechanism and the dynamic characteristics of the process under control. Thus emphasis is again placed upon the need to describe KR more closely than is traditional in work in this field

The third requirement is that the state of motivation of S towards the objectives of the task allow the internal mechanism to effect performance. The necessary motivation may be produced in many ways, by monetary reward, by comparison of

performance among peers by the so called, "Protestant Ethic", by fear of the consequences of low performance etc.

One very interesting way that motivation might be increased to an effective level is through an intra subject comparison. This would assume an additional feed forward loop between the mechanism and motivating function. Thus the information would be compared by S with his own past performance and it might be suggested that the motivating effect of this situation would depend upon the personality of S. Fortunately the existence of such a loop, besides offering a useful explanation of previously found results appears to be amenable to test by variations on utilising false KR which are expounded in IX.

This hypothesis offers an alternative method of examining the effects of KR and also the motivational aspects of signals, a confusion of which may have caused problems in earlier work. There are two important consequences of such a hypothesis, rejection of either under any conditions would invalidate the hypothesis as outlined.

1) Improvement of performance may not occur in the absence of information transfer.
2) Improvement of performance may not occur in the absence of motivation.

It can be seen that the hypothesis does not contradict the current feeling that arousal is an important factor in the performance of certain tasks and that performance is related to arousal by an inverted-U curve. The model outline would have these characteristics provided the amplifiers are arranged so that their respective attenuations are thus:

$$a_1 > a_2 > a_3 > \ldots a_{n/2} < a_{n/2+1} \ldots < a_n$$

VIII.2 Discussion of Current Findings

The primary objective of this investigation was to clarify the effect of KR on the performance levels of operators during an industrial operation. There was some doubt; one investigation showing a very marked improvement in this condition, whilst another showing no significant effects following the provision of KR. These two cases are examined in some detail in Section VIII.3.

VIII.2.1 Differences between Subjects

The analysis of variance showed that the performance levels of operators were highly significantly different ($F = 37.3$, $df = 6$) and examination of earlier production record sheets had predicted this would be the case. This is in direct contradiction to Brown and Gibbs who found no such significant difference. However, this is in accord with the general findings within industry, operators can usually be ranked in order of performance in a reliable manner. There appear to be several possible explanations for such a phenomenon, inate individual differences, financial need, attitudes etc. The data was tested for only one explanation: length of service, which besides being quantifiable, covered a very wide range and might be expected to affect this measure by virtue of long term training and by the anchoring of any concept of pace held by S. The correlation between length of service and performance under any of the three treatments did not approach significance when tested by the Spearman Rank Correlation Coefficient.

VIII.2.2 Differences between Periods

The performance of S varied from period to period during the working day in a significant manner. ($F = 43.2$, $df = 15$).

However, two sorts of variation make a contribution to this effect. In certain periods performance is consistently high, eg. period 15 and this effect may be considered to be a true variation in performance. The very low levels of performance in periods 5, 14 and 16 are artifacts due to the method of measurement and the system of working. During periods 5 and 14, a 10 minute break for tea is scheduled. Frequently this break is longer, resulting from a premature start or a late finish; as the hourly performance rate was calculated on the remaining, hypothetical 20 minute period, any reduction in this period will lower the performance. This was an elective decision since it was thought that KR might operate in a 'supervisory' manner. Similarly, premature cessation of work affects period 16. These effects can be readily seen in graphs 2 - 8.

VIII.2.3 Differences between Treatments

The analysis of variance showed the considerable differences in performance during varying treatments, to be very highly significant ($F = 94.1$ $df = 2$), these differences may be examined further.

VIII.2.3.a Product Mix Changes

A very ready explanation of the different performance levels between treatments could be in terms of product mix changes - a variable outside the control of E. Consequently, every item passing through the section for the whole of the three treatments was collated and the product mixes for each period are shown in the graph 17. No significant differences could be discerned in the three histograms. The reliability of each histogram may

be judged by the number of observations utilised in their construction; 17,239, 34,939 and 18,448 respectively.

VIII.2.3.b Differences between Subjects

Examination of graph 1 suggests that the various treatments produce similar effects on all S, notwithstanding the differences found in VIII.2.1. The order of increasing performance is unchanged between treatments 1 and 2, and little changed in treatment 3. The analysis of variance discovered no significant interaction between S and treatments, ($F = .826$, $df = 90$). This was examined further by examining the effect of length of service and the differences between treatments 1 and 2, and treatments 2 and 3 by the Spearman Rank Correlation Coefficient Test, (Siegal 1956), no significant effect at the 0.05 level of confidence was found ($r = 0.508$).

VIII.2.3.c Differences between Performance Levels

The analysis of variance revealed significant performance increases, treatment 1 $<$ treatment 2 $<$ treatment 3 and this can be seen in graph 1. That is KR improved original performance significantly and withdrawal of KR produced another significant increase. However, this might be misleading, examination of Graph 9 shows that after an initial peak centring on day 11 a steady increase in average hourly performance for successive days of the treatment took place. After day 30 there is some evidence to suggest that this increase stops and the performance remains essentially static. In spite of variations it can be seen that the remaining points are distributed around a value of

7,200 units per hour, in a manner, if not random, at least lacking a visible relationship which might be expected if the performance level was increasing or decreasing, viz:

Below : Below : Below : Above : Above : Below : Above : Below : Below : Above

The peak mentioned in treatment r = 2, indicates a general increase in performance around day 11. This was in fact the Spring Holiday which might be expected to disturb any motivational levels, upwards or downwards. In this context the existence of a financial 'incentive''scheme may be relevant, it was possible for S to increase the rewards of her labour, by increasing performance, to satisfy a financial need. Thus the average level of performance under the KR treatment is heavily biased to give a low mean value, by the values recorded at the beginning of the treatment. In the absence of further information it is only possible to conclude that withdrawal of KR has little or no effect on performance.

From a consideration of the literature and from experience of investigating mal-functioning bonus schemes KR was expected to affect performance in one or more of the following ways:

(i) Supervisory: in an industrial situation S frequently stops work completely and engages on personal tasks rather than the one being measured. For example conversation frequently develops when new work is fetched or completed work collected, visits to lavatories are extended for smoking or conversation, similarly time is lost starting work after breaks and again by premature cessation of work before breaks. By demonstrating to

S the effects of such 'mal-practices' in terms of the subsequent increased effort required, 'supervisory' KR might be expected to improve 'performance' by increasing the time spent on task.

(It is not intended to make a value judgement of such practices but to illustrate a common cause of low performance which was in fact found and is well illustrated in graphs 2 - 8.)

(ii) Motivational effects of KR on motivation have been often suggested and the idea that KR increase the motivation to perform well is attractive. In some way it has been hypothesised KR might reduce the boredom or monotony of a task and performance improvement might occur as a result.

(iii) Reinforcement of Methods Changes KR would enable small changes in method beneficial to the achievement of the objectives to be reinforced with consequent learning of new methods. In the industrial context such an effect could be far from beneficial, for whilst small motor variations may reduce the labour content, one of the easiest ways of producing a performance change is to ignore inspection and checking elements. Although no evidence was found of this here, S was under constant observation for this effect. Any attempts to benefit in industry, from the present findings must have maintenance of quality as an explicit complementary objective.

(iv) Reinforcement of Pace Changes It is widely held that industrial workers have a concept of pace which is remarkably constant and is job specific. In the author's experience two plants with identical jobs required different time study standards, that is, it was possible to allow less time in one location for

the performance of a task than in another. Conversely in the low pace situation it was widely held that such a performance rate was impossible and initial attempts to attain such a performance failed. In the present task and in many others including Gibbs and Brown where the task almost certainly did not approach the physiological or data processing limitations of S the significant differences in performance maintained by S, maybe explained in terms of variations in acceptable pace. It was considered that KR might allow S to learn a new pace and to maintain it.

Thus four ways in which KR might affect performance in this situation appear rational, however, the results and the analysis of the present investigation offer varying amounts of support for these options.

If KR acted in a manner suggested in (i) then the effect could be expected to disappear with the withdrawal of KR. The analysis showed clearly that this was not the case, no deterioration in performance could be seen over a ten day period of withdrawn KR. Similarly an explanation in terms of (ii) would demand that continuing KR was required to maintain motivation and hence performance, any subsequent reduction in the number of stimuli of KR presentations would presumably, by the same mechanism, allow motivation to fall with a subsequent fall in performance level.

Both methods (iii) and (iv) would produce performance increases relatively insensitive to withdrawal of KR, perhaps it would be reasonable to expect that performance improvement attained

through (iii) might be more resistant than (iv) to such withdrawal. The data and subsequent analysis show that, like Chaponis and unlike Gibbs and Brown a change in performance level occurs in treatment 2. This supports equally the explanations offered in (iii) and (iv). However, it must be emphasised that withdrawal of KR in this case did not mean S received no information; bonus sheets, completed work piles etc. all provide some information.

In such highly skilled operators it is difficult to accept that small methods changes could account for such a large increase in performance, although they might contribute to the improvement. The amount of improvement of performance found was large (20 - 30%) and was felt to be too large without gross changes in method, such as the ignoring of examination requirements and although this was looked for, no such changes were evident.

An alteration in the pace which is acceptable to S, could easily account for such an increase. (cf the work study engineers concept of basic and standard pace, which are in fact in the ratio of 2:3, (thus the original performance was identified by work study as already 30-40% above their concept of basic performance).)

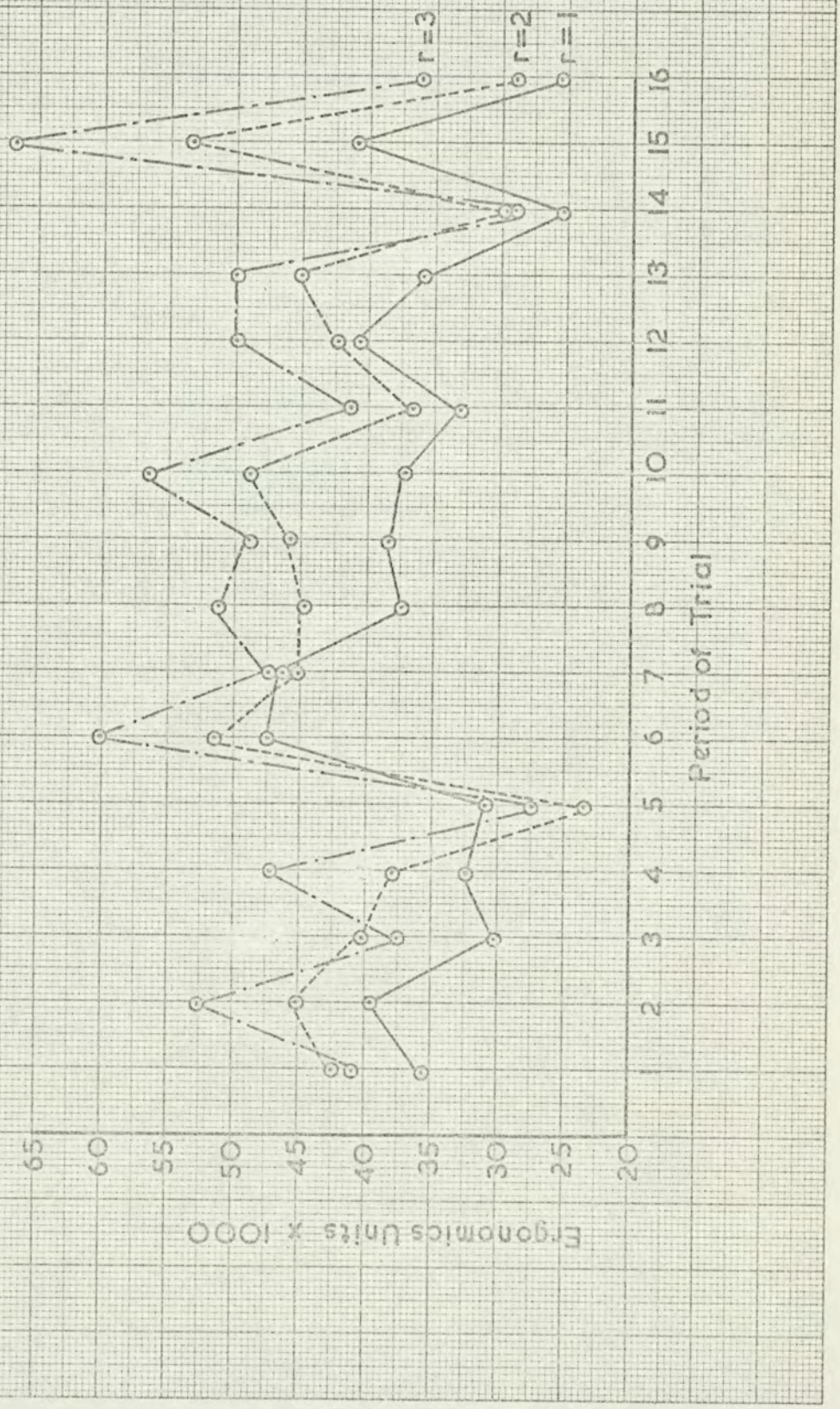
Further rather weak evidence against a change in method being very significant was the finding that the correlation between length of service and order of improvement gave a Spearman Rank Correlation Coefficient, (Siegal 1956) of 0.508 which was not significant at the 0.05 level of confidence.

Wilkinson (1961) suggests that KR raises motivation and that its effect would be expected to be disproportionally large at lower levels of motivation. This appears not unreasonable and a

consequence of such a mechanism would be that the patterns of daily performance would change; the extremes of performance levels would be reduced. That is, where S was highly motivated and straining to achieve high performances the effect of KR, if acting directly as a motivating influence, would be low compared with a situation of low, existing motivation. This was not found to be the case and by-eye assessment of graphs 2 - 8 performance patterns, show a remarkable consistency which suggests that KR is not providing an increase in motivational level. However, a significant interaction between period of trial and KR was found in the analysis of variance, ($F = 3.41$, $df = 30$). Consequently the analysis of variance was examined further and the profile of the BC interaction was drawn. The profiles of the simple main effects for period of trial are shown in the figure were obtained from the BC summary table. It can readily be seen by inspection of these profiles, that differences attributed to period of trial are less marked in $r = 1$, i.e. no-KR than in either KR or withdrawal of KR treatments. Thus this investigation provides evidence to show that KR produces effects which exaggerate the effect due to motivational levels which is contradictory to predictions based upon the hypothesis that KR would provide a mainly motivational effect in this investigation.

Thus, the results and analysis of the present investigation have shown that provision of KR will improve the performance of operators engaged in monotonous repetitive tasks by considerable amounts. Furthermore it has been shown that withdrawal of KR is not equivalent to a no-KR treatment which argues for a

Profiles for Simple Main Effects for Period of Trial



'learning' process being established by the provision of KR. This is reinforced by the gradual improvement in performance which was found during the KR condition. The general hypothesis for the manner in which KR is utilised to change performance, supports the strenuous attempts to maintain the existing levels of motivation throughout the design and conduct of the investigation, (levels due, that is to outside influences). The changes which were found, are in accord with KR providing information to a constant motivational level and did not produce the type of effect which might have been expected, had a KR signal provided motivation improvement qualities, as well as, or instead of, the hypothesised informational qualities.

Thus this investigation, together with the discussion of other work supports the separation of motivation and information in the manner suggested in VIII.1 and the way that the flow of information is subsequently modulated. More exhaustive testing is required to show the effects of varying motivational levels and information flow levels with regard to this hypothesis and suggestions for this are contained in Section IX.

VIII.3. Discussion of Two Similar Investigations

The first two conditions of this investigation bear strong resemblances to the experiments of Gibbs and Brown, (1955) and Chapanis (1964) at least in their mutual objectives of attempting to determine the effects of KR on an 'industrial' task. Broadly it would appear that the present work supports the former and contradicts the latter, however, this may not prove to be the case, but a comparison of the three investigations is unlikely to be useful, unless each can be assessed in a common framework, which allows the experimental findings to be explained in differences in the experiments.

Gibbs and Brown showed:

1. No difference in order of presentation of KR and no KR.
2. KR produced 25% improvement in performance v. a no KR treatment.
3. No change in performance over the KR treatment.
4. No changes in performance within trials.
5. No interaction effects.

(However, in a subsidiary 'control' experiment, two S were given a KR treatment for two weeks and showed a 6% increase in performance between weeks one and two. The other S with a no KR treatment showed a performance decrement of 7% in the same period).

Chapanis found:

1. No difference of performance between 3 separate KR and one no KR treatments.
2. Significant differences in performance over a trial.
3. Significant changes of differences over a trial with treatment duration.

The present investigation found:

1. Significant performance difference with a KR treatment.
2. Significant performance changes through KR treatment.
3. Significant performance differences through each trial.
4. Interaction between KR and period of trial.
5. By deduction the order of presentation was highly significant.

Gibbs and Brown intended to investigate the motivational effect of the information of KR on performance and do not discuss the direct role of the informational content of KR. This is at variance with the present hypothesis in which any effect of KR in this mode is thought to be a minor and a secondary one.

The photocopying situation of Gibbs and Brown appears to have been essentially a learning task in which the method and some concept of acceptable 'pace' of work had to be established. As the task was very simple it might be assumed that the method was rapidly learned, or alternatively the variation in performance due to learning the method was insigificant with respect to the variations in pace. The performance level which is dependent upon the subjective concept of acceptable pace, would be little affected by small reductions in time due to method changes provided the pace was low. Support is provided as no increase in performance through the trials was found, that is all the initial learning had been accomplished so early that it had no effect whatsoever on the overall performance of trial one which was not reduced.

If this is a correct analysis then this investigation concerns the effect of KR on the initial learning of pace, except that withdrawal of KR caused the performance to be immediately and adversely affected for

it was claimed that there was no significance in the order of presentation. However, Chapanis suggests that a basic error in the analysis of their data into component sources of variation occurred. This observation could be in the assumption that a lack of significance in their AB interaction, (S_{1-12} and KR : no KR) indicated no differences in the order of presentation. Such a conclusion could have been drawn if no interaction had been found between the groups, (one KR → no KR and one no KR → KR) and KR treatment.

If this was so there may have been no justification for combining the two groups. The problem of the finding that following KR, subsequent no KR performance was not significantly different to a true no-KR performance might be resolved if an assumption on the method of combining data is made. It is impossible to determine from the report the procedure of combining results and it must be emphasised that the only justification for making the following assumptions is nota priori. It is suggested that alternative S in the presentation in the report were selected from each group. In particular S_1, S_3, S_5, S_7, S_9, S_{11} came from the KR : no KR group and S_2, S_4, S_6, S_8, S_{10}, S_{12} from the other group.

Examination now shows that the improvement in performance of $S_2 - S_{12}$ is greater in all cases than the adjacent S, ($S_1 - S_{11}$). Further with one exception, in each direction, all the no KR performances of $S_2 - S_{12}$ fall below 4800 units and for $S_1 - S_{11}$ the performances exceed this value.

This immediately reveals an effect similar to the present findings and those of Lavery and others, namely that introduction of KR will improve performance more than withdrawal of KR reduces it. This explanation would be consistent with KR information being utilised in a learning situation.

In addition an invalid combination of groups could be responsible for the finding of no variation in mean daily output. If this was the case and the combination of trends with opposite directions is responsible for this finding then the results of all three investigations are in accord on this point.

Hence the objection to regarding this situation as one of learning has been shown to be based upon an invalid argument. Although this does not necessarily invalidate the findings a feasible explanation has been put forward which, if valid, advances positive evidence as to the nature of the situation. The results of the 'control' group also support the idea of an essentially learning situation.

If this is the case the motivation to utilise the information would almost certainly come from the inter S comparison which Chapanis points out as being so likely. (Two S in each trial were seated close and worked in close proximity.) Further as Chapanis suggests, S certainly perceived the experimental nature of the task, (S had volunteered for psychological tests) and this would be also conducive to intra-S comparison, which in turn would be facilitated by S recording his own performance in a log book - a requirement of the experimental task. "To sum up it may be that Gibbs and Brown did not really succeed in isolating the incentive aspect of KR," (Chapanis 1964), nor indeed the informational aspects.

The subsidiary results of Gibbs and Brown, which are not drawn upon in their discussion, obtained from their two 'control' groups. These data furnish evidence of learning with KR and deterioration of performance in a no-KR treatment. This strongly supports the general hypothesised mechanism of this investigation; all the motivating factors advanced by Chapanis, inter-S rivalry, intra-S rivalry, artificial and experimental conditions are all present in both treatments, what is lacking is the informational means of even maintaining performance in the no-KR condition.

This evidence of improvement or decrement is much more significant indicator of the effect of KR on performance than is a consideration of performance level. In the Gibbs and Brown experiment the actual levels present very confusing evidence, (unless as suggested the order of treatments is important). In the control experiment an improvement in excess of 100% was found, (output 1 = 81,300 units, output 2 = 37,400 units, 2 S, two weeks) which is at variance with the claimed 25% improvement.

Even more significant, and adding finally to the case for massive fluctuations in motivating factors associated with the experiment, is the consideration of actual performance levels. The output in the first week of S under a no-KR treatment was 9,700 units, this is almost 1,700 units (21%) greater performance than the best performance obtained in a main KR condition. It is 2,700 units, (39%) better than the best performance in the main no-KR condition.

Hence it is suggested that this investigation failed to isolate an effect of KR on performance except in a very small sample, in which KR caused a performance improvement to occur and no-KR permitted a similar decrement in performance.

The investigation of Chapanis (1964) appears to be well controlled and an explanation of a difference of results requires a more sophisticated comparison of the experiments.

Both experiments made serious attempts to disguise the experimental nature of the tasks, Chapanis attempted to create the impression of a real work situation, whilst the present investigation actually took a real situation and attempted to disguise the significance of the KR loop. The impression in both experiments was that the stratagems were effective but in neither case, could this effectiveness be assessed rigourously.

In purely informational terms, the KR of all of Chapanis's 3 conditions were equivalent in terms of measurement of the controlled process, but varied in their compatibility with S. Condition II required S to calculate a performance figure by adding a time structure to the data display. Condition III had a similar requirement, before a performance figure could be obtained and Condition IV required a subtraction before differences in performance could be ascertained. In the present work the KR was most similar to condition IV, actual performance was presented, intra-S comparisons were facilitated over a longer period, (8 hours) other forms of feedback existed, (finished work etc.), the S was in a working group and increase in performance was rewarded by a financial payment scheme.

Thus, although the information was essentially equivalent, or could be made so by two simple subtractions, the effects of KR were tremendously different. It is concluded that Chapanis's desire to remove all motivating effect of KR was successful and that the KR did not affect

performance under a non-motivating condition. However, the amount of information contained in these KR did prove sufficient to alter performance in another task, (the present one) provided S were motivated to use it. It seems appropriate to consider that KR functions by the transfer of information and not by any inherent incentive or motivating factor.

VIII. 4 Examination of Some Findings of the Effects of KR on Performance in the context of the Hypothesised Mechanism

An interpretative examination of the literature surveyed in I was carried out, the common ground for examination of all the findings was the mechanism proposed in VIII.1. On consideration of the experimental situations described in these terms, namely the informational content of KR and the motivating influences also present, the various findings were all in accord with these factors acting separately and sequentially. That is, the effects could be explained in terms of varying components of what was usually called KR.

This is not to say, that widespread as the agreement might be, that this post hoc comparison in anyway reduces the need to predict and test the effects of this hypothesis. In particular no experiment was designed to test the present hypothesis and consequently each of the investigations contributes to or subtracts from the evidence for the goodness of the hypothesis. Thus the goodness of the hypothesis rests on the breadth of a large number of studies or at least those parts of the studies with a relevance to such a proposal, rather than the formal testing of a null hypothesis. In VIII.1 null hypothesis are formed. This is, of course, the normal situation for any hypothesis, which exists without modification only so long as it explains all the observed facts.

Hardesty, Trumbo and Bevin (1963) found on a Mackworth clock situation that observer presented KR produced a superior performance and removed performance decrement, compared with a no-KR treatment. KR presented by signal lamps neither improved, nor removed the decrement in, performance. The lamps signalled both hits and misses whilst the

observer said: "Right" or "Wrong" respectively. Thus there appears to be both an information input, (the same in each task),and in one case a value judgement of performance together with the motivating factor that the latter was presented by a figure in an apparent position of authority. Thus the mechanism would predict that the effectiveness of KR would be increased by an increase in the motivational level. This difference is emphasised by the experimental design, the S did not serve as their own control, but one group received only lamp signals throughout the experiment and another group always received the verbal judgement. It is surprising that information by lamp did not prevent decrement in light of other work, but examination of the fig. 1A of Hardesty et als is illuminating. In the first two ten minute periods of performance the percentage of detections fell by 6% in the KR-by-observer condition and 12% in the KR-by-lamp; one being described as showing no decrement, whilst the other as showing a decrement. The trials lasted forty minutes and in the last three periods the KR-by-lamp condition allowed a 3% fall off in performance, whereas the no-KR condition allowed a 27% fall off. It appears to be justifiable to interpret the findings rather differently, namely that KR by observer prevented decrement, whilst KR-by-lamp reduced such decrement considerably.

The postulate of Hebb (1966) has already been mentioned and it has been shown that this postulate, that the relation of performance to arousal is represented by an inverted-U curve, is complementary to the present hypothesis.

J.F. Mackworth (1964) suggested a mechanism to explain decrement in performance on a vigilance task and examined the effects of KR on such a decrement. She found that both true and false KR improved initial performance, but false KR did not prevent decrement, whereas KR did. Only missed signals were reported back to S. This is a very interesting situation since provision of false KR is one way of almost completely reducing information transfer and thus the effect of this type of feedback would not be predicted to maintain performance in a situation where a mechanism to produce a decrement exists. The hypothesis further suggests that even if false KR does increase motivation, no increase such as that found by Mackworth, would occur in the absence of information transfer. However, examination of the method of deriving false KR indicates that to use this as a description of the actual treatment is misleading. False KR was added to some very genuine KR, as false signals only occurred after the no signal case, thus each time S responded, he gained KR, in terms of no signal for correct response. It is suggested that the improvement from 'false KR' could have arisen either from the information present or from some motivating effect. Thus consideration of the mechanism suggests that false KR for both commissive and omissive errors, would produce a situation in which any effect could be safely considered to be the result of an effect of the procedure or motivation.

Wilkinson (1961) suggests that the main finding of the reported work using a 5-Choice Test of Serial Reaction was that "lowered reward ($r_{\text{reduced KR}}$) increased the effect of lack of sleep". The hypothesised mechanism suggests that this is too strong a conclusion, since the KR in this study describes a mixture of:

1. Signals for misses
2. Signals for incorrects
3. Observer presented summaries every five minutes
4. Observer presented assessment, "Better", "Worse" or "No Change" with respect to the preceding period.

Wilkinson found that such KR gave marginally better results than no-KR in a normal (sleep) situation. The marginal effect, rather than some larger effect, might be due to the task that is S can provide his own feed-back more readily in this 'light cancelling' situation, than in some others, or as a result of the balancing of treatments: that is if any carry over effect exists then the net difference between the conditions will be reduced.

Thus it is suggested that KR has not been demonstrated to raise the level of motivation, but that a situation known to have motivating properties, (observer present, value judgements, comparison of performance with peers) has not unreasonably increased the motivational level and Wilkinson's description of KR as a 'known motivational factor' is unwarranted.

Johnson and Payne (1966) concluded that in the vigilance task studied, the effect of frequency of KR significantly altered performance, but did not prevent decrement. Examination of the experimental procedure suggests that very little KR as described in this hypothesis was transferred. The 0, 25, 50, 75 and 100% proportions discussed, in fact refers to the number of signals which occurred in a period before S was informed that "a signal had appeared". Thus eight signals had appeared in the 100% situation before S was informed that a signal had appeared; as an average S had made 6 - 8 responses in this period, the

informational content of such KR would be slight. Consequently the present hypothesis would suggest the initial increase was due to an increase in motivation utilising the intrinsic KR information. Such a situation might be predicted to show no effect in the rate decrement.

However, Johnson and Payne found, as a result of analysis of variance, that this frequency of presentation produced a significant difference in performance. This finding contradicts the prediction of the hypothesis since on four occasions all S were told a signal had occurred and this was the case for all treatments, 25, 50, 75 and 100%. Thus this lack of equivalence of effects, due to a motivation level is embarrasing to the hypothesis until figure one is examined. The results of 25, 50, 75 and 100% 'KR' are all very similar, the superiority of any regime varied and no relationship could be detected between these treatments, by eye. (This is borne out by Johnson and Payne's further analysis.) However, the 0% treatment, i.e. no-KR, was very inferior, measured in terms of percentage of missed signals and this treatment undoubtedly contributed largely to the variation found between treatments. If the treatments were to be regarded as a (no interference situation) v.a. (four audio stimuli treatment), then in such a boring and monotonous task, the finding of performance level differences is not in conflict with an interpretation in terms of the present hypothesis.

In part of the work reported by Church and Camp (1963) relevant to this discussion, further evidence in favour of the informational importance of KR vis a vis any motivational effect. Over four days, simple reaction time was measured repeatedly over a fifty minute period, (260 measurements were taken). During this period the reaction time, for a group with KR, fell consistently, whilst no change occurred with

a no-KR group.

On day five each group (of 20 S) was split and half of each group was subjected to trials under the differing treatments.

The S with previous KR, in the day 5 KR treatment showed a further improvement in performance. S without KR previously and without trial 5, showed no improvement. S whose KR was in effect withdrawn immediately produced results similar to the unchanged level of the no-KR treatments. S who were provided for the first time with KR, showed an improvement similar to the KR group on day 1. This suggests an informational mode for the mechanism of KR in the performance improvement situation.

Larimer and White (1964) found that there was no difference in the levels of accuracy of judgements of weight, when KR or monetary reward were provided, both improved accuracy over the no-KR treatment. However, the monetary reward condition provided exactly the same information as the KR treatment but in addition to a five reward was dispensed by machine. This contrasts with the reported work of Siegal and Goldstein (1959) who added a motivational factor - experimenter presented rewards and found that this increased accuracy in a guessing game. A change in effect, in accord with the present hypothesis.

Suddon and Lavery (1962) and Lavery (1962) found that acquisition of a simple motor skill was improved when KR was given for each response, but this was obtained at the expense of retention. KR which was delayed for five responses or which was presented at the end of a trial respectively, improved retention as explained earlier. At the end of the with-KR treatment, trials were carried out without the

augmented feedback of KR and in the former case performance fell, but the 5 response delay group were superior to the no delay group. In the latter investigation the no-delay-KR group's performance deteriorated, but the KR-at-completion-of-a-trial group showed no performance decrement.

In all the tasks used some intrinsic KR existed, the golfer does not need to see the ball to know if his range is correct and similar audio or kinesthetic feedback existed for all the tasks. However, the task reported by Suddon and Lavery had little feedback as the task was to exert a force on a gauge by hand.

The prediction from the hypothesis would be that any procedure which increased the learning of intrinsic cues would increase the information content available in a non-augmented KR condition. Similarly, the task with fewest cues, would be most lacking in intrinsic KR and performance on such a task in a no-KR treatment would be worse than on others. This is a statement of the relevant findings in these two reports.

Examination of the work reviewed has shown that apparent disagreements with predictions from the hypothesised mechanism, have been largely the result of unregarded experimental conditions. The mechanism further has been shown to be useful in explaining differences in experimental findings.

Its utility appears to be great, in that KR may be a useful variable for investigating basic mechanisms such as the mechanism of vigilance decremented, provided that such a variable is itself controlled. It has been shown that frequently this has not been the case and this hypothesis suggests a family of variables which must be carefully

controlled to ensure consistent effects attend its application.

IX PROPOSALS FOR EXTENSION OF THIS WORK

IX.1. Replication of Field Investigation

The present investigation appeared to be larger in terms of time per trial and number of trials than any other investigation to date. This reflected a desire to remove as much as possible the effects of novelty from this situation and an attempt to determine the nature of any effects of KR in a truly industrial situation. The lack of decrement suggests that a permanent, (at least over 10 days), change in performance occurred and this important conclusion must be tested in some other situation, over if possible even more trials to approach more closely the industrial situation.

Such investigations are expensive in observer time and in computational time and any replication study could also test other hypotheses. It was seen that the improvement in the KR treatment was continuing at the cessation of the treatment which suggests an experimental design with five KR conditions:

treatment 1 : no KR (establishing current performances)
2 : KR each 30 mins.
3 : KR each 60 mins.
4 : KR each 30 mins.
5 : Withdrawal of KR

As in the present investigation, during the treatment 5 it will be necessary for the observer to take the half hourly collections of data.

The predictions under test would be:

a) KR produces improvement in performance

b) performance changes with time under KR treatment

c) performance changes rate depends upon the amount of KR information

d) KR produces stable long term alterations in performance

The verification or otherwise of these predictions would enable an assessment of the worth of KR in an industrial situation to be made. In addition it would provide a basis for the arrangement of KR in the industrial situation for optimum improvement.

IX.2. Laboratory Testing of the Hypothesised Mechanism of VIII.1.

IX.2.1. Effect of delay on presentation of KR

The literature has suggested that delay of KR adversely affects its effects upon performance, but there is some evidence that two variations on the method of presentation are described as delayed KR. Firstly the information on each trial is delayed and this delay may or may not result in the KR being

presented after the succeeding trial or trials. Alternatively delayed KR may mean information averaged over several trials, that is accummulated KR, which has been referred to as knowledge of performance.

The former has chiefly been tested upon very simple motor tasks and this has resulted in some confusion between the effects produced by KR. Often the KR information has not in fact augmented the intrinsic information feedback loop from the task but has displaced such information. This effect is likely to be reduced if a considerable time elapses before the KR is presented and facilitated by immediate presentation, if the information content of KR is the reason for the change. That is if intrinsic information has been produced and attended to, the information content of the succeeding KR presentation will be reduced, and a reduction in the effect might be expected. Thus it is suggested that an effect due to manipulation of information and not of time has been studied. In order to investigate the effect of delay on the mechanism it is necessary to choose a task with a minimum of intrinsic feedback or, more easily it is suggested, a task with a highly incompatible form of feedback. A body of tasks suggested are those in which time to perform a task is the measure used. Thus simple assembly tasks lasting 5 - 10 seconds with

many manipulations are suggested, when the only feedback on performance might come from large errors, such as a fumble, and these might be trained out, or in the event of an isolated occurrence might be discarded.

Thus an experiment consisting of presentation of KR with various delays on a simple assembly task is suggested. To overcome the long lasting effects of KR, subjects should not be used as their own control, unless a difference in rates of performance improvement is sought namely H_o : delay of KR has no effect upon rate of change of performance.

The effect of accummulated KR may also be tested in such an experimental situation, it is suggested that the most important requirement is that the KR presented does not displace the intrinsic feedback as this would result in a comparison between KR v. (intrinsic feedback and KR). Again the suggested way to prevent this is to use a situation without useful information, (including of course kinesthetic feedback) or with incompatible feedback as outlined earlier.

IX.2.2. False KR

False KR provides an elegant way of varying KR and suggests a method of separating the effects of KR and the motivating effects associated with the presentation of feedback. The experiment would require

that S are trained to a plateau of performance level with the normal intrinsic feedback. Then false KR would be presented to S each cycle, the information content of such "KR" would then be increased by the introduction of true KR until finally the signals or presentation contain no false KR.

A simple means of effecting this dilution would be to add to each reading, before presentation a random value, positive or negative, and gradually reduce the range of the rectangular distribution from which these values are selected, until the value reads $\pm$ 0

A special form of false KR might be applied with interest to a situation with little intrinsic feedback especially one designed to be sensitive to KR such as a vigilance situation. The "KR" would have a false relationship added to the already false information; two cases are suggested a) where successive KR presentations suggest a steadily improving performance, and b) the converse, where performance apparently is deteriorating. It is suggested that these are two strongly motivating situations which would demonstrate, that KR is not the mechanism which alters motivation, provided no improvement in performance occurs. The full experimental situation could be represented thus

	NO - KR	KR
Ascending Additions	1	2
Descending Additions	3	4

Where the KR consist of the true performance index plus the increasing or decreasing additions.

IX.2.3. Alteration of Information Content

It is possible to alter the information content of true KR signals whilst maintaining the other variables constant, and it is suggested that this would alter any effects upon performance. The easiest way of achieving this is to provide three KR stimuli representing, "Above" "Average" "Below" to a situation, and then to alter the proportion of responses in each category. That is the range of the possible responses would be determined and this range would be allocated among the three categories. Thus the information content of a KR signal would be a maximum when probability of a signal occurring in any category is equal, i.e.,

$$P_{Above} = P_{Average} = P_{Below} = \frac{1}{3}$$

and this could be varied by allotting various proportions of the signals to these categories, e.g.,

$$\text{Above} \doteq 20\%\text{ile}$$

$$\text{Average} = 21 - 80\%\text{ile}$$

$$\text{Below} \doteq 81 - 100\%\text{ile} \quad \text{etc.}$$

Clearly this sort of treatment is applicable to simple motor tasks such as line drawing and rod striking as well as the sort of task suggested in earlier proposals.

IX.2.4. Modification of the Chapanis (1964) Experiment

It would be illuminating if the hypothesised mechanism could predict an outcome for a modification, as well as explaining the results of Chapanis' investigation. The mechanism suggests that if the motivational level of S was increased in such a situation, a difference between KR and no-KR would appear. Monetary reward linked to number of digits punched, or the provision of a target might be expected to produce this increase in level.

X BIBLIOGRAPHY

1. Adam J.A. & Humes J.M. — Monitoring of Complex Visual Displays IV, Training for Vigilance. Hum. Factors, 1963, 5, 147-53.

2. Annett & Kay. — Skilled Performance. Occup. Psychol. 1956, 30, 112-17.

3. Annett & Kay. — K.R. & Skilled Performance. Occup. Psychol. 1957, 31, 69-79.

4. Baker, C.H. — Three Minor Studies of Vigilance. Defen. Res. Med. Lab. Rep. 1959 - No. 234-2.

5. Barnes, R.N. — Motion and Time Study. (John Wiley, New York).

6. Bergum B.O. & Lehr D.J. — Monetary Incentives and Vigilance. J. exp. Psychol. 1964, 67, (2), 197-198.

7. Bilodeau E.A. & Bilodeau I. McD. — Variable Frequency of KR and learning of a simple skill. J. exp. Psychol. 1958, 55, 379-83.

8. BilodeauE.A. & Ryan F.J. — A Test for Interaction of Delay of KR and Two Types of Interpolated Activity. J. exp. Psychol. 1960, 59, (6), 414-419.

9. Chapanis A. Knowledge of Performance as an Incentive in Repetitive, Monotonous Tasks. J. App. Psychol. 1964, 48, (4) 263-267.

10. Church R.M. & Camp D.S. Change in Reaction-Time as a Function of KR. Am. J. Psychol. 1963, 78, 102-106.

11. Crawley S.L. An experimental investigation of recovery from work. Arch Ps. NY No. 80.

12. Gagne & Fleishman. Psychology & Human Performance. (Henry Holt & Co. 1959).

13. Gibbs C.B. & Brown I.D. Increased Production from the Incentive in a Repetitive Task. Med. Res. Council, Appl. Psychol. Res. Unit, GB 1955, (March) No. 230.

14. Greenspoon J & Foreman S. Effect of delay of KR on learning a motor task. J. exp. Psychol. 1956, 51, 226-228.

15. Hardesty D. Trumbo D. Beven W. Influence of KR on Performance in a Monitoring Task. Percept. mot. Skills 1963, 16, 629-634.

16. Hebb D.O. A Textbook of Psychology. (W.B. Saunders Co. 1966).

17. Holding D. Principles of Training. (Pergamon 1965).

18. James, Mitton & Fitz. Eye Fixation for Aircraft Pilots. U.S.A.F. Aero Medical Lab. AF Tech. Rep. 5957.

19. Johnson E.M. & Payne M.C. Vigilance: Effects of Frequency of KR. J. App. Psychol. 1966, 50, (1), 33-34.

20. Lansman H.J. & Turkewitz. Delay of KR and Performance on a Cognitive Task. Psychol. Rep. Aug., 1963, (11), 66.

21. Larimer G.S. & White B.J. Some Effects of Monetary Reward & KR on Judgement. J. exp. Psychol. 1964, 67, (1), 27-32.

22. Lavery J.J. Retention of Simple Motor Skills as a Function of Type of KR. Canad. J. Psychol. 1962, 16, (4), 300-311.

23. Leamon T.B. Examiner Performance - Considerations arising from Analysis of Faults. Unpublished Ergonomics Report, Pilkington Brothers, St. Helens, England.

24. Mackworth J.F. The Results of True and False KR on the Detectability of Signals in a Vigilance Task. Canad. J. Psychol. 1964, 18 (2), 106-117.

25. Mackworth N.H. Researches on the Measurement of Human Performance.
Med. Res. Council, Sep. Rep. Series No. 268.

26. Maynard H.B. Industrial Engineering Handbook.
(McGraw-Hill, 1956).

27. Montague W.E. & Webber C.E. Effects of KR and Differential Monetary Reward on Six Uninterrupted Hours of Monitoring.
Hum. Factors. 1965 April, 173-180.

28. Mc.Cormack P.D. & Mc.Elheran W.G. Follow-up of Effects on Reaction Time with Partial KR.
Percept. mot. Skills 1963, 17, 565-566.

29. Raju, C.S. An Investigation of Interaction in Elemental Times. 1962.
College of Aeronautics Library,
Cranfield, England.

30. Rubin & Rabson. Studies in Psychology of Memorising Piano Music.
J. Educ. Psychol. 1941, 32,48.

31. Saltzman I.J. Kanfer F.H. & Greenspoon J. Delay of Reward and Human Motor Learning.
Psychol. Rep. 1955, 5, 139-42.

32. Spencer J. Estimating Averages.
Ergonomics 1961, 4, 317-328.

33. Stennett R.G. The Relationship of Performance Level to Level of Arousal.
J. exp. Psychol. 1967, 54, (1), 54-61.

34. Stevens S.S. Handbook of Experimental Psychology.
(New York: John Wiley, 1951).

35. Suddon F.H. & Lavery J.J. The Effect of Training on Retention of a Simple Motor Skill with 0- and 5- trial delays of KR:
Canad. J. Psychol. 1962, 16, (4), 312-317.

36. Wiedenfeller E.W. Baker R.A. & Ware J.R. Effects of KR on Vigilance Performance.
Percept. mot. Skills, 1962, 14, 211-215.

37. White K.C. Predetermined Elemental Motion Times.
J. Am. Soc. Mech. Eng. Nov. 1950.

38. Wilkinson R.T. Interaction of Lack of Sleep with KR, Repeated Testing and Individual Differences.
J. exp. Psychol. 1961, 62, (3), 263-271.

39. Winer. Statistical Principles in Experimental Design.
(Mc.Graw-Hill, 1962).

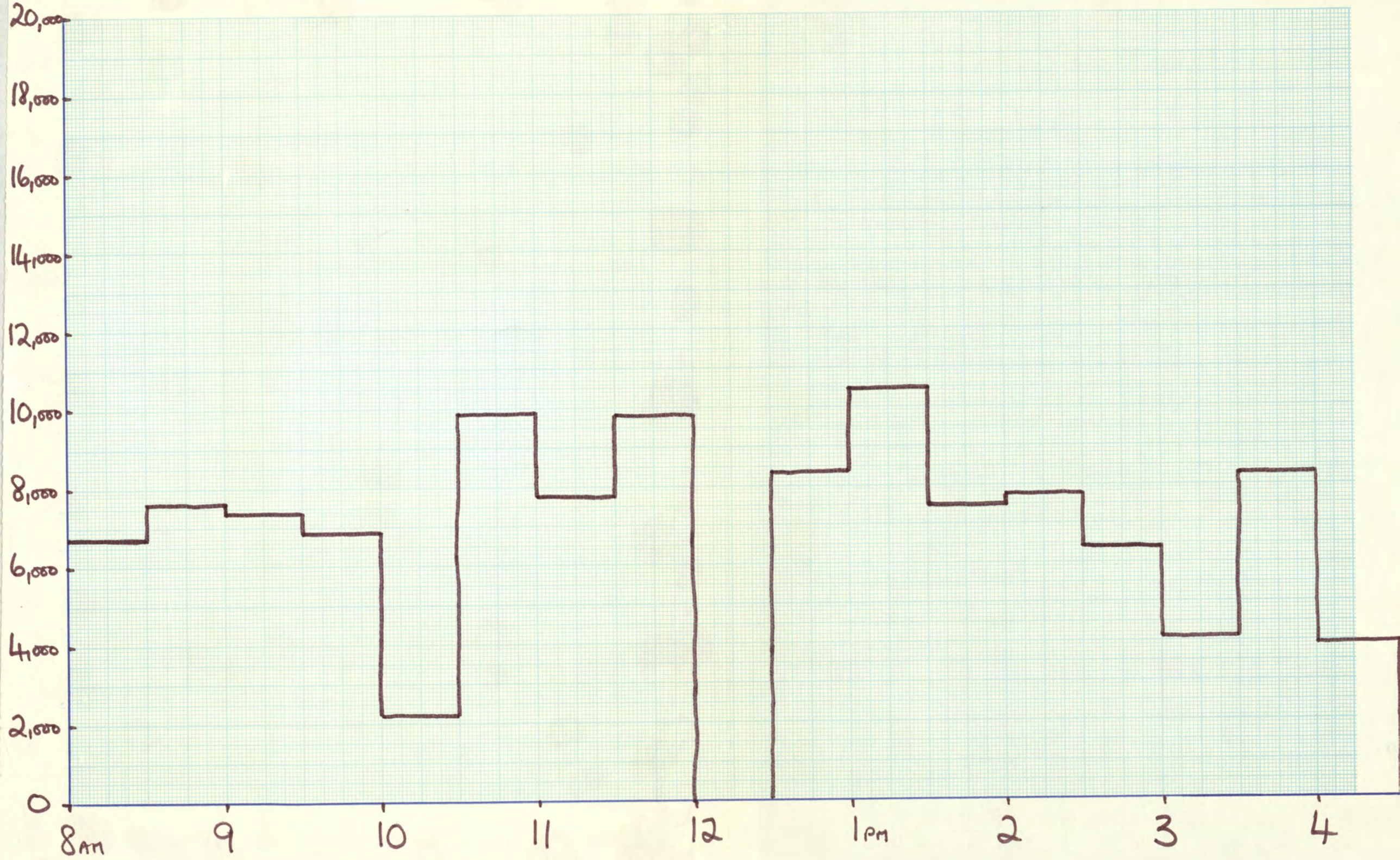
40. Woodworth R.S. & Schlosberg H. Experimental Psychology.
(Methuen 1954).

Examination & Packing Fiberglass Battery Separators

[redacted]

H

20-6-69



[redacted]

SUMMARY OF PERFORMANCE S_1

Day \ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	5066	5662	5066	3616	14400	8644	14440	5426	4506	4524	1930	5600	4848	2940	5406	672
4	5076	4488	5744	1072	3780	–	–	–	2800	4760	1960	10832	9912	5640	5064	6960
7	4320	5472	3168	4960	4632	8560	5344	4536	7488	4896	3744	6464	4768	–	–	–
8	–	–	4032	4896	5184	7488	5344	6384	7856	5345	2880	6336	3024	3456	5492	3424
9	4848	5472	3296	4768	3888	6236	3000	3100	6918	7120	6840	3720	3696	3456	6624	3296
10	6336	4608	4546	5472	5868	8760	5948	8770	5976	4690	–	–	–	–	–	–
16	7000	6456	4810	6150	4350	6418	6820	4650	5366	5140	4508	4278	5940	4125	6826	4542
17	9126	8376	3868	5152	4314	7408	5814	4608	8000	5988	4098	6560	5422	2535	7046	5044
18	5168	5220	4310	5154	3354	5662	6338	5100	5066	6882	3214	8790	6250	3354	5364	3298
19	6092	5006	5580	2674	3546	5890	5736	4682	8406	6248	3002	6820	6510	3954	6910	4182
20	7448	8884	8982	6136	3954	6820	9064	6930	5270	8216	7130	8036	7268	3720	10870	1932
24	5380	3294	3342	4826	3150	4266	4746	3410	4086	3680	3290	3676	5612	1710	–	–
33	–	–	–	–	–	–	–	–	6200	8990	4222	6092	5539	–	–	–
34	–	–	–	–	4419	7130	5116	7078	6200	8216	5532	7440	7576	4650	666	6086

SUMMARY OF PERFORMANCE S_2

Period / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	3864	5474	12162	6240	5760	20480	7800	5724	6720	7280	6160	5400	6720	4200	5368	1904
4	6952	6448	5780	5684	-	7000	7096	5192	5880	7280	7280	5640	5400	4620	6000	2872
5	3640	5720	7000	7904	7680	9888	5992	5776	6160	6160	5880	5392	5144	2940	5860	3918
6	6624	6912	6072	5216	4752	6624	7200	4520	7200	7200	7000	5116	7584	4650	6692	5312
7	4784	6912	7200	4480	3032	6336	7200	4552	8960	4440	7200	6080	6784	3168	6336	4432
8	6048	8064	7104	4928	4740	8120	5296	5744	5880	5320	6336	5576	4072	4752	8064	3328
9	5472	7440	6160	2800	3780	7128	4888	5648	6060	7440	5648	5344	5472	3888	6912	3648
10	6912	6344	7958	5894	8640	5132	7130	5296	6510	5580	6572	6868	3110	-	-	-
13	7906	8954	8560	6150	4650	7906	7620	4806	7750	7750	6106	6200	5396	3954	6666	5538
15	5056	4266	5368	6222	3150	6976	4786	5640	7130	7044	9256	8118	8992	6375	7332	4954
16	8750	7322	8306	6200	3489	7130	9146	5166	6166	6068	7656	6876	7750	2898	5448	2270
17	6846	5644	7808	5846	3750	7472	8366	6536	7890	5964	6216	6590	7748	3576	5960	4510
18	6110	8046	6748	4708	4002	6612	6872	5322	4498	4662	7004	7340	5790	5250	7528	6868
19	6544	4960	6444	3934	2325	6046	6666	3906	8060	7286	7354	7338	7280	4830	7526	7646

SUMMARY OF PERFORMANCE S_2

Period / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
20	6356	6356	8136	5542	3360	6266	7972	6556	8370	7906	8216	6170	8060	4185	7102	4268
21	7440	8990	8222	6710	3028	7906	6982	5944	8060	8990	6016	8216	7372	3363	8344	5838
22	8046	7152	6982	5140	4470	8196	5635	4284	8940	7450	7450	5756	6556	3129	8792	4144
24	5776	4986	6198	4612	2607	5688	7426	4770	5372	5214	5398	6508	6636	3081	6192	4582
27	-	-	-	-	-	-	-	-	-	-	7280	7580	6544	4029	7276	-
28	7442	5638	8756	6190	4650	9146	6164	8044	6882	8836	7596	5956	6652	4875	7946	3628
29	6750	8250	5376	6528	4503	9082	6948	7328	5080	6320	6936	6322	7210	6000	7094	4562
30	5426	7750	5590	3232	4875	11250	9986	7500	6750	11250	9258	7110	7450	3801	7394	2778
31	7152	7152	7466	5766	2310	9100	8506	10908	11294	6898	8026	6142	6004	2460	7304	3834
32	7898	14030	7926	10168	3489	7132	6500	4666	6820	7596	7868	5706	5892	4650	8526	3684
33	7440	8216	7080	6976	3720	8428	7184	6990	6510	8526	5102	9456	6976	4884	7906	5340
34	8836	7906	7048	12044	8070	15212	9108	5012	6820	6200	6046	4624	17500	9753	11050	4520
35	6046	6820	6958	5492	4185	16742	8268	6406	8060	7750	7286	42 70	6932	3489	7236	5464
36	6356	8060	7286	4318	1395	6046	6666	5150	7440	8060	7818	5282	7222	4419	7286	3028

SUMMARY OF PERFORMANCE S_2

Period / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
39	7750	7906	7220	5818	3954	8370	8368	5364	6510	8276	6808	8748	7286	5115	7834	4722
40	12250	9500	8668	7110	-	-	-	-	-	-	-	9530	7458	3375	9022	5172
½ Day Sat. 41	10000	9750	8206	7810	5250	11500	8812	5028	-	-	-	-	-	-	-	-

SUMMARY OF PERFORMANCE S_3

Period / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	-	-	-	-	-	13440	9220	6098	4488	2592	-	-	-	-	-	-
6	-	6624	2032	5344	4232	6144	5472	7132	5820	7432	7448	6788	6540	3318	7300	4288
8	2800	6432	4368	5200	3816	6720	4880	6672	3744	7200	2816	7776	3648	4280	6912	3328
10	2240	6040	3456	4672	3648	7200	7796	5776	6454	9610	4370	8100	5300	-	-	-
21	4030	8990	6046	3896	465	11546	2294	10392	5580	11316	5116	6236	10204	3489	10452	5244
22	2086	6854	7152	6208	1761	9366	7152	7728	9662	6556	3874	7152	7470	4470	6706	6300
23	-	6258	4172	6408	1104	5472	2860	6050	7280	5050	960	5762	6660	6090	8528	3262
27	-	-	-	-	-	-	-	-	-	-	3100	7690	7424	3408	-	-
28	2370	7712	3194	7908	4650	9998	5444	10840	7966	10696	2418	10292	7314	5130	10162	3632
29	-	-	-	-	-	-	-	-	5690	6422	3350	12000	6452	3462	10542	4430
30	-	8480	4180	5706	2910	10822	6750	10288	7274	11198	6960	5960	6846	3129	10580	5138
39	2170	10076	2852	7460	3255	9300	3822	8656	6300	8830	1898	9046	8060	6510	12892	3810
40	-	5098	4870	10950	-	-	-	-	-	-	-	13354	6650	2520	14656	8542

Period / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3	5364	4652	8660	5440	3864	5364	2620	4622	5174	5844	2984	3336	5688	4034	4396	1756
5	5688	4752	5468	3384	3381	3848	5880	4200	3624	5320	4760	5112	1624	4200	2896	3302
6	3168	6336	5376	3584	432	7136	17200	6032	6336	5952	4160	4224	7200	4740	3880	4000
7	5472	6520	3568	3168	3396	7976	5216	5952	5176	5616	3542	4448	5664	4080	6336	2816
8	6336	6048	4168	3456	3888	5504	7296	3680	5664	8016	4824	3584	6336	2880	6720	3296
9	4608	6624	2960	5696	2688	8000	6208	5152	6188	5130	5258	4552	7448	-	-	-
10	.4896	7488	4796	4646	5184	7485	7130	6406	8990	8592	6734	14080	9524	-	-	-
12	6200	4932	7698	2042	5670	7876	13190	11502	7468	6734	6172	7628	12532	9426	5698	5598
13	7596	6162	7310	5292	6276	7874	7456	5710	10076	6824	7998	5872	7130	3255	12246	2810
14	10386	5082	8510	3100	2820	5828	2038	7390	8060	5060	8370	4082	6772	5814	7224	5260
15	5942	5990	7332	4122	3954	6138	6012	6464	7336	6960	2804	7432	7810	2631	9250	7014
16	5500	5010	9300	4474	2169	7130	11936	5174	6924	11006	3524	6148	4824	4524	7660	3194
17	3220	5636	-	-	-	-	-	4636	5006	9048	6650	5276	4996	5142	10806	1820
18	9834	7032	7866	7456	2331	11026	7410	8286	5458	11176	6698	5545	8340	4248	9552	8662

Period / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
19	5790	8526	3572	6884	1701	5564	9868	5918	9938	7726	10230	2526	10754	4419	8566	7198
20	10076	6656	9880	4800	6744	8960	11470	7676	9456	8266	5600	5164	10710	4419	10504	4192
21	8836	8250	7192	6300	4521	11006	9456	8564	10696	10938	5854	7750	6246	3984	6854	5242
22	5514	8344	4540	3804	2460	8704	9046	5810	5662	8680	5770	3210	7060	4248	8196	3942
23	7302	5388	3912	6636	4248	5618	5796	5256	4636	6280	6440	3026	5272	6090	9520	3816
25	7152	6612	5120	5726	2616	7028	6320	8512	8652	5258	4772	4912	3548	-	-	-
27	-	-	-	-	-	-	-	-	-	-	8240	2668	5700	3762	11284	-
28	8848	8532	6700	5234	7905	9780	6758	10692	8438	12710	6350	8060	5060	1125	5750	4804
29	5400	6838	2414	7794	5439	10176	4718	6702	-	-	-	-	-	-	-	-
30	7000	8000	3834	7716	3648	7890	4750	9326	10432	8932	5100	7748	9046	7377	11772	2122
31	7748	8322	6278	10566	4023	9334	8440	9068	8614	10136	7248	5370	9550	2235	8940	4350
32	6510	9766	4056	7734	3720	8716	6154	4772	6356	6904	6560	2354	7154	2790	7906	7780
33	7130	7906	5840	4496	4278	9338	6980	8112	7660	8822	7440	5146	6740	3954	10696	5374
34	7440	7440	3980	6510	5115	8060	12578	13682	9300	10230	7260	7312	9814	4185	12864	4600

Period / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
35	8370	9610	4244	5150	5115	10540	13222	15920	11602	8836	8036	4778	7906	4185	7544	2548
36	6666	8060	3914	5646	6279	10230	3360	8836	9834	8404	2480	10064	8484	5814	9920	7370
37	7440	6910	3338	7256	2655	9480	5726	8484	10540	9240	6232	9992	9300	6045	9880	4074
38	4806	6442	2778	6510	2862	6168	9676	7324	10386	8546	6738	8622	8078	5580	9920	5206
39	7596	9920	4994	7740	4185	9580	3390	8954	7582	10230	5302	6102	6750	4008	8378	3990
40	6976	4376	3876	6164	3255	8954	2614	5186	5430	11376	2914	8150	11250	2217	9624	2840
½ day Sat. 41	6750	11000	8212	7852	3189	9876	8188	5658	-	-	-	-	-	-	-	-

Period / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3	5960	4238	634	4834	5264	6622	5364	5132	2938	5068	2528	5820	3480	3132	5060	516
6	-	-	-	-	-	-	13056	8776	6336	5088	3968	4896	37184	888	4896	3936
7	5760	5568	3744	5856	3888	4896	6720	3552	5760	5856	3456	7480	7752	2496	6624	1400
10	5760	3840	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	5426	4834	9322	13494	2409	7052	5494	5130	5952	5270	3256	5890	5650	5934	13352	4452
13	6046	6666	5116	5252	3489	6510	7130	3632	4960	7208	4200	5612	4806	4650	6510	1936
14	6820	4660	3410	5280	1983	5302	2946	5426	3662	4846	2066	3724	-	-	-	-
17	6250	5500	3946	4984	4002	6532	7276	5756	7704	4332	2980	4934	5744	4002	7244	2448
18	6118	4024	6258	4238	3576	6204	7302	4712	5364	5728	4470	5335	5005	3129	6724	5484
19	4696	5736	4340	4732	1875	6976	9606	4966	6200	6200	3566	6460	6510	3252	7648	2996
20	6200	7236	5230	4640	4419	7906	6550	5954	7568	6968	4496	6666	5422	2727	6600	1678
23	7450	4984	4470	4914	3150	4052	3624	4788	-	-	-	-	-	-	-	-

Period / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3	5960	4940	2704	4450	3513	4470	3576	2748	2980	2852	4104	4308	3476	2235	3096	2212
5	3360	3640	3376	1904	1400	3640	3376	2288	3536	2816	3192	4680	944	2100	6904	3616
7	3744	4892	2400	2304	2592	5472	4224	3016	4320	3456	3360	2592	5492	1764	5320	4280
8	3168	5472	4416	1536	1296	6336	5184	2400	4896	3744	2752	3232	5600	3780	4392	3936
9	4032	4320	3456	3904	2160	2690	530	3668	2672	5270	4032	2798	1550	2172	6452	5200
10	4896	5030	3070	3312	2325	4650	4650	4344	4960	5968	6386	14790	2952	-	-	-
12	10760	6946	5736	2326	3024	5426	4444	5270	4030	4776	5200	2790	5170	3570	4316	3226
13	11836	6502	5426	1860	3255	5408	5236	5270	5426	5362	4044	3396	3014	3024	5408	4310
14	4546	5270	3818	5150	3780	8120	4234	4806	4650	4340	1478	478	4496	1860	5426	2964
15	3502	5214	3524	2326	1062	4816	5008	3952	4030	5426	2310	5000	5500	3939	5402	4598
16	5250	6250	4168	3720	2790	5270	4960	3306	4680	4960	3100	3368	3572	2415	3656	3116
17	4640	4176	3052	4988	2154	5028	4876	4238	5614	4268	4620	2980	4172	1728	4746	2546
18	4470	3262	3364	3480	2784	4814	5448	4078	3726	4768	5364	1790	3550	1989	4068	3832

Period / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
19	5116	4960	3344	5890	1629	5344	5044	4186	5568	5224	3590	4186	5736	1992	5578	2766
20	5580	4960	6028	4862	2790	6046	5686	3716	5580	4806	6356	2846	5296	4200	6312	2088
21	5270	6200	4536	5116	2418	6200	7130	4990	4262	7286	5580	2450	4944	2325	4806	3532
22	6156	5960	4024	4172	1788	6258	5066	4648	3874	4322	4768	3428	4620	1566	5048	2912
23	2980	6706	5662	2832	1917	4120	5314	3600	4186	4670	4830	2738	3542	1419	4846	3456
28	4582	4740	4302	1820	4650	7596	4682	6170	6432	6416	6302	4030	4516	2625	5126	3098
29	5000	4010	4424	4500	4875	6300	6564	7038	6750	5560	5184	4806	6356	1947	4652	3992
30	3652	5890	5666	6500	3573	7940	8250	6570	6146	8750	6266	5692	6854	2907	5166	5266
31	5216	5038	4322	6258	3384	5812	7450	4874	5216	6110	3792	4470	5228	2337	14298	4204
32	1860	5270	3256	3876	3024	6200	5116	3646	3752	5426	4306	2480	5070	3954	6046	3298
33	5426	6356	4030	3700	2976	7596	4704	7236	5990	4630	6428	3902	4210	2790	7130	4220
34	4186	6114	4650	3410	2790	6556	13720	9500	6746	6356	5426	3328	4992	3720	6200	4064
35	4650	6586	4024	4960	3699	4924	5580	5236	5436	11328	15920	6578	4978	3207	7286	3066

Period / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
4	7584	7088	2144	4884	3606	3384	3980	6540	6728	6328	5180	5112	5848	2250	7080	4592
7	7144	6368	6912	6324	3024	8584	6464	6336	7488	5120	7488	6160	6784	4752	6017	3584
9	7840	4360	6336	4672	3600	7656	6872	2544	5400	6432	6912	7200	5888	4152	6528	3520
21	8370	6810	7692	6424	3354	9146	6708	7842	7286	8620	7202	8468	6800	3489	7616	5520
22	6508	8792	6104	6940	4089	8196	6696	8064	7748	7586	8282	6098	7428	3801	7654	3250
24	6308	7630	6212	4566	3813	4526	6282	6012	6690	5688	6978	5908	8216	3081	4322	2044
28	-	-	-	6364	4884	8990	7554	-	-	-	-	-	7642	3720	7270	5980
29	8216	7412	7848	5822	4248	8836	6316	6404	6294	7476	5006	6280	4576	4872	8560	5800
30	6704	7588	7374	6864	2193	9836	7742	9806	8362	10470	7490	7748	6396	4086	8278	3928
31	8610	8186	7452	6928	3990	8246	11788	7194	9118	7448	8314	6244	7092	3696	15462	7828
32	7014	7262	7906	6180	1767	9146	7906	5460	5776	8680	5732	7446	6560	3675	9090	6204
33	7656	7780	8136	5610	4185	9766	6626	7578	7724	7826	7004	9562	7482	4242	7444	5994
34	7862	7130	6760	7858	8877	15144	11112	6458	6692	6316	7400	4398	6958	3489	7500	3744
35	6510	6356	8526	5576	2517	5943	-	-	-	-	15960	7720	-	2964	15128	5678

Period / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
12	-	-	-	-	1722	2946	1396	2946	3100	2776	2786	1550	3468	1395	3542	1582
13	3100	3256	1706	1516	2094	4650	3248	2628	2946	4456	480	3410	3256	1860	2768	1086
14	2946	2480	1744	2806	2094	4030	2264	2016	3410	2336	1208	2480	3566	1344	2704	862
15	2636	-	-	2946	2094	2516	-	-	3100	2484	5250	1750	3586	1440	2702	3352
16	4750	3500	3680	3518	2325	4030	2946	2456	1710	2170	2790	930	4536	2958	3978	1836
17	3828	3712	1130	4092	2088	3896	3478	3750	3250	2538	1564	4000	2674	2214	3316	2506
18	2682	4024	894	3726	2235	3196	2384	3576	2086	5114	1060	4650	3040	1341	2778	1788
19	3876	4030	2326	2294	2094	4030	3566	2648	2636	4496	3844	2946	3666	1164	4792	2088
20	2790	4650	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	4024	4322	2384	3484	1524	3874	1490	3874	-	-	-	-	-	-	-	-

Wrap Tape

N	Small d	Largest Dimension D																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	18	20	24	28	32	34
TAPE		16	16																			
			16	16	16	16	16	16														
				16	16	16	16	16														
					16	16	16	16														
						16	16	16	16	16	16	16	16	16	16	16	25	25	25	25	25	25
							16	16	16	16	16	16	16	16	16	16	25	25	25	25	25	25
								16	16	16	16	16	16									
									16	16	16	16	16									
										16	16	16	16									
											16	16	16									
												16	16									
													16									
WRAP		39	39																			
			39																			

All others 40

N.B. Same values for 25, 50 & 100
" " " all thicknesses.

XI.4.

Smallest Dimension D — Largest Dimension D

N	d	1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	18	20	24	28	32	34
25	1	84	84																			
25	2		90	90	90	90	90	90														
25	3			93	93	93	93	93														
25	4				96	96	96	96	96													
25	5					99	99	99	99	99	99	99	99	108	108	117	117					
25	6						102	102	102	102	102	111	111	120	120	129	138					
25	7							102	105	114	114	114	123									
25	8								114	114	123	123	132									
25	9									126	126	135	135									
25	10										138	144	144									
25	11											147	156									
25	12												168									
50	1	129	129																			
50	2		138	138	138	138	141	141														
50	3			147	147	147	147	147														
50	4				153	153	153	153	153													
50	5					159	159	159	159	159	159	159	159	177	177	195	195					
50	6						162	162	162	162	162	183	183	201	201	219	237					
50	7							168	168	186	186	186	204									
50	8								189	189	207	207	225									
50	9									213	213	228	246									
50	10										234	252	252									
50	11											255	273									
50	12												294									
100	1	219	219																			
100	2		237	237	237	240	240	240														
100	3			252	252	252	255	255														
100	4				264	264	267	267	267													
100	5					276	276	276	276	276	279	279	279	305	305	351	354					
100	6						285	285	285	285	288	324	324	360	360	396	432					
100	7							294	294	333	333	333	369									
100	8								339	339	375	375	411									
100	9									384	384	420	453									
100	10										426	462	462									
100	11											468	504									

Count, Examine Wrap.

46 6 0:01

Count, Examine Wrap

N	Small d	Largest Dimension D																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	18	20	24	28	32	34
25	1	96	96																			
25	2		102	102	93	93	93	93														
25	3			105	105	96	96	96														
25	4				99	99	99	99	99													
25	5					102	102	102	102	102	102	108	108	117	117	132	138					
25	6						102	102	102	102	111	120	120	135	135	153	165					
25	7							111	111	120	120	126	135									
25	8								123	123	138	138	156									
25	9									138	138	153	168									
25	10										153	168	168									
25	11											171	189									
25	12												201									
50	1	153	153																			
50	2		162	162	144	144	147	147														
50	3			171	169	153	153	153														
50	4				156	156	159	159	159													
50	5					162	162	162	162	162	165	177	177	195	198	225	237					
50	6						165	165	165	165	180	198	198	228	228	267	288					
50	7							180	180	198	201	201	231									
50	8								204	204	224	234	261									
50	9									237	237	264	294									
50	10										270	297	297									
50	11											300	339									
50	12												360									
100	1	267	267																			
100	2		288	288	252	252	255	255														
100	3			300	300	264	267	267														
100	4				273	273	276	276	276													
100	5					285	285	285	285	285	288	302	302	348	351	408	435					
100	6						291	291	291	291	318	357	357	414	417	445	534					
100	7							321	321	360	363	384	420									
100	8								366	366	426	426	483									
100	9									432	432	492	546									
100	10										498	552	552									
100	11											558	630									

0.045" → 0.2"

XI.4.

Count Estimate Map

N	Small d	Largest Dimension D																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	18	20	24	28	32	34
25	1	84	84																			
25	2		90	90	81	81	81	81														
25	3			93	84	84	84	84														
25	4				87	87	87	87	87													
25	5					87	87	87	90	90	90	90	90	99	99	108	108					
25	6						90	90	90	90	90	99	99	108	108	117	126					
25	7							90	93	102	102	102	111									
25	8								102	102	111	111	120									
25	9									114	114	123	132									
25	10										123	132	132									
25	11											135	144									
25	12												153									
50	1	108	108																			
50	2		117	117	99	99	99	99														
50	3			123	105	105	105	105														
50	4				111	111	111	111														
50	5					114	114	114	114	114	114	114	114	135	135	153	153					
50	6						117	117	117	117	120	138	138	156	156	174	192					
50	7							120	120	141	141	141	159									
50	8								144	144	162	162	180									
50	9									165	165	183	201									
50	10										186	204	204									
50	11											204	222									
50	12												243									
100	1	174	174																			
100	2		201	201	159	159	159	159														
100	3			207	171	171	171	171														
100	4				180	180	180	180	180													
100	5					189	189	189	189	189	189	189	189	228	228	264	264					
100	6						195	195	195	195	198	198	198	270	270	306	342					
100	7							201	201	240	240	240	276									
100	8								246	246	282	282	318									
100	9									288	288	324	360									
100	10										330	366	366									
100	11											369	405									

0.01" = 0.0

Count, Examine Tape

up to 0.01

N	Small d	Largest Dimension D																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	18	20	24	28	32	34
25	1	60	60																			
25	2		66	66	66	66	66	66														
25	3			69	69	69	69	69														
25	4				72	72	72	72	72													
25	5					75	75	75	75	75	75	75	75	84	84	93	105	114	123	141	150	159
25	6						78	78	78	78	78	87	87	96	96	105	126	126	144	162	171	180
25	7							78	78	90	90	90	99									
25	8								90	90	99	99	108									
25	9									102	102	111	120									
25	10										111	120	120									
25	11											123	132									
25	12												144									
50	1	105	105																			
50	2		114	114	114	114	117	117														
50	3			123	123	123	123	123														
50	4				129	129	129	129	129													
50	5					135	135	135	135	135	135	135	135	135	135	171	183	201	219	255	273	291
50	6						138	138	138	138	138	159	159	177	177	195	222	222	258	294	312	330
50	7							144	144	162	162	162	162									
50	8								165	165	183	183	201									
50	9									186	186	204	222									
50	10										210	225	225									
50	11											231	249									
50	12												270									
100	1	195	195																			
100	2		216	216	216	216	216	216														
100	3			228	228	228	231	231														
100	4				243	243	243	243	243													
100	5					252	252	252	252	252	255	255	255	291	291	327	339	375	411	483	519	555
100	6						261	261	261	261	261	300	300	336	336	372	420	420	495	564	600	636
100	7							270	270	306	309	309	345									
100	8								315	315	351	351	387									
100	9									360	360	393	429									
100	10										420	438	438									
100	11											440	460									

Count Examin
Tape

N	Small d	Largest Dimension D																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	18	20	24	28	32	34
25	1	72	72																			
25	2		78	78	69	64	69	69														
25	3			81	81	72	72	72														
25	4				75	75	75	75	75													
25	5					78	78	78	78	78	78	84	84	93	93	108	126	135	150	180	195	210
25	6						78	78	78	78	84	96	~~96~~	108	~~111~~	129	~~150~~	~~162~~	~~180~~	~~210~~	225	240
25	7							87	87	96	96	102	111									
25	8								96	96	114	114	126									
25	9									114	114	129	144									
25	10										129	144	144									
25	11											144	165									
25	12												174									
50	1	129	129																			
50	2		141	141	123	123	123	123														
50	3			147	147	129	129	129														
50	4				132	132	135	135	135													
50	5					138	138	138	138	138	141	150	150	171	171	201	225	249	273	333	366	393
50	6						141	141	141	141	156	174	174	204	204	243	276	297	333	393	426	453
50	7							156	156	174	177	~~189~~	207									
50	8								180	180	210	210	240									
50	9									213	213	240	270									
50	10										243	273	273									
50	11											276	302									
50	12												336									
100	1	243	243																			
100	2		264	264	228	228	231	231														
100	3			282	276	240	243	243														
100	4				249	249	253	253	253													
100	5					261	261	261	261	261	264	288	288	324	327	384	423	456	519	630	690	750
100	6						267	267	267	267	294	333	333	390	393	471	519	564	630	750	810	870
100	7							297	297	333	339	360	396									
100	8								342	342	402	402	459									
100	9									405	405	468	522									
100	10										471	528	528									
100	11											534	600									

0.045" — 0.0
XI.4.

Count Examine Tape

0.01" → 0.0

N	Small d	Largest Dimension D																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	18	20	24	28	32	34
25	1	60	60																			
25	2		66	66	57	57	57	57														
25	3			69	60	60	60	60														
25	4				63	63	63	63	63													
25	5					63	63	63	63	63	66	66	66	75	75	84	96	105	114	132	141	150
25	6						66	66	66	66	66	75	75	84	84	93	114	114	132	150	159	168
25	7							66	66	78	78	78	87									
25	8								78	78	87	87	96									
25	9									90	90	99	108									
25	10										99	108	108									
25	11											111	117									
25	12												129									
50	1	84	84																			
50	2		93	93	75	75	75	75														
50	3			99	81	81	81	81														
50	4				87	87	87	87	87													
50	5					90	90	90	90	90	90	90	90	111	111	129	141	159	177	213	231	249
50	6						93	93	93	93	93	114	114	132	132	150	180	180	216	249	267	285
50	7							96	96	114	117	117	135									
50	8								132	132	150	150	168									
50	9									141	141	159	174									
50	10										162	177	177									
50	11											180	198									
50	12												219									
100	1	150	150																			
100	2		171	171	135	135	135	135														
100	3			183	147	147	147	147														
100	4				156	156	156	156	156													
100	5					165	165	165	165	165	165	165	165	204	204	240	252	288	324	396	432	468
100	6						171	171	171	171	174	210	210	246	246	282	330	330	402	471	510	543
100	7							177	177	216	216	216	252									
100	8								222	222	258	258	300									
100	9									264	264	300	333									
100	10										306	342	342									
100	11											345	381									

	d	1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	18	20	24	28	32	36
25	1	45	45																			
25	2		51	50	50	50	50	50														
25	3			53	53	53	53	53														
25	4				56	56	56	56	56													
25	5					59	59	59	59	59	59	59	59	68	68	77	77					
25	6						62	62	62	62	62	71	71	80	80	89	98					
25	7							62	65	74	74	74	83									
25	8								74	74	83	83	92									
25	9									86	86	95	95									
25	10										98	104	104									
25	11											107	116									
25	12												128									
50	1	90	90																			
50	2		99	98	98	98	101	101														
50	3			107	107	107	107	107														
50	4				113	113	113	113	113													
50	5					119	119	119	119	119	119	119	119	137	137	155	155					
50	6						122	122	122	122	122	143	143	161	161	179	197					
50	7							128	128	146	146	146	164									
50	8								149	149	167	167	185									
50	9									173	173	188	206									
50	10										194	112	112									
50	11											115	133									
50	12												154									
100	1	180	180																			
100	2		198	197	197	200	200	200														
100	3			212	212	212	215	215														
100	4				224	224	227	227	227													
100	5					236	236	236	236	236	239	239	239	265	265	311	314					
100	6						245	245	245	245	248	284	284	320	320	356	392					
100	7							254	254	293	293	293	329									
100	8								299	299	335	335	371									
100	9									344	344	380	413									
100	10										386	422	422									
100	11											428	464									
100	12												506									

Count & Examine

up to 5.0.

XI.

	d	1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	18	20	24	28	32	34
25	1	57	57																			
25	2		57	62	53	53	53	53														
25	3			65	65	56	56	56														
25	4				59	54	54	54	54													
25	5					62	62	62	62	62	62	68	68	77	77	92	98	107	122	152	167	182
25	6						62	62	62	62	71	80	80	95	95	113	125	134	152	182	197	212
25	7							71	71	80	80	86	95									
25	8								83	83	98	98	116									
25	9									98	98	113	128									
25	10										113	128	128									
25	11											131	149									
25	12												161									
50	1	113	113																			
50	2		122	122	104	104	107	107														
50	3			131	129	113	113	113														
50	4				116	116	119	119	119													
50	5					122	122	122	122	122	125	137	137	155	158	185	197	215	245	305	338	365
50	6						125	125	125	125	140	158	158	~~155~~	~~158~~ 155	227	248	269	305	365	398	425
50	7							140	140	158	161	161	191									
50	8								164	164	194	194	221									
50	9									197	197	224	254									
50	10										230	257	257									
50	11											260	299									
50	12												320									
100	1	228	228																			
100	2		249	248	212	212	215	215														
100	3			260	260	224	247	247														
100	4				233	233	236	236	236													
100	5					245	245	245	245	245	248	262	262	308	311	368	395	428	490	602	668	722
100	6						251	251	251	251	278	317	317	374	377	455	494	536	602	722	788	842
100	7							281	281	320	323	344	380									
100	8								326	326	386	386	493									
100	9									392	392	452	506									
100	10										458	512	512									
100	11											518	540									
100	12												650									

Count 9 E Kansas

XII.

	d	1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	18	20	24	28	32	34
25	1	45	45																			
25	2		51	50	41	41	41	41														
25	3			53	44	44	44	44														
25	4				47	47	47	47	47													
25	5					47	47	47	50	50	50	50	50	59	59	68	68					
25	6						50	50	50	50	50	59	59	68	68	77	86					
25	7							50	53	62	62	62	71									
25	8								62	62	71	71	80									
25	9									74	74	83	92									
25	10										83	92	92									
25	11											95	104									
25	12												113									
50	1	69	69																			
50	2		78	77	59	59	59	59														
50	3			83	65	65	65	65														
50	4				71	71	71	71														
50	5					74	74	74	74	74	74	74	74	95	95	113	113	131	149	185	203	218
50	6						77	77	77	77	80	98	98	116	116	134	152	152	188	221	239	257
50	7							80	80	101	101	101	119									
50	8								104	104	122	122	140									
50	9									125	125	143 143	161									
50	10										146	164	164									
50	11											164	182									
50	12												203									
100	1	135	135																			
100	2		162	161	119	119	119	119														
100	3			167	131	131	131	131														
100	4				140	140	140	140	140													
100	5					149	149	149	149	149	149	149	149	188	188	224	224	260	296	368	404	440
100	6						155	155	155	155	158	158	158	158 230	230	266	302	302	374	443	482	515
100	7							161	161	200	200	200	236									
100	8								206	206	242	242	278									
100	9									248	248	284	320									
100	10										290	326	326									
100	11											329	365									
100	12												407									

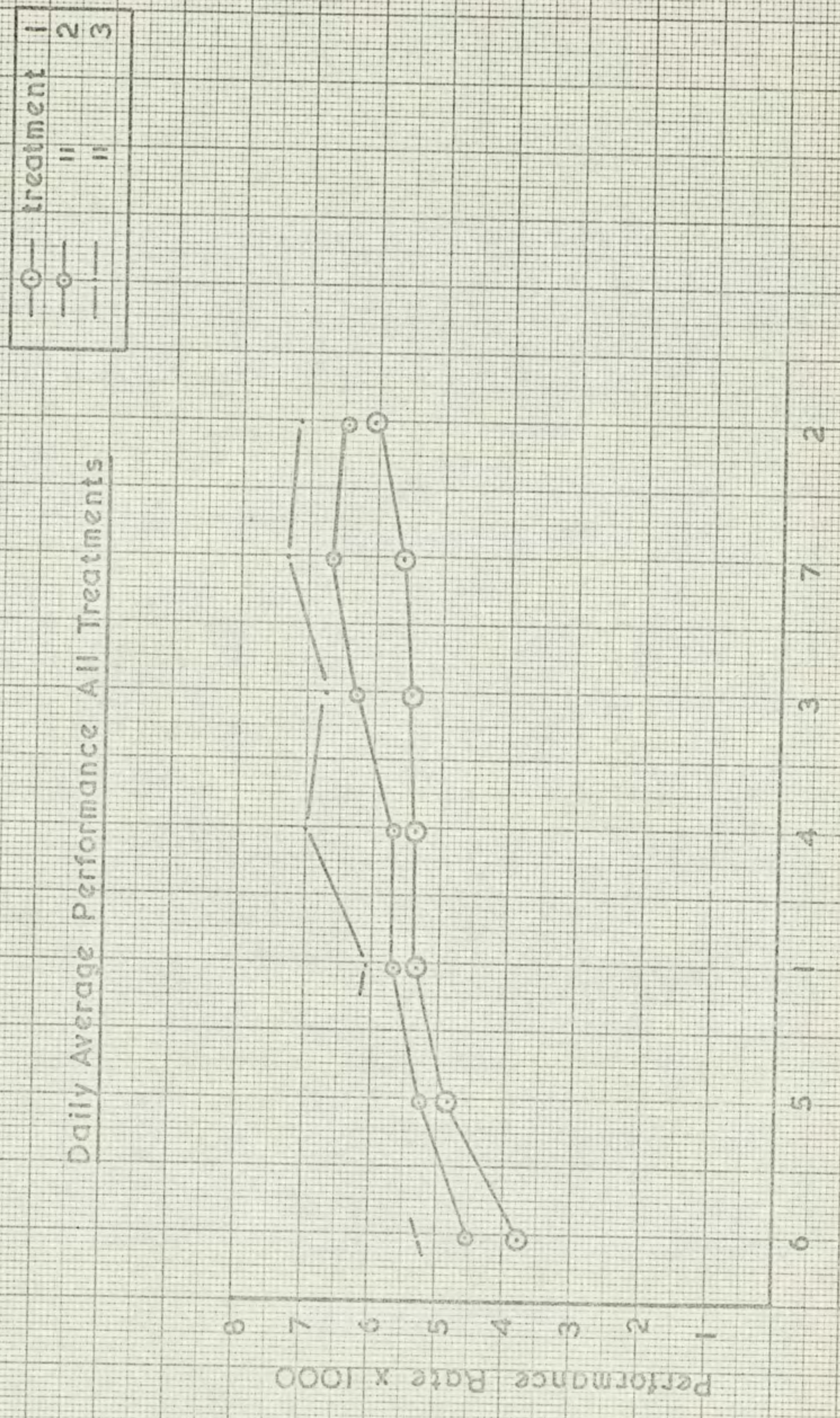
Counts of Kernels

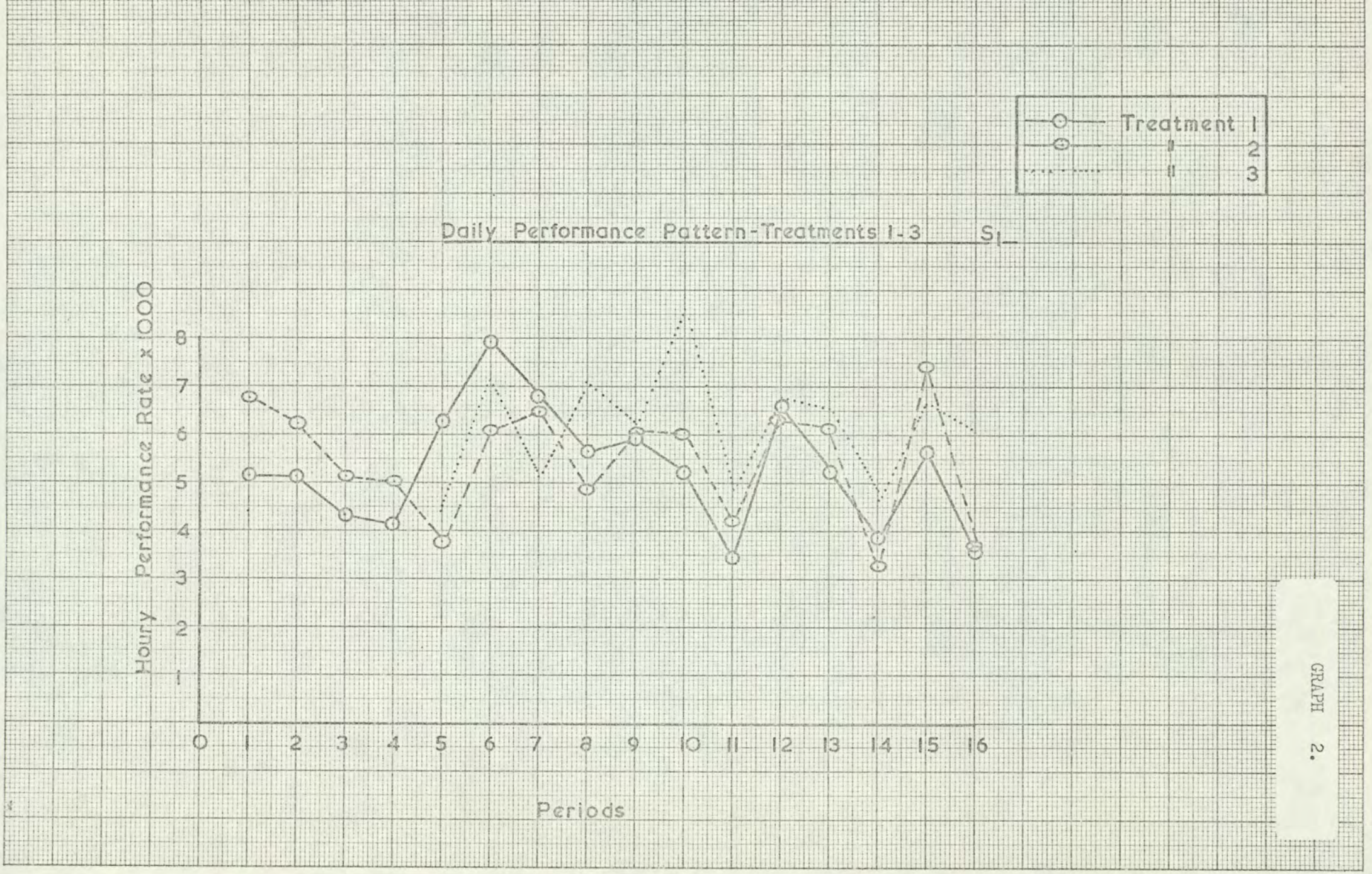
XI.

Packing Taped or Wrapped Bundles into Carton

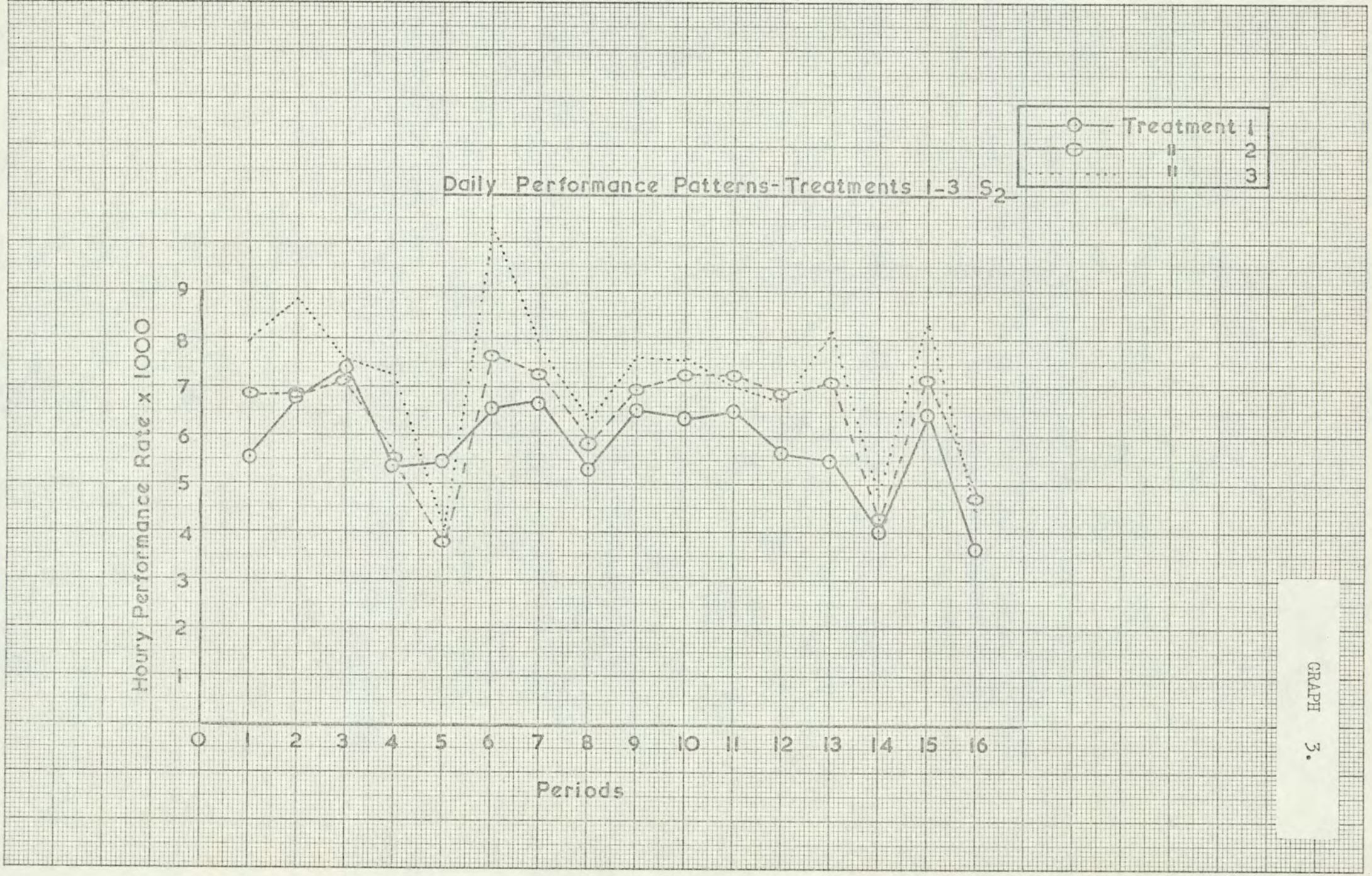
Separator Thickness	Ergonomic Units/Bundle		
	25	50	100
0.01			100
0.02		100	207
0.03		147	294
0.04	100	207	411
0.045	114	228	516
0.05	129	258	516
0.06	147	294	
0.07	171	345	
0.08	207	411	
0.09	228	516	
0.1	258	516	
0.15	411		
0.2	516		

GRAPH 1.

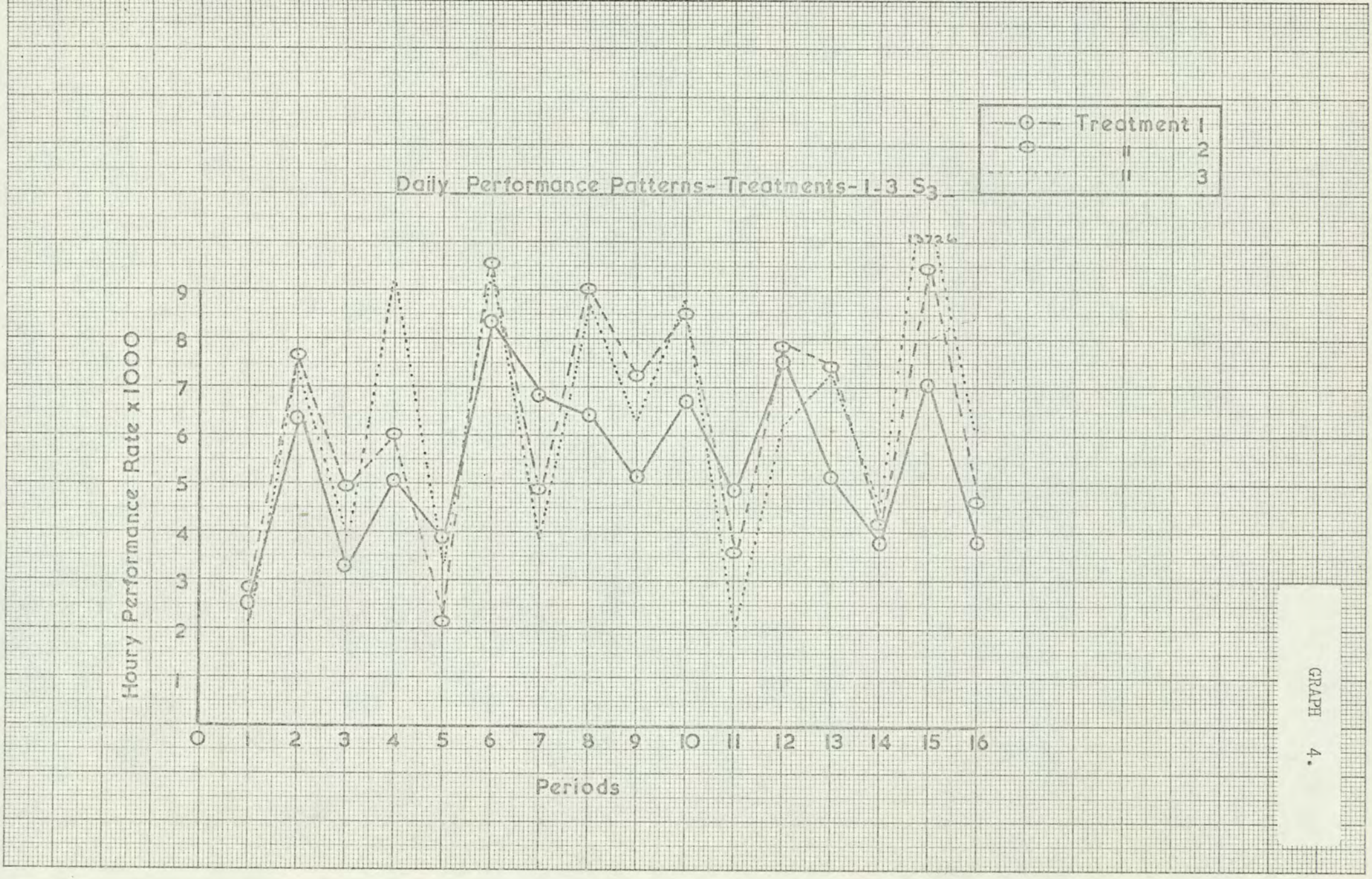

Daily Average Performance All Treatments
treatment 1
" 2
" 3
Performance Rate x 1000
8
7
6
5
4
3
2
1
Subjects
6
5
1
4
3
7
2


Treatment 1
" 2
" 3
Daily Performance Pattern-Treatments 1-3
S1
Hourly Performance Rate x 1000
1
2
3
4
5
6
7
8
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Periods

GRAPH 2.

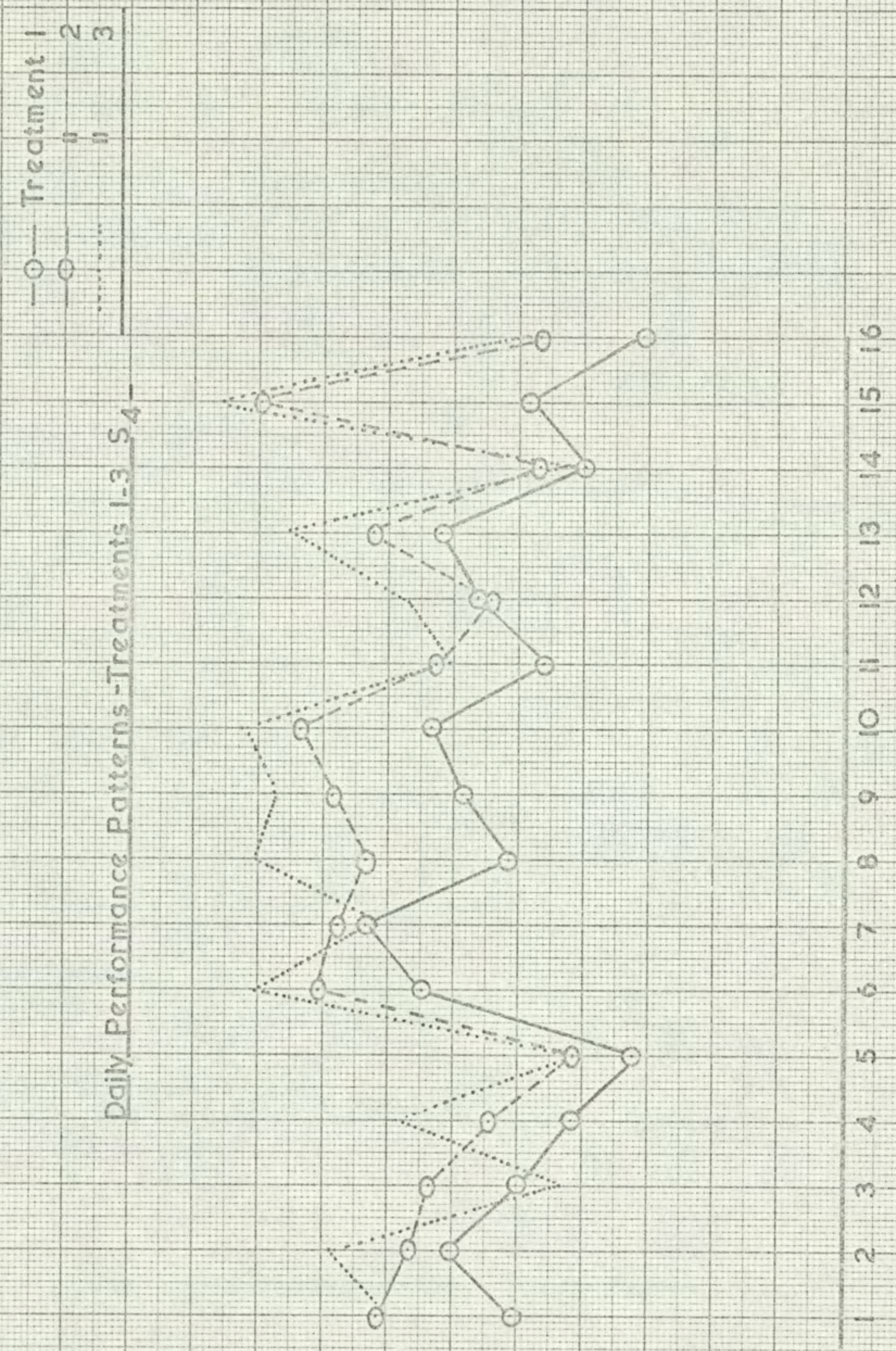

Daily Performance Patterns-Treatments 1-3 S2
Treatment 1
" 2
" 3
Hourly Performance Rate x 1000
1
2
3
4
5
6
7
8
9
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Periods

GRAPH 3.

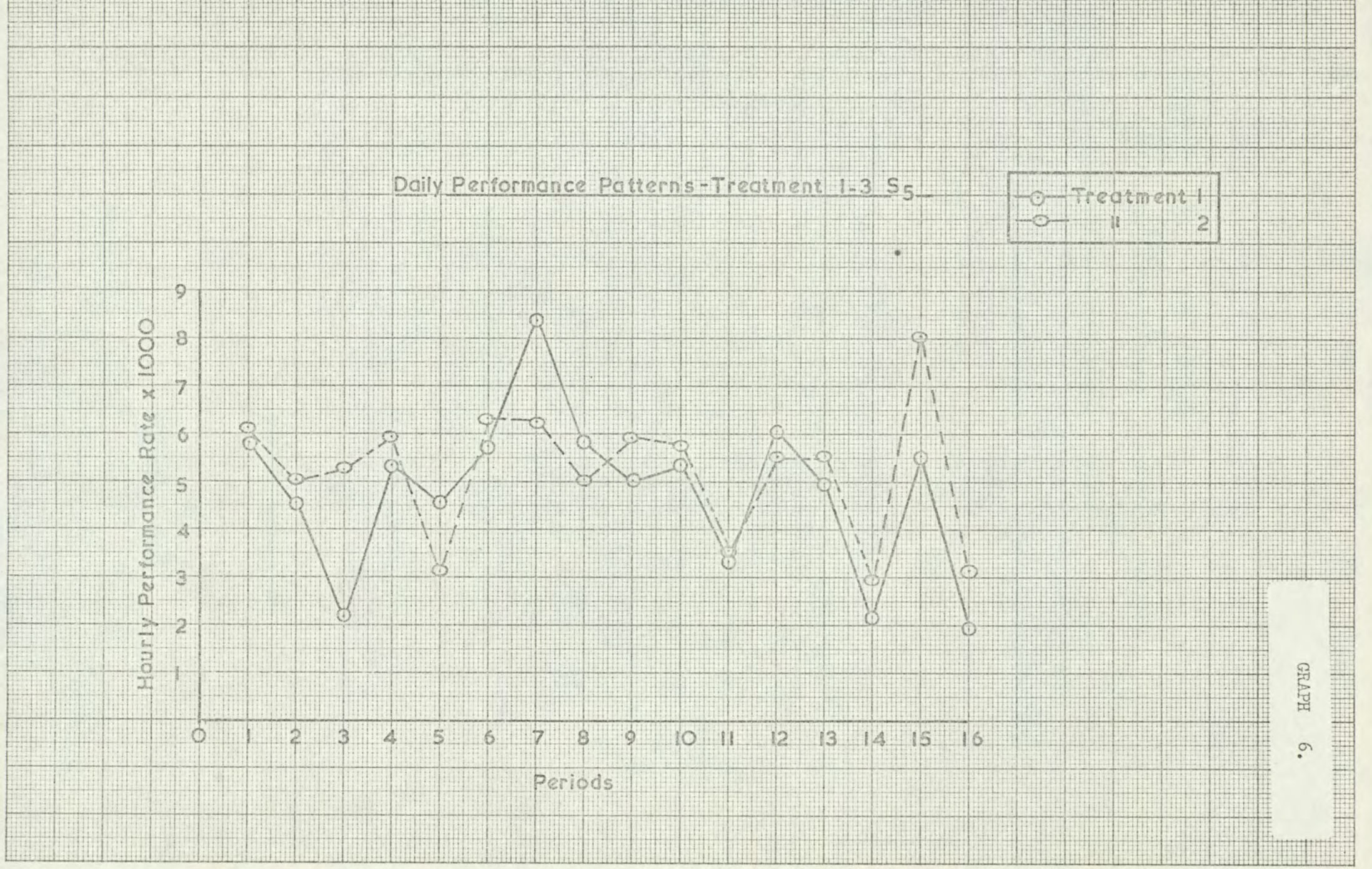

Daily Performance Patterns- Treatments- 1-3 S3
Treatment 1
" 2
" 3
Hourly Performance Rate x 1000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Periods

GRAPH 4.

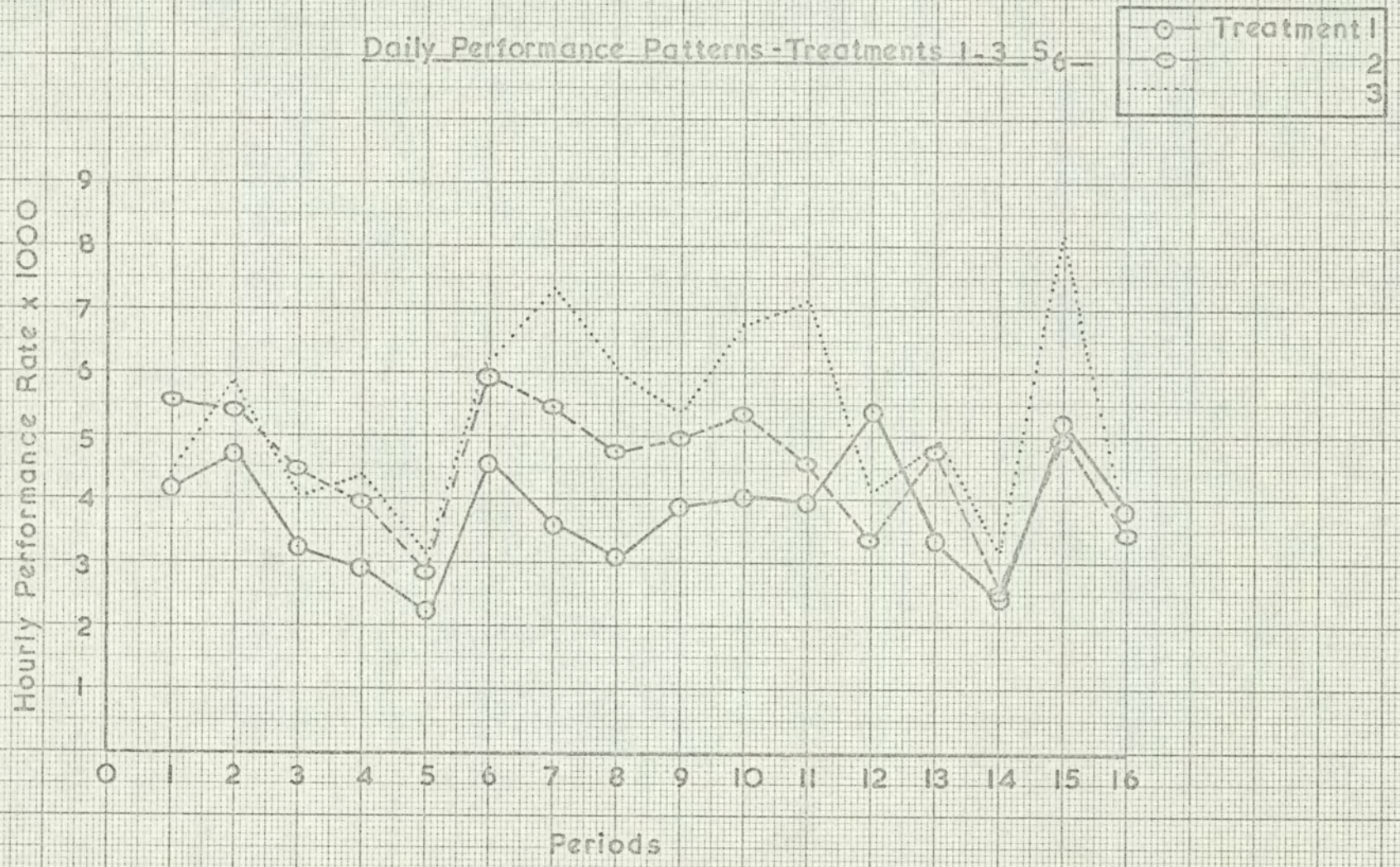
GRAPH 5.



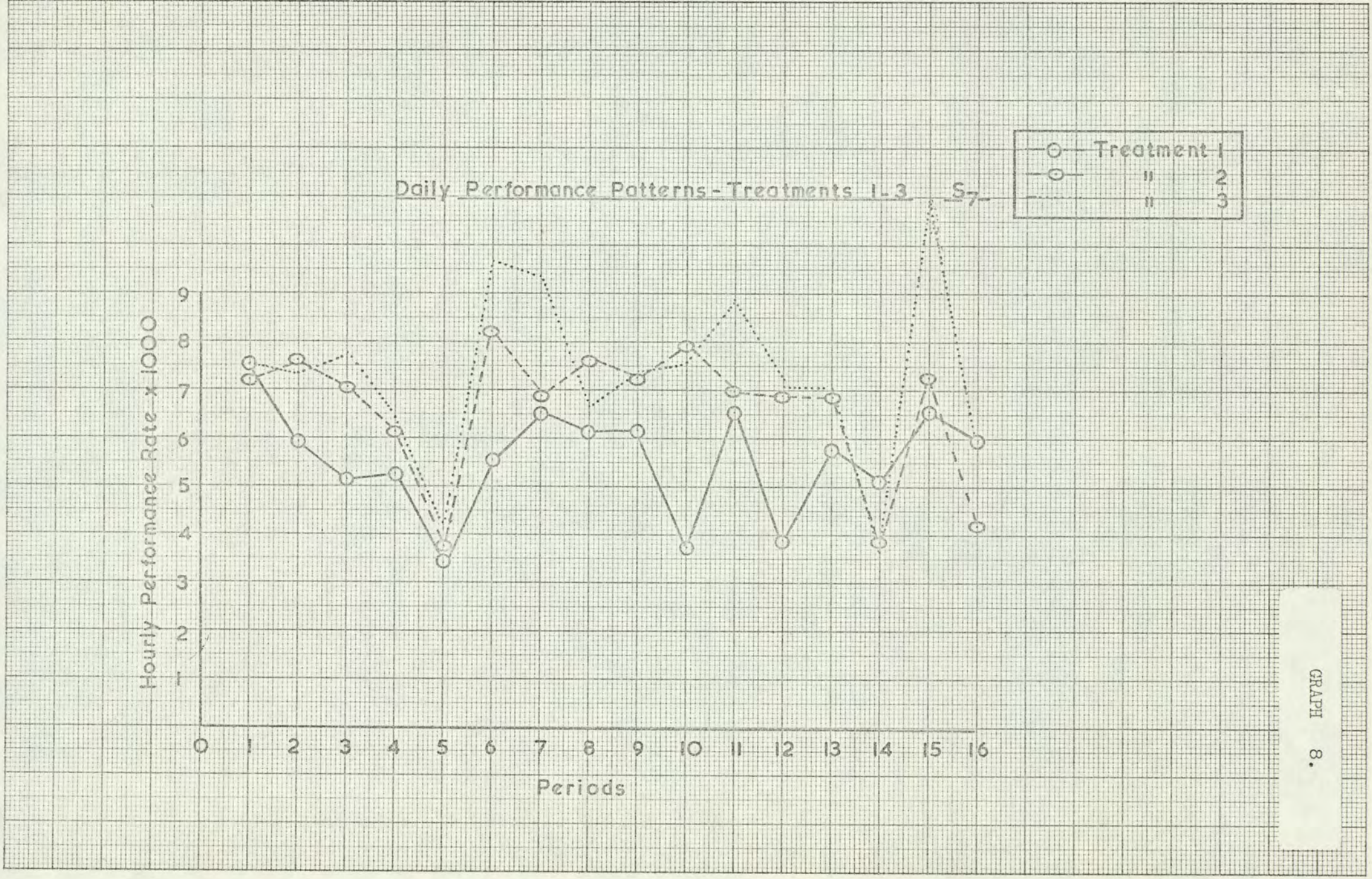
Daily Performance Patterns - Treatments 1-3 S4
Treatment 1
" 2
" 3
Hourly Performance Rate x 1000
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Periods


Daily Performance Patterns - Treatment 1-3 S5
Treatment 1
1 2
Hourly Performance Rate x 1000
0 1 2 3 4 5 6 7 8 9
Periods
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

GRAPH 6.

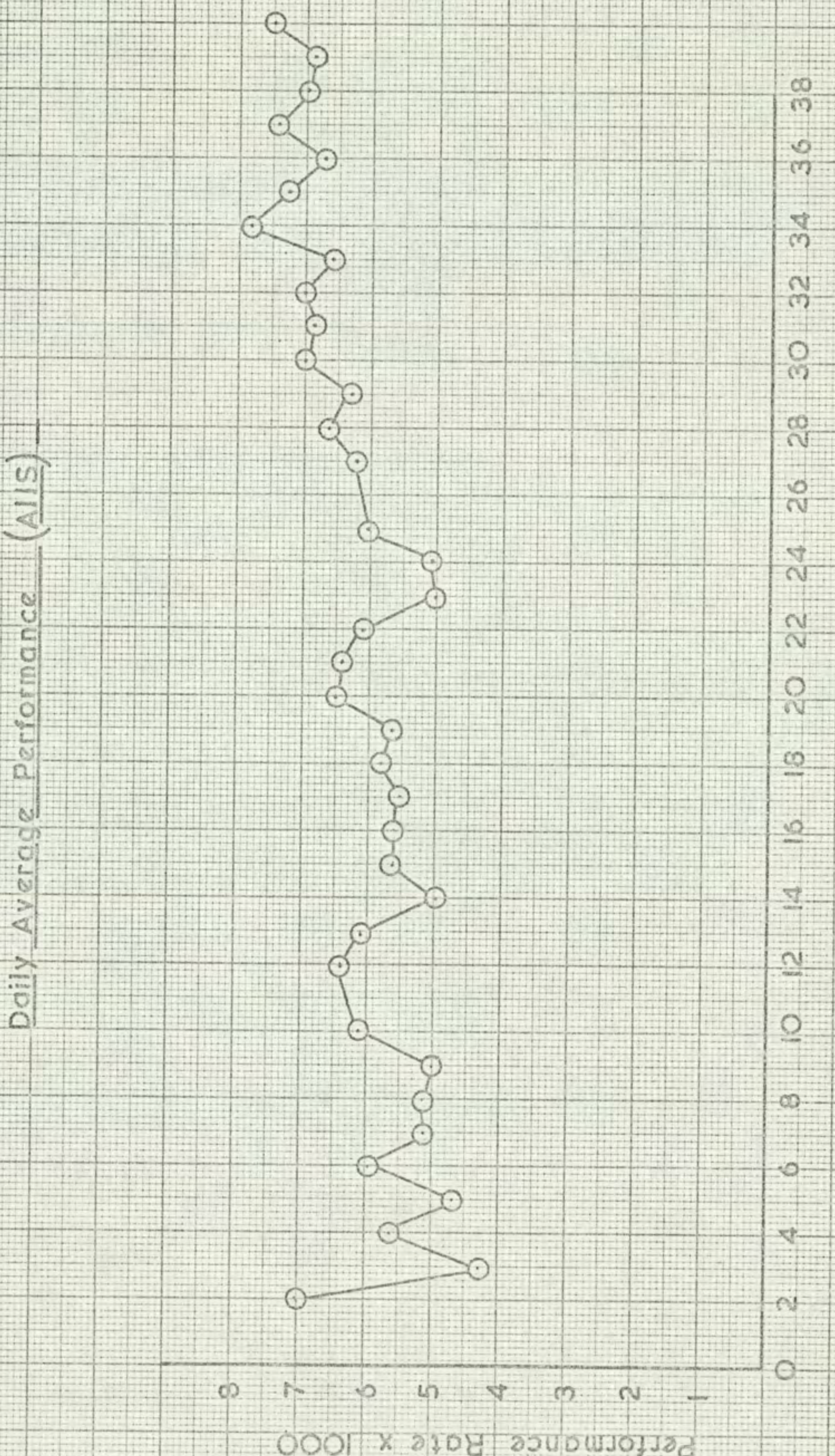

Daily Performance Patterns - Treatments 1-3-5-6
Treatment 1
2
3
Hourly Performance Rate x 1000
1
2
3
4
5
6
7
8
9
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Periods

GRAPH 7.

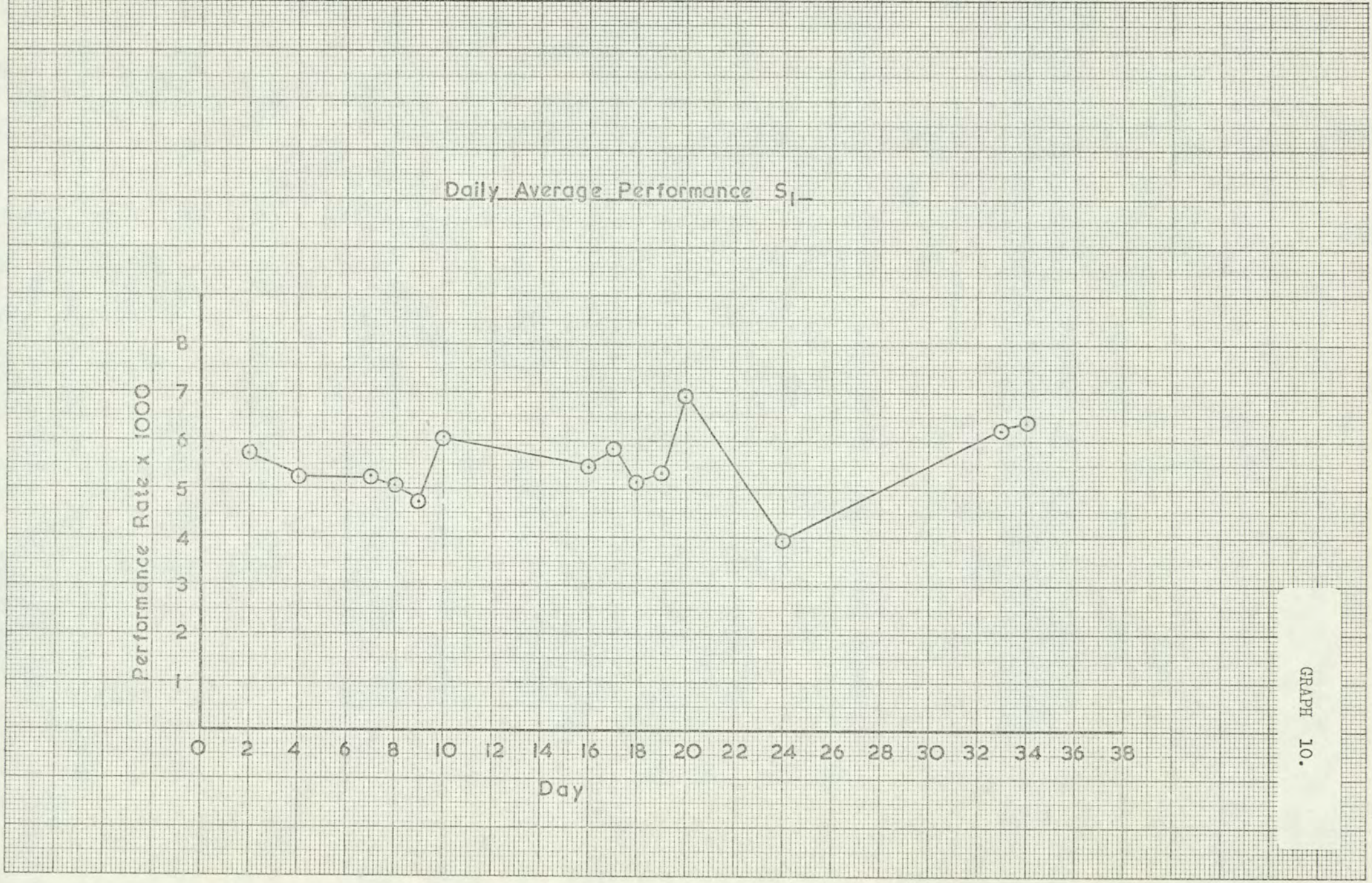

Daily Performance Patterns - Treatments 1, 2, 3 -S7-
Treatment 1
" 2
" 3
Hourly Performance Rate x 1000
1
2
3
4
5
6
7
8
9
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Periods

GRAPH 8.

GRAPH 9.

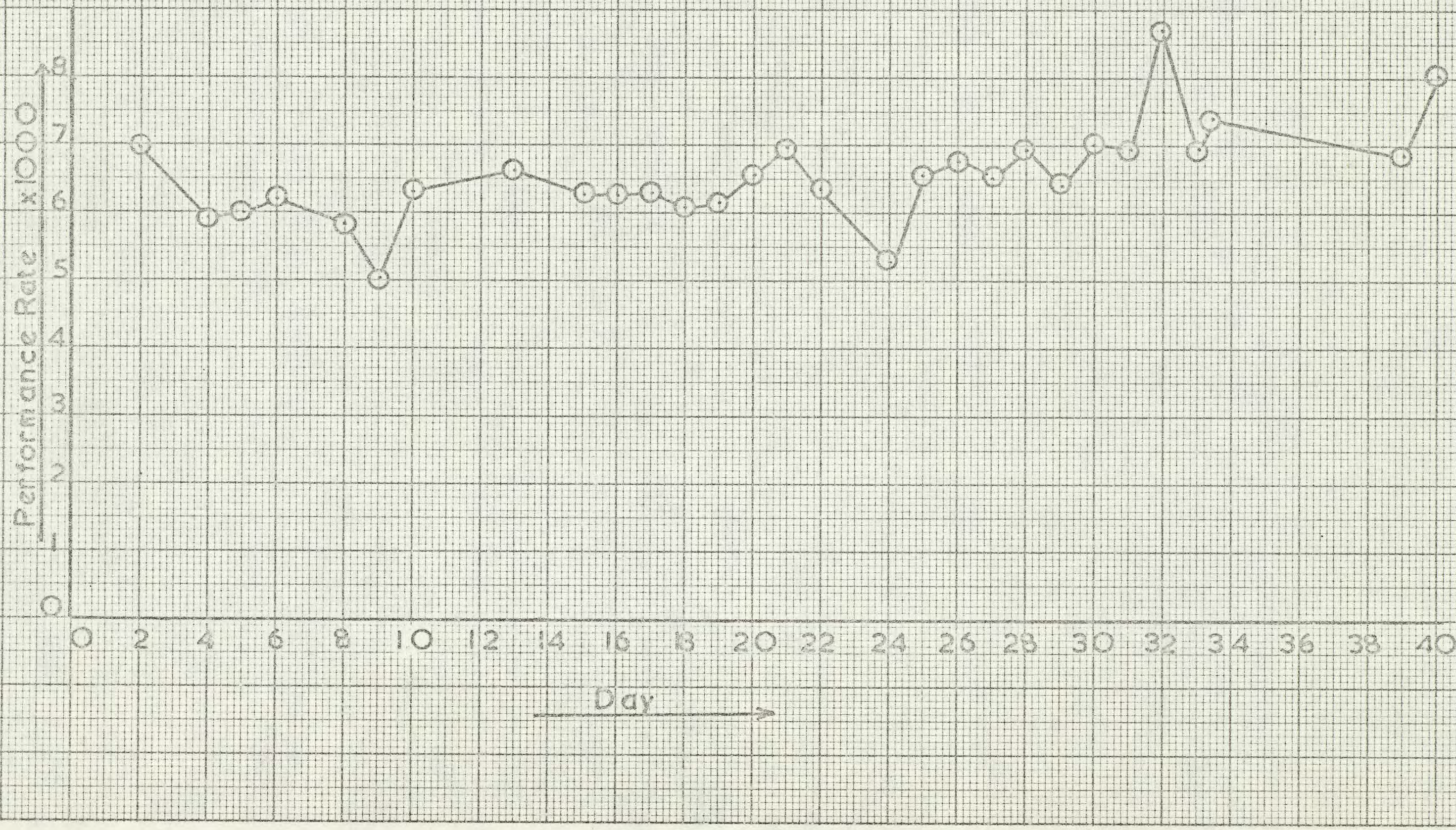


Daily Average Performance (AIIS)
Performance Rate x 1000
Day
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
1
2
3
4
5
6
7
8


Daily Average Performance S_1
Performance Rate x 1000
1
2
3
4
5
6
7
8
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
Day

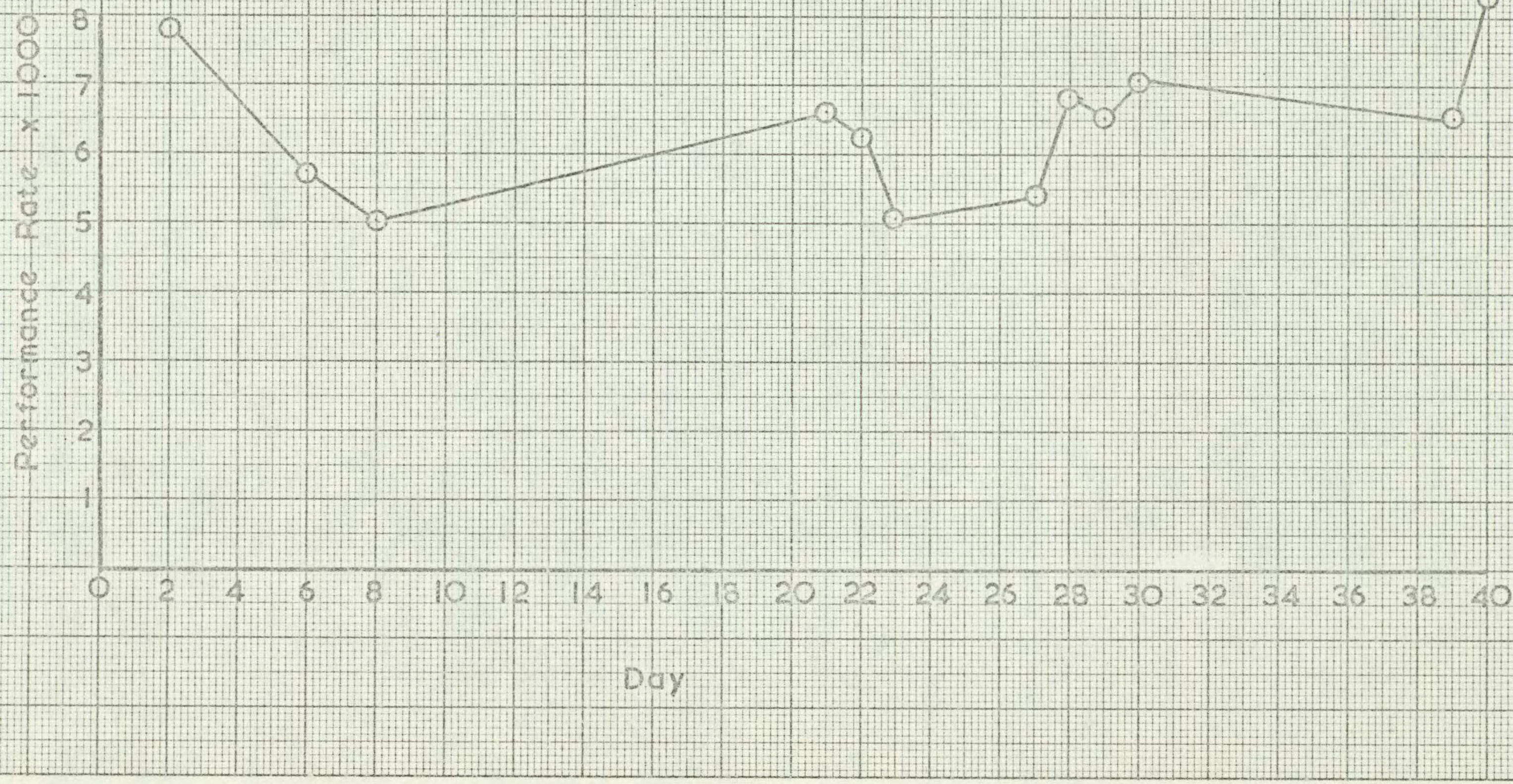
GRAPH 10.

Daily Average Performance S_2



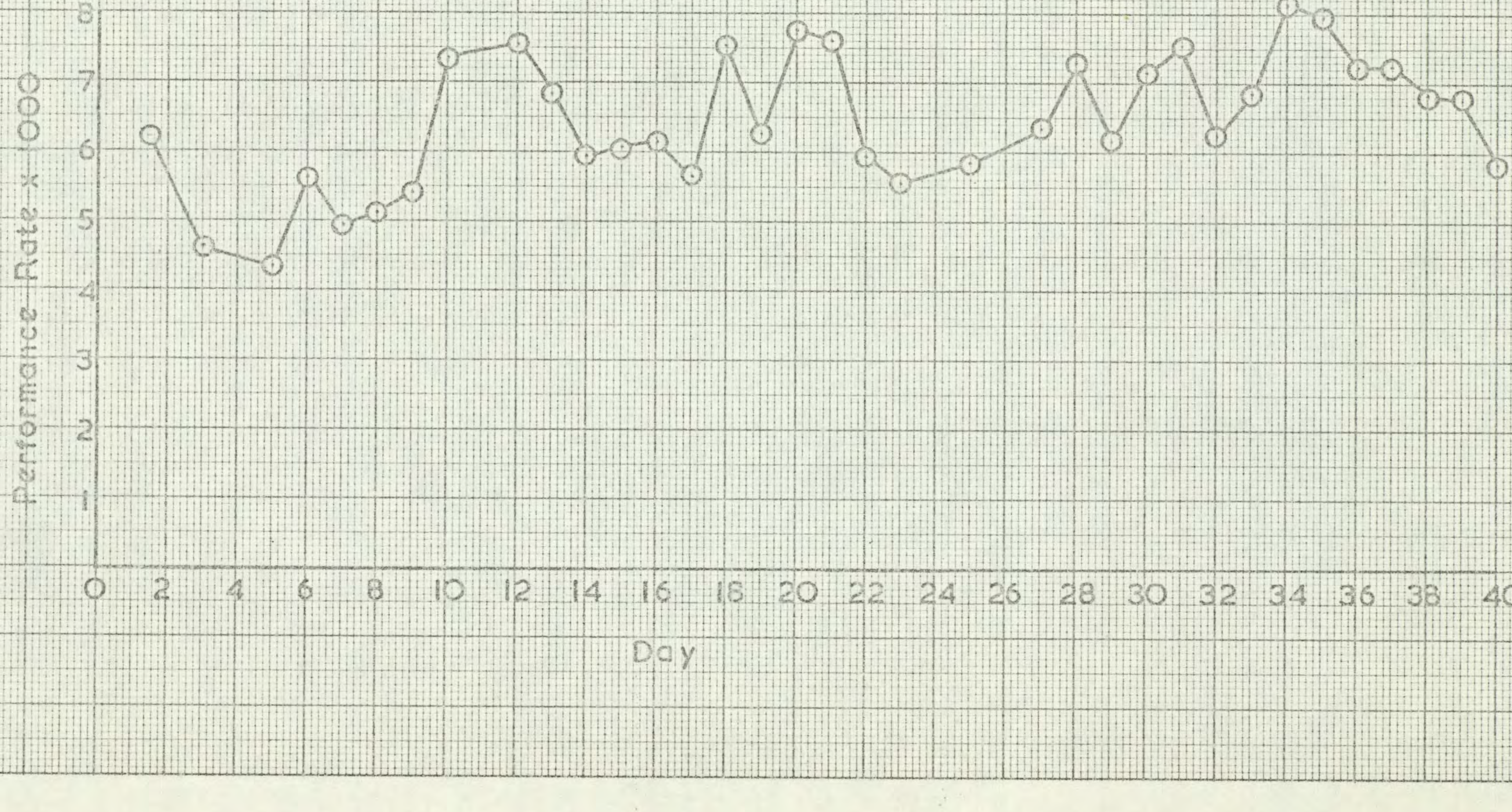
GRAPH 11.

Daily Average Performance S_3



GRAPH 12.

Daily Average Performance S_4

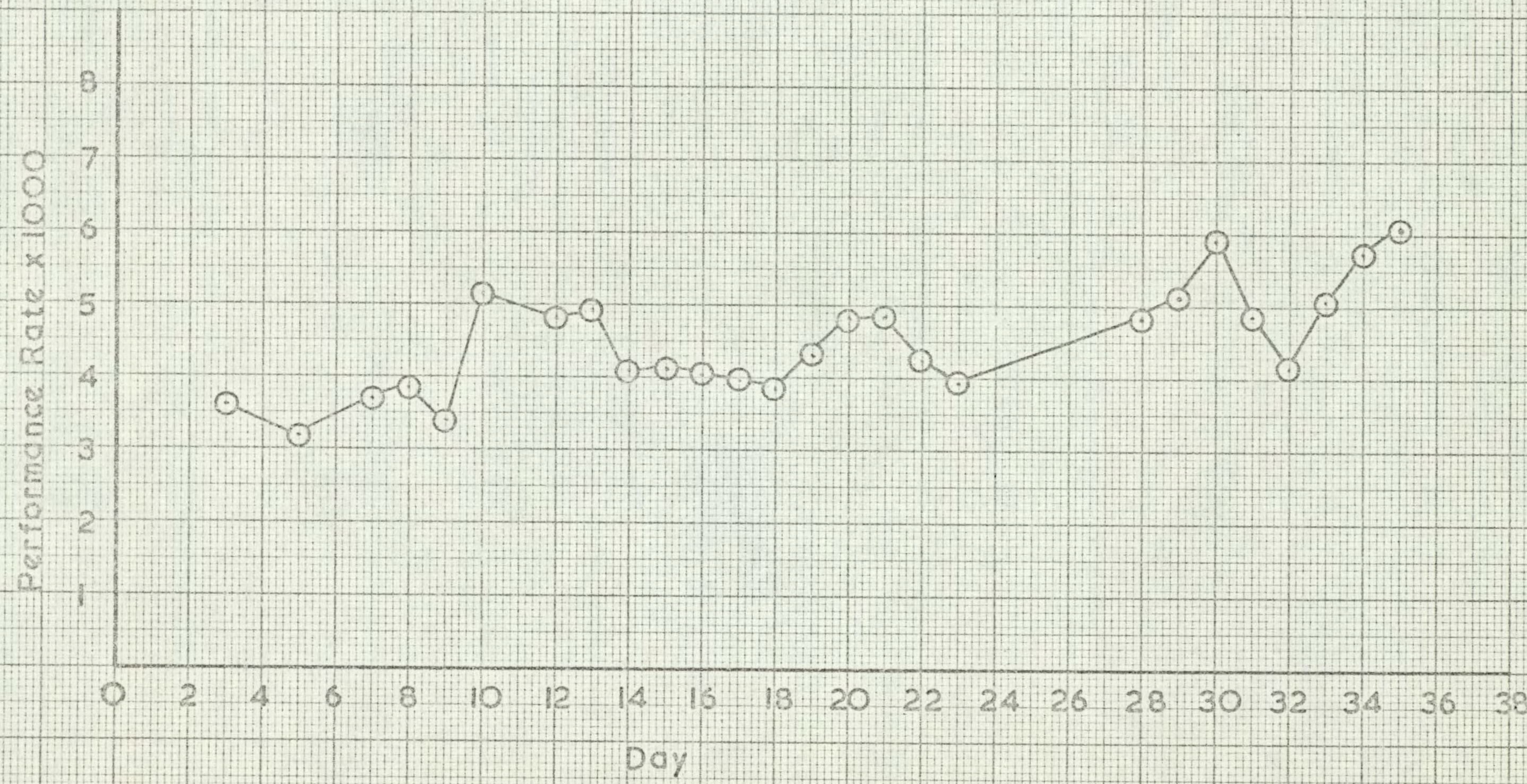


GRAPH 13.

Daily Average Performance S_5

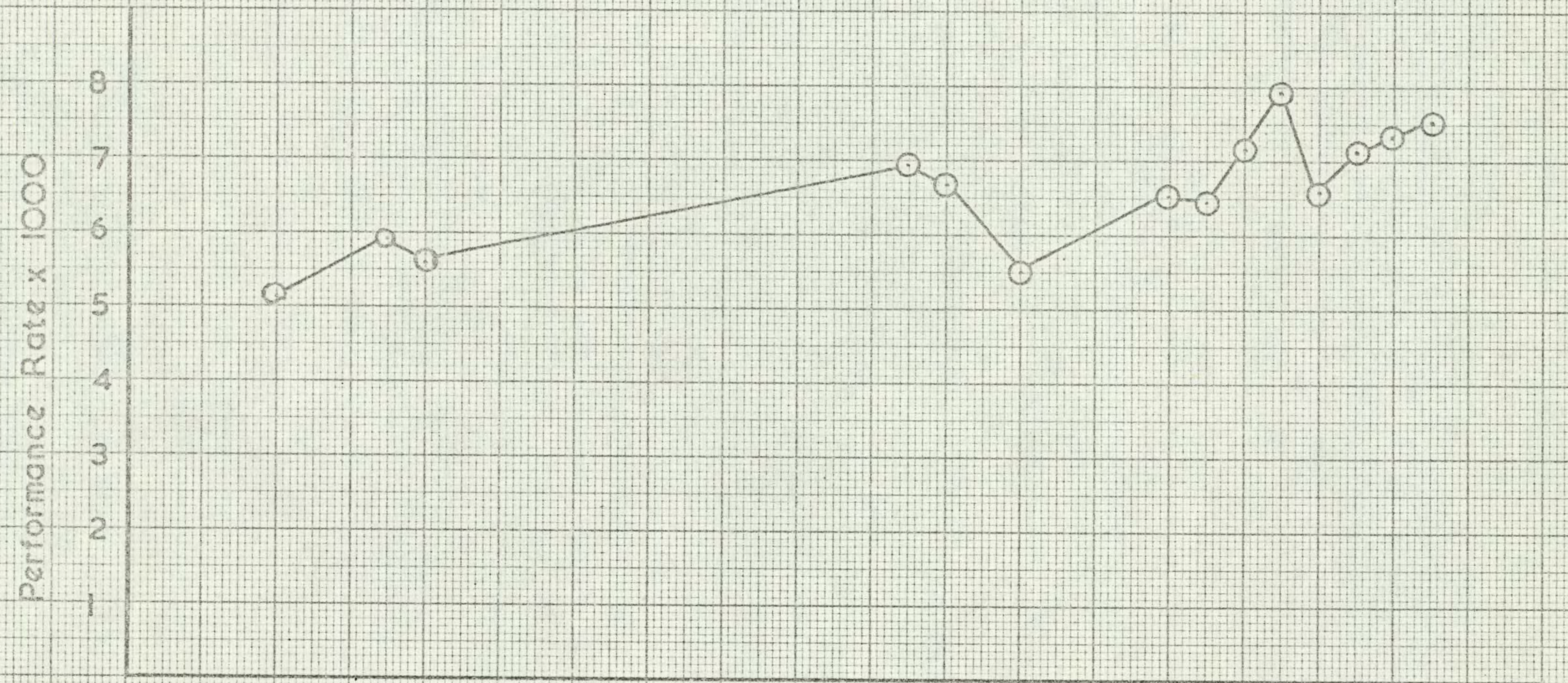
GRAPH 14.

Daily Average Performance S_6



GRAPH 15.

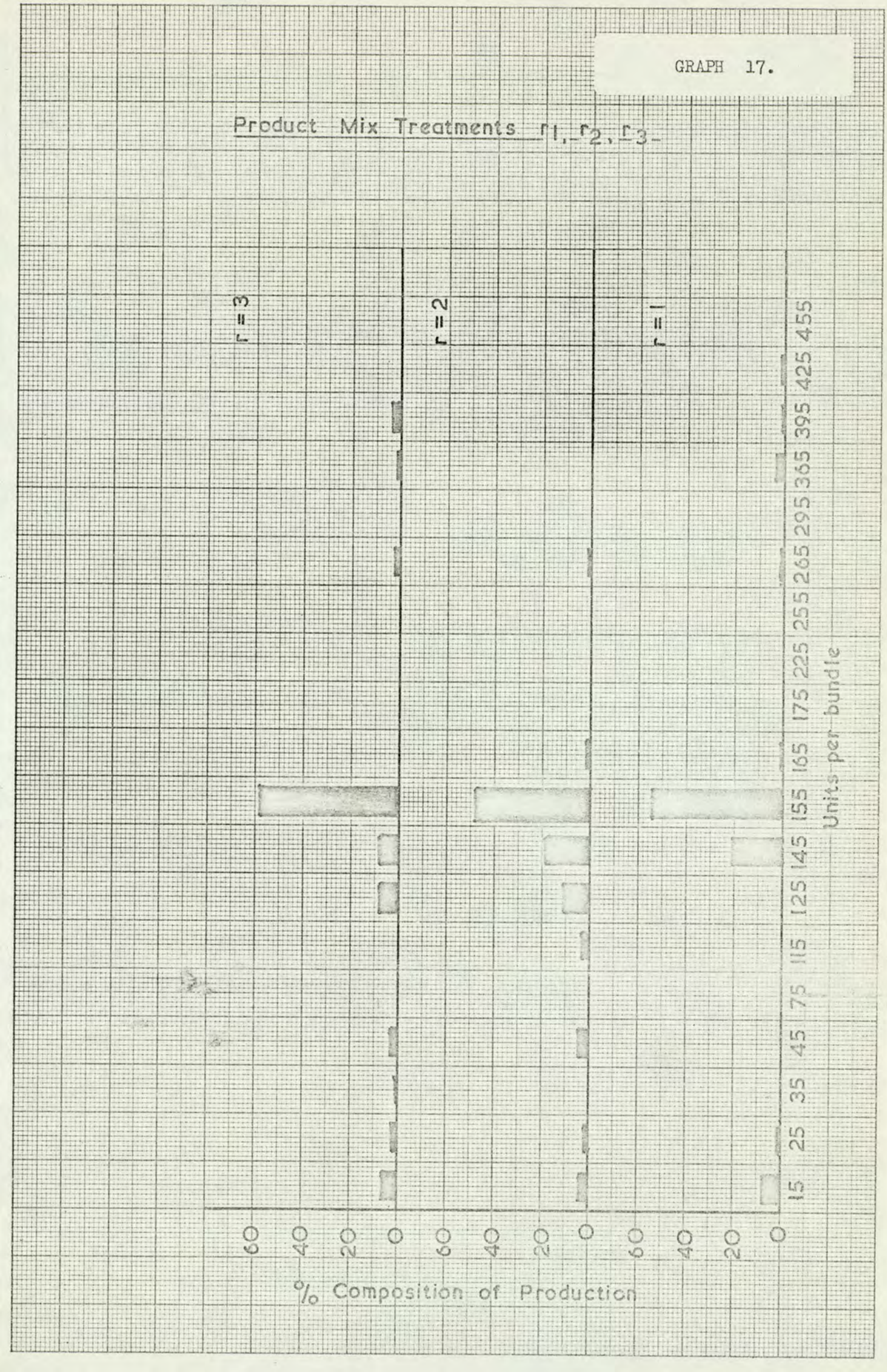
Daily Average Performance S7



GRAPH 16.

GRAPH 17.

Product Mix Treatments r_1, r_2, r_3-



Acknowledgements

I would like to record my gratitude to Professor W.T. Singleton for the supervision I received during this investigation. I am also indebted to Fibreglass Limited of the Pilkington Group, for permission to carry out this work and to Pilkington Brothers Limited and the College of Aeronautics for allowing me the time to do so.